Maximising the yield of biomass from residues of agricultural crops and biomass from forestry

Final report

EUROPEAN COMMISSION

Directorate-General for Energy

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UNIQUE Forestry and Land Use GmbH – Forest expertise

Scientific Engineering Centre "Biomass" (SECB) – Regional expertise on Ukraine, Russia and Belarus

Executive Summary

There is a huge potential for yield increase of agricultural crop residues and biomass from forestry in the European Union, Ukraine, Russia and Belarus. A stepwise approach was used to identify the realistic potential in the study area, starting with an estimate of the theoretical potential based on crop- and forest-type specific best practices for yield increase, which is then narrowed down to a technical-sustainable potential.

The **theoretical potential** describes the physical upper limit of the yield increase of residues for a specific crop- or forest-type in an ideal scenario due to defined best practices. There are no limitations for the use of best practice strategies.

The **technical-sustainable potential** is derived from the theoretical potential and takes into account limitations for yield increase of residues due to technical constraints. In addition sustainability constraints are also considered which reduce the use and effect of best practice strategies for yield increase. It is important to note that sustainability here is limited to environmental factors and that socio-economic factors are not covered.

The **realistic potential** is derived from the technical-sustainable potential. Developed best practice strategies for residue yield increase were assessed with regard to their feasibility of application in the EU, Ukraine, Russia and Belarus. The realistic potential is further limited due to identified barriers which prevent or reduce the impact of best practice strategies of residue yield increase. A **barrier** is **only caused by regional aspects**, e.g. policies, social acceptance, regional economic resources.

The estimated realistic potential for agricultural crop residues and biomass from forestry in the European Union, Ukraine, Russia and Belarus is displayed in table 1 below.

Table 1: Realistic potential from agricultural crop residues and biomass from forestry

<table>
<tr><th>Region</th><th>Agricultural crop residues, excluding grass -
Realistic potential (Mt / year)</th><th>Biomass from forestry –
Realistic yield increase (Mt/year)</th></tr>
<tr><td>EU</td><td>74.89</td><td rowspan="3">43.5</td></tr>
<tr><td>Ukraine</td><td>17.67</td></tr>
<tr><td>Belarus</td><td>1.75</td></tr>
<tr><td>Russia</td><td>27.00</td><td>2.57</td></tr>
<tr><td>Total</td><td>121.30</td><td>46.07</td></tr>
</table>

Increasing the yield of agricultural residues

The comprehensive analysis in the agricultural sector focusses on yield increase for straw from cereal (wheat, barley, rye, and oat) and oil crops (rape seed, sunflower), maize stover and cobs, sugar beet leave and wood from wine production. The table below displays the estimated realistic potential for agricultural crop residues. Based on Eurostat data for cultivated area for 2013, about 121 million tonnes of biomass could have been produced by agricultural crop residues.

Additionally, the study estimates the potential biomass from grassland. Grass is not a residue, but offers an enormous potential for additional biomass, as grassland need to be mowed for maintenance. The realistic potential for grasslands is 31.47 million tonnes per year, so that the overall estimated **realistic potential for agricultural crop residues and grassland is 152.77 million tonnes per year.**

Within the EU, residues from wheat, maize and barley contribute most to the realistic potential. Depending on the actual yield, the yield increase effect due to best practice strategies adds up to 16% for straw residues and even up to 21% for sugar beet leaves. The detailed analysis in this study divides EU Member States into regions with low, medium and high yields. In high yielding regions like France the impact is low as French farmers already apply proper crop management. Whereas in Romania, which is a low-yielding country, the impact is higher.

The realistic potential of agricultural crop residues for the EU is provided in the table below.

Table 2: Realistic potential (RP) of agricultural crop residues in the EU

Crop	*Yield increase in RP through best practice strategies*	*High yielding (i.a. France) Mt/year*	*Medium yielding (i.a. Poland) Mt/year*	*Low yielding (i.a. Romania) Mt/year*	*Total Realistic potential (Mt/year)*
Wheat	4-11%	5.095	6.891	19.298	31.285
Barley	7-13%	2.379	4.755	4.856	11.990
Maize	9-16%	3.096	5.020	7.339	15.455
Rye	7-13%	0.130	0.880	0.924	1.935
Oats	7-13%	0.388	0.568	0.504	1.460
Sunflower	9-16%	0.118	0.802	0.832	1.752
Rape	9-16%	0.614	2.113	5.933	8.661
Sugar beet	14-21%	0.047	0.321	0.333	0.701
Wine	13-17%	0.031	0.655	0.558	1.244
Total		11.9	22.0	40.6	74.5

For each **agriculture crop** the authors have developed best practice strategies to increase actual yield for a specific crop and best practice strategies specific to residue recovery rate and harvest technology. Best practice strategies to increase actual yield for a specific crop cover ideal management practices for: **Crop variety, Fertilisation, Crop protection, Cultivation practices, Crop rotation** and **other management practices** like for instance irrigation.

The effects of applying best practices to maximise the yield in all regions have been estimated without taking into account any constraints in a first step. The results represent the "theoretical potential". In a second step the best practice strategies have been optimised in order to mitigate negative impacts on the environment. Table 3 illustrates the optimisation approach for cereals.

Table 3: Comparison of theoretical and optimised best practice strategies for cereals

	Description of management practices	Low yielding (i.a. Romania)	Medium yielding (i.a. Hungary)	High yielding (i.a. France)
Theoretical best practice strategies				
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 170 kg/ha • Entec • Split application (2-3)	• 150 kg/ha • Entec • Split application (3-4)	• 150 kg/ha • Entec • Split application (3-4)
	P fertilisation	80 kg/ha P_2O_5	70 kg/ha P_2O_5	60 kg/ha P_2O_5
	K fertilisation	100 kg/ha K_2O	90 kg/ha K_2O	80 kg/ha K_2O
Crop protection	Fungicides	Dimoxsystrobin, Boscalid, Epoxiconazole		
	Herbicides	Pre emergence, Post emergence 2 times application (autumn, spring), 4 kg/ha		
Optimised best practice strategies				
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 140 kg/ha • Split application (2-3)	• 120 kg/ha • Split application (3-4)	• 120 kg/ha • Split application (3-4)
	P fertilisation	60 kg/ha P_2O_5	50 kg/ha P_2O_5	50 kg/ha P_2O_5
	K fertilisation	70 kg/ha K_2O	60 kg/ha K_2O	60 kg/ha K_2O
Crop protection	Fungicides	Boscalid, Epoxiconazole		
	Herbicides	Pre emergence, Post emergence 2 times application (autumn, spring), 2.5 kg/ha		

Based on literature a sustainable removal rate has been calculated thereby also taking into account soil organic carbon content in the specific regions and the provision of alternative sources of organic matter, with the aim to increase the removal rate without negative impacts. Due to environmental concerns some measures have been excluded from the best practice strategy, like for instance irrigation which might lead to water stress or Clearfield technology. Technical constraints mainly result from general cost limitation, i.e. investment in residue-specific machinery.

The realistic potential for agricultural crop residues and biomass from forests is lower than the technical-sustainable potential. Whereas the technical-sustainable potential for agricultural crop residues excluding grassland in the EU is 104 million tonnes a year, the realistic potential is only 74.89 million tonnes per year. This reduction is due to identified barriers for the deployment of the technical-sustainable potential, which prevent the application of some measures of the specific best practice strategy.

Increasing the yield of biomass from forests

The information base for the forestry section of this study was unfortunately quite insufficient. A harmonised dataset of European Forest Types (EFT) had to be created for the assessment. There is a high potential for yield improvements in forestry, especially in south-eastern Europe, Belarus, Ukraine and Russia. This can be seen not only in the yield increase which is achieved through the application of best practices, but is also evident when it comes to improving the rate of utilisation (e.g., through improved forest accessibility) of forest biomass which is currently readily available.

Table 4 provides the overview of estimations for the realistic potential for biomass from forestry in the EU, Belarus and Ukraine for the most relevant forest types. The highest realistic yield increase of 21% was calculated for boreal forests.

Table 4: Realistic potential for biomass from forestry in EU, Belarus and Ukraine (in tonnes dry matter)*

European Forest Type	Realistic Yield increase			Realistic utilisation rate	Realistic additional harvest potential	
(EFT)	in %	1,000 t/year	t/ha/year	in %	1,000 t/year	t/ha/year
Boreal Forests	**21%**	12,852	0.41	**0%**	0	0.00
Hemiboreal Forests	**15%**	13,236	0.39	**2%**	1,637	0.05
Alpine Forests	**12%**	1,859	0.34	**4%**	507	0.09
Mesophytic Deciduous Forests	**19%**	4,853	0.39	**10%**	2,791	0.23
Beech Forests	**13%**	1,925	0.51	**3%**	326	0.09
Mountainous Beech Forests	**20%**	4,114	0.55	**13%**	2,284	0.31
Thermophilous deciduous Forests	**15%**	1,081	0.15	**2%**	130	0.02
Coniferous forests of the Mediterranean	**17%**	1,992	0.20	**1%**	117	0.01
Introduced tree species Forests	**11%**	1,594	0.26	**0%**	0	0.00
Total	**15%**	43,507	0.30	**2%**	7,792	0.05

* Please note the figures are provided in t/ha here to allow a comparison with the realistic potential of biomass from agricultural residues, whereas the calculation in chapter 3 forestry are in m^3/ha.

A realistic outcome, when applying all yield measures and under consideration of regional barriers, would increase the yield by 15% or 0.3 t/ha/year, whereas the improved utilization rate only results in an improvement of 2% or 0.05 t/ha/year. About 80% of the absolute yield effect can be obtained in the four forest types Boreal Forests, Hemiboreal Forests, Mesophytic Deciduous Forests and Mountainous Beech Forests. These forest types are dominant due to the area and yield within the nine forest types under consideration.

In Russia, when applying all yield measures and under consideration of regional barriers, the yield would increase by 10%, whereas the improved utilization rate results in an improvement of 26%. The Boreal Forests are the dominant forest type which contains about 80% of the area and 60% of the yield.

For the assessment on forests best practice strategies are formulated for the nine most relevant forest types by bundling single yield measures in appropriate combinations. In contrast to the agricultural part the focus of the assessment on forests was clearly on maximising the total wood biomass production and is not limited to particular tree parts. Best practice strategies for forests included measures on different levels:

1. **Species level** (Breeding, Introduction of non-native species)
2. **Site level** (Optimised species-site matching, Water management, Soil improvement)
3. **Forest stand level** (Tree species composition and mixture, Optimised management regime, Coppice improvement, Improving degraded forests
4. **Forest Management level** (Preventing biotic and abiotic damages, Fire management, Improving forest accessibility)
5. **Forest operations level** (Optimised harvesting technique, Use of previously unexploited tree compartments)

The concept of sustainable forest management (SFM), as agreed by the Ministerial Conference on the Protection of Forests in Europe (MCPFE), were always taken into consideration as guiding principles while developing the yield measures and defining best practice strategies. Due to the varying climate, topography, site conditions and forest structure not all of the yield measures can be applied within each forest type. It is important to bear in mind that the majority of management measures conducted in forestry have a long-term perspective of more than 20 years. Changes require more time than in agriculture before they take significant effect.

A number of barriers limit the application of best practice strategies to all recommended regions. As a result, the yield increase and the additional harvesting potential cannot be achieved completely within the timeline of 20-30 years. Whereas in the technical-sustainable potential the additional harvest potential of biomass from forests is 28,431,000m^3/a, it decreases to 13,244,000m^3/a in the realistic potential.

Policy recommendations to overcome barriers

Whereas barrier have been identified in all regions, policy recommendation focus on the EU, where the European Commission can pro-actively strive towards overcoming the barriers.

Two main barriers have been identified that can prevent the realistic potential of **agricultural residues** to be achieved. The main barrier is the lack of a mature market for residues. Subsequently, there is no clear incentive to invest in residue collection equipment and infrastructure. In less developed agricultural regions within the EU the additional barrier is the lack of education among farmers that prevents them from running farms efficiently.

The European Commission could stimulate the residue market by **incentivising demand**, by for instance encouraging Member States to introduce a binding target for advanced biofuels, or by highlighting residue use for heat in power as happens in Denmark as a best practice for residue use and encourage Member States to follow the Danish example.

Monetary incentives could include subsidies per tonne of straw used by biomass conversion facilities as in the USA or promoting showcases to demonstrate added value on farm level. One idea is to fund projects upgrading residues to pyrolysis oil in small-scale installations on-site by the NER300 or Horizon 2020 programme.

In addition **improvement of harvest logistics** by defining a unified format for straw bales and organising a **better exchange of transport supply and demand information** across Europe to use currently long-haul trucks or empty ship loads for residue transport will help to develop a functioning market for residues.

There are more barriers for deploying **forest biomass** than for deploying agricultural crop residues. In absence of a harmonised forest policy within the EU the impact of the EC is limited. However the EC could encourage Member States to apply the proposed measures.

The market for biomass from forests would benefit from creating a **supportive policy framework**, including but not limited to reorganisation of state forest administration and further support toward market-oriented state forest enterprises. Policy and legal framework should allow both state and private forest owners and enterprises to manage forests and market wood according to economic-based performance.

There is insufficient awareness as well as lack of knowledge and educations especially in south-eastern Europe regarding the positive effects of improving forest structures to achieve i) a yield increase and ii) to improve the quality of forest resources. Furthermore there is a lack of social acceptance, at least to some degree, associated with a conflict of interests between the forestry sector and the nature conservation sector (mainly represented by NGOs). Quite frequently it is believed that alterations to the “natural forest” will threaten or lower the existing biodiversity. Overall, options to overcome the lack of knowledge and education on options to increase yield will include a **combination of education training, and research**, concentrated on private forest owners. The European Commission could support this **capacity-building** by launching conferences or workshops on forest biomass yield increase or by funding show-case projects.

Private forests have structural deficits as they are often too small to be regarded as manageable entities. These structural deficit could be removed by **land consolidation**, which however could by highly conflict-prone and expensive, **wood mobilisation and bundling of management activities by forest associations or cooperatives.**

All of the measures discussed here should be applied for a sufficiently long period of time to allow market actors the time to react to improved market conditions.

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1 Introduction

An increased use of biomass for energy requires large quantities of agricultural and forestry biomass. Biomass for energy competes with other uses, such as food, animal feed, pulp and paper, biochemical, biomaterials and biomass used in cosmetics and other products. With a world population expected to grow from the current 7 billion to 9 billion by 2050, pressure on agricultural land and forests will increase. This raises the question whether sufficient biomass is available for bioenergy by 2030 while still securing biomass supply for other sectors. If bioenergy will supply half of the total volume of renewable energy in the EU in 2020 as Member States expect, the quantity of biomass required would equal the total current harvest of forest biomass in the EU[1]. Of course part of the required biomass will come from imports, but nevertheless, the availability of biomass for other sectors should be ensured.

Furthermore sustainability has become a major aspect in the sourcing of biomass. Feedstocks for biofuels are subject to a sustainability regime in the EU and also in other countries, for instance in the USA. Both competing uses and sustainability demands promote the use of residues for advanced biofuel production as well as solid biomass for heat and power. Residues can either result from processing of a feedstock or the cultivation and harvest of a feedstock. By their nature, residues are not the main product aimed for in production. Farmers have therefore focussed on reducing the amount of residues produced whilst at the same time increasing the amount of the main product. Increasing use of residues for energy or material from existing biomass production is seen as a promising way to fulfil the increasing demand for biomass from different sectors and avoiding further pressure on land and food security. Biomass residues occur in agriculture and in forestry, but there a different characteristics that need be to taken into account when discussing how to increase the respective amount of biomass.

It has to be stated that the term residue is not properly defined in current EU legislation. We therefore used our own definition for agricultural residues which is described in chapter 2.3. For forestry the focus was on overall biomass yield increase.

1.1 Objectives and definitions

The aim of this project was to estimate the realistic potential for yield increase of agricultural residues and forestry biomass in the EU, Ukraine, Russia and Belarus (the study area) combined with policy recommendations to promote the deployment of this potential.

[1] New EU Forest Strategy COM(2013)659, p. 2

Analysing the potential to maximize yield in agriculture and forestry needs to consider changes in productivity caused by climate change. Climates change will improve growth conditions in Scandinavia (temperature, vegetation period) and will cause negative effects in south Europe. It will also lead to a shift in the occurrence and site matching of forest types in the future. These general trends can be seen as the basic conditions for the active management of forest and in agriculture. The study – however – is focusing on active management and optimizing strategies here. The relative improvement in yield are more relevant than the absolute. Therefore we have decided to ignore the role of climate change. The second reason is that although it is possible to anticipate a general shift in forest structure associated with climate change, it is very difficult to predict definitive changes in aspects such as temperature and precipitation for a given location and forest type.

In order to reflect the differences between agriculture and forestry the following definitions for maximising the yield of biomass are used within this report:

	Maximising the yield of biomass
from agriculture	1) The yield of biomass from residues of agricultural crops
from forestry	2.1) The yield of total biomass from forest production: Increment or growth of forest trees and forest stands with the primary constraint that the assortments and the amount of round wood is kept or even increased
	2.2) The yield of biomass residues from forest production: Maximising harvesting rate of all different biomass compartments

A stepwise approach was used to identify the realistic potential in the study area, starting with an estimate of the theoretical potential based on crop- and forest-type specific best practices for yield increase, which is then narrowed down to a technical-sustainable potential.
Within this report the different types of potential for yields are defined as displayed in Figure 1.

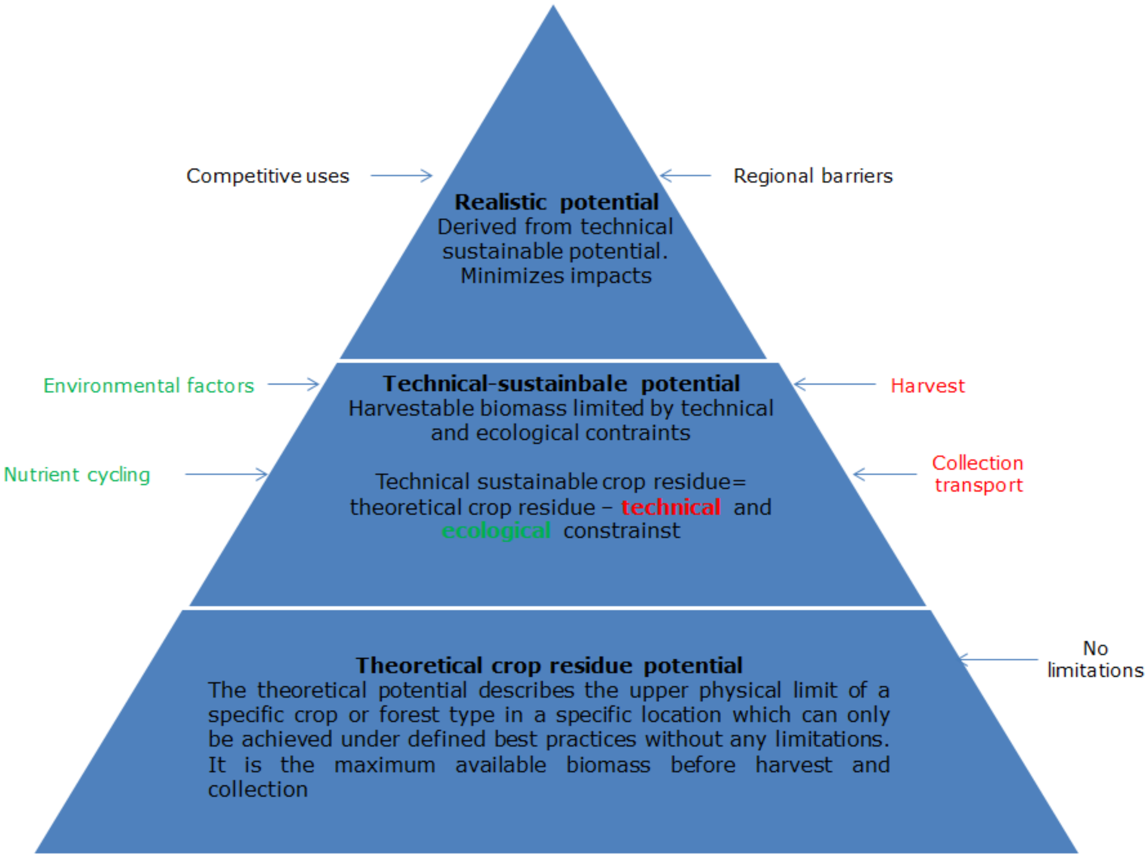

Figure 1: Definition of potentials

Source: (Zeller et al. 2010) (Reicosky and Wilts 2005) Author's own diagram

The **theoretical potential** describes the physical upper limit of the yield increase of residues for a specific crop- or forest-type in an ideal scenario due to defined best practices. There are no limitations for the use of best practices.

The **technical-sustainable potential** is derived from the theoretical potential and takes into account limitations for yield increase of residues due to technical constraints. In addition sustainability constraints are also considered which reduce the use and effect of best practices for yield increase. It is important to note that sustainability here is limited to environmental factors and that socio-economic factors are not covered. A **constraint** is defined as **anything that has a limiting effect on the implementation of a measure to increase (residue) yield) on a general level without taking into account regional aspects**.

The **realistic potential** is derived from the technical-sustainable potential. Developed best practice strategies for residue yield increase were assessed with regard to their feasibility of application in the EU, Ukraine, Russia and Belarus. The realistic potential is further limited due to pre-assessed barriers which prevent or reduce the impact of best practice strategies of residue yield increase. A **barrier** is **only caused by regional aspects**, e.g. policies, social acceptance, regional economic resources. If a machinery for residue collection is widely used in central Europe but is seen as too expensive for farmers in for instance Belarus it is a regional barrier. However if a new fertiliser like Entec is very expensive and therefore hardly used by any farmers in the study area it is a constraint.

It is important to note that the study only focusses on the supply side without assessing the potential for any specific end-use. The assessment was done as a meta-level approach where the EU as well as Russia, Ukraine and Belarus are considered as one region. Ideally the potential should be assessed on more detailed level, but this was beyond the scope of the project. The outcome is an estimated potential to highlight the impact of applying the identified best practice strategies. This report is a guidance for farmers and forest owners on how to increase the yield of residues or biomass from forestry. In addition it outlines regional barriers which prevent the deployment of the technical-sustainable potential. Regional barriers have been identified in a qualitative assessment based on experts' opinion and have been approved by the European Commission.

1.2 How to read this report

Within this report the applied methodology, the findings of the data collection and literature review, as well as an assessment of residue yield increase measures for agricultural crops (chapter 2) and forest types (chapter 3) are outlined in detail. Furthermore, best-practise strategies for yield increase have been developed for both sectors.

In chapter 2 the production, yield and crop management of the ten assessed crops are described, followed by the assessment of agricultural crop residues in chapter 2.3. The residue yields for each crop are summarised in Table 21 in chapter 2.4. A general description of the development of best practice strategies for agricultural residue yield increase is given in chapter 2.7, followed by specific best practice strategies for all ten assessed crops in the subsequent chapters. Chapter 2.15 covers the constraints for the best practice strategies and their application then leads to the technical-sustainable potential in chapter 2.16. Finally the barriers for implementing the best practice strategies in the EU, Ukraine, Russia and Belarus have been analysed (chapter 2.17) to derive the realistic potential (chapter 2.18).

Chapter 3 starts with a detailed description of the applied methodology to establish a baseline for forest types in the study area. The geographic distribution of these forest types is displayed in chapter 3.2.4. Measures to maximise the yield of forests are assessed in chapter 3.3 and are applied to the nine most relevant forest types in the assessed regions in chapter 0 allowing the estimation of the technical-sustainable potential and subsequently the realistic potential (chapter 0).

Policy recommendations to overcome the identified barriers in the EU are outlined in chapter 4.

2 Agricultural residues – Realistic potential for yield increase

The objective of this chapter is the estimation of the theoretical potential for increasing the yield of agricultural residues in the EU, Ukraine, Belarus and Russia by identifying best practices for yield increase of the most relevant crops. The detailed description of best practices will be covered in the final report at the end of the project. The main sources used for this report include Eurostat, literature based data, Food and agriculture organisation (FAO) and National offices' statistics.

2.1 Methodology

The methodology applied in this study to estimate the theoretical yield potential and yield increases for agriculture residues comprises five main data generating processes (see Figure 2). However, in this report, the focus is mainly on assessment of cropping data and assessment of crop residues.
The overall data generation process for this project is listed below (1-5):

1. Assessment of cropping data: It covers the description of selected crops.
2. Assessment of residue data: Assessment of residue-to-crop ratios, factors determining residue yields and estimation of residue yield based on actual grain yield and residue to crop ratio.
3. Best practice strategies for crop residue yield increase: The detailed description of development of best practice strategies for maximizing residue yields will be covered in the final report.
4. Estimation of theoretical potential yield: Through application of best practice strategies, theoretical yield potential will be estimated; however, complete description will be presented in the final report.
5. Assessment of technical- sustainable potential: Sustainability and technical constraints reduce the impact of the best practice strategies.
6. Estimation of realistic potential: Identified regional barriers hamper the full deployment of technical-sustainable potential, and lead to a reduced realistic potential.

In this report the assessment of cropping data (1) and assessment of residue data (2) is covered. In addition, first approaches to describe best practice strategies (3) are presented and the theoretical potential yield (4) is estimated considering these preliminary best practice strategies.

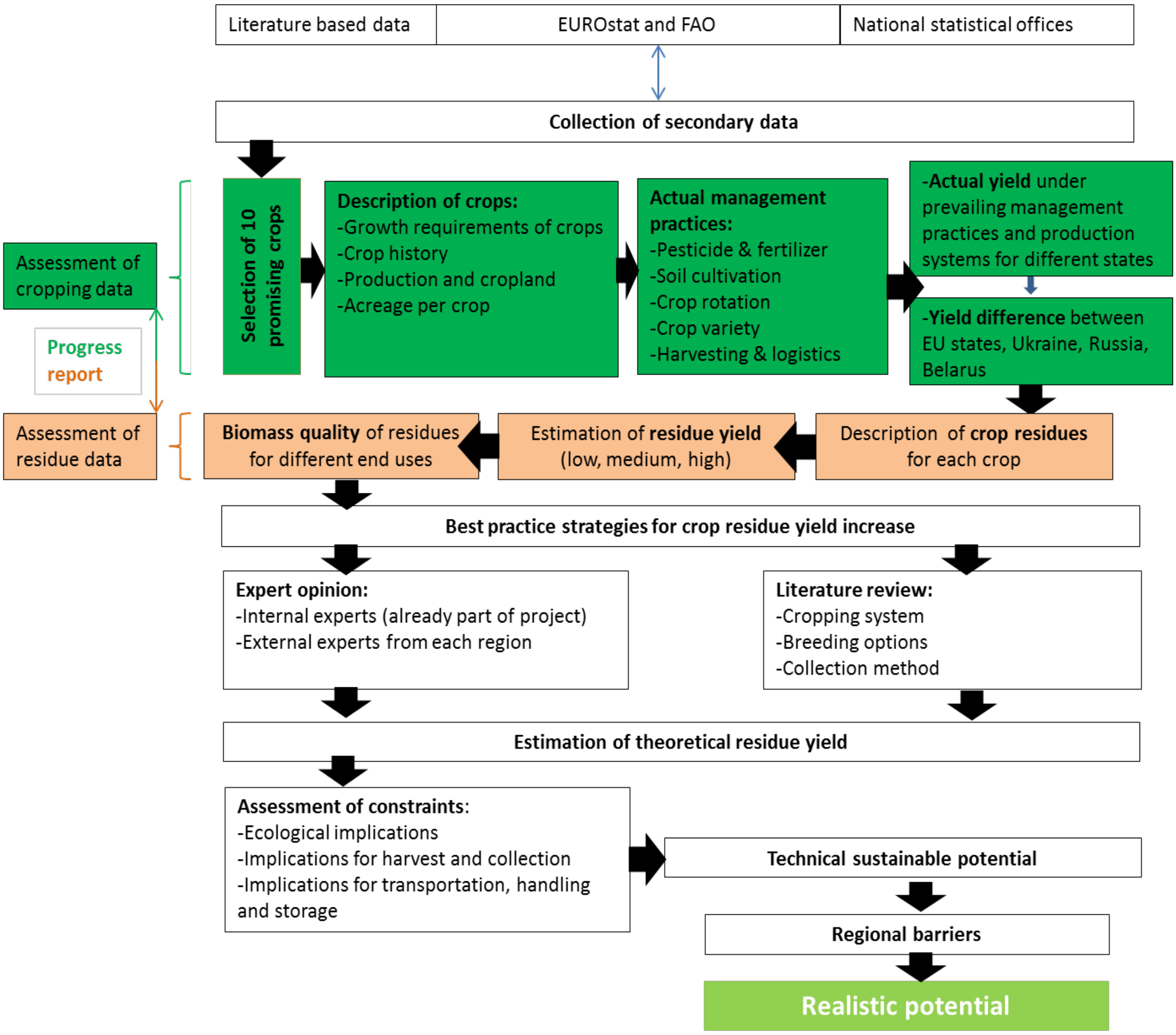

Figure 2: Work flow – Potential analysis for agricultural residues

1. Assessment of cropping data: The main aim of this phase was to select the 10 most promising crops in terms of residue yield potential and to assess the crop yield difference between EU member states (EU-27), Ukraine, Russia and Belarus. Therefore, at first the information about crops was collected. The main source of this information is literature based data, Eurostat, FAO and National statistical offices.

The cropping data assessment covers:

- Description of crops
- Actual management practices for each crop
- Actual yield under prevailing management practices
- Yield difference among the EU-27, Ukraine, Russia and Belarus

The selection of crops was mainly performed with the objective of identifying those crops that can deliver high amounts of residues and by assessing the **crop acreage, crop production, prevailing cropping systems, cropping patterns and crop to residue ratio in EU, Belarus, Ukraine and Russia**. The crops which were selected for agricultural residue yield assessment include cereal crops (wheat, maize, barley, oat and rye), oil crops (rape and sunflower), sugar beet, wine and grasslands. At first step, the selected crops were described with the main focus on crop growth requirements, crop history, and production and cropland area.

The area harvested for each crop was calculated based on % of utilised agricultural area (UAA) from Eurostat.
Eurostat defines **utilised agricultural area** as follows:

"Utilised agricultural area shall mean the total area taken up by arable land, permanent pasture and meadow, land used for permanent crops and kitchen gardens" (Eurostat).

The crop production data from past decades for each crop was collected to show the historical development of crop yield. Inclusion of this step enables us to present the breeding developments in past decades and to reveal the main aims of breeding programs conducted in past decades. In addition, the inclusion of data for past 5-10 years (depending on availability) for each EU member state, Belarus, Ukraine and Russia helped to cover the annul variation in crop production as a result of variable climatic conditions and different management practices.

In a second step, the main focus was on management practices for each crop being grown in EU-27, Ukraine, Russia and Belarus. The literature based information was collected to explain the role of management practices in yield increase over the years. The information was mainly collected for use of pesticides, fertilisation, soil cultivation practices, crop rotation, crop variety, harvesting and logistics. As a part of this step, actual yield was estimated under prevailing management practices and production systems for each EU member state, Ukraine, Russia and Belarus.

Actual yield is defined as: "The yield being achieved under prevailing management practices for a specific region and a specific crop".

The crop yield data for all crops for EU-27, Ukraine, Russia and Belarus was collected mainly from Eurostat and FAO. However, the data about management practices for a specific region was collected from peer reviewed published literature.

2. Assessment of residue data: In the residue data phase, the data was mainly collected for crop residue. It covers:

- Description of crop residues for each crop including residue to crop ratio
- Estimation of residue yield (low, medium and high)
- Biomass quality of residues for different end uses

The description of crop residue for each crop includes availability of residue from each crop, factors affecting the residue yield and sustainable removal rate for each crop. The data about residue yield was mainly collected through published literature. For each crop, the residue to crop ratio were varied greatly, therefore, all the values were collected and used to calculate the residue yield.
The residue yield was calculated as follows:

Residue yield (t / ha) = crop to residue ratio × actual crop yield (t / ha)

The residue yield gives the quantity of residue generated from one hectare in a specific region. For the calculation of total residue yield for a specific crop in a specific region, the following equation was used:

Total residue yield (t / region) = crop to residue ratio × total production (t / region)

Total residue yield was defined as: "The total amount of residue produced from a specific crop in a specific region (e.g. total wheat residue production in Bulgaria)."

For the calculation of residue yield and total residue yield, one value for crop to residue ratio was used. However, for residue yield (t/ha) estimation, three actual crop yield (t/ha) levels were used to cover the yield variation among EU-27, Ukraine, Russia and Belarus. For example, actual crop yield values were taken for all countries in the category of lowest yielding, medium and the highest yielding countries across EU-27, Ukraine, Russia and Belarus.
At the end the total residue yield (t/region) was summed up to make two grand totals which represent:

- Residue production (t/EU-27) in EU-27 by summing up total residue yield of each member state for a specific crop
- Residue production (t/Ukraine + Russia + Belarus) in Ukraine, Russia, Belarus by summing up total residue yield of all three.

After the estimation of residue yield, the data about biomass quality was collected for different bioenergy routes. The main source of the data collected was peer reviewed published articles. The main bioenergy routes which were considered include direct combustion, ethanol production, biogas and Biomass to liquid (BtL). These routes were considered because they are currently the most relevant for energetic use of biomass or are expected to become the most relevant in the near future.

3. Best practice strategies for crop residue yield increase: The yield difference between member states and management practices were compared to identify the potential areas in which crop residue yield can be improved. The main focus was to collect information to explain the differences in yields between EU member states, Ukraine, Russia and Belarus. The development of best practice strategies is performed through:

- Literature review - with the main focus on management practices, breeding options and collection methods
- Expert opinion - including expertise from the University of Hohenheim as well as from other institutions and breeding companies. In the table below, the names of companies and cooperating Institutes are listed.

Table 5: List of Co-operating institutes conducting breeding programs for different crops

Institution	Crop
Norddeutsche Pflanzenzucht Hans-Georg Lembke KG (NPZ)	Rapeseed
University of Hohenheim, Plant Breeding	Maize
LSA, University of Hohenheim, Research group Rye	Rye
LSA, University of Hohenheim, Research group Wheat	Wheat
LSA, University of Hohenheim, Research group Sunflowers and leguminosae	Sunflower
KWS Saat AG	Sugar beet
PZO Pflanzenzucht Oberlimpburg	Oat

The formulation of best practices strategies comprises information collected in previous steps. For example, the information was collected about determinants of crop production, which helped to identify the areas with low crop yield. This yield difference will be explained by collecting the literature based information about optimal management practices for a specific area to achieve maximum yield potential. The increase in yield for main crop product will subsequently lead to increase in residue yield. The focus of these strategies is mainly on cropping systems, management practices, breeding options and collection methods. In addition, it also focuses to find out the improvement options in residue harvest, collection, transport and storage.

4. Estimation of theoretical yield potential: The theoretical yield potential can be defined as the maximum residue yield that can be obtained in a given agro-ecological zone for a specific crop type and variety. The theoretical potential is the yield that can potentially be achieved if no constraints, such as water shortage or inefficient harvest technologies are limiting. The following approach was adopted to estimate the theoretical yield potential (Figure 3).

Actual residue yield per hectare

x

% residue yield improvement through optimized management systems (best-practice strategy)

=

Achievable yield per hectare on regional level (EU, Ukraine, Russia and Belarus)

x

Acreage per crop per region

=

Theoretical production of residues per crop per region in million tons

Figure 3: Approach for the calculation of the theoretical production potential for residues

2.2 Description of assessed crops

The main focus in this chapter is on identification and description of selected crops. The description of selected crops includes historical development of these crops and their yield along with management practices for EU, Ukraine, Belarus and Russia.

Table 6: Selected crops for assessment

Cereal crops	Oil crops	Other
Wheat	Rapeseed	Sugar beet
Barley	Sunflower	Wine
Rye		Grassland
Oat		
Maize		

The selection of the crops with the highest potential for delivering residues for energetic use in the EU-27, Ukraine, Belarus and Russia were mainly based on:

1) **Crop acreage:** crops with significant acreage in the EU, Belarus, Russia and Ukraine were selected.
2) **Residue yields**: residue to crop ratio and the amount of recoverable biomass from residues during the harvest process.
3) **Crop yields:** yield potential of main crop components was also considered as one of the selection criteria for each crop.
4) **Biomass quality:** The properties of residues for different bioconversion routes and the suitability of the residues for energetic use were also considered for selection of crops.
5) **Handling:** The feasibility of harvesting, collection, transportation and management of selected crops were also taken into account.

The residue yield is directly linked with crop yields. Therefore the crop performance needs to be evaluated. The performance of different crops under different climatic conditions and specific management practices is also described in this chapter. There are two main barriers to consider when explaining the yield difference between the EU member states, Ukraine, Russia and Belarus. First, there are natural limitations like climatic conditions and soil properties that cannot be changed. Secondly, there are management practices, which, on the contrary, can be varied and adapted according to the prevailing natural conditions to make cultivation most suitable. Therefore, for each crop category (e.g. grain cereals, oilseeds, beets) the "Lowest yielding member states" (LYM) and the "Highest yielding member states" (HYM) will be compared with each other.

2.2.1 Historical development agriculture

Agriculture has changed considerably since the early part of the 20th century. Over the last decades, there is a strong increase in crop yield worldwide as well as in Europe. The main drivers of this yield increase are; a) breeding programs; b) better management practices. Through breeding programs, new varieties with high grain yield potentials were developed. The development of new varieties for each crop was supported by improved management practices. The combination of improved varieties and better management practices led to realisation of yield potential of each crop. In some cases, along with research work, governmental support prices also contributed towards increased grain yield, which had made agriculture production economically viable for farmers.

In the course of the 1950s, the so-called 'green revolution' took place. With the modern methods of the plant breeding (or plant production) highly productive varieties for the main crop species were developed (e.g., maize, millets, potatoes, soybean) which delivered good yields through efficient use of production resources.
In the 1980s, there was the next revolution called 'The green biotechnology' where knowledge and methods from different life sciences were applied to produce crops with better pest and disease resistance. In aforementioned eras, one of the main contributing factors was developments of breeding methods. The progress in breeding methods and how it evolved over the years is presented in the table below.

Table 7: Historic development of breeding methods

Time period	Progress in breeding methods	Definition
1860-1940	Open pollination	Development of varieties through uncontrolled pollination. Wind, birds, insects or other natural mechanisms are main carriers of pollens
1940-1960	First generation hybrids	Developed through crossing of two genetically different plants
1960-2000	Second generation hybrids	Developed through self or cross pollination of first generation hybrids
2000-now	Biotechnology	Collection of techniques applied to improve the genetic makeup of plants

The example of maize is used to demonstrate the increase of grain yields through development of different breeding methods over the years (Figure 4). However, over the last decades, breeding efforts rather focussed on grain than on straw yield and the share of straw decreased during this time period.

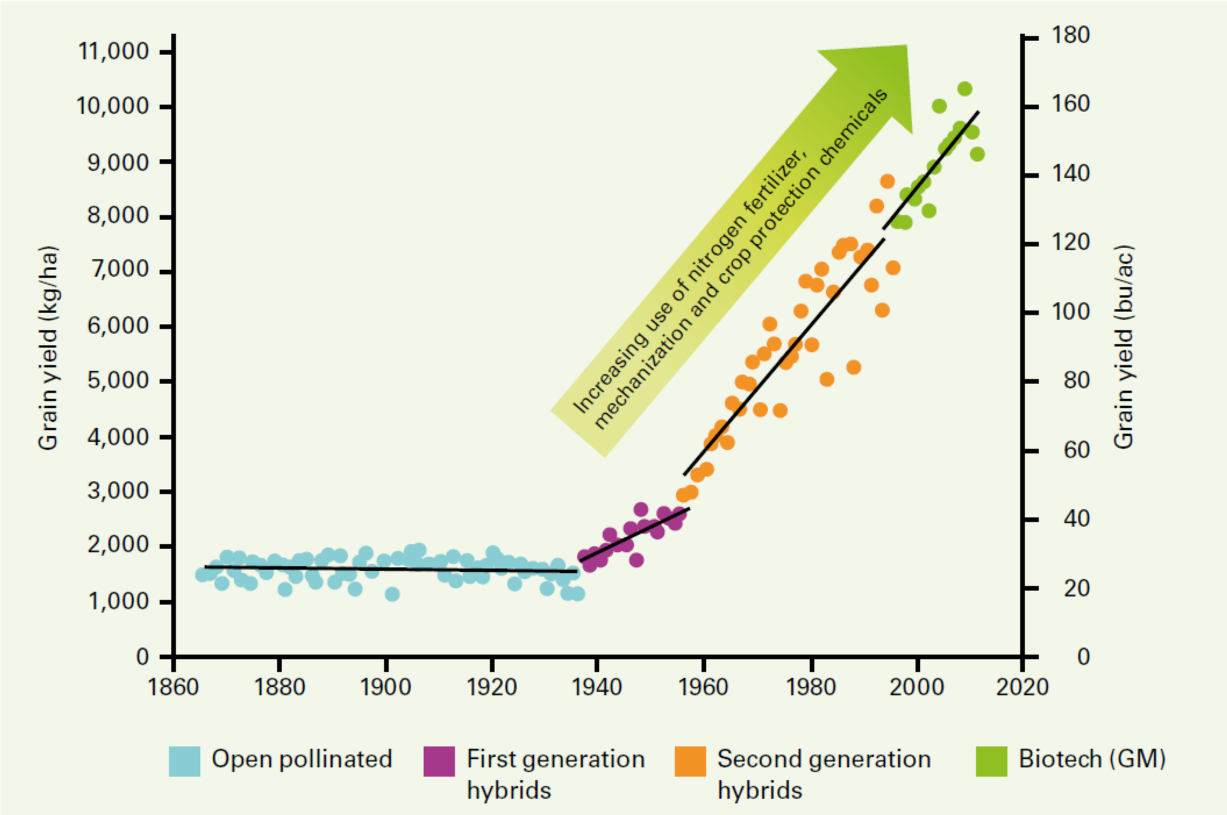

Figure 4: Corn grain yields from 1866 in bushels/acre and kg/ha (Davis S.C, Hay W, and Pierce J 2014)

An example for decreasing share of residues is wheat, where the development of so-called semi-dwarf cultivars strived for increasing grain yield by shortening the straw. During the 1950s, breeding of adapted semi-dwarf wheat cultivars was a major technological advancement. For instance Gaines winter wheat was released during 1961. Release of new wheat cultivars resulted in improved grain yields, shorter plant height, and improved lodging resistance compared to traditional standard height varieties. The straw weights of short semi-dwarfs were lower than standard-height varieties and medium-tall semi-dwarf, such as Gaines, produced straw weights similar to the standard-height varieties (Langer and Hill 1982). Ratios of straw to grain for standard height varieties ranged from 1.9 to 3.0 and for semi-dwarf varieties ranged from 1.5 to 1.7.

Langer and Hill (1982) reported that dwarf and semi-dwarf wheat varieties had lower straw yields because a higher percentage of the total biomass was in the form of grain. Over the years, the harvest index[2] has continuously increased (Langer and Hill 1982; McClellan, McCool, and Rickman 2012; McClellan, Nelson, and Sporcic 1987) and in the same time straw length decreased. Smill (1999) also reported the same trends over the years for wheat yield development (Smil 1999). Traditional wheat varieties cultivated at the beginning of the twentieth century were approximately 1 m tall and had a harvest index mostly between 0.25 and 0.35, producing 1.8-3.0 times more crop residue than grain (Singh and Stoskopf 1971). Now the harvest index is 0.5 or even higher (Bassam 2010).

Another study (Ahlemeyer and Friedt 2012), conducted by a group of scientists has examined 90 winter wheat varieties at five locations within Germany. The outcome of the study shows that the progress in yield is due to the significant rise of the grain number per ear. The average annual increase of 34 kilogrammes per hectare resulted from progress in breeding. In Figure 5 and Figure 6, the data about the increase in grain yield and decrease in plant height in wheat is presented.

An early starting ear emergence of new varieties can be seen as a better adaptation to the changing environmental conditions. These cultivars begin about one day earlier with the ear emergence. This accelerates the ripening of the grain and allows an early harvest. However, a former ear emergence could also lead to a lengthening of the average vegetation period. The plants would get more time to fill their grains.

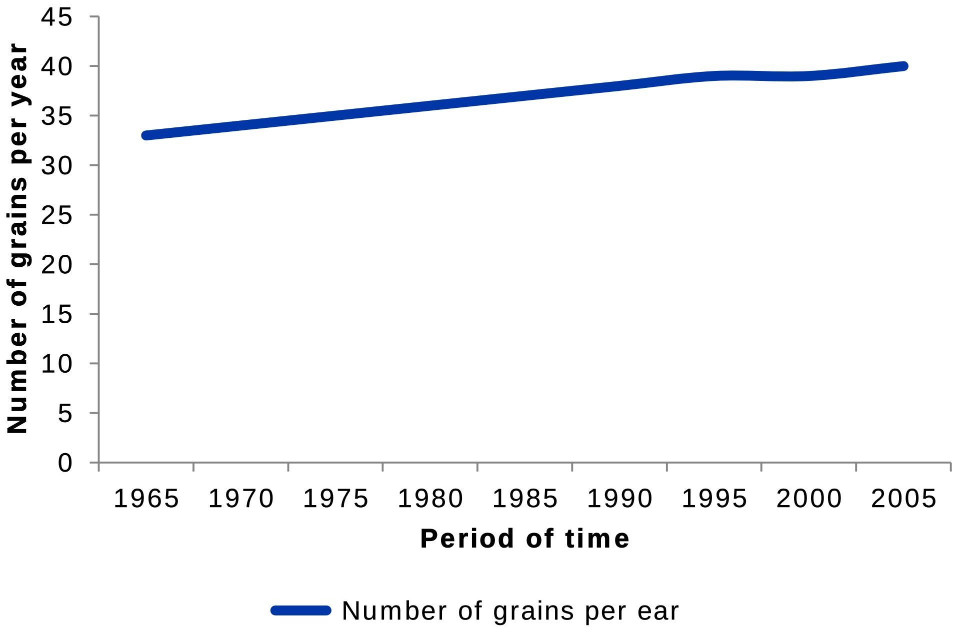

Figure 5: Development of the number of grains per year from 1965 to 2005.

[2] Harvest index: Ratio of grain to total biomass

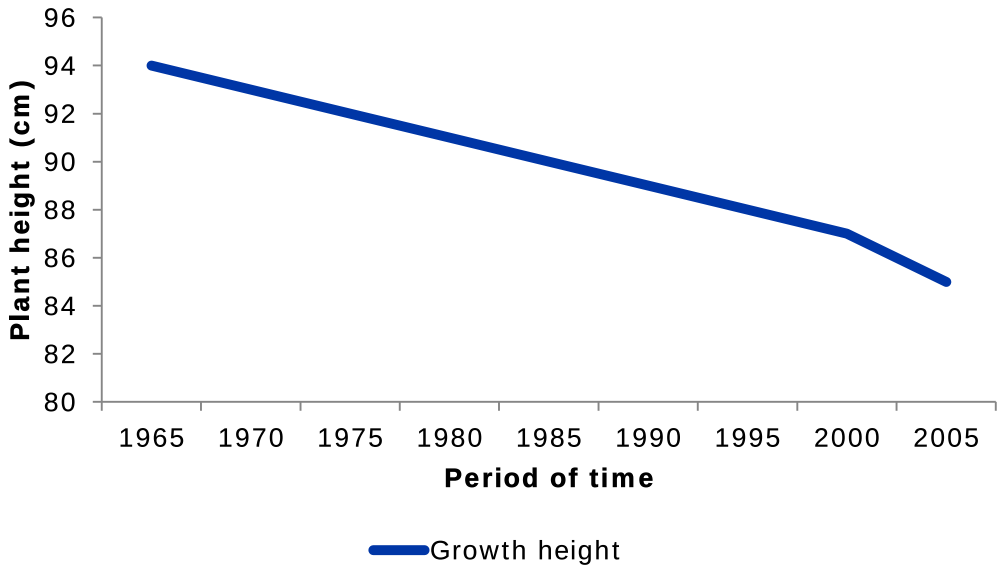

Figure 6: Development of the growth height from 1965 to 2005 (Ahlemeyer and W. Friedt 2012)

The study by Ahlemeyer & Friedt, 2012 also revealed that more than 30 percent of wheat yield development in winter wheat between 1966 and 2007 was achieved through selection of improved varieties (Ahlemeyer and W. Friedt 2012).

The role of breeding efforts and agronomic practices in improvement of wheat yield over the years is presented in the following table.

Table 8: Increased performance of wheat from 1952 to 1993

Period	Mean yield (dt/ha)	Increased performance (Sum dt/ha)	Breeding efforts (dt/ha)	Agronomic practices (dt/ha)	Share of breeding efforts (%)	Share of agronomic practices (%)
1952-93	57.3	0.98	0.49	0.49	50	50
1952-69	44.8	0.57	0.34	0.23	59	41
1952-75	48.8	0.9	0.4	0.5	44	56
1952-86	53.7	0.95	0.42	0.53	44	56
1970-86	62.2	1.28	0.41	0.87	32	68
1986-93	75.6	1.27	0.98	0.29	77	23

Source: Hartl, L. (2010): Zuchtmethoden und –erfolge in der Getreidezüchtung. LfL Pflanzenbau

Along with developments in breeding processes, the cropping system also changed over the years. This was also supplemented with better crop protection practices and improved mechanisation. In the 60s, rye, winter wheat, winter barley and potatoes dominated in cultivation.

Along with development in breeding and management practices, climatic conditions also played a key role in defining cropping system for a specific region (Hoffmann et al. 2009).

2.2.1.1 Wheat

Wheat is one of the first cereals known to have been domesticated, and wheat's ability to self-pollinate greatly facilitated the selection of many distinct domesticated varieties.

Figure 7: Illustration of wheat plant along with straw and grain (http://en.wikipedia.org/wiki/wheat)

Worldwide, most of the cultivated wheat varieties are hexaploids (*Triticum aestivum*). Wheat is a tall, annual plant with a height ranging from 0.61-1.83 m in early varieties. The plant is made up of leaves surrounding a slender stalk that terminates in spikes, or ears, of grain at the top of wheat. Each spike, ear, of grain is made up of spikelets, which encloses the wheat grain in between the lemma and the palea. The grain may also vary in its length of brush hairs, either long or short. Cultivated wheat is most commonly grown with physical characteristics of fusiform spikes, which are awned (bearded) and can be easily threshed (Valant 2010).

Growth requirements: Wheat, like most grains, thrives in cool climates and tends to do poorly in warm, humid climates, which often ruins the crop through diseases. The growing period of wheat lasts approximately 90 days (Katz and Weaver 2003). Wheat also ideally requires land free of competition (weeds), which could draw its water supply and potentially block sunlight; however, it has the ability to compete with weeds (Kiple and Coneè Ornelas 2000).

Domesticated wheat requires nitrogen-rich soils, and supply of macronutrients, mainly potassium, lime, and phosphoric acid (Katz and Weaver 2003). Wheat can survive in regions with low rainfall

mainly because their roots have the ability to take up nutrients from dry upper soil as long as they have access to moist lower soil (Bowden, Ma, and Rengel 2006).
Wheat, including other cereal crops, can also tolerate high levels of copper and zinc, making them very stable crops (Valant, 2010) but wheat has aluminium toxicity in low pH soils (soils with high acidity).

Crop History: Figure 8 illustrates the historical yield development (1961 to 2010) of grain of wheat, which was selected as one of the main cereal crops for this project. The blue line demonstrates the worldwide crop yield, the red one represents the yield of the European Union (EU-27), the purple line represents Russia and the green one is for the crop yield of the Ukraine.

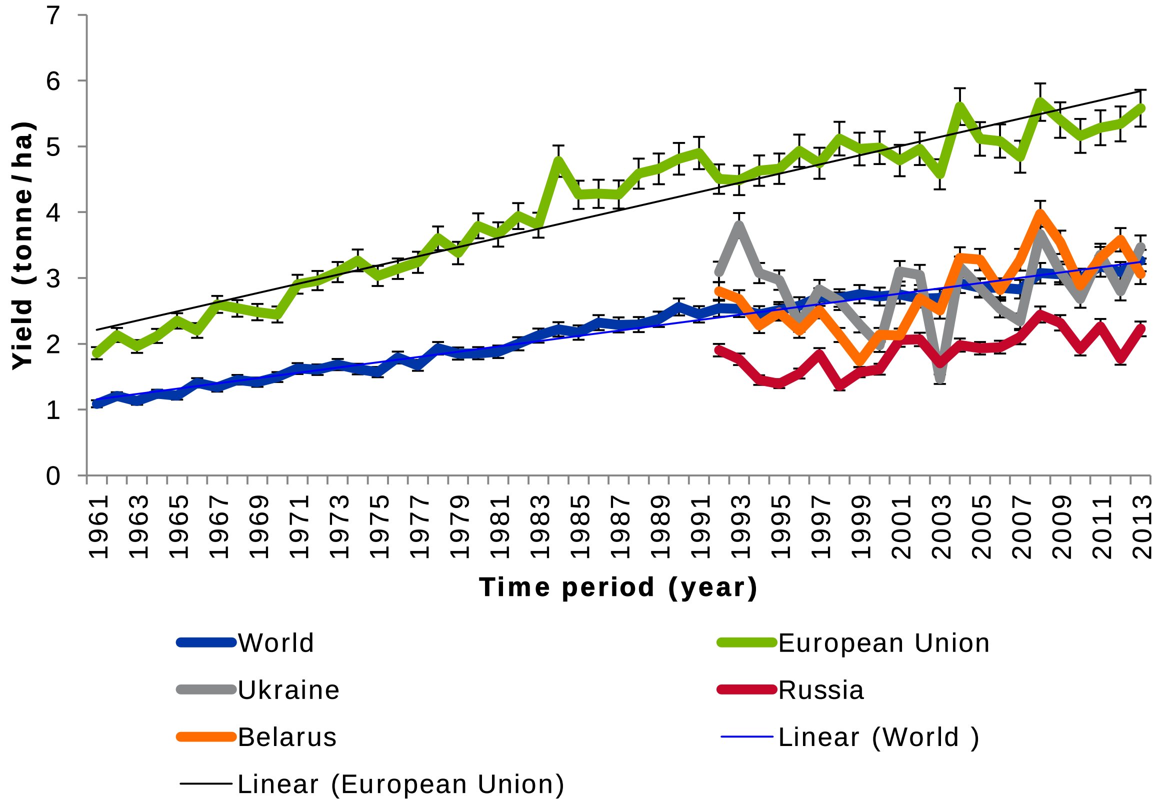

Figure 8: Grain yield development of Wheat in 1961–2013. Source: FAOSTAT, Author's own diagram

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

In 1961, the World average grain yield of wheat was 1.1 t/ha, the European grain yield was 1.3 t/ha and the yield of the European Union (EU-27) was 1.9 t/ha. After 1980, the crop yield doubled and in 2013 reached 3.3 t/ha on a global average, and 5.9 t/ha in the European Union.
Also in Russia, Ukraine and Belarus, there is an increase in yield from 1992 to 2013 with large variations over the years.

Production and cropland: During 2012, the area harvested in EU-27 for wheat was 25,284,952 hectares with production of over 135 million tonnes of grains. France holds the top position in terms of production with a production of 40.3 million tonnes on a harvested area of 5.3 million hectares. Russia produced over 37 million tonnes while Ukraine produced over 15 million tonnes in the same year (2012) (FAOSTAT).

The biggest wheat producers across the Europe between year 2011 and 2013 are shown in Figure 9.

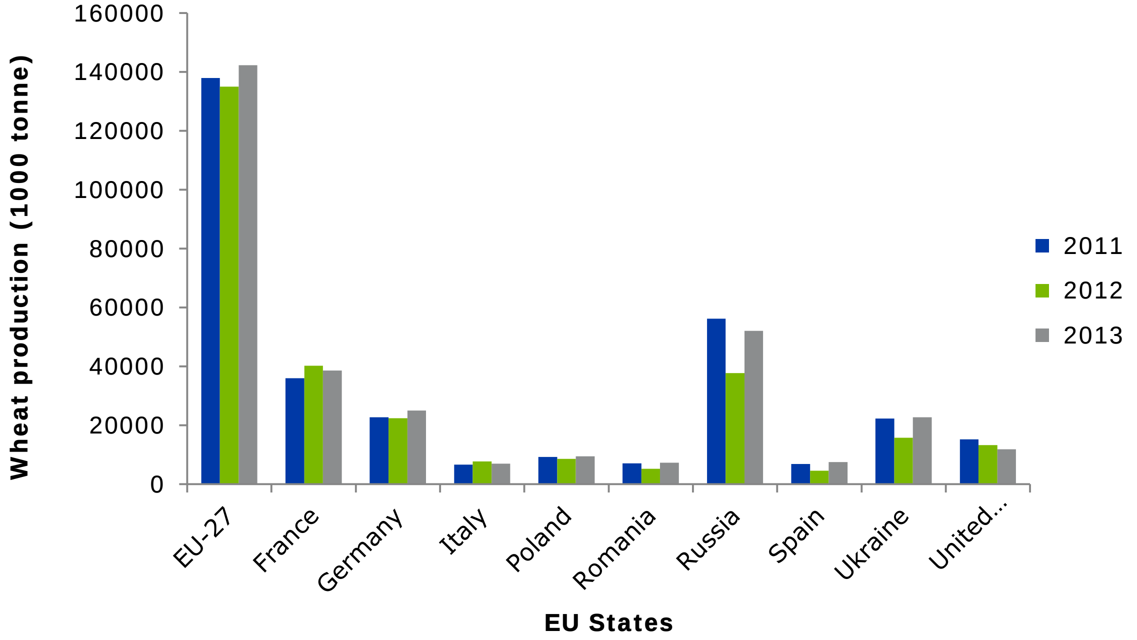

Figure 9: The biggest wheat producers (1000 tonne) in the EU-27, Ukraine, Russia and Belarus between 2011 and 2013.

Yield level: The study area (EU-27, Ukraine, Russia, and Belarus) can be divided into three main groups based on current per hectare wheat production. It includes:

a) a group of countries with lowest per hectare wheat yield production;
b) the countries with medium level of per hectare wheat production;
c) Third group includes countries with the highest wheat grain yield production.

For the countries falling in the category of lowest yielding countries, the average per hectare yield is < 3.5 t/ha, for the countries in medium yielding countries, the average per hectare yield is 3.5-7.0 t/ha. The mean per hectare yield for the highest yielding countries is > 7.0 t/ha.

Within EU, the lowest per hectare wheat grain yield is obtained in Portugal with the value of 1.6 t/ha, the country with the highest per hectare wheat grain is Ireland with yield of 8.8 t/ha.

Table 9: Wheat yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 3.5	Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Portugal, Romania, Spain, Belarus, Russia, Ukraine
medium	3.5 – 7.0	Austria, Finland, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Slovakia, Slovenia, Sweden
high	> 7.0	Belgium, Denmark, Germany, Ireland, Netherlands, United Kingdom, France
lowest	1.6	Portugal
highest	8.8	Ireland

There are two main barriers to consider when explaining the yield difference between the EU Member States (EU-27), Ukraine, Russia and Belarus. First, there are natural limitations like climatic conditions and soil properties that cannot be changed. Secondly, there are management practices, which, on the contrary, can be varied and adapted to the prevailing natural conditions to make cultivation more productive. For *cereals* Romania was selected as a representative for lowest yielding countries and France was selected for highest yielding countries. The yield difference between two countries can be explained mainly through difference in management practices.

Crop management: Nitrogen should be applied in three fertiliser applications to prevent tendency to lodge (bending of the stalk of the plant or the entire plant) and diseases. The overall requirements are 80 to 210 kilogrammes per hectare (depending on soil type) which are divided into three applications: 1st and 2nd application in the spring, 3rd application as late-nitrogen fertilisation before ear emergence (the main stage used in determining the heading date of crop). The basic fertilising with phosphate should be 30 to 85 kilogrammes per hectare and potassium about 20 to 60 kilogrammes per hectare and be given favourably in an application before the sowing.
A cultivation portion of 25% of wheat in the crop rotation (every 4 years on the same field) is recommended. Ideal previous crops are root crops like potatoes and sugar beets, oil seeds, maize and legumes. Inappropriate crop rotation choice can lead to infestation by stalk break illness, blackleg, little grain cyst ale (nematodes) or wheat gall midge (Bowden, Ma, and Rengel 2006).

2.2.1.2 Barley

Barley (*Hordeum vulgare* L.) belongs to a grass family and is considered as one of the main cereal grains (Figure 10). It has for instance been used as main staple food in Tibetan cuisine and is also used as animal fodder. The other main uses of barley include production of distilled beverages and supply of fermentable material for beer production.

Figure 10: Illustration of barley plant (http://en.wikipedia.org/wiki/Barley)

Growth conditions: Barley can grow under wide range of environments, including extremes of latitude and longitude. In general, barley is a cool season crop and grown best in temperatures of 15-30 °C, but it can tolerate high temperatures if humidity is low. It needs a mild winter climate and does better in dry, cool climates than in hot, moist areas (Poehlman, 1985), (McLeod, 1982), (Madson, 1951), (Anderson and Reinbergs 1985; Stoskopf 1985), (Stoskopf, 1985), (McLeod, 1982; Poehlman, 1985), (McLeod 1982).

Barley is well adapted to a wide range of soils. Barley develops best on coarse-textured, well drained, fertile loams or light clay soils with annual rainfall ranging from 325 mm to 750 mm. It can tolerate loam to heavy soils (Madson, 1951). Barley tolerates alkalinity, but does not grow well on very acid soils (McLeod, 1982), e.g., below pH 6.0 (Stoskopf, 1985). Barley is particularly sensitive to soil acidity compared to the other cereals and also sensitive to aluminium and Boron toxicity, which is linked to acidic soils. Barley has a low requirement for lime (McLeod, 1982).

Crop history: In 1961, the World grain yield of Barley was 1.3 t/ha and the yield of the European Union (EU-27) was 2.3 t/ha. The data for Russia and Ukraine starts at 1992 with per hectare crop yield of 1.9 t/ha and 3.1 t/ha, respectively. From 2004 to 2012, per hectare yield of Belarus was higher that one of world, Ukraine and Russia but less than European Union (EU-27). The increase has not been taking place in the same speed like Wheat crop yield. In 2013, the World barley yield was 2.9 t/ha, and the European Union (EU-27) yield was 4.8 t/ha. Russia and Ukraine had the lowest barley yield in comparison to EU-27 and World with 1.9 t/ha and 2.3 t/ha, respectively. Large variation was observed over the years in per hectare yield for Ukraine, Russia and Belarus (Figure 11).

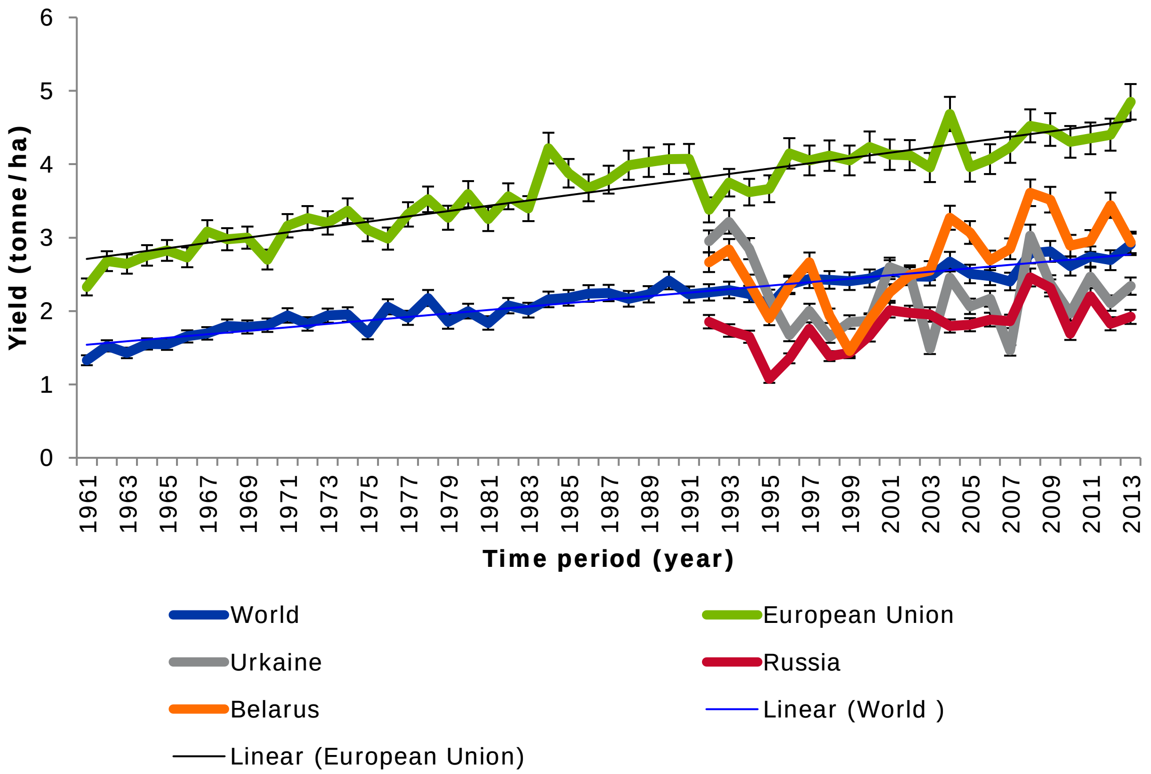

Figure 11: Grain yield development of Barley in 1961–2013. Source: FAOSTAT, Author's own diagram

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

Production and cropland: In 2011, the barley production in EU-27 was over 51 million metric tonnes with an average yield of about 4.5 t/ha and area harvested of over 11.5 million hectares across the member states (EUROSTAT). In 2011, Russia was the highest producer of barley in comparison to EU member states with almost 17000 metric tonnes, while in Malta lowest production was recorded, with 2100 metric tonnes (FAOSTAT).

Figure 12 shows the largest producers of barley in the EU-27, Ukraine, Russia and Belarus.

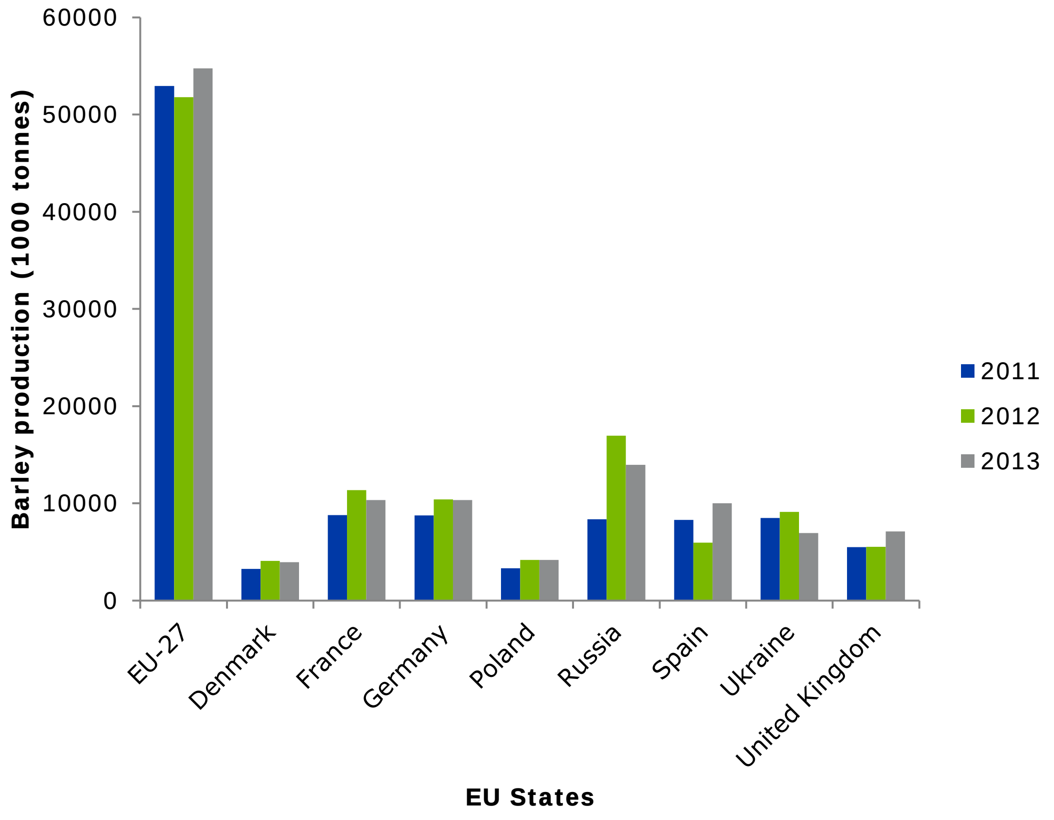

Figure 12: Largest producers of Barley in the EU-27 including Russia and Ukraine during 2011–2013 (in kt).

Yield level: The already defined categories (lowest, medium, highest) for wheat based on per hectare yield were used for barley as well. For the countries falling in the category of lowest yielding countries, per hectare yield is <3.0 t/ha, for the countries in medium yielding group, the per hectare yield is 3.0-6.0 t/ha. The mean per hectare yield for the highest yielding countries is > 6.0 t/ha. Within EU, the lowest per hectare barley grain yield is obtained in Cyprus with the value of 1.6 t/ha, the country with the highest per hectare barley grain yield is Belgium with yield of 8.0 t/ha.

Table 10: Barley yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 3.0	Cyprus, Estonia, Greece, Latvia, Lithuania, Portugal, Romania, Spain, Russia, Ukraine
medium	3.0 – 6.0	Austria, Bulgaria, Czech Republic, Denmark, Finland, Hungary, Italy, Luxembourg, Poland, Slovakia, Slovenia, Sweden, United Kingdom, Belarus, Malta
high	> 6.0	Belgium, France, Germany, Ireland, Netherlands

Yield range	Average yield (t/ha)	Country
lowest	1.6	Cyprus
highest	8.0	Belgium

The yield difference between within the EU-27, Russia, Ukraine and Belarus is mainly because of natural barriers such soil quality, variation in rainfall and temperature, management practices and available machinery.

Crop management: The nitrogen requirements are 65 to 150 kilogrammes per hectare which are normally divided into several applications: 1st and 2nd application in the spring, 3rd application as a nitrogen-late fertilisation before ear emergence. The basic fertilising with phosphate should be 30 to 75 kilogrammes per hectare and potassium about 20 to 55 kilogrammes per hectare (Savoy and Joines 2009). Of the cereals, barley has the poorest resistance to lodging (Stoskopf, 1985).
Pathogens, particularly fungi, viruses and nematodes (multicellular animals or roundworms), can lower grain yield and quality. Disease management strategies include using resistant varieties and rotation without non-host crops (Olsson and Gerhardsson 1992).

Recommended seeding rates are typically from 67.2-100.8 kg/ha (Madson, 1951; McLeod, 1982). Higher seeding rates of barley may be appropriate where rainfall is heavy (Stoskopf, 1985), but low sowing densities do not necessarily lead to less water use because vegetative growth will be increased (Poehlman, 1985). High-density plantings of barley were better at suppressing weeds than were intercropped barley and field pea. Weed suppression appeared to be due to competition for soil moisture (Mohler and Liebman 1987). Inclusion of barley, oat, or rye in a mix of cover crops along with vetches and beans appears to reduce infestation by the weed called common fiddleneck (Amsinckia intermedia) (Bugg et al. 1991). Long-term barley monoculture led to development of low quality soils that decreases the production of barley (Olsson and Gerhardsson 1992).

Low sowing densities do not necessarily lead to less water use because vegetative growth will be increased (Finch and Sharp 1983). Some barley varieties are liable to lodging at high sowing densities, e.g. cultivar 'Beecher' (Finch and Sharp 1983). Shallow seeding is feasible in areas with high soil moisture and promote to more rapid emergence and declined incidence of root rot disease (Stoskopf, 1985). Seeding dates range from October - January (Madson, 1951). Winter varieties may be sown from September through February, and spring varieties from April–May. To seed barley, drills with disk or double-disk openers should be used (Baldbridge et al. 1985).

Barley is physiologically mature when kernel moisture decreases to about 40%, but kernels are largest if harvested at 35%. However, allowing barley to stand until the safe level is reached typically leads to shattering; shatter-resistant cultivars (cultivars with low yield losses at maturity because of less susceptibility to shattering) are especially important, where relative humidity can drop quickly following maturation (Mohler and Liebman 1987).

2.2.1.3 Rye

Rye (*Secale cereale*) belongs to grass family, which is mainly used grain fodder and also sown as cover crop (Figure 13). Rye is one of the species in cereal crops which grow wild in central and eastern Turkey.

Figure 13: Illustration of rye plant (http://en.wikipedia.org/wiki/rye)

Growth conditions: Cereal rye is cultivated in the cool temperate zones or at high altitudes (Munz, 1973). It is the most winter hardy of all small cereal grains (Stoskopf, 1985). Its cold tolerance surpasses that of wheat (Stoskopf, 1985). A minimal temperature for germinating cereal rye seed varies from 1 to 5 °C; optimal range has been given as 25 to 31 and 13 to 18 °C. Cereal rye is one of the best crops under low fertility and extreme winter temperatures (McLeod, 1982). Rye demonstrates the widest geographic distribution of all cereal crops (Stoskopf, 1985): production is possible throughout the temperate and subtropical zones, within the Arctic Circle, and in southern Chile.

In the Himalayan mountains, cereal rye can be produced at 4,300 m elevation (Stoskopf, 1985). Its wide range of adjustment is due to its great winter hardiness and tolerance of marginal soils: it can be grown in soils too acidic for wheat (Stoskopf, 1985) and is more drought tolerant than oat. The range of best suitability is pH 5.0-7.0, but tolerance is between 4.5 and 8.0 (Stoskopf, 1985). It has a low requirement for lime (McLeod, 1982). According to McLeod (1982), cereal rye grows best on well-drained loam or clay loam soils, but even heavy clays, light sands, and infertile or poorly drained soils are practicable. It will grow on soils too poor to produce other grains or clover (McLeod, 1982). Cereal rye can outyield other cereals on droughty, sandy, infertile soils (Stoskopf, 1985).

Crop history: In 1961, the World crop yield of rye amounted 1.2 t/ha, and the yield of the European Union (EU-27) was 1.7 t/ha. The increase in crop yield of rye was not as sharp as the wheat crop yield. In 2013, the World rye yield was 2.8 t/ha, and) 3.9 t/ha in the EU-27. The yield of Ukraine and

Russia (2.3 t/ha and 1.9 t/ha, respectively) was lower than EU-27 and world (Figure 14). The yield of Belarus was highest at beginning but then decreased over the years.

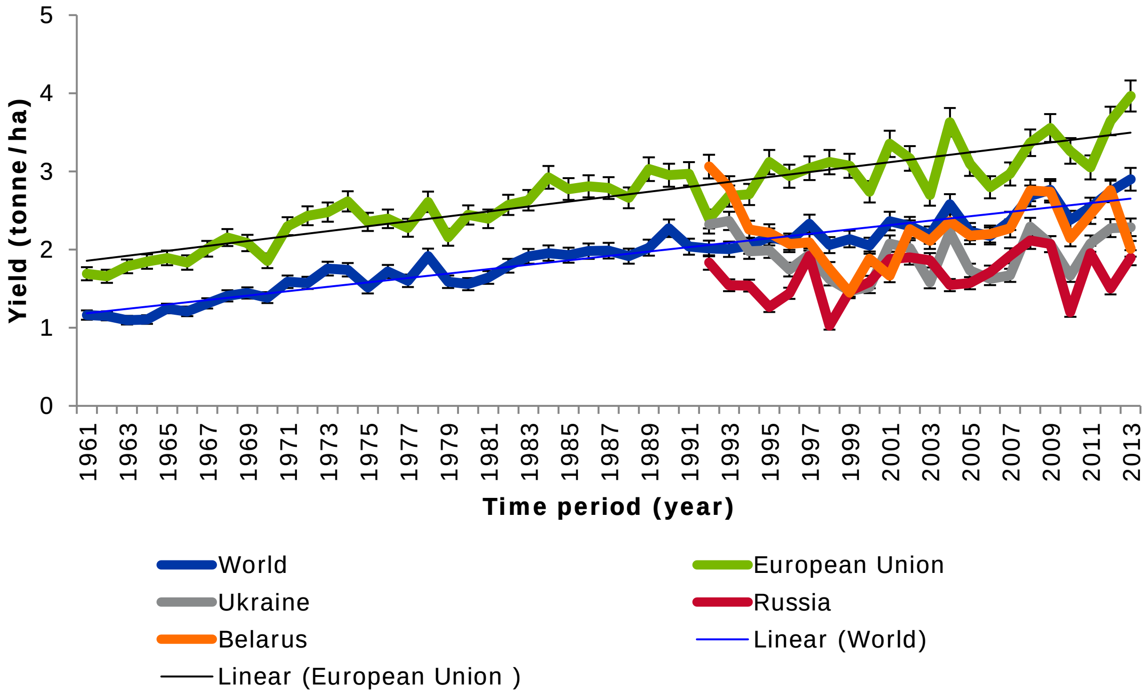

Figure 14: Grain yield development of rye in 1961–2013. Source: FAOSTAT, Author's own diagram

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

Production and cropland: Germany and Poland have been the leading producers of rye among the EU-27 member states in the last 4-5 years. In 2013, Germany produced about 4.7 million tonnes of Rye from harvested area of 0.78 million hectares with a crop yield of about 6 t/ha (FAOSTAT). During, 2013 the yield of Russia was almost equal to Poland, whereas yield for Ukraine and Belarus was lowest among all (Figure 15).

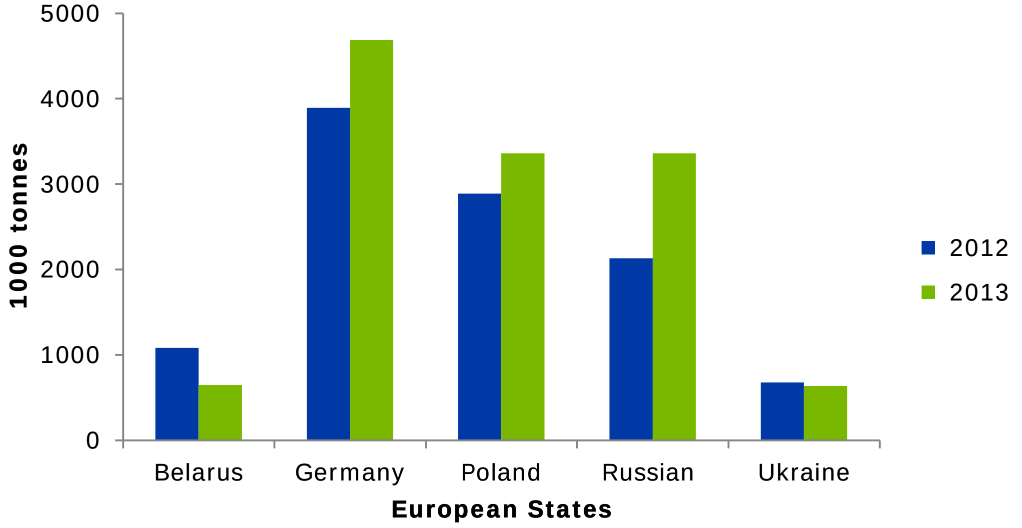

Figure 15: Largest producers of rye in the EU-27 including Russia and Ukraine during 2011–2013

Yield level: Rye areas were divided into different categories (lowest, medium, highest) based on per hectare yield. For the countries falling in the category of lowest yielding countries, the per hectare yield is < 2.4 t/ha, for the countries in medium yielding group, the per hectare yield is 2.4-4.8 t/ha. The mean per hectare yield for the highest yielding countries is > 4.8 t/ha. Within EU, the lowest per hectare rye grain yield is obtained in Portugal with the value of 0.9 t/ha, the country with the highest per hectare rye grain yield is United Kingdom with yield of 9.6 t/ha (Table 11).
For Cyprus and Malta, no data is available for rye production.

Table 11: Rye yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 2.4	Bulgaria, Lithuania, Romania, Spain, Belarus, Russia, Ukraine, Hungary, Portugal, Greece,
medium	2.4 – 4.8	Austria, Finland, Czech Republic, , Italy, Latvia, Poland, Slovakia, Slovenia, Estonia, Netherlands ,Ireland
high	> 4.8	Denmark, France, Germany, Luxembourg, United Kingdom, Belgium, Sweden
lowest	0.9	Portugal
highest	9.6	United Kingdom

The yield difference between states can be explained through difference in agroecosystems. The Mediterranean basin is confronted with lower crop yields, variability in yield and run-off, and reduction of suitable land for traditional crop growth. Biodiversity patterns and ecological functioning of agroecosystems are still not sufficiently known for many areas, in order to guide sustainable management. During the last 50 years the policy followed by the governments of Mediterranean countries aimed at the unification of small agricultural fields into expanded monocultures to permit the use of large machinery. Crop rotations have become simpler or substituted by monocultures like cereals and olive groves. Intensive olive cultivation threatens traditional agroecosystems such as winter cereals, extensively grazed pastures and low-input olive farming. The replacement of the traditional mosaic landscape with intensive olive monocultures led to a substantial reduction of biodiversity (Sokos et al. 2013). In north western Italy, landscape simplification, expansion of maize cultivation, winter ploughing practices, and conversion of highly diverse grasslands to tilled lands caused the decline of many bird species. The shift from rain-fed to irrigated crops in Mediterranean Europe has had major consequences on the timing of agricultural practices, with a change from autumn to spring-sown crops (Sokos et al. 2013). The low yield in Belarus, Russia and Ukraine could be due to crop management practices such as fertilisation, weed and pest control. The difference in yield is also due to awareness among farmers, in highest yielding countries such as Germany, France etc., farmers are usually well aware of the development taking place in the field of crop production.

Crop management: The nitrogen requirements are 60 to 150 kg/ha which are divided into three applications: 1st and 2nd application in the spring, 3rd application as a nitrogen-late fertilisation before ear emergence. The basic fertilising with phosphate should be 30 to 80 kg/ha and potassium about 20 to 60 kg/ha(Savoy and Joines 2009).
Inclusion of barley, oat, or rye in a mix of cover crops along with vetches and bell beans appears to reduce infestation by common fiddleneck (*Amsinckia intermedia*).

Cereal rye monocultures reduced residual soil N by 62 and 37%. Bicultures with cereal rye and legumes reduced residual soil N by 44 and 15% for the same years.
The best method to plant rye following potatoes, corn, soybeans, and other row crops, is to drill the seed one inch deep using a conventional grain drill machine. Another satisfactory technique is to broadcast the seed followed by a shallow disking or harrowing. Recommended seeding rates are: 90-112 kg/ha) and 100 to 180 kg/ha for green manure (McLeod, 1982). According to (Stoskopf, 1985), cereal rye is normally seeded at 112 kg/ha but when seeded late the rate should be increased up to 336 kg/ha to achieve rapid and complete vegetation cover and reduce erosion.
Optimal crop rotations vary between rye and root crops or foliage plants. Favourable previous crops are early-field-removing crops as for example barley and oat or potatoes. Rye is a positive previous crop for other cereal crop varieties, because it is harvested early in the year, maintains relatively low chances of diseases and pests.
Some suppressive effects of cereal rye may relate to tie-up of soil nitrogen by decomposing rye residues. Cereal rye is susceptible to glyphosate (Bugg et al. 1991) and to paraquat. Grain of cereal rye can be harvested like wheat, but the large amount of straw makes harvest less efficient (Stoskopf, 1985).

2.2.1.4 Oat

The scientific name is *Avena sativa* L.; however, cultivated oat is of polyphyletic origin. Oat is an erect annual grass. There are both hulled and hull-less varieties of oats available. It has moderate to heavy density of growth and shows a succulent growth type (Madson, 1951).

Figure 16: Illustration of oat plant (http://en.wikipedia.org/wiki/Oat)

Oat varieties usually have a lower ability to produce tillers than do barley varieties (Stoskopf, 1985). Of the cereals, barley and oat have the poorest resistance to lodging (Stoskopf, 1985).

Growing requirements: Oat shows moderate resistance to cold (Madson, 1951). Winter forms of oat are not as cold hardy as rye, triticale, wheat (Stoskopf, 1985), or barley (Miller, 1958). A temperature of -8 degrees Centigrade is required to kill seedlings of oat or barley (Stoskopf, 1985). (Miller, 1958) considered that oat is not as drought or cold resistant as barley, rye, or wheat. Oat grows best in cool, moist climates, yet it is adapted to many climatic extremes. It is an excellent winter cover crop in the South and in areas where winter freezes are not severe (McLeod, 1982). Oat is susceptible to damage by hot, dry weather that occurs during reproduction (Stoskopf, 1985). The best areas for oat production have relatively cool summers (Coffmam, 1977). In the Northeast, oat is a common late-summer-sown cover crop, leaving protective dead mulch that is easily incorporated in the spring. Oat originated in North Africa, the Near East, and temperate Russia (McLeod, 1982), and the best areas for oat production have relatively cool summers (Coffmam, 1977). Few varieties of oat are adapted coast to coast (Stoskopf, 1985). Oat is not as drought or cold resistant as barley, rye, or wheat (Miller, 1958). Oat is more tolerant of wet soil conditions than barley, and it requires more moisture than the other small grains (McLeod, 1982). Higher seeding rates of oat or barley may be appropriate where rainfall is heavy (Stoskopf, 1985). Oat can tolerate a soil pH as low as 4.5 (Stoskopf, 1985). Under moderate fertility and drainage, oat tolerates a wider pH range than wheat or barley and has a low lime requirement (McLeod, 1982). Oat can be grown on loam to heavy soil (contain more clay and are sticky and hard to work but very fertile) (Madson, 1951) and is regarded as not being particular as to soil because it is adapted to many soil types.

Crop history: The World crop yield of oat was 1.3 t/ha in 1961, and the yield of the European Union (EU-27) was about 2 t/ha. The crop yield of oat showed a very continuous increase in world oat production. During 2006-2008 the oat yield slowly decreased. In 2013 the world crop yield was 2.4 t/ha and the European Union (EU-27) yield was 3.2 t/ha. Ukraine and Russia had 1.9 t/ha and 1.6 t/ha, respectively (Figure 17). From 2003 to onward, the oat production in Belarus was higher than world production, Ukraine and Russia.

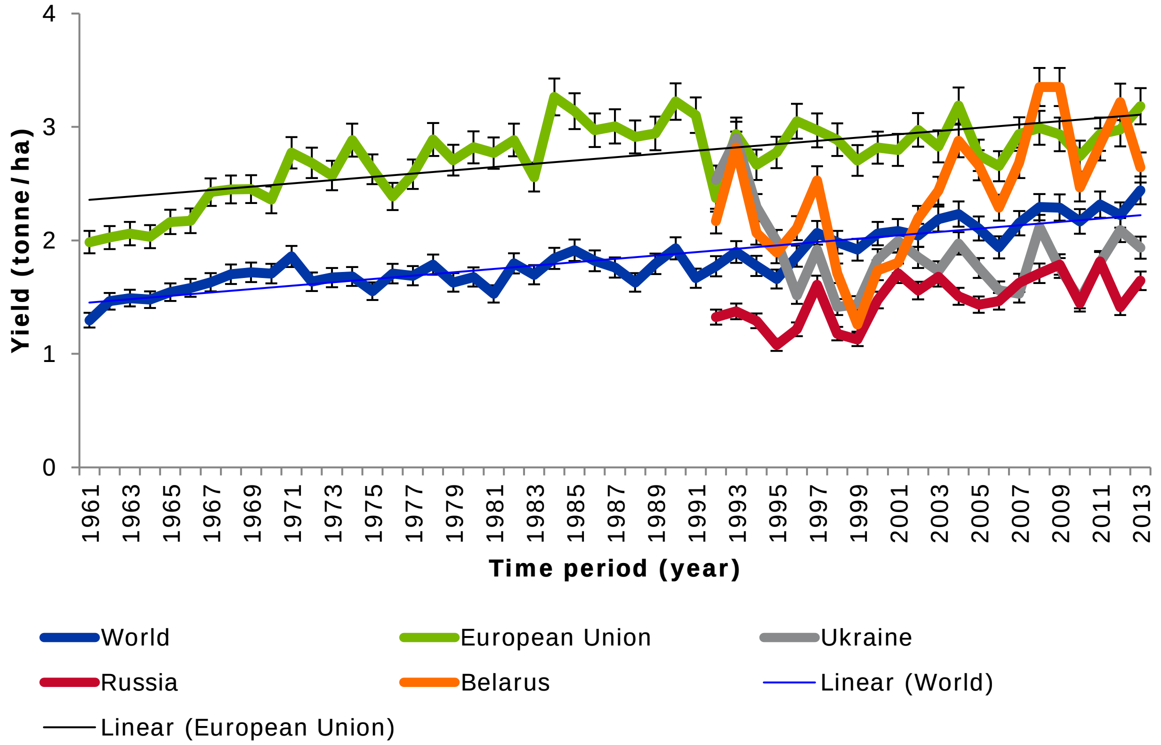

Figure 17: Grain yield development of oat in 1961–2013. Source: FAOSTAT, Author's own diagram.

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

Production and cropland: The average Oat yield is about 3 t/ha across the EU-27, with Poland taking the lead in production during the last decade with annual average production of 1.3 million tonnes (EUROSTAT). Russia is the biggest European producer of oats. In 2013, Russia produced about 5 million tonnes of oats from a production area of about 3 million hectares quantity that surpassed the half of the aggregate production of EU-27 (FAOSTAT). Cyprus had the lowest production between 2011–2013 among the EU-27 with an average production of 766 tonnes per year (EUROSTAT).

Figure 18 below shows the major oats producer across the Europe.

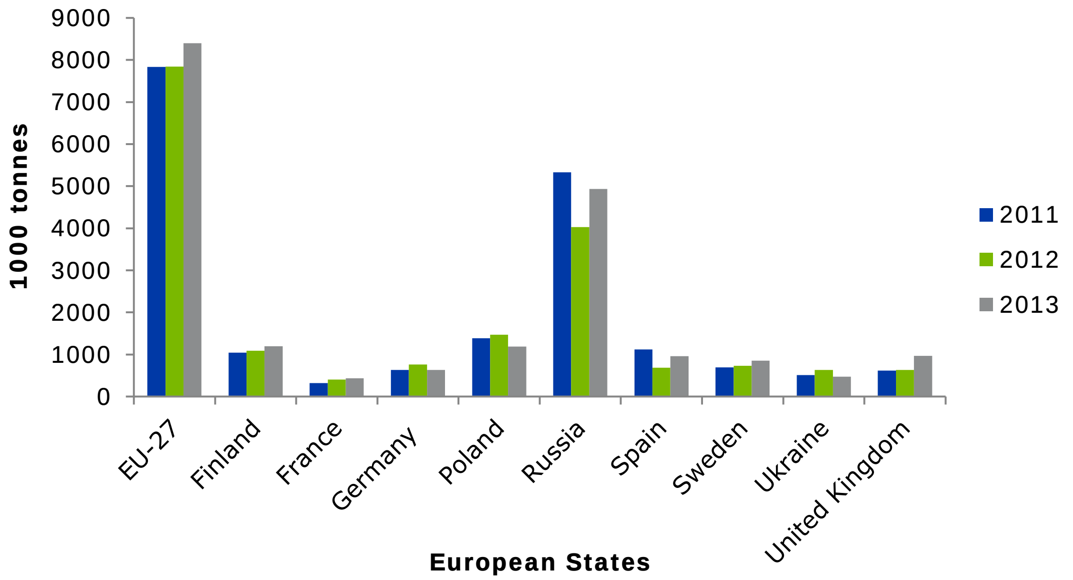

Figure 18: Largest producers of oat in the EU-27, Russia and Ukraine, during 2011, 2012 and 2013.

Yield level: To figure out the areas with lowest, medium and highest potential for oat production, the same three categories were applied for oat production. For the countries falling in the category of lowest yielding countries, the average per hectare yield is < 2.1 t/ha, for the countries in medium yielding group, the average per hectare yield is 2.1-4.6 t/ha. The average per hectare yield for the highest yielding countries is > 4.6 t/ha. Within EU, the lowest per hectare oat grain yield is obtained in Cyprus with the value of 1.0 t/ha, whereas the Ireland has the highest per hectare oat grain yield with yield of 7.4 t/ha (Table 12).
There is no data available for Malta.

Table 12: Oat yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 2.1	Bulgaria, Lithuania, Romania, Cyprus, Estonia, Latvia, Russia, Ukraine, Spain, Greece, Portugal, Slovakia
medium	2.1 – 4.6	Austria, Czech Republic, Hungary, Italy, Luxembourg, Poland, Slovenia, Finland, Sweden, Belarus
high	> 4.6	Denmark, Belgium, Germany, Netherlands, Ireland, United Kingdom, France
lowest	1.0	Cyprus
highest	7.4	Ireland

Oat is a cereal widely grown as a spring crop throughout the temperate zones, being particularly adapted to areas with cool and wet summers such as Northwest Europe. Oats are mostly cultivated in cool moist climates and they can be sensitive to hot, dry weather between head emergence and maturity. For these reasons, world oat production is generally concentrated between latitudes 35 and 65° N. Traditionally oats have been grown in cropping areas not suitable for wheat, barley or maize. Due to its good adaptation to a wide range of soil types and because on marginal soils oats can perform better than other small-grain cereals, there is an rising interest to expand oat cultivation to southern countries and even to subtropical areas (Sánchez-Martín et al. 2014). Some of the cultivars were the highest yielding cultivars significantly different from the others were also the most stable cultivar across over the environments tested. Grain yield was strongly affected by agroclimatic conditions (Sánchez-Martín et al. 2014). The management practices played a key role in the countries falling in category of highest oat yielding.

Crop management: Seeding rates are given as 67-101 kg/ha (McLeod, 1982; Miller, 1958). Higher seeding rates of oat may be appropriate where rainfall is heavy (Stoskopf, 1985). Seeding depth should be 2.5 cm (McLeod, 1982), and for barley or oat should be no greater than 5 cm (Stoskopf, 1985). Shallow seeding is possible in areas with high soil moisture and leads to more rapid emergence and lessened incidence of root rot disease (Stoskopf, 1985). A firm seedbed prevents frost heaving of the plants from the soil during the winter (McLeod, 1982). Barley or oat are usually planted in rows 15 to 20 cm apart (Stoskopf, 1985). Oat can be seeded into the sod of bermuda grass (Miller, 1958). Sowing can be conducted in the spring or fall (McLeod, 1982). Oats take up excess N and small amounts of P and K when planted early enough. Shallow seeding in moist soil provides rapid emergence and reduces incidence of root rot disease. Rotating cereal grain crops is an efficient way to control weeds. In addition, oats are often planted with red clover, which helps out to suppress the weed populations and can be left in the ground for another year of growth.

Oat varieties have been changed rapidly in response to development of new strains of pathogens (Coffmam, 1977). Allelopathic (naturally occurring herbicidal) compounds in oat roots and residue can hinder weed growth for few weeks. These compounds also can slow germination or root growth of some subsequent crops. Rotary hoeing or other pre-emerge mechanical weeding of solo-seeded oats can improve annual broadleaf control. Oats are less prone to insect problems than wheat or barley.

If the oats are harvested as a cereal crop, their stalks can be chopped and left on the ground, and the stubble will catch snow and protect the soil through the cold northeast winter. Because the roots and stalks of oats are rich in carbon, they can then be turned into the soil the following spring to improve soils. Oats should have 12 to 12.5% moisture for harvesting and storage, and should be harvested only when conditions are dry. Oats are harvested with a grain harvester. Mature oat hay has a high C/N ratio and decomposes slowly. Seed bed preparation can be hindered by large amounts of oats in a cover crop mix.

2.2.1.5 Maize

Maize is a tall, fast-growing annual grass reaching two or three metres at maturity in a single growing season (Figure 19). Using the highly productive C4 photosynthetic pathway (mechanism of carbon fixation into a compound containing 4 carbon atoms), it produces corncobs that grow from nodes on the stem. There are a few different types of corn. Flint (or Indian), silage, flour, sweet, pop, and ornamental varieties exist, but flint and flour corn are the types most commonly grown for human consumption (Heininger and Van Duyn 2011).

Figure 19: Illustration of maize plant (http://en.wikipedia.org/wiki/Maize)

Selective breeding of the original species focused on developing larger kernels and creating varieties with different sugar levels. There are tens of hybrids, the first of which was created to give resistance to the potentially devastating European corn borer (*Ostrinia nubilalis*) (Jemison and Bhowmik 2007). Use of hybrids is linked to yield increases and reduced pesticides use. Additional transgenic hybrids have been developed for stress tolerance and resistance to certain pests and herbicides. Innovations in crops genetics, mechanisation, fertilisation, and pest and crop management have resulted in an increase in maize yields over the past years (Heininger and Van Duyn 2011).

Growth requirements: Maize needs a frost-free growing season with optimal growing temperatures of 24-30 °C. Plants grow best in warm climates but are damaged by temperatures above 45 °C. It is grown successfully over a broad latitudinal range, from 54° North to 34° South (Heininger and Van Duyn 2011). In temperate climates it is sown in spring and harvested in autumn, in climates with a pronounced wet season it is planted with first rains and harvested as rainfall tails off. The crop needs adequate rainfall, in the range of 670-790 mm during the growing season. It is most common in temperate grassland and temperate broadleaved forest biomes.
Maize is well adapted to medium-textured (0.25-0.5mm) soils and will grow well in well-drained loam with a pH of between 5.6 and 7.5 (Heininger and Van Duyn 2011).

Crop history: The increasing trend for maize yield was recorded in world production, European Union (EU-27), Ukraine, Russia and Belarus. In 1961, the World crop yield of maize was 1.9 t/ha, and the yield of the European Union was 2.1 t/ha. The crop yield of maize showed a rapid increase. However, the increase in maize yield for European Union was faster than the world yield increase. The maize yield of the European Union was doubled in 1977, whereas the World yield took longer (1994) to reach the same level. The maize yield is still increasing and during 2013, reached to 5.5 t/ha and 6.7 t/ha for world and European Union (EU-27), respectively. The yield for Ukraine, Russia and Belarus also increased sharply (Figure 20).

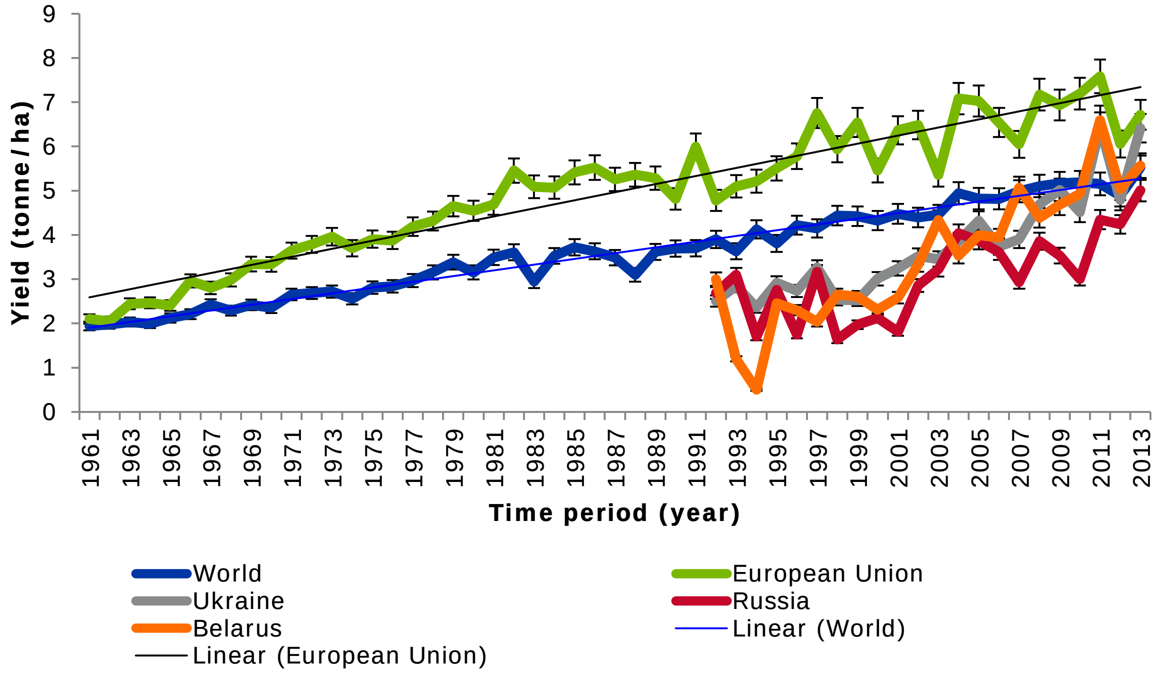

Figure 20: Crop yield development of maize in 1961–2013. Source: FAOSTAT, Author's own diagram.

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

Production and cropland: In 2012, the maize production across the EU-27 was about 58 million metric tonnes with a harvested area of about 6.6 million hectares (FAOSTAT). In 2012 and 2013, Ukraine was the highest maize producer compared to the European Union. In 2013, Ukrainian maize production increase by 47% increase to 33 million metric tonnes, which was almost half of the production achieved by the EU-27.

Figure 21 shows the largest maize producers in EU-27, Ukraine and Russia in 2012 and 2013.

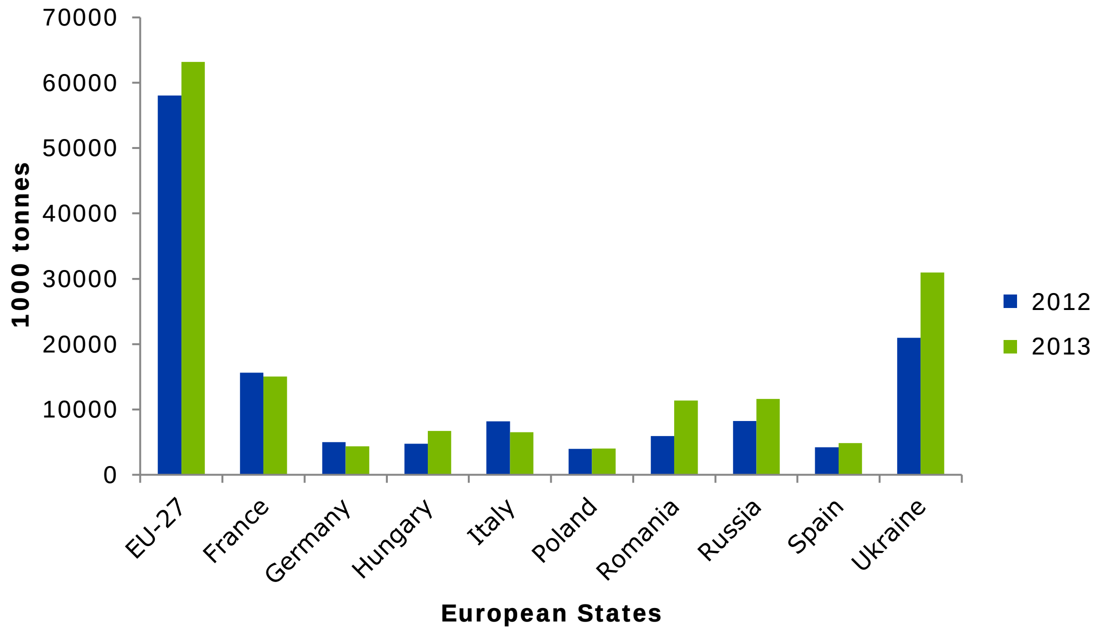

Figure 21: Largest producers of maize in the EU-27 including Russia and Ukraine, during 2011, 2012 and 2013.

Yield level: In order to assess the maize yield the countries assessed in this study were divided into three categories based on per hectare yield production potential. For the countries falling in the category of lowest yielding countries, the per hectare yield is < 6.0 t/ha, for the countries in medium yielding group, the per hectare yield is 6.0-9.3 t/ha. The mean per hectare yield for the highest yielding countries is > 9.3 t/ha. Within EU, the lowest per hectare maize production is obtained in Romania with the value of 3.6 t/ha, the country with the highest per hectare maize production is Netherlands with yield of 11.8 t/ha (Table 13).

No recent maize yield data was available for UK. There was no data for Estonia, Finland, Ireland and Cyprus.

Table 13: Maize yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 6.0	Bulgaria, Lithuania, Romania, Russia, Ukraine, Poland, Belarus
medium	6.0 – 9.3	Czech Republic, Denmark, Hungary, Italy, Luxembourg, Slovakia, Slovenia, Portugal
high	> 9.3	Austria, Belgium, France, Germany, Netherlands, Spain, Greece
lowest	3.6	Romania
highest	11.8	Netherlands

For maize, Germany was picked to represent the highest yielding countries and Czech Republic was selected for lowest yielding countries. The main factors, which contributed towards this yield difference, were, soil, climate, fertilisation, irrigation and other mechanisations used in field operations. The better cropping system played key role to achieve high yields in high yielding states. The awareness among farmers about better management practices also played a key role. For example, Spain showed lower levels of progress, which was probably due to the lower farmers' knowledge, and lower inputs and lower investments which ultimately lead to low crop yield.

Crop management: In crop rotation maize is self-compatible (monoculture cultivation possibly) and for nematodes of root crops (pests) it is even considered as an enemy's plant. Since maize is harvested very late (harvest date at the end of September) winter wheat (November as a date of sowing) can be mostly post sowed (Heininger & Van Duyn, 2011; (Jemison and Bhowmik 2007).
The maize production for commercial purposes is boosted by the application of nitrogen, phosphorus and potassium (N-P-K) fertilisers. Nitrogen is needed in relatively large quantities (140-200 kg/ha), especially on light sandy soils. Many herbicides are used to control weeds on non-GMO varieties. Glyphosate is widely used on GM maize bred for resistance to this herbicide (Heininger and Van Duyn 2011).
The basic fertilising with phosphate should be 23 to 50 kg/ha and potassium about 63 to 150 kg/ha (Heininger & Van Duyn, 2011; (Jemison and Bhowmik 2007). Reduced-tillage methods such as direct drilling protect the soil and improve soil organic carbon sequestration. Maize has higher yield when planted in a two-year rotation in combination with nitrogen-fixing crop such as soybeans. This is the most common rotation, but maize is also sometimes grown without rotation, in a three-year rotation with wheat and soybean, or in a three-year rotation that follows the sequence maize-maize-soybean. Intercropping is also possible and practiced in some places, with variety of crops that can be planted between the rows of maize (Heininger & Van Duyn, 2011; (Jemison and Bhowmik 2007). Many different pesticides (e.g. against armyworms) are used on maize, the type and amount depends on the area (Jemison and Bhowmik 2007).

Mechanical harvesting is carried out on large scale for commercial purposes to ensure harvest at the optimal time. For maize kernels, optimum moisture to avoid seed damage during harvest is usually

22% (Kludze et al. 2010). Moisture above 30% will result in poor kernel separation, and below 15% will result in a large portion of the kernels being cracked and broken. Corn for silage is harvested with a higher moisture level (30-32%), and then immediately chopped and packed; in both cases, the stover (or leaves and stalks left in the field after harvesting) can be grazed directly or dried down and used for animal feed (Kludze et al. 2010).

2.2.2 Oil crops: Rapeseed and Sunflower

2.2.2.1 Rapeseed

Rapeseed is an important food and energy crop (Figure 22), a fact that was made possible through modern plant breeding. Around 1960, researchers started developing new rapeseed cultivars that enabled the crop's rapid growth in recent years (Pekrun, Hewitt, and Lutman 1998). During the last decades the demand for vegetable oils as food, non-food and biofuel had grown significantly. Improved agronomic practices, better processing methods and the improvement of the varieties played a significant role (Pekrun, Hewitt, and Lutman 1998).

Figure 22: Illustration of rapeseed plant (http://en.wikipedia.org/wiki/Rapeseed)

These improved rapeseed cultivars were free of erucic acid and glucosinolates. Erucic acid tastes bitter, which had prevented the use of rapeseed oil in food. Gluconsinolates, which were found in rapeseed meal leftover from pressing, are toxic and had prevented the use of the meal in animal feed. These new cultivars are known as "double-zero" rapeseed. In Canada, where "double-zero" rapeseed was developed, the crop was renamed "canola" (Canadian oil) to differentiate it from non-edible rapeseed (Colton & Sykes, 1992; Liebmann, 1989).

Rapeseed is very important for European agriculture and has increased its potential during the last years. In EU-27, oilseed is cultivated on large scale, yellow flowering rapeseed mainly winter oilseed rape covers more than half of the total area allocated for rapeseed (Perlack et. al, 2005). There is a high demand for rapeseed oil due to the high quality of the oil for food as well as non-food uses. New varieties with high oleic acid and low linolenic acid have been introduced into the market, their oil have a future potential mainly because of high oil stability.

The development of a biodiesel market in the EU since the mid-2000s led to additional demand for rapeseed oil, which has an almost ideal fatty-acid profile in terms of stability and winter operability.

In the European Union (EU-27) the rapeseed cultivation concerning the oilseed production plays a crucial role. The production of rapeseed in EU-27 was increased over the years (Perlack et. al, 2005). In 2004 Lithuania and Poland (two of the ten new entry states) became the most important countries for rapeseed cultivation in the EU. In ten new EU states about 2.50 million tonnes of rapeseed was produced in 2004. From 1996 to onward, the yield for Ukraine, Russia and Belarus increased again and in 2013 the yield for Ukraine reached to highest level which was even higher than world production (Perlack et. al, 2005).

Growth requirements: Canola is mostly grown as a winter annual in winter dominant rainfall environments (between 30° S and 38° S) (Diepenbrock, 2000). The growth of canola is almost restricted by the amount of water available to the crop, particularly during seed maturation (Walston et al. 1999). Rapeseed is grown in areas receiving annual rainfall from 325 to 700 mm. Optimal germination conditions for rapeseed are 20 °C, high water availability and exposure to light (Diepenbrock, 2000; Perlack et. al, 2005). Rapeseed is relatively frost tolerant, however, damage can occur at seedlings. Plants become more frost tolerant as they develop (Colton and Sykes 1992) Rapeseed has been successfully cultivated on soil from pH 5.0 to 8.0 (Colton and Sykes 1992). Aluminium toxicity and very acid soils where manganese occurs, affect yield. Liming is used on these soils before sowing (Potter et al. 1999).

Crop history: The World crop yield of rape seed was 0.57 t/ha in 1961, and the yield for the European Union (EU-27) was 1.59 t/ha, which was higher than the World yield of rapeseed. The increasing trend was recorded for World and European Union. Surprisingly, the rapeseed production in Ukraine, Russia and Belarus was high in 1992 but decreased sharply and reached to its lowest level in 1996. However, in subsequent years, the increasing trend was observed with large yield variations over the years (Figure 23).

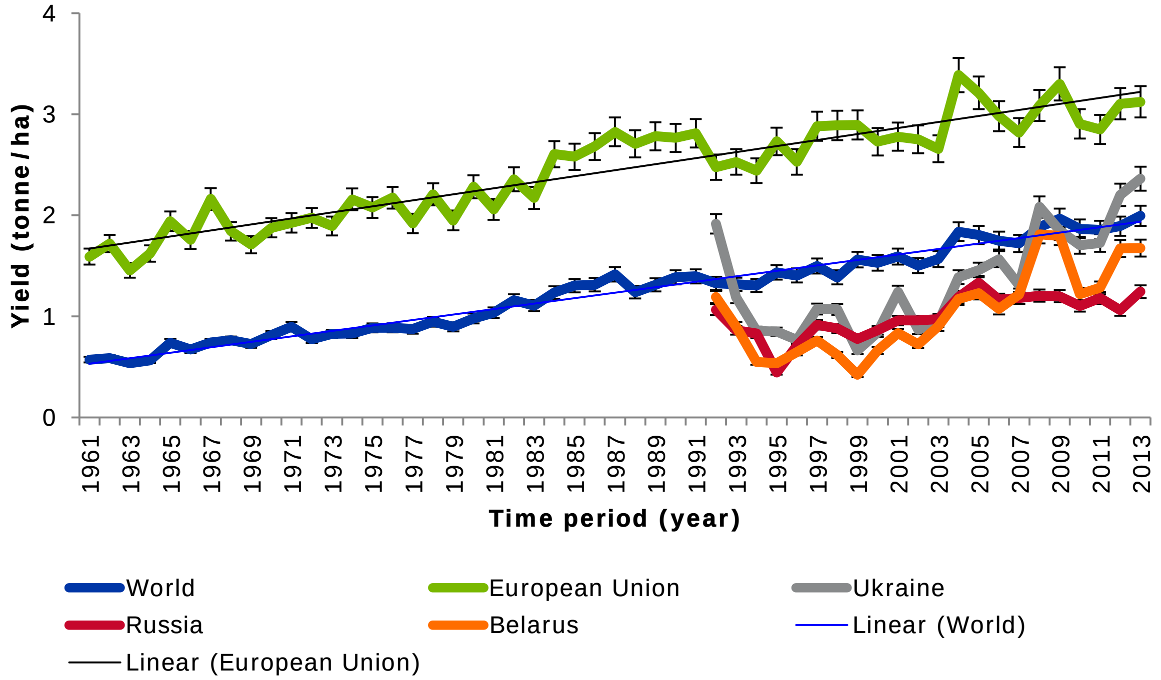

Figure 23: Crop yield development of rapeseed in 1961–2013. Source: FAOSTAT, Author's own diagram.

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

Production and cropland: Germany and France were the leading countries in EU for rapeseed production in the last decade and Greece was the lowest producer (FAOSTAT).

In 2013, Germany produced about 5.8 million tonnes and the largest among the EU-27 member states with a crop yield of about 4 t/ha (FAOSTAT) (Figure 24).

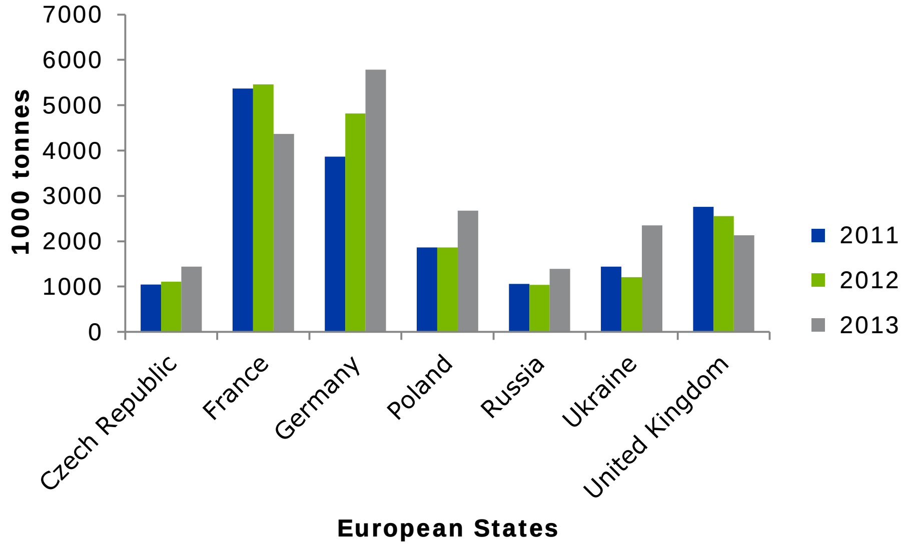

Figure 24: Major rapeseed producers in the EU-27, Ukraine and Russia.

Yield level: To estimate the yield difference for rapeseed between EU-27, Russia, Ukraine and Belarus, the countries were grouped into low yielding, medium yielding and high yielding groups as for cereal crops. The countries with rapeseed yield lower than 2.2 t/ha were categorised into low yielding group, the countries with yield of 2.2-3.3 t/ha fall into medium yielding category and the countries with the yield higher than 3.3 t/ha fall into the group of highest yielding. Russia, Ukraine and Belarus along with some other EU-27 member states fall into lowest yielding group (Table 14). There was no yield data for Cyprus, Malta and Portugal.

Table 14: Rapeseed yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 2.2	Bulgaria, Estonia, Finland, Italy, Lithuania, Romania, Spain, Belarus, Russia, Ukraine
medium	2.2 – 3.3	Austria, Belgium, Czech Republic, Greece, Hungary, Latvia, Poland, Slovenia, Slovakia, Sweden
high	> 3.3	Denmark, France, Germany, Ireland, Luxembourg, Netherlands, United Kingdom
lowest	1.4	Estonia
highest	4.0	Belgium

The main factors which contributed towards this yield difference were, soil, climate, fertilisation and other agronomic practices used in field operations. The use of better varieties in Germany played a significant role, especially the N efficient cultivars contributed towards high yield (Diepenbrock 2000; Rathke, Behrens, and Diepenbrock 2006).

Variation in yield of winter oilseed rape is due to availability of N during growth and development (Diepenbrock 2000; Rathke, Behrens, and Diepenbrock 2006). The availability of reduced N has a major role in establishing and preserving a photosynthetically active leaf canopy. Soil conditions, water availability and ambient temperature are important environmental factors determining N-management strategies (Colton and Sykes 1992). Water stress is mainly affected by soil type. As compared to irrigation, effects of drought on seed yield and seed quality were more evident on sandy soils than on loamy soils due to lower soil water content at seeding as well as higher reductions of soil water content during drought. Ploughing leads to increased vegetative biomass and transpiring plant surface until flowering compared with reduced tillage (Diepenbrock 2000; Rathke, Behrens, and Diepenbrock 2006). The N-fertilisation increases water turnover in agro-ecosystems because aroused growth increases transpiration of the canopy further decreasing soil water potential of the soil. Direct drilling is a mean to conserve soil moisture. In Sweden and Denmark, direct drilling has become very popular for winter oilseed rape especially in dry summers. (Christian and Bacon 1990) described for Great Britain higher yields of winter oilseed rape after direct drilling rather than after ploughing. Sowing date of winter oilseed rape is an important determinant of length of growing season, insect's infestation, seed and oil yields. Early sowing of winter canola in Australia resulted in high yield and oil regardless of location and variety. A group of scientists demonstrated that delayed sowing increase seed yield in Great Britain due to maritime climate (Leach, Rainbow, and Mullen 1999). In contrast, in northern Germany delayed sowing decreased grain yield. Crops grown at high plant densities (150–250 plants m^2) are often more susceptible to lodging and increased disease incidence without the benefit of any yield increase, but the presence of fewer pod-bearing branches should produce more synchronous pod and seed development and result in more uniform seed maturation, improved harvestability, lower seed glucosinolate and higher oil contents. Growth regulator use is often combined with fungicides application (Diepenbrock, 2000). During shooting application of growth regulators decreases plant height and improves plant stability to prevent lodging and influences yield structure where effectiveness depends on cultivar. Once the plant is shortened, higher N-doses are applied without triggering lodging (Diepenbrock, 2000). Therefore, it can be concluded that difference in climatic conditions mainly temperature, rainfall along with other management practices such as fertilisation, crop protection strategies and sowing time played a significant role in defining the yield potential of each defined category. Winter oilseed rape is a crop of temperate climates. Temperature is the major factor determining the success and timing of agricultural crop production. Soil conditions, water availability and ambient temperature are important environmental factors determining N-management strategies.

Crop management: The average sowing rate tends to be between 4 and 6 kg/ha, with hybrid seed sown are 3 kg/ha (Walston et al. 1999). Lower stocking densities assure the development of stronger and stable plants. Rapeseed has a higher requirement for nitrogen, phosphorus and sulphur than cereals and other crops. It needs approximately 40 to 50 kg of nitrogen (30% more than wheat), 8 kg phosphorus and 10 kg sulphur per tonne of grain produced (Colton and Sykes 1992).
Broad leaf weeds, particularly weeds from Brassicaceae family, are the most challenging in canola crops. There are no post-emergent herbicides available to control Brassicaceae weeds in conventional canola. Thus for better weed control, herbicide tolerant canola are preferred (Carmody and Cox 2001).

Rape seed is harvested in early summer when the seeds have reached their maximum dry weight (seed moisture approximately 35%) and the crop can be windrowed (swathed). As an alternate to swathing, can be harvested directly. This method works well in small or low-yielding areas with uniform maturity and moisture content. But the best option for maximising yield and quality is swathing (Carmody and Cox 2001). Early harvest can lead to losses because immature pods will not be or only partially threshed and get lost. The rape straw is still green and humid, the threshing concave is pulled a little more narrowly, the stalks are squeezed. Thereby threshed punches stick to the wet straw and get also lost.
Rape seed has a high previous crop value. Wheat after rape achieves approx. 10% additional yield towards wheat after wheat. Good preceding crops are early broached winter barley and wheat varieties which are short stalked and early ripening. Summer cereals especially oats could cause problems due to late harvesting (Carmody and Cox 2001).
On lighter, dry or clayey locations where decomposition is slow, it is mentioned to remove straw because quick sufficient rotting of the crop residues is not guaranteed.

2.2.2.2 Sunflower

Sunflower (Figure 25) is one of a few crops that originated in the U.S., with the southwestern U.S. likely its centre of origin. Records show that wild sunflower was used as a food by Native Americans and was domesticated and spread by their movements (Seiler and Rieseberg 1977).

Figure 25: Illustration of sunflower plant (http://en.wikipedia.org/wiki/Helianthus)

Following the discovery and settlement of the U.S., sunflower was spread to other parts of the world, with European countries and Russia being the major producers (Putt, 1997). Modern sunflower varieties trace much of their lineage back to reintroduced varieties that were developed in Europe and Russia. Sunflower was not an important agronomic crop until the 1950s, however since the mid-1960s it turned out to be an economically important crop. Expanded world production of sunflower resulted through the development of varieties with high oil potential (Putt, 1997).

Growth requirements: Sunflower is an annual, erect, broadleaf plant with a strong taproot and prolific lateral spread of surface roots. Studies had indicated that Sunflower seeds will germinate at 3.9 °C, but temperatures of at least 7.8 °C to 10 °C are required for satisfactory germination. It has also been reported that, seeds are planted 45 cm apart and 2.5 cm deep especially in a commercial planting. In early germinating stages, sunflower seeds are not affected by vernalisation (cold), but maturing sunflower plants are killed by temperatures less than -2.2 °C. Sunflower leaves are phototropic and will follow the sun rays with a lag of -11.1 °C behind the sun's azimuth (Seiler and Rieseberg 1977). This characteristic behaviour has been suggested to increase light interception and perhaps photosynthesis. Although, sunflower is not known as a highly drought tolerant plant, it often produces satisfactory outputs when other crops are possibly destroyed during drought. During water stress period, sunflower is usually aided by its extensively branched taproot which can penetrate up to 6.5 feet. A critical time for this water stress period is 20 days before and 20 days after flowering.
For the sunflower plants to grow best, full sun is necessary as well as a fertile, moist, well-drained soil with heavy mulch (Putt, 1997).

Crop history: In 1961, the global crop yield of sunflower was about 1.0 t/ha, and the yield of the European Union was 1.1 t/ha. Until 1990, the crop yield of sunflower increased globally. Then it decreased until 1995. The yield of the European Union kept on increasing until 1992, then it decreased slightly. In 2004 it showed an increase again. The global sunflower yield reached to 1.8 t/ha, and 2.0 t/ha in the European Union. In 1992, Russia and Ukraine yielded 1.1 t/ha and 1.3 t/ha, respectively. In 2013, Ukraine even superseded with a crop yield of 2.2 t/ha the EU's yield. Russia yielded the lowest crop return with 1.5 t/ha. Belarus started in 1992 with a value of 1.3 t/ha and showed large variation over the years. After 2011, the yield decreased and was reached to 0.8 t/ha in 2013 (Figure 26).

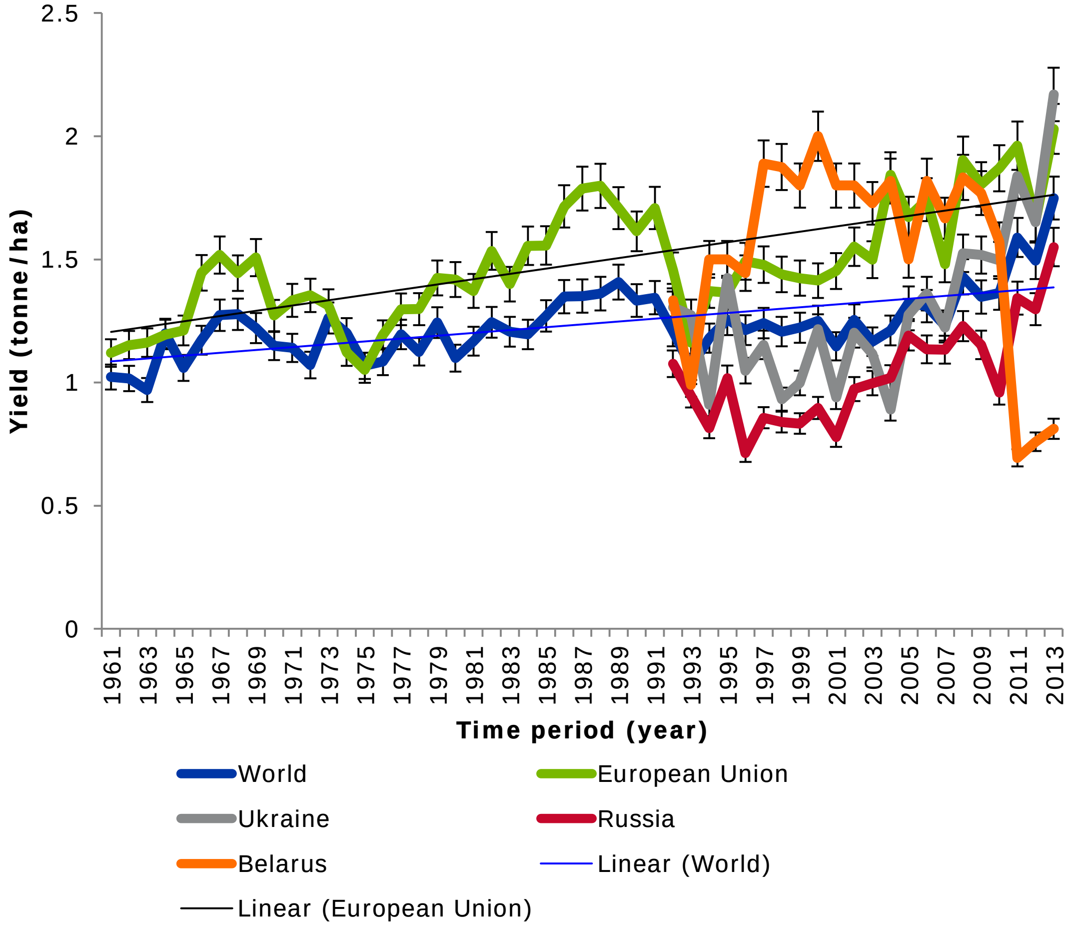

Figure 26: Crop yield development of sunflower in 1961–2013. Source: FAOSTAT, Author's own diagram.

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

Production and cropland: Russia and Ukraine were the highest producers of sunflower across the Europe in the last decade. In 2013, Russia produced 10.5 million tonnes while Ukraine produced over

11 million tonnes. This was more than the EU-27 production of about 9.2 million tonnes altogether (FAOSTAT).
Slovenia is the least producer among the EU-27, producing 506 tonnes in 2013 with a harvested area of 273 hectares (FAOSTAT) (Figure 27).

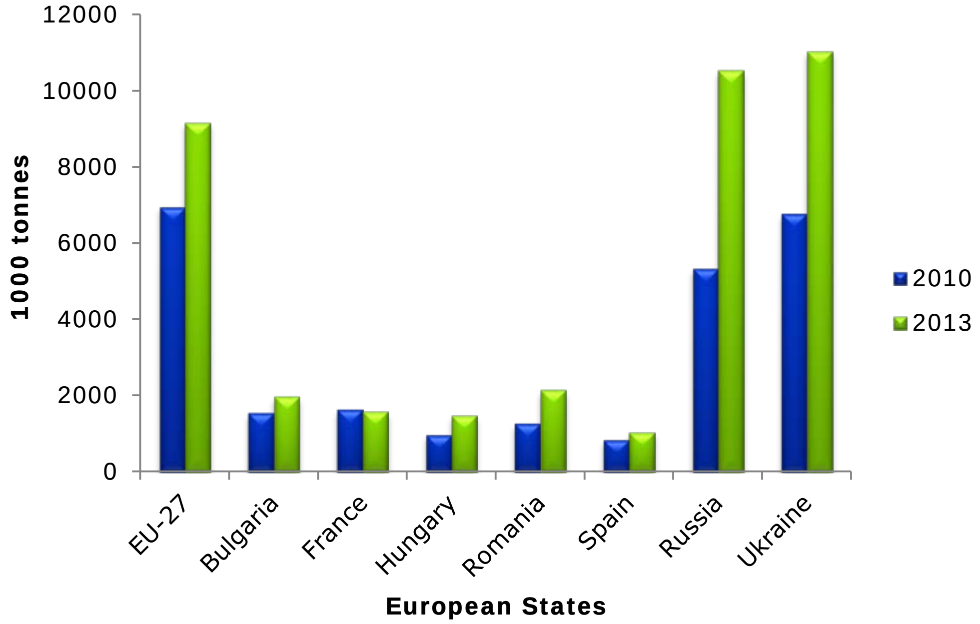

Figure 27: Major sunflower producers in EU-27, Ukraine, Russia.

Yield level: To estimate the yield difference for sunflower between EU-27, Russia, Ukraine and Belarus, the countries were grouped into low yielding, medium yielding and high yielding groups as for cereal crops and rape seed. The countries with sunflower yield lower than 1.5 t/ha were categorised into low yielding group, the countries with yield of 1.5-2.2 t/ha fall into medium yielding category and the countries with the yield higher than 2.2 t/ha fall into the group of highest yielding. Russia, Ukraine and Belarus along with some other EU member states fall into lowest yielding group (Table 15).

Table 15: Sunflower yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 1.5	Portugal, Romania, Slovenia, Spain, Belarus, Russia, Ukraine
medium	1.5 – 2.2	Bulgaria, Germany, Greece, Poland, United Kingdom

Yield range	Average yield (t/ha)	Country
high	> 2.2	Austria, Czech Republic, France, Hungary, Italy, Slovakia
lowest	0.56	Portugal
highest	2.6	Austria

The main factors which contributed towards this yield difference were, soil, climate, fertilisation and other agronomic practices such as sowing time, sowing density played a major role in determining the yield for a specific region. Along with climatic conditions and soil quality, the selection of cultivars, timings of fertilisations, sowing density and distance between rows had significant effect on yield output in a specific region.

The high yields were mainly achieved through better management practices. For example, appropriate crop rotation to ensure the N reserves for sunflower. However, N uptake by sunflower is likely to be increased if there is adequate available soil water. In this respect, the introduction of no-tillage (NT) has been presented as a way to increase soil water uptake (Andrianasolo et al., 2014).

Crop management: Sunflower is not highly sensitive to soil pH and will grow in a wide range of soil types from sands to clays. For commercial production, sunflower is reportedly is grown on soils ranging in pH from 5.7 to over 8 (Aiken, 2005). As with other non-leguminous grain crops, nitrogen is usually the first limiting factor for yield. Medium to high levels of macronutrients are usually required for good plant growth. Yield increases from fertiliser rates up to 196 kg N/ha have been observed, but rates considerably lower than this are usually recommended (Aiken, 2005).

In order to maximise the use of natural resources, the appropriate sowing date is very important since it ensures good seed germination, as well as the timely appearance of seedlings and the optimum development of the root system.

Nitrogen requirements in dryer regions can be made from the soil nitrate-nitrogen estimate, but this may not be feasible in wetter regions. On higher organic matter soils, amounts should be lowered. Fertiliser dosage of about 90 kg N/ha with pH of 6 has been recommended. Sunflower is also known as low salt tolerant and does not differ substantially from other field crops in flooding tolerance (Heiser, 1976).

Sunflower is a strong weed competitor especially for light, but does not cover the ground early enough to prevent weed establishment. Therefore, early season weed control is essential for good yields. Successful weed control should include a combination of cultural and chemical methods (Heiser, 1976).

The major fungal diseases of sunflower include rust, downy mildew, verticillium wilt, sclerotinia stalk and head rot, Phoma black stem and leaf spot. Bees are beneficial to sunflower yield due to the cross pollination. Insects also caused major yield losses in sunflower, these include the larvae of three months; sunflower moth, banded sunflower moth and sunflower bud moth, Sunflower head-clipping weevil, sunflower beetle, sunflower maggot etc. Resistance to seed insects can be improved by the presence of a dark coloured "armour" layer in the seed coat. Also, insect control should be carried out with the only approved insecticides (Heiser, 1976).

Birds can also be major pests in sunflowers e.g. blackbird, goldfinch, dove, grosbeak and sparrow. The damage and yield losses caused by these pests can be minimised through the use of scarecrows, fright owls, aluminium strips that flutter in the wind and carbide exploders. Currently, no chemicals are approved for bird control in sunflower (Heiser, 1976).

2.2.3 Sugar beet

In 18th century, the mangel wurzel (large rooted beets) was developed to feed cattle. Later on, through breeding efforts, the sugar content has been raised from 5 to more than 20%. About one-third of the world's production of sugar is from sugar beets, the second most important source of sugar (Schneider, 1942). Currently, nearly half of the sugar produced worldwide is coming from sugar beets (Lacoste and Ribera 2010) (Figure 28).

Figure 28: Illustration of sugar beet plant (Source: USDA)

In the beginning, the development of new varieties focused earlier only the continuous increased returns and since the 1970s also the systematic plant breeding of quality aspects. As a result of the breeding strains there has been development of tolerant or resistant varieties against Rhizomania since ten years, beet cyst nematodes (*Heterodera schachtii*) and turnip decay caused by a fungal infection (*Rhizoctonia solani*) (Lacoste and Ribera 2010).

At beginning of the 19th century Franz Karl Achard improved beet cultivation and opened the world's first experimental beet sugar factory in Silesia in 1801, which produced its first beet sugar in the following year. Europe saw it as the solution to its sugar supply problems and the success of beet sugar soon expanded. In the following years, sugar beet cultivation and processing gradually increased throughout Europe. Today, the EU beet and sugar sector is a modern, high-performance sector that is essential for EU consumers. Over the last 200 years it has constantly improved its technology and the quality of its products in line with consumer expectations (Smith, 1983; Schneider, 1942).

Overall, the number of beet sugar factories in the EU-27 has been reduced by 44% since the CMO (Common marketing organisation) reform was adopted in 2006 (from 189 factories in 2005/06 to 106 in 2009/10). At the same time, the average size of sugar beet factories has continued to increase, in particular in Western European Countries where the bulk of EU beet sugar production (85% of production in 2009) is concentrated (Lacoste and Ribera 2010).

Sugar beet is one of the main raw materials for the production of bioethanol in the EU. Currently, there are 21 bioethanol plants, which can process sugar beet and/or molasses in the EU to produce bioethanol (Lacoste and Ribera 2010). In 2012 580 kt biofuels equivalent were produced from sugar beet in the EU (forthcoming report, Ecofys 2015). This represents around one third of total EU bioethanol production. Biogas production from sugar beet is developing rapidly across the EU. Biogas from sugar beet constitutes an excellent contribution from EU farmers to the development of decentralised energy production in the EU, which can provide electricity, heating, transport fuel to farms and sugar factories, as well as to rural communities and the general public (Lacoste and Ribera 2010).

Growth requirements: Sugar beets grow exclusively in the temperate zone, in contrast to which grows exclusively in the tropical and subtropical zones. Sugar beet is best grown in bright, sunny regions with long day length with temperatures of about with 18.3 °C to 26.7 °C followed by night time temperatures of 4.4 °C to 10 °C. It takes about 70–90 days for the planting and harvesting of sugar beet. Its taproot system can utilise water and soil nutrients to depths of 1.5 to 2.4 m.
The most important requirement is the soil must be rich in humus and have the capacity of retaining a great deal of moisture. However, ideal soil is a sandy loam, i.e., a mixture of organic matter, clay and sand. Sugar beets do not grow well on highly acidic soils and grow best on soils with a pH of 6.0 to 8.0. A soil free or nearly free of stones is particularly desirable (Højland and Pedersen 1994) .
A subsoil of gravel, or the presence of hard-pan, is not desirable, as cultivation to a depth of from 30.5 to 38.1 cm is necessary to produce the best results (Højland and Pedersen 1994).

Crop history: The following figure demonstrates the development of the sugar beet yield from 1961 to 2013. The global yield of sugar beet was 23.2 t/ha in 1961, and the yield of the European Union amounted to 30.3 t/ha. The yield of sugar beet showed a sharp increase over the past years. In 2013 the sugar beet yield was 56.3 t/ha in the World, and 68.3 t/ha in the European Union. In 1992 Russia and Ukraine yielded 17.8 t/ha and 19.4 t/ha, respectively. In Russia and Ukraine the sugar beet yields were doubled within 10 years and in 2013 reached to about 40.0 t/ha in Russia and 44.2 t/ha in Ukraine. Belarus recorded notable increases, as well, starting in 1992 with a value of 21.9 t/ha and reaching in 2013 about 43.7 t/ha (Figure 29).

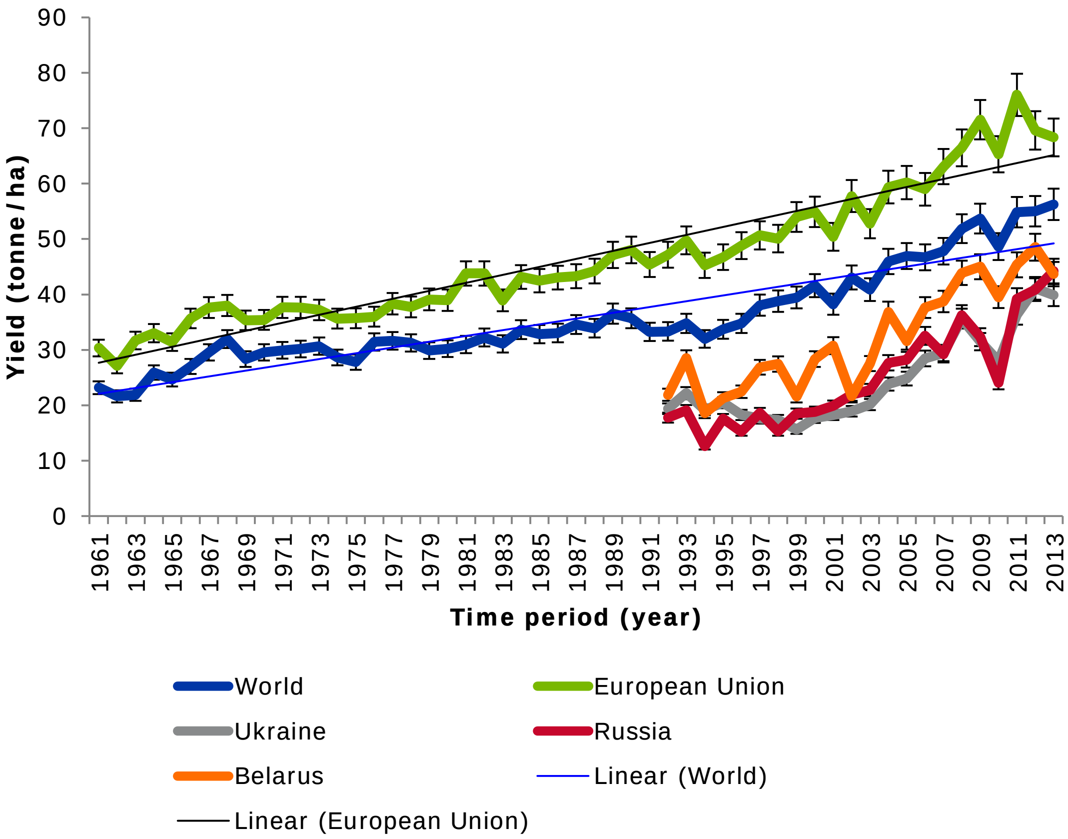

Figure 29: Crop yield development of sugar beet in 1961–2013. Source: FAOSTAT, Author's own diagram.

For Ukraine, Russia and Belarus, the yield data was only available from 1992–2013. The error bars indicate the error values calculated for data series at 5%. The thin lines are linear trend lines.

Production and cropland: Russia leads the global sugar beet production. In 2013, Russia produced over 39 million tonnes, from harvested area of about 0.9 million hectares (FAOSTAT).
France is the highest producer amongst the EU-27 group, producing 33.7 million tonnes from about 0.4 million hectares with a crop yield of 85.4 t/ha (EUROSTAT).
Bulgaria remains the l producer of sugar beet in the last decade with an average annual production of 18,860 tonnes (EUROSTAT).
The figure below shows the leading countries in sugar beet production across the Europe.

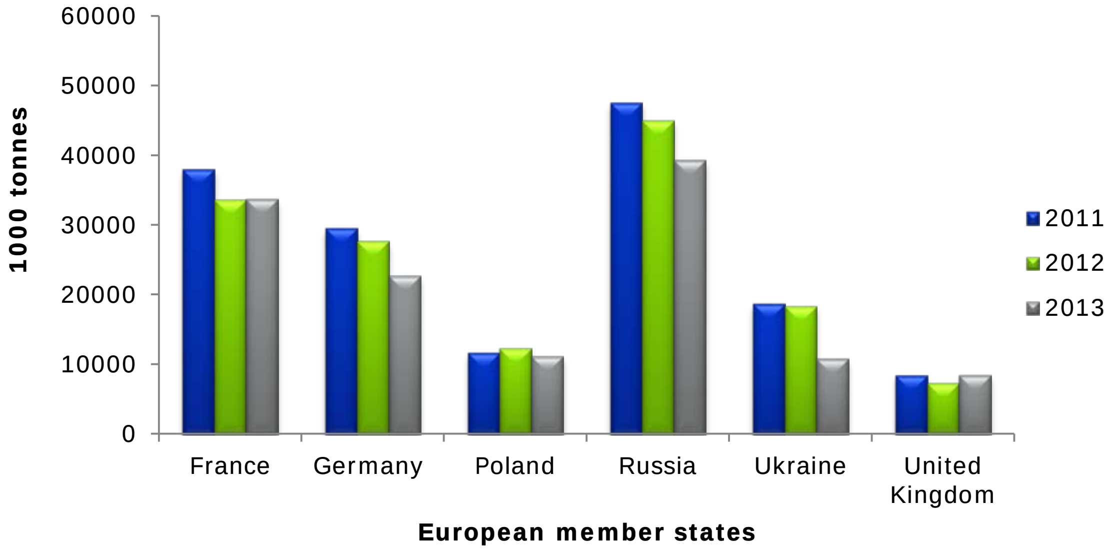

Figure 30: Leading countries in sugar beet production across EU-27, Ukraine, Russia

Yield level: To estimate the yield difference for sugar beet between EU-27, Russia, Ukraine and Belarus, the countries were grouped in the same way as for cereal crops, rapeseed and sunflower. The countries with sugar beet yield lower than 45.0 t/ha were categorised into low yielding group, the countries with yield of 45.0-65.0 t/ha fall into medium yielding category and the countries with the yield higher than 65.0 t/ha fall into the group of highest yielding. For sugar beet also, Russia, Ukraine and Belarus along with some other EU member states fall into lowest yielding group (Table 16).

Table 16: Sugar beet yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Yield (t/ha)	Country
low	< 45.0	Bulgaria, Finland, Latvia, Lithuania, Romania, Belarus, Russia, Ukraine, Slovenia
medium	45.0 – 65.0	Czech Republic, Denmark, Germany, Hungary, Ireland, Poland, Portugal, Slovakia, , Sweden, United Kingdom, Italy
high	> 65.0	Austria, Belgium, France, Greece, , Netherlands, Spain
lowest	18.7	Bulgaria
highest	85.3	France

The main factors which contributed towards this yield difference were soil type, soil pH, climate, fertilisation and other agronomic practices such as conservation tillage played a major role in determining the yield for a specific region. The awareness among the farmers also played significant role, for example farmers in Bulgaria showed lower levels of progress, which was probably due to the lower motivation of farmers in collective farming system, lower inputs and lower investments (Hoffmann et al. 2009). In sugar beet production, socio-economic factor also played a significant role. Due to economic value and market demand, farmers try to produce good quality crop through appropriate management practices.

Glyphosate-resistant sugar beets applied with the glyphosate herbicide two or three times had an increase in white sugar yield from 4 to 18% in comparison to the high dosage conventional herbicide systems.

Also in Russia, Belarus and as well as in Ukraine more and more fertilisers were applied in the period from 2002 to 2010. But the amounts applied in Ukraine were almost more than twice in Russia. The use of fertilisers in Belarus was even higher than in Ukraine. In 2002, the application was about 56.0 t/1000ha and increased to 135 t/1000ha in 2013. This fact might also explain the higher yields of Belarus compared to Russia and Ukraine.

Crop management: Profitable sugar beet production depends largely on a high tonnage crop with high sucrose content. In order to achieve this, growth-limiting factors such as soil fertility must be managed effectively (Hoffmann et al. 2009). Sugar beets are unique in their requirements of nitrogen. Inadequate nitrogen results in premature yellowing, poor leaf canopies and reduced yields, while excess nitrogen leads to reduced sucrose content, an increase in impurities and lowered sucrose extraction (Højland and Pedersen 1994).

For proper nitrogen management, it is important to determine the amount of nitrate-nitrogen (NO_3-N) already present in the soil. NO_3-N is mobile in the soil so residual nitrogen level should be determined annually while phosphorus and potassium should be determined every three to four years (Hoffmann et al. 2009).

Excessive amounts of either residual or fertiliser nitrogen usually significantly lowers sugar beet quality. For expected yield of 40-50 t/ha in a sandy loam soil, fertiliser dosage of 180-220 kg N/ha has been recommended (Hoffmann et al. 2009).

It has been reported that higher sugar beet yields and quality can be accomplished when it follows barley or wheat in the crop rotation.

To avoid yield loss from weed competition, because sugar beets are not good weed competitors, weeds should be totally controlled by four weeks after sugar beet emergence and this should be maintained throughout the season. A combination of cultural, chemical, and mechanical weed control methods should be used to maximise weed control in sugar beets (Nichterlein et al. 2013).

Similarly, yield losses of sugar beet are caused by seedling blights, root rots and foliar diseases. The most common seedling pathogens are soil borne fungi which include *Aphanomyces cochlioides, Rhizoctonia solani* and several *Pythium* species. Appropriate control methods should be adopted in order to eliminate or reduce losses from diseases, since disease severity and prevalence varies among regions. Sugar beets are successfully produced under irrigation in regions with very low rainfall (Nichterlein et al. 2013).

2.2.4 Wine

Most grapes come from *Vitis vinifera*, including the European grapevine native to the Mediterranean and Central Asia (Figure 31). Grapes are generally a non-climacteric type of fruit which occur in clusters and can be eaten raw or used for making wine, jam, juice, jelly, grape seed extract, raisins, vinegar, and grape seed oil.

Figure 31: Illustration of vineyard (http://www.vineyard.org/)

Crop history: In 1961, the world grapes yield was 4.6 t/ha and EU had about 4 t/ha. The Russian and Ukrainian data commenced in 1992 with about 5 t/ha and 4.7 t/ha, respectively. All the areas increased in yield over the time period and in 2013, world grapes yielded 10.8 t/ha, followed by Russia with per hectare yield of 9.5 tonnes.

Meanwhile, the EU yield increased to 8.2 t/ha and Ukraine had 8.6 t/ha (FAOSTAT). The yield for Belarus was remained almost stable from 2006 to 2009, from 2009 to 2012, it increased but in 2013, it dipped down again (Figure 32).

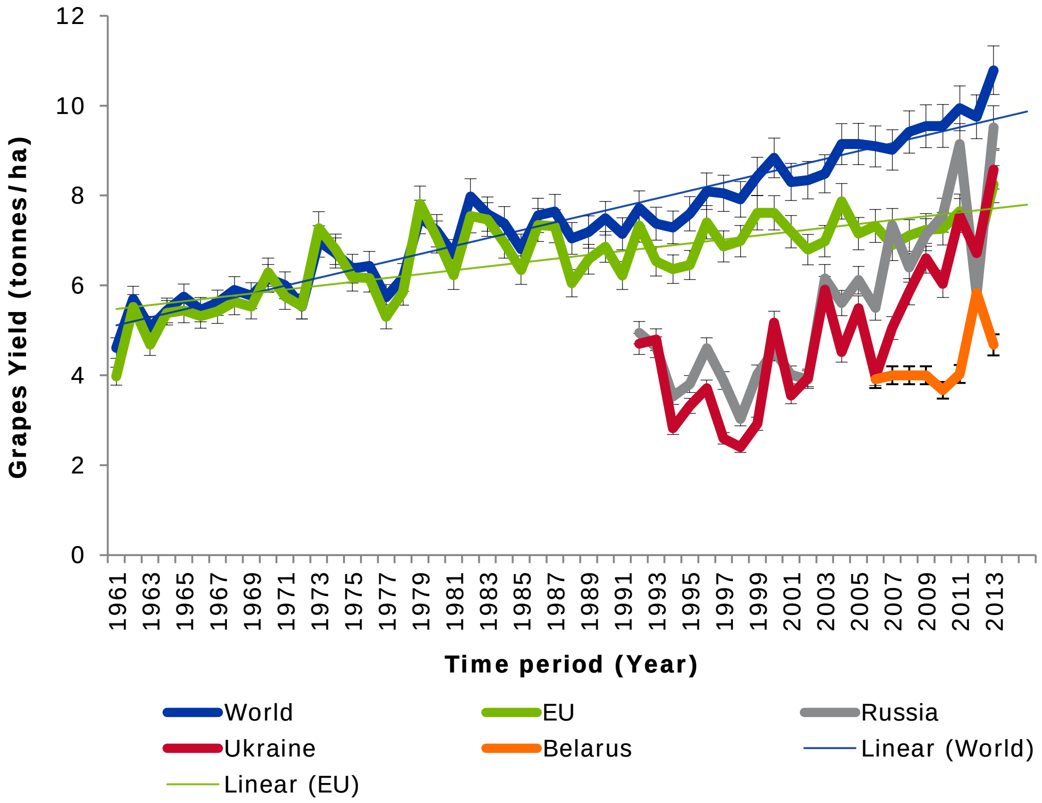

Figure 32: Crop yield development of grapes in 1961–2013. Source: FAOSTAT, Author's own diagram.

For Ukraine and Russia, the yield data was only available from 1992–2013, for Belarus the yield data started from 2006. The error bars indicate the error values calculated for data series at 5%.

Production and cropland: In the last decade, Italy had been the highest producer of vineyards for wine within the EU-27 with average production of over 6 million tones and average yield of 9.3 t/ha. Malta produced the least with an average yield of about 4 t/ha (EUROSTAT).

The Figure 33 shows the major producers of vineyards for wine/grapevine in Europe.

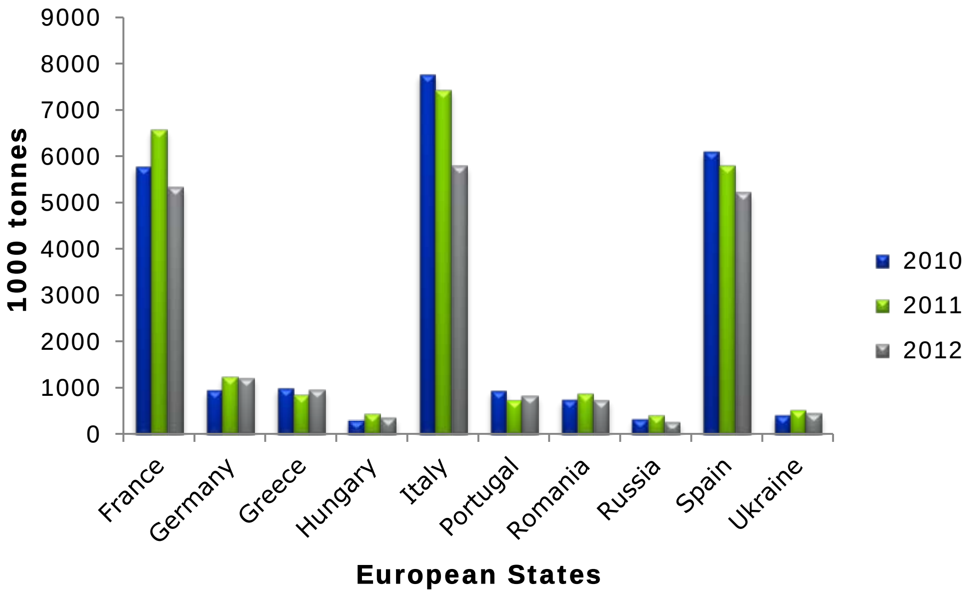

Figure 33: Major grape producing countries in EU-27, Ukraine, Russia

Source: EUROSTAT, Author's own diagram.

Yield level: For grape production, to estimate the between EU-27, Russia, Ukraine and Belarus, the countries were grouped in the same way as for cereal crops, oil crops and sugar beet. The countries with grape yield lower than 4 t/ha were categorised into low yielding group, the countries with yield of 4.1-8 t/ha fall into medium yielding category and the countries with the yield higher than 8 t/ha fall into the group of highest yielding. The lowest per hectare grape yield was recorded in Bulgaria and highest per hectare yield was recorded in Luxembourg (Table 17).

Table 17: Grape yield difference between EU-27, Ukraine, Russia and Belarus

Yield range	Average yield (t/ha)	Country
low	< 4	Bulgaria, Cyprus, Malta, UK
medium	4.1 – 8	Austria, Czech Republic, France, Hungary, Portugal, Romania, Slovakia, Slovenia, Spain, Belarus, Russia, Ukraine
high	> 8	Germany, Italy, Greece, Luxembourg
lowest	3.3	Bulgaria
highest	14.5	Luxembourg

The main reason for yield difference among the EU-27, Ukraine, Russia and Belarus is selection of variety, climatic conditions and soil type. The selection of variety plays a vital role in defining the yield of residue generated from vineyards through pruning. There are different methods being practiced in different regions to manage vineyards, which also affect the ultimate residue yield.

Crop Management: Grapes need a sheltered site in full sun with ideal aspect against a south- or south-west facing wall, or on a south- or south-west facing slope with the rows running north to south. Vines tolerate a range of soil types, provided they are free draining. A pH of 6.5-6.8 is required. The soil can be double dug before planting if necessary. A light dressing of well-rotted manure or compost, plus general purpose fertiliser can be incorporated.
After planting, mulching can be done with a well-rotted organic matter to protect the lower buds from the frost. During spring, the mulch should be removed to avoid rotting of the stem.
Although grapes are fairly drought tolerant but drainage systems can be installed if necessary. Grape vines can suffer from powdery mildew in hot, dry weather or when growing in crowded positions with poor air circulation as well as nutrient deficiencies, particularly magnesium deficiency.

2.2.5 Grasslands

Grassland (Figure 34) can be defined as ground covered by vegetation dominated by grasses, with little or no tree cover. UNESCO defines grassland as land covered with herbaceous plants with less than 10% tree and shrub cover. According to FAO, grasslands are largest habitat type in the world with an area estimated at 40.5% of the earth's landmass (EC, 2008).

Figure 34: Illustration of grassland (http://en.wikipedia.org/wiki/Grassland)

Up to 70% of global agricultural areas are covered with grasslands, which contain approximately 20% of the world's soil carbon stocks (FAOSTAT, 2009; FAO, 2010). Grassland ecosystems cover about 90 million ha in Europe and 5 million ha in Germany (Gilmanov et al., 2007). In most regions of Europe large permanent grassland areas are not needed any more or their use for fodder production is no longer economically viable. Due to its higher nutrient content, farmers also prefer maize silage over grass silage for beef production (Peeters, 2008).

However, policies in the EU are targeted at maintaining grasslands because of their high biodiversity value, high soil carbon storage capacity and the protection of erosion and water resources.
This is also addressed by EU regulations, which restrict the percentage of grassland that can be converted to arable land. Member States of the European Union have to ensure that the ratio between arable and grassland does not decrease more than 10% to the detriment of grassland at regional level (European Union, 2004). The energetic use of grassland, e.g. for biogas production or as solid fuel, could be an alternative, which gives the farmers a source of income from grassland (e.g. Tonn et al., 2009; Pöschl et al., 2010). There is a running project, funded by the "Stiftung Naturschutzfond", implemented by the University of Hohenheim on assessing the management options for grassland that maintains biodiversity and at the same time delivers biomass for energetic uses. Own publications on this subject deal with biomass produced from grassland and its use as a solid fuel (Tonn et al. 2009) or as substrate for biogas production (Gützloe et al., 2014).
Grassland can be differentiated into following categories:

- **Temporary grassland**: Grass plants for grazing, hay and silage included as a part of normal crop rotation, at least one crop year and less than five years sown with grass or grass mixtures.
- **Permanent grasslands**: Defined as land used to grow grasses or other herbaceous forage naturally (self-seeded) or through cultivation (sown) and that is not included in the crop rotation of the holding for five year or longer. Other suitable grazing species may also be included. Most of the permanent grasslands were sown when animal production had to be boosted. It can be agriculturally improved, semi natural or no longer used for production. Prochnow defines permanent grassland as land used for five years or more for herbaceous forage crops, either cultivated or growing wild. It comprises of three main types of managed grasslands namely, sown, intensive permanent grassland and semi-natural grassland (Prochnow et al. 2009). Permanent grasslands cover 57 million ha (Eurostat, 2010) or about 13% of EU-27 territory and 33% of its agriculturally utilised area. Arable land covered 24% and forest 41% of EU territory. 5 countries contribute 64% of total permanent grassland area of the EU-27, UK (17%), France and Spain (15%), Germany (9%), Romania (8%).
- **Agriculturally improved permanent grasslands:** This category is characterised by good or medium quality soils, used with more frequent defoliations, higher fertilisation rates, higher stocking rates, and producing higher yields than semi-natural grasslands (Peeters et al, 2013).
- **Semi-natural grasslands:** Low yielding permanent grasslands, dominated by indigenous, naturally occurring grass communities, other herbaceous species and in some cases shrubs and trees. These mown and grazed ecosystems are not substantially modified by fertilisation, liming, drainage, soil cultivation, herbicide use, introduction of exotic species and sowing (Peeters et al, 2013).

Permanent grasslands have been in constant decline since 1975, but the extent differs between regions (Smit, Metzger, and Ewert 2008). Similarly, Prochnow et al reported a decadal decrease in grassland area especially in developed countries (Prochnow et al. 2009). Data on grassland productivity, its spatial distribution and temporal changes are scarce. Currently, the only data

available about grasslands is mainly referring to permanent, there is no data about different categories at EU-27 level such as semi-natural grasslands.
Grassland productivity is affected by climatic factors such as rainfall and temperature, and depends on the specific management practices such cutting frequency, fertilisation (Smit, Metzger, and Ewert 2008).

The main grassland types along with pathways for biomass use are presented in Figure 35.

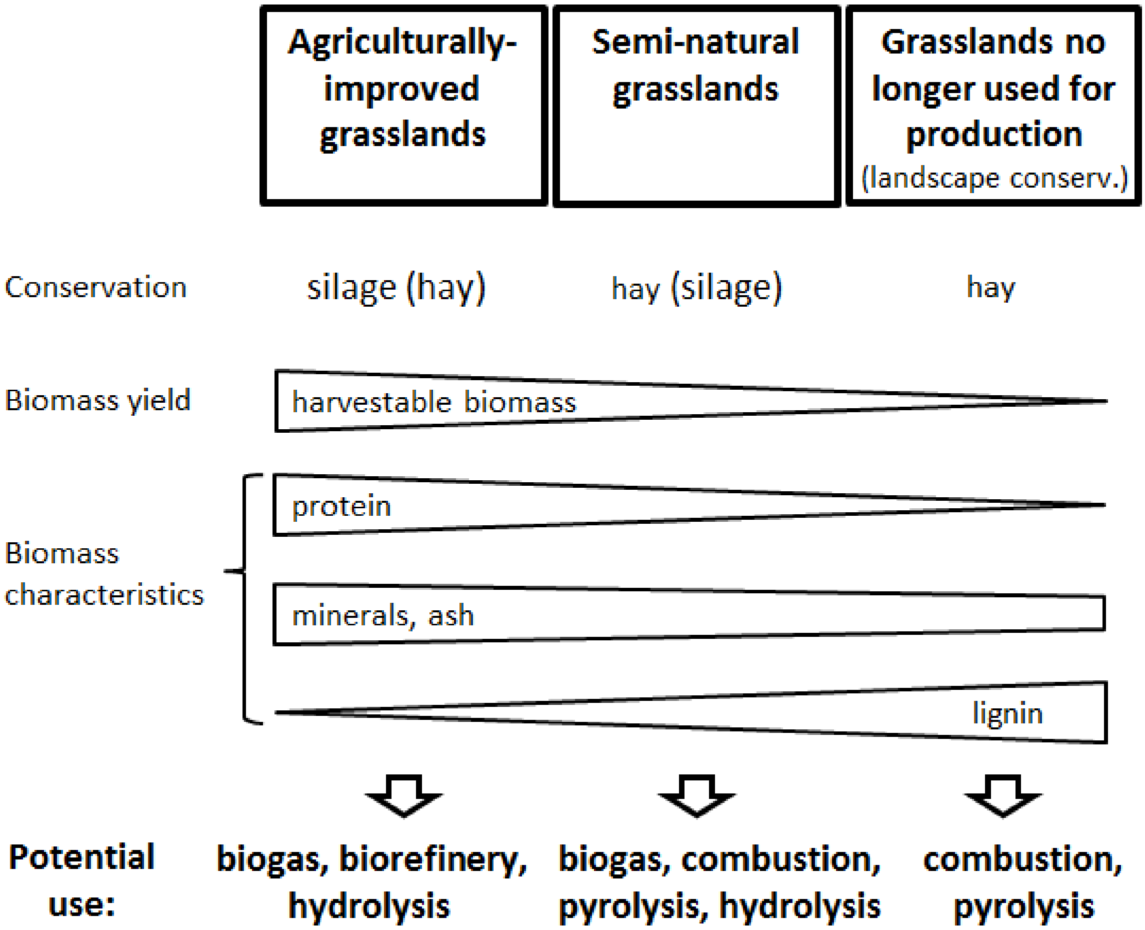

Figure 35: Grassland types and pathways for biomass use

Production and cropland: In the last decade, EU-27 produced over 200 million tonnes of grassland with Poland being the highest producer with average production of 55 million tonnes. Among Russia, Ukraine and Belarus, the grassland production in Russia is highest among all even higher than EU member states. Netherlands has the highest percentage allocated agricultural area of 72% to grassland amongst the EU-27 (EUROSTAT). Figure 37 shows the average production and agricultural land use for grassland within EU-27.

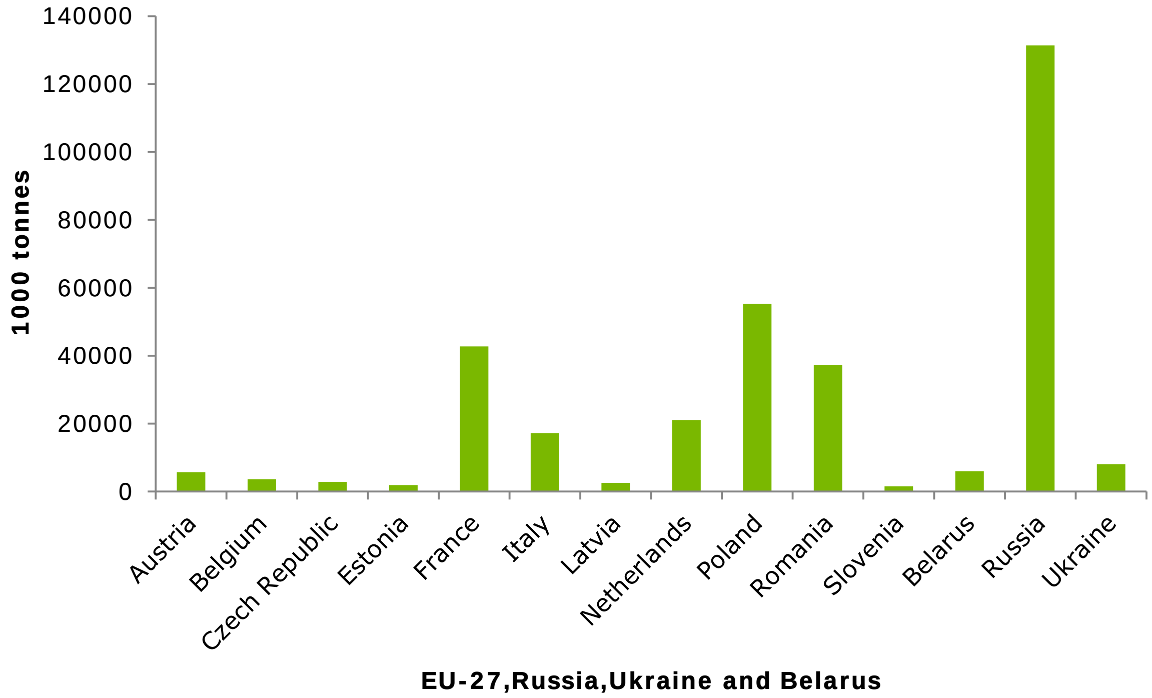

Figure 36: Average grassland production (2004–2013) in the EU major producers and Ukraine, Russia and Belarus

Source: EUROSTAT, Author's own diagram.

The area under grasslands is more than 50% in Austria, Ireland, Netherlands, Luxembourg, Slovenia and UK.

Germany, Italy and Spain have grassland area between 20-30%. The area allocated for Russia is more than 40%. The area under grassland in Belarus is higher than Ukraine (Figure 37).

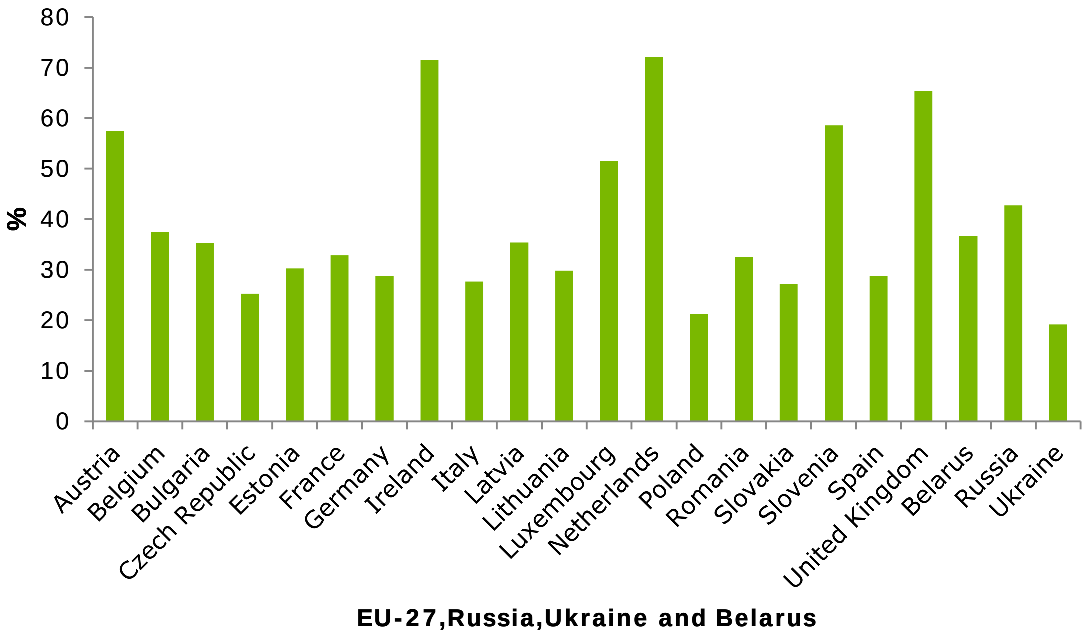

Figure 37: Average Agricultural land use for Grassland (2004–2013) among the EU major producers, Ukraine, Russia and Belarus

Source: EUROSTAT, Author's own diagram.

Grasslands are predominantly used in animal husbandry with a basic role in feeding herbivores and ruminant animals and provide important regulating ecosystem services which include erosion reduction by supporting slope stability, regulation of water regimes, purification of water from fertilisers and pesticides etc. Grasslands also support biodiversity and cultural service, for instance, by contributing to a region's cultural heritage (diverse landscapes) as well as recreational values (a form of rural economic development) (Smit, Metzger, and Ewert 2008).
However, studies from (Prochnow et al. 2009) had suggested that with the constant decline in ruminant numbers especially in developed countries and increasing amount of surplus grasslands, the biomass is more often used as bioenergy feedstock. Moreover, compared to ruminant husbandry, biogas production generates considerably low greenhouse gas emissions with a higher percentage of carbon and nitrogen cycles within the system (Prochnow et al. 2009).

Crop management: Generally, grasslands are considered as having positive impacts on biodiversity. The species and communities diversity of grasslands is a result of management practices which comprise of grazing or cutting as well as management intensity (fertilisation) (Prochnow et al. 2009).
Animal grazing on the grasslands affect the vegetation in many ways such as direct biomass consumption, selective grazing, trampling, urination, defecation etc. Mowing favours different types of vegetation than grazing. Biodiversity can be improved through low mowing frequencies of one or two cuts per season. The material collected through mowing can be used for bioenergy purposes. Therefore, on the one hand it will help to improve biodiversity but on the other hand it will also become a source of biomass for energy production.

The nutrient availability for plants is altered considerably by fertilisation. The application of fertiliser favours a few fast growing plants and eliminates the less competitive ones. The decrease in the plant diversity of grassland has been strongly linked with increasing amounts of fertiliser application. (Prochnow et al. 2009).

Management practices of grasslands are mainly characterised by frequency and date of harvesting (cutting), type and level of fertilisation, water-table control, re-seeding pesticide application and mechanical treatment (Prochnow et al. 2009). The site conditions and intensity of management practices (cutting frequency, N fertilisation) for different types of grasslands are presented in Figure 38. Agriculturally improved grasslands need better soil, climatic conditions and more N fertilisation and high cutting frequency.

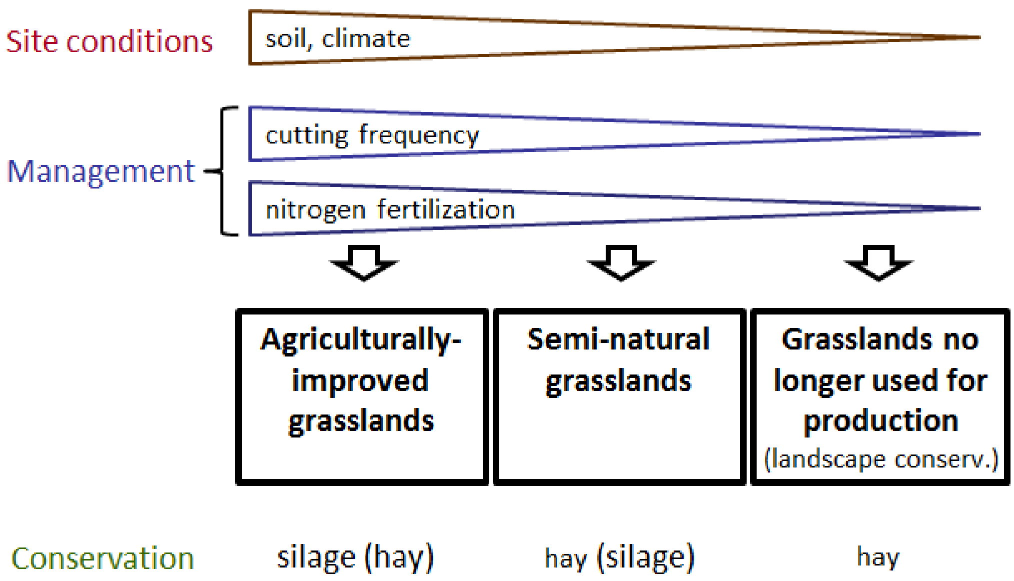

Figure 38: Specific site conditions and management practices required for different grassland types

Examples of common grass species in Europe include:

Cocksfoot	*Dactylis glomerata*
Meadow foxtail	*Alopecurus pratensis*
Meadow fescue	*Festuca pratensis*
Perennial ryegrass	*Lolium perenne*
Red fescue	*Festuca rubra*
Reed canary grass	*Phalaris arundinacea*
Smooth meadow grass	*Poa pratensis*
Tall fescue	*Festuca arundinacea*
Timothy	*Phleum pratense*

2.3 Agricultural crop residues

Definitions of crop residues: Lal (2004) defined crop residues as the non-edible portion of plants that remain on fields following harvest. These residues are differentiated from other biomass resources (e.g. energy crops) as they are in most cases not purposely produced for energy resources (Lal 2004). Some researchers also include leftovers that are generated through harvesting of crops or that are discarded during crop processing into the generic category of crop residue (Lal 2004).
The author Adolfsson (2006) defines crop residues as biological yield excluding the grain yield and 1-2 cm stubble but including husk and chaff (Adolfsson 2006). The available parts of different agriculture crops as residue along with their potential energetic use are presented in Table 18.

Table 18: Residue generated from different crops along with potential energetic use

Crop	Residue	Potential for energetic use
Wheat	Straw	Solid fuel, Gasification, Ethanol, Biogas
Barley	Straw	Solid fuel, Gasification, Ethanol, Biogas
Maize	Stover, cobs	Solid fuel, Gasification, Ethanol, Biogas
Sugar beet	Leaves	Biogas, Ethanol
Rape seed	Straw	Biogas, Biodiesel
Rye	Straw	Solid fuel, Gasification, Ethanol, Biogas
Oat	Straw	Solid fuel, Gasification, Ethanol, Biogas
Sunflower	Straw	Biogas, Biodiesel
Wine	Wood	Solid fuel, Gasification,
Grassland	Grass	Solid fuel, Gasification, Biogas

According to the Directive EN 14588 the European Committee describes agricultural residues as „biomass residues originating from production, harvesting, and processing in farm areas“ (Europäisches Komitee für Normung, 2010). It is distinguished between the residues of the food industry (‘food processing industry residues’), for example, press cake produced out of juice production, and others. The remains from keeping of animals (‘animal husbandry residues’) are recorded separately. If a subsequent treatment of raw materials occurs in the food industry the residues are usually called industrial residues (Mahro and Timm 2007).

Crop residues have been discussed as ‘wastes’ but as a natural and valuable resource which can be used efficiently to produce energy. Crop residues offer a large potential for further utilisation e.g. carbon sequestration and nutrient cycling (Reicosky and Wilts 2005).

The residues can also be divided into the point of arising during the production process and are classified in primary, secondary and tertiary residues. The origin of primary residues is the first step of a process chain, the harvest of the raw materials. The further processing steps result in the so-called secondary residues. Tertiary residues are the remains that arise from a (partial) final consumption (e. g. food leftovers) (Hoogwijk et al., 2003) (Figure 39). In this project the focus and scope of research will be on primary residues.

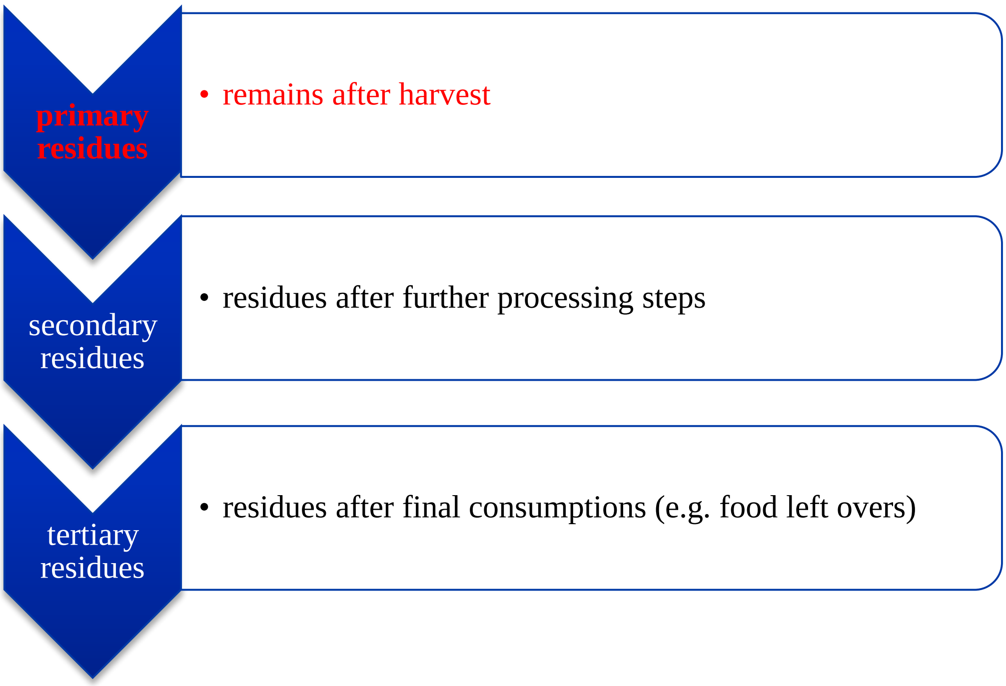

Figure 39: Agricultural residues classified according to point of arisal

In this study cop residues are defined as agricultural residues that are left over after the harvesting of main crop and have not been utilised.

2.3.1 Factors affecting residue yield

There is a large annual variation in crop production and productivity; therefore the amount of agricultural crop residues varies significantly. In the European Union, cultivated area, types of crops grown and yields achieved differ largely between EU-27 due to climate conditions, specific soil condition and management practices. Cereals and oilseeds are important crops, in terms of area cultivated and production. Annual crops are quite variable in yield from one year to another, depending on precipitations in rain-fed conditions that lead to a variability in the crop residues produced (Nicolae Scarlat, Martinov, and Dallemand 2010).

Therefore, the amount of residues is directly related to the crop production system, and depends on yield, residue-to-grain/main product ratio (Perlack et al. 2005), cultivated area (Nicolae Scarlat, Martinov, and Dallemand 2010), plant variety, harvesting techniques, the cutting height and specific climate and soil conditions (Monforti et al. 2013). The factors affecting residue yield can be grouped into those that are non-controllable, i.e. site conditions and climate, and two main controllable categories; a) crop breeding; b) management practices including harvesting and logistics.

Breeding

Breeding has direct effects on crop yield such as development of new cultivars with high yield potential which subsequently affects the residue yield. Breeding also has direct effects on residue to crop ratio because currently, the breeding of crops has primarily aimed at maximizing yield of main food/feed product. It has led to decrease in straw length mainly because breeding programs has focussed on increased plant allocation to the grain to have high yield, and also to avoid lodging (bending of stalks or whole plant). Even among new cultivars with high grain yield, considerable differences in straw and grain yield are recorded.

Another study (Lewandowski and Kauter 2003) was conducted to estimate the location and N fertilisation effect on crop yield and residue yield. Results revealed that for yield and all quality parameters, the interactions between species and location were significant. Strong yearly influences were recorded for all parameters (quality and yield). All parameters showed significant interactions between year and location.

Effect of N fertilisation

The nitrogen (N) fertilisation had a significant influence on yield and the composition of biomass. Strong interactions between year and N fertiliser were calculated for yield. The graph below depicts residue to crop ratio (RCR) for wheat on two locations over two years. N fertiliser application was varied, ranging from 0 kg N/ha, 70 kg N/ha and 140 kg N/ha. At this site the yield of main crop product and straw increased but the residue to crop ratio was highest at lowest N fertilised plots Figure 40.

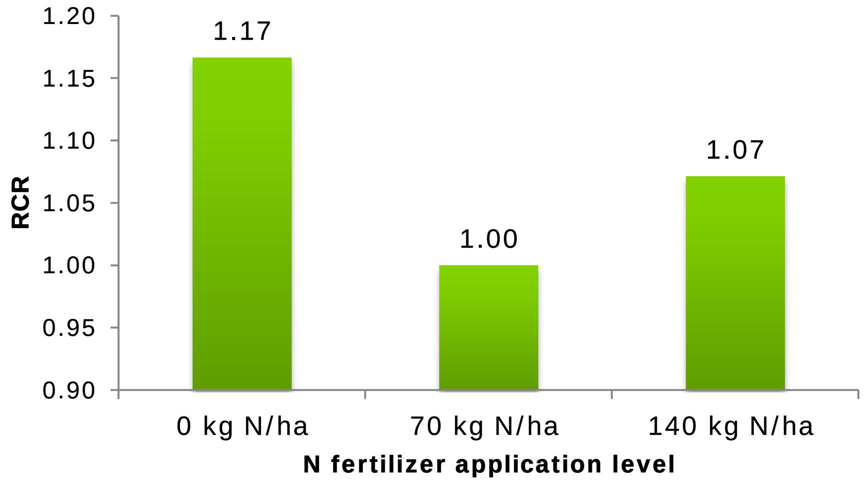

Figure 40: Effect of N fertilisation on Residue-to-crop-Ratio (RCR) for wheat in 1996 in Hohenheim, South West Germany

Source: (Lewandowski and Kauter 2003) , Author's own diagram

Almost the same trend was observed in 1997, where residue to crop ratio decreased for wheat at high N fertilisation levels. At another location, the results were slightly different. At this location, no significant difference between residue to crop ratio was recorded at three different N fertilisation levels Figure 41.

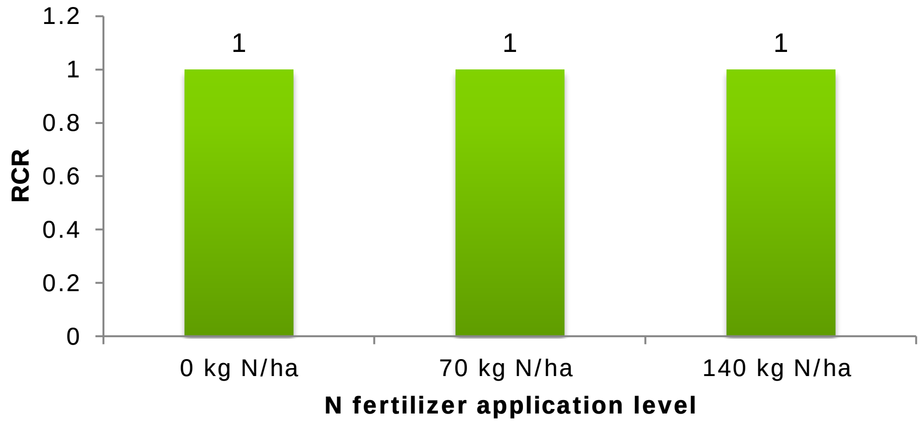

Figure 41: Effect of N fertilisation on Residue-to-crop-Ratio (RCR) for wheat in 1996 in Gut Germany

Source: (Lewandowski and Kauter 2003) , Author's own diagram

In the same study (Lewandowski and Kauter 2003), the effect of N fertilisation and location was evaluated for rye also. When N fertilisation was increased from 0 to 70 kg/ha, the residue to crop ratio for rye also increased but at 140 kg/ha the residue to crop ratio decreased again.

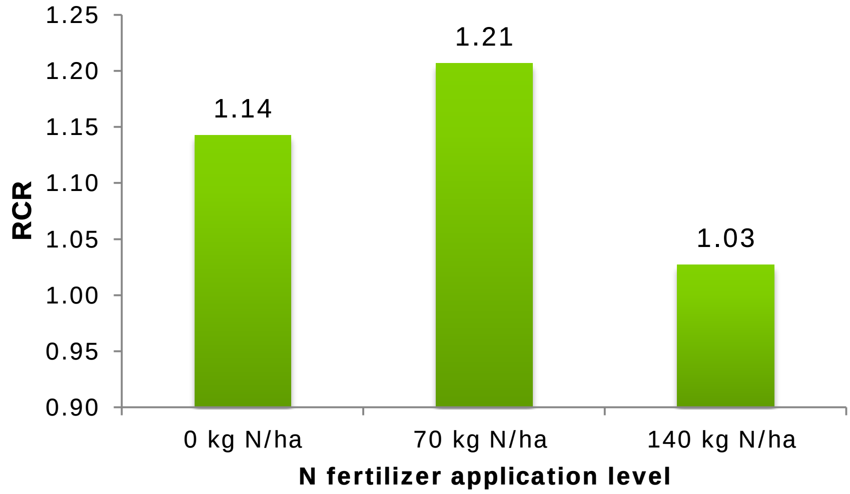

Figure 42: Residue-to-crop-Ratio (RCR) for rye in 1996 in Hohenheim, South West Germany

Source: (Lewandowski and Kauter 2003) , Author's own diagram

However, at the other location Gut, the effect of N fertilisation was positive on crop to residue ratio. The crop to residue ratio for rye increased with increase in N fertilisation.

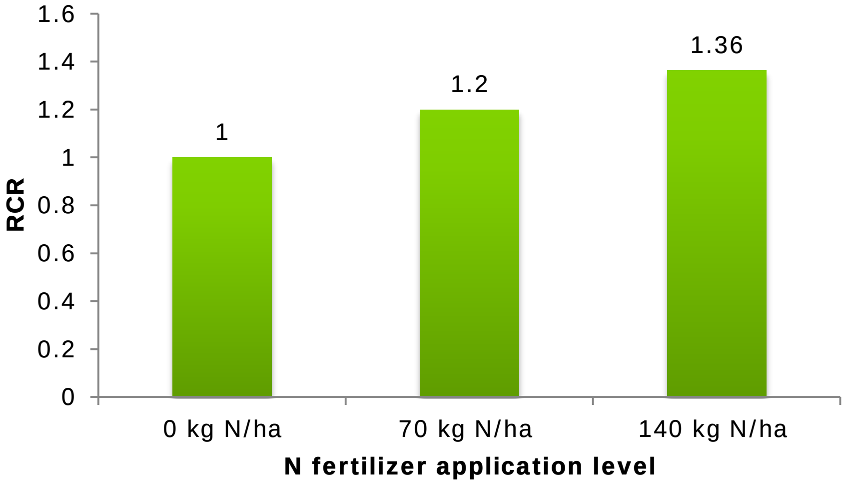

Figure 43: Residue-to-crop-Ratio (RCR) for rye in 1996 in South West Germany Gut under different N fertilisation levels

Source: (Lewandowski and Kauter 2003) , Author's own diagram

In another study (Thomsen, Djurhuus, and Christensen 2003), the residue to crop ratio spring oat increased with increase in N fertilisation. The fertilisation was increased from 0 to 200 kg/ha. The influence of N fertilisation was positive on residue to crop ratio except for when fertilisation was increased from 0-50 kg/ha, where no significance difference was observed.

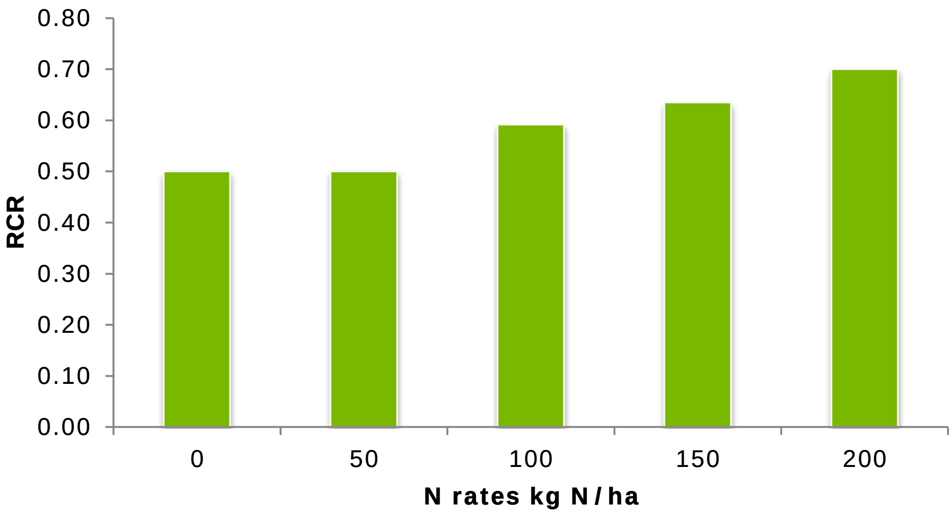

Figure 44: Residue to crop ratio for spring oat under different N fertilisation levels

Source: (Thomsen, Djurhuus, and Christensen 2003) , Author's own diagram

In the same study (Thomsen, Djurhuus, and Christensen 2003), the effect of N fertilisation was evaluated for spring barley as well. The effect of N fertilisation was estimated separately for straw as well as grain yield. The effect of N fertilisation was significant on straw yield and grain yield for spring barley. The increase in fertilisation increased the residue to crop ratio for barley, therefore the areas where N fertilisation is not applied properly, has the chance to improve residue yield.

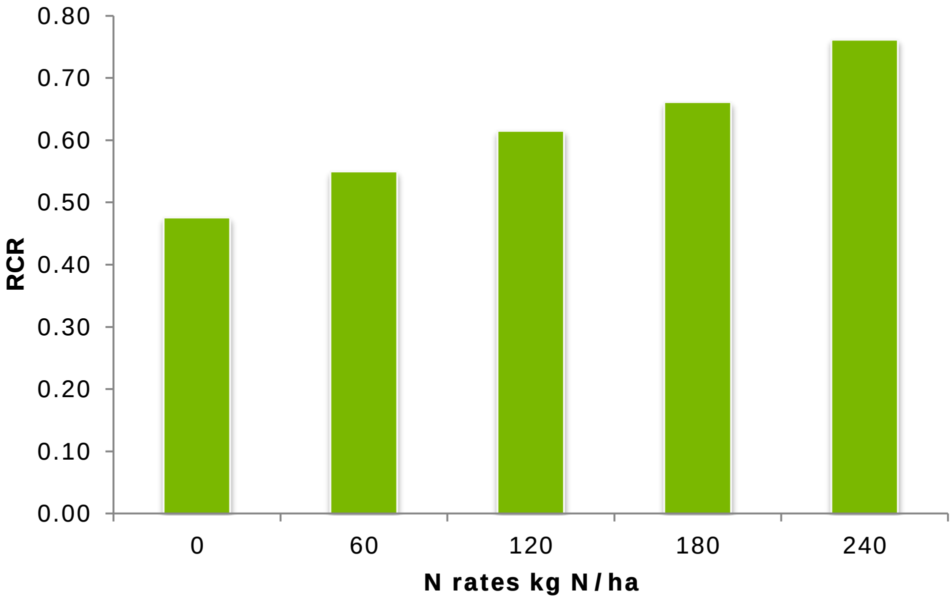

Figure 45: Residue to crop ratio for spring barley under different N fertilisation levels

Source: (Thomsen, Djurhuus, and Christensen 2003) , Author's own diagram

Conclusion: For wheat, effect of N fertilisation was not clear and there was no significant increase in residue to crop ratio observed. For rye, the residue to crop ratio increased with increase in fertilisation except for one location. The spring barley and spring oat have shown significant increase in residue to crop ratio with increase in N fertilisation.

Impact of variety

The selection of cultivar also plays significant role in defining the residue to crop ratio. For example in Denmark, during 2008 and 2009, different wheat cultivars were compared to estimate the effect of cultivars on residue to crop ratio.

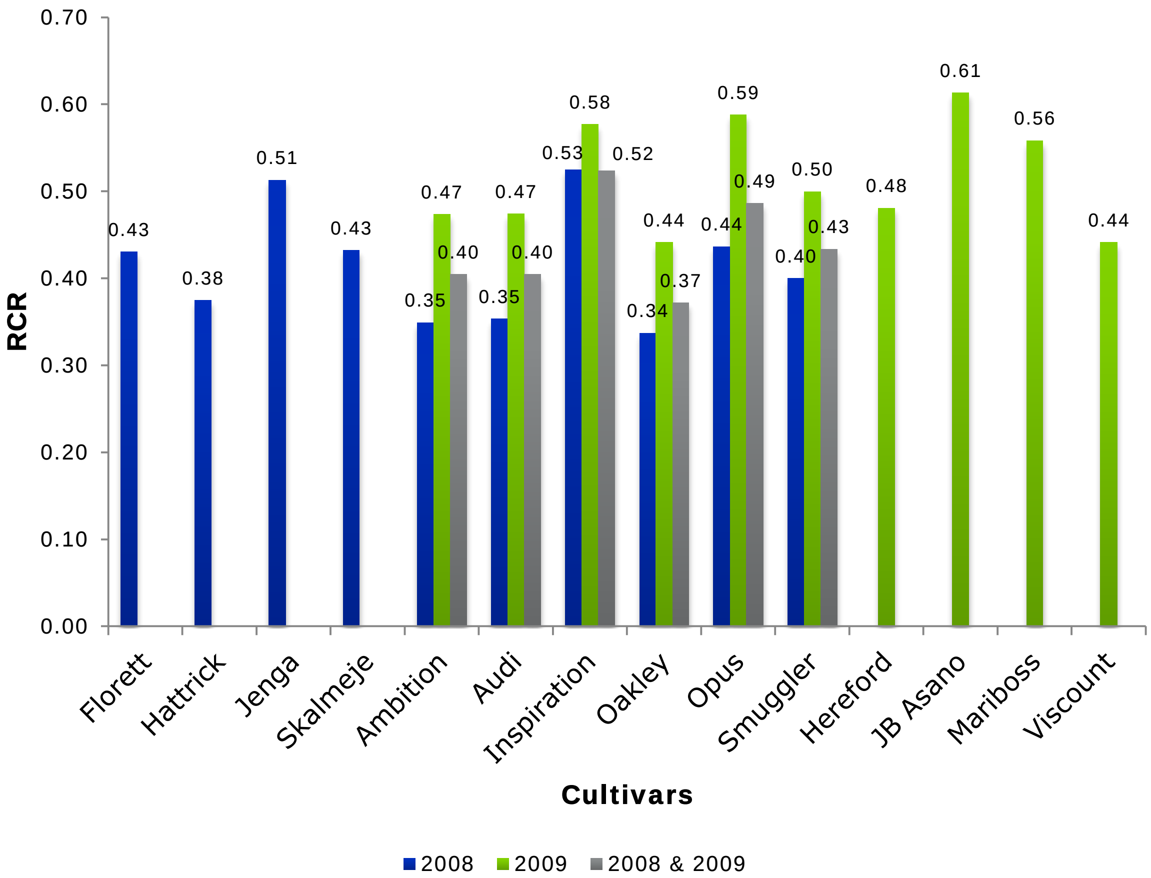

Figure 46: Residue to crop ratio (RCR) for different wheat cultivars during 2008–2009 in Denmark

Source: (Larsen, Bruun, and Lindedam 2012) , Author's own diagram

Grain yield did not differ significantly between the species, but winter rye yielded up to 59% more straw dry matter than the other species. The fact that straw yield was significantly different among the diverse species while there were no differences in grain yields, demonstrates a possibility for farmers to grow cultivars with higher straw yield without compromising the grain yield. Explicitly, total biomass yield from winter wheat production may be increased by selection of the right cultivars. However, grain yield is still the primary goal of cereal production, and increased straw yield should not bring along negative consequences such as increased susceptibility to lodging and diseases. Also, from a farmer's perspective, increased straw yield may increase fuel consumption, reduce the capacity of harvesting machinery as well as increase the demand for fertilisation, and these aspects must also be included in economic considerations (Larsen, Bruun, and Lindedam 2012).

Impact of fungicide use

In management practices, the use of fungicides also had significant effect on residue to crop ratio. In Denmark, fungicide treatments and varieties significantly influenced residue to crop ratio. The yield increases in straw varied between 0 and 1.0 tonnes/ha depending on year and variety, and was on average 0.42 tonnes/ha for two fungicide treatments, but the increase in straw yield did not depend on straw length. Although fungicide treatments on average increased straw yields significantly, the differences between one and two fungicide treatments were only 0.1–0.2 t/ha, and this difference was not significant. The difference between tall (Terra) and short (Pentium) varieties was approximately 1.5 t/ha. This indicates that if a high straw yield is important for the farmer tall varieties like Terra should be given higher priority than use of fungicides.

The use of triademefon for control of mildew (*Erysiphe graminis*) has been discovered to increase both grain and straw yield in wheat. In case of application during elongation, straw yields were increased by more than 20% in winter wheat. Yellow rust (*Puccinia striiformis*) reduced straw yield significantly. Fungicide treatments decreased residue to crop ratio. The following graphs illustrate the influence of several fungicide treatments on residue to crop ratio for different cultivars (Jørgensen and Olesen 2002). For all cultivars, the untreated fields has shown high residue to crop ratio.

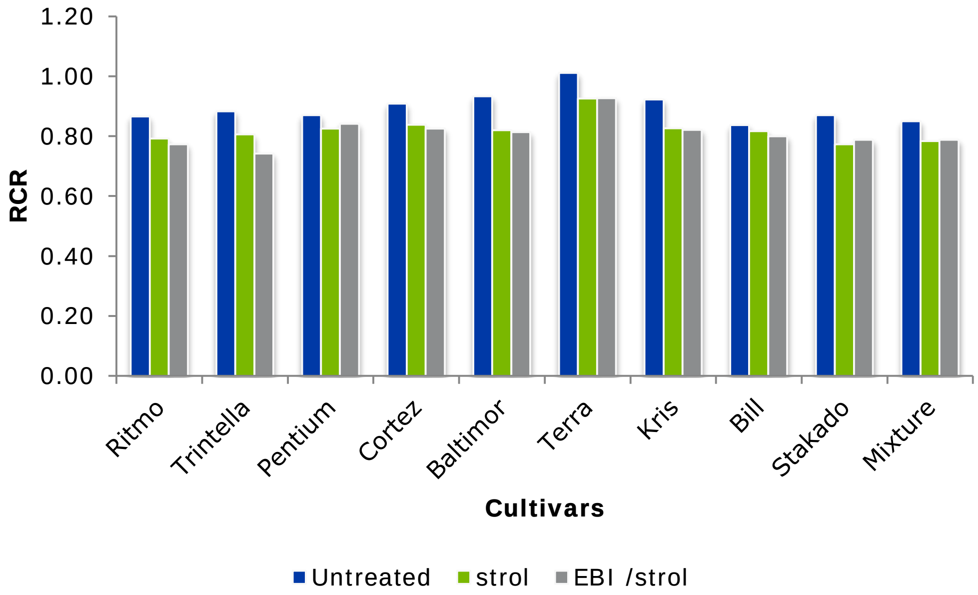

Figure 47: Residue to crop ratio (RCR) for different wheat cultivars under different fungicide treatments in Denmark in 1999–2000.

Source: (Jørgensen und Olesen 2002), Author's own diagram

Other management practices such as sowing rate also had an influence on residue to crop ratio. For example in winter wheat the sowing date and sowing rate had influenced the residue to crop ratio. Figure 48 illustrates the influence of different sowing rates and dates on grain and residue yield. It can be stated that a lower sowing rate results in higher grain yield and lower straw yield if it was early sown.

Seeding in August results in highest yield and straw levels and in higher residue to crop ratios. The residue to crop ratio increases with increase in sowing rate. Early sowing favours higher yield returns.

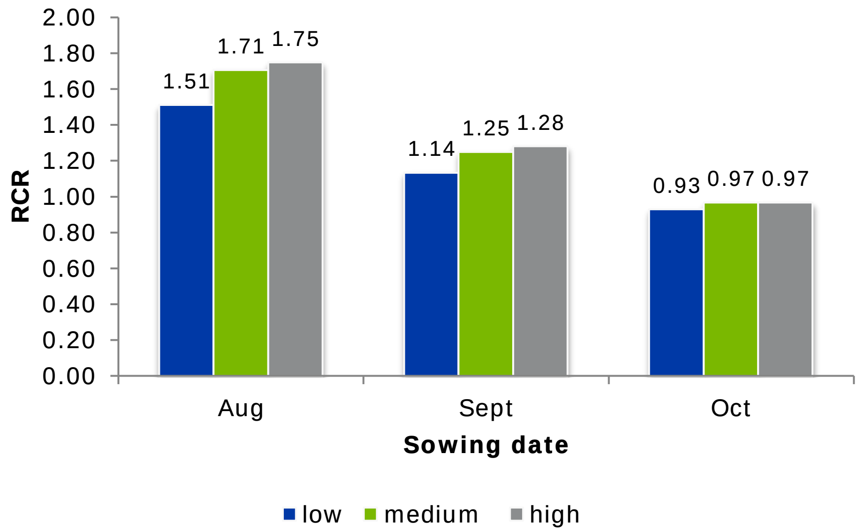

Figure 48: Effect of sowing date and sowing density on residue to crop ratio tested in 1994–1997

2.3.1.1 Residue to crop ratio

The main factor for crop residue yield is residue to crop ratio. It has great influence on defining the ultimate residue yield. The residue to crop ratio residues to crop ratio only describes the relationship between the biomass that grows as the main product and the residue. It does not yet indicate how much of this biomass is technically harvestable. Also, the quality of residues in terms of potentials for energetic uses or with regard to storage and transportation demands differs between crops. The residue to crop ratio for different crops is presented in Table 19.

Table 19: Residue to crop ratio for different crops

Crop	Residue to crop [Ratio]
Wheat	0.8–1.6
Rye	0.9–1.6
Barley	0.8–1.3
Oats	0.9–1.4
Maize	0.9–1.2
Rapeseed	1.4–2.0
Sunflower	2.2–3.2
Sugar beet	0.2-0.4
Wine	0.2-0.6

(Patterson et al., 1995; Nikolaou et al.,2003; Christou et al., 2007; Scarlat et al. 2010).

The relationship between residue-to-main-product is very specific to the type of crop and plant variety. It is very difficult to make a straight estimation of this ratio, since it is influenced by climate and soil conditions and management practices (tillage, density of planting, fertilisation, etc.) (Patterson, Markus, Momont, & Robertson, 1995). The unfavourable field conditions and crop stress, such as insufficient nutrients and water that might reduce the Harvest Index (HI) (Johnson, Allmaras, and Reicosky 2006; N. Scarlat et al. 2013; Wilhelm et al. 2004). Methods and the use of fertilisers and/or straw shortening chemicals also influence the relation between crop residues and seed (Larsen, Bruun, and Lindedam 2012).

2.3.1.2 Availability of crop residues and sustainable removal rate

In regions where large quantities of cereal straw are produced and left on soil surface straw can sometimes pose a management problem. In these areas, there may be opportunities for removing straw or other crop residues for alternative uses while maintaining optimum soil organic matter level. However, before recommending residue removal the impact of this practice on crop yield and soil properties must be considered. Management options such as no-tillage (growing of crops or pastures without disturbing the soil through tillage), choice of crops in a rotation and rotation length, and adequate fertilisation can be used to enhance level of organic matter in soil, which might counterbalance the potentially negative impact of residue removal Application of fertiliser N improved seed, straw, and chaff yields and root mass of barley, wheat and canola grown in rotation. Straw retention and no tillage showed considerable beneficial influence on these parameters for rapeseed (Malhi et al. 2006).
Crop management recommendations for maximum residue production require basic scientific research information regarding site-specific soil and climate pattern and cultivated crops (Reicosky and Wilts 2005).

The availability of crop residues is limited due to preserving land fertility and to reducing the risk of erosion (Christou et al. 2007; Nikolaou, Remrova, and Jeliazkov 2003; Patterson et al. 1995) and to other competing uses such as feed, organic fertiliser, or fibre.

Straw yield is affected by many factors including water availability, nitrogen availability, sowing rate and sowing date, fungicide treatment and harvesting and collection method.

Scarlet et al. (2010) also confirm that residue production depends on a number of factors that include the types of crops, crop rotation, crop mix and agricultural practices and weather conditions and whether the crop is irrigated or rain-fed, moisture availability, temperature and soil, etc.
In addition to the environmental constraints and economic considerations, the availability of crop residues for bioenergy production depends on other competing uses. The main competitive uses of crop residues are for incorporating into soil, animal feed and bedding, mushroom cultivation, surface mulching in horticulture and industrial uses.

Crop residues are often incorporated in the soil to protect against soil erosion, as fertiliser, and soil structure improver. Straw is used for crop protection, mainly in cold climates when crops are left in the ground during winter. Straw for surface mulching is also a valuable option for controlling soil erosion in combination with no or conservative tillage. Wheat straw is used as substrate for the mushroom production, together with horse manure or poultry litter. Straw can also be used in industry to produce pulp and paper or as insulating material for buildings. However, the industrial uses of straw were estimated to count for a very small proportion (around 1.5%) of total production (Ecofys 2013).

The use of straw for livestock is the most important competitive use of straw and stover mainly for animal feeding and bedding. Straw is commonly used as bedding for cattle, horses and pigs and even as fodder. Maize stover is a potential feed for cattle, providing an important share in their diet, although its nutritive quality is low. The amount of straw used depends on the straw availability, livestock, farming and housing systems, and how long they stay indoors.

In areas with low soil carbon, there is a higher demand of crop residues in field for soil. But the areas with high carbon, more residues can be taken away from those areas. The sustainable removal of straw residue for different crops is presented in Table 20.

Table 20: Sustainable removal rate for different crops along with residue to crop ratio

Crop	Residue to crop [Ratio]	Removal (%)
Wheat	0.8–1.6	40
Rye	0.9–1.6	40
Barley	0.8–1.3	40
Oats	0.9–1.4	40
Maize	0.9–1.2	50
Rapeseed	1.4–2.0	50
Sunflower	2.2–3.2	50

Source: (Nicolae Scarlat, Martinov, and Dallemand 2010)

The residue removal rate varies depending on a combination of aspects, prevailing management practices (crop rotation, tillage, fertilisation, crop protection), harvest equipment limitations (Wilhelm, Johnson, Hatfield, Voorhees, & Linden, 2004), plant variety and the harvest height, crop yield variations, environmental requirements, water availability (Patterson, Markus, Momont, & Robertson, 1995) climate (wind, precipitation patterns), and soil conditions like organic matter, soil carbon, moisture, topography and slope and risk of erosion (Panoutsou, Eleftheriadis, & Nikolaou, 2009; Scarlat et al., 2010). The residue-to-crop-ratio and the production system are influencing parameters as well.

The most important factors are listed below:

- Management practices (crop rotation, tillage, fertilisation, crop protection)

- Site specific conditions (soil and climate)
- Harvest machinery (recovery rate and harvest height)
- Plant variety (residue to crop ratio)

Most studies assume that about 25% of the total available agricultural residues can be recovered (Hoogwijk et al., 2003). According to Panoutsou et al. (2009) from the total agricultural residues produced in WEC (Western European Countries), 48% are being exploited in non-energy (e.g. animal feeding) or traditional energy applications and a further 40–45% of the unexploited quantity cannot be exploited for various technical and/or economic reasons (Panoutsou, Eleftheriadis, & Nikolaou, 2009). Other studies show that only around 35% of the maize residue is available in conventional tillage. In the case of reduced tillage, farming might allow an increased removal rates and higher availability of straw for other uses (Johnson, Allmaras, & Reicosky, 2006; Scarlat, Dallemand, Motola, & Monforti-Ferrario, 2013). In case of no till farming, 68–75% of the maize residue can be available, or up to 76–82% (Johnson, Allmaras, and Reicosky 2006; Nicolae Scarlat, Martinov, and Dallemand 2010). Most residue recovery operations pick up residue left on the ground after primary crops have been harvested (Perlack et al., 2005). Collection of residues from these crops involves multiple passes of equipment over fields and results in no more than 40% removal of stover or straw on average. This low recovery amount is due to a combination of collection equipment limitations, contour ridge farming, economics, and conservation requirements. It is possible under some conditions to remove as much as 60-70% of corn stover with currently available equipment.

However, this level of residue collection is economically or environmentally viable only where land is under no-till cultivation and crop yields are very high. Future residue collection technology with the potential of collecting up to 75% of the residue is envisioned. These systems are likely to be single-pass systems that would reduce costs by collecting the grain and residue together. Single-pass systems will also address concerns about soil compaction from multiple pieces of residue collection equipment, unless the single pass system is heavier than the current grain harvesters (Wilhelm, Johnson, Hatfield, Voorhees, & Linden, 2004). Further, one-pass systems for corn and grain will need to have selective harvesting capability so that some portions of the residue stream can be reapplied to the field to meet conservation requirements (Perlack et al., 2005).

2.4 Estimation of residue yield (t/ha) (Low, medium, high)

To estimate the overall potential for the increase of residue yield in the EU, Ukraine, Belarus and Russia the acreages of production of these crops are needed. Secondly, the yields of the crops need to be assessed. Since the residue yield is directly linked to the yield of the main product, the grain/main product-to-residue ratios need to be considered for each crop. The ratio of residue to crop yield is the amount of residue available during harvesting of a specific crop.

Under normal circumstances, crop production of course varies from year to year, which subsequently leads to variations in residue production. Therefore, for precise estimation and coverage of the whole range of variation, average, minimum and maximum residues yields need to be considered for each crop.

Among cereals, maize, wheat and rye have the highest residue to crop ratio, which subsequently lead to highest residue to crop yield among all cereals. It shows that crop yield and residue to crop ratio are two very important factors to define the residue yield of a certain crop. The factors which affect the crop yield as well as residue to crop ratio ultimately affect the residue yield. The residue yield of maize is higher than other cereals, which is mainly because of high yield potential of maize and high residue to crop ratio as well.
The residue yield for rapeseed and sunflower is lower than maize. Despite of low crop yield of rapeseed and sunflower, the residue yield is still higher. This is mainly because of high residue to crop ratio for oilseeds compared to cereals.
The residue yield for sugar beet is higher than cereals. Despite of lowest residue to crop ratio of sugar beet, the residue yield is still high, due to the highest crop yield among all crops.

The crops with low residue to crop ratio, can be improved further by selecting cultivars with high residue to straw ratio without compromising grain yield. The other important component to increase the residue yield is crop yield. Crop yield can be improved further through improved management practices especially for countries in the lowest yielding category.

The per hectare residue yield (t/ha) for each crop was calculated by taking residue to crop ratio and multiplying it with low, medium and high actual crop yield. The residue yield from wheat was 1.48 t/ha, 3.62 t/ha and 7.90 t/ha for low, medium and high actual yield respectively.
The crops with low residue to crop ratio but high actual crop yield also led to high residue yield such as in sugar beet, the residue yield reached up to 19.60 t/ha despite of low residue to crop ratio. Therefore, it can be concluded that, actual crop yield and residue to crop ratio play significant role in defining the final residue yield.

The low residue to crop ratio has been used as a conservative assumption to estimate the residues yield for each crop.

Table 21: Overview of residue yield estimation for all crops

Crop	Medium residue to crop ratio	Actual crop yield (t/ha)			Residue yield (t/ha)		
		Low	Medium	High	Low	Medium	High
Wheat	0.9	1.64	4.03	8.78	1.476	3.627	7.902
Barley	0.8	1.60	5.27	7.96	1.28	4.216	6.368
Rye	0.9	0.94	6.25	9.60	0.846	5.625	8.64
Oats	0.80	0.96	4.70	7.40	0.768	3.76	5.92
Maize	1.00	3.60	7.86	11.75	3.6	7.86	11.75

Crop	Medium residue to crop ratio	Actual crop yield (t/ha)			Residue yield (t/ha)		
		Low	Medium	High	Low	Medium	High
Rapeseed	1.50	1.50	2.75	4.00	2.25	4.125	6
Sunflower	2.30	0.56	1.70	2.60	1.288	3.91	5.98
Sugar beet	0.23	18.7	37.40	85.30	4.301	8.602	19.619
Wine	0.20	3.30	8.70	14.50	0.66	1.74	2.9

2.5 Biomass quality assessment of crop residues

There are several examples of energetic uses of residues in Europe, such as heat and power production from wheat straw in Denmark (Scarlat, 2010; DPCleanTech, 2009) and the use of sugar beet leaves in biogas plants in Poland (Mioduszewska, 2009). Especially straw from cereals has a multitude of potential energetic uses, such as heat and power production from the combustion of solid fuels, the production of syngas or liquid fuels through the gasification of the biomass, the enzymatic hydrolysis and fermentation to ethanol or, after a pre-treatment, the use for biogas production. Also biomass from permanent grassland has several potential applications and both, straw and grass, have the advantages that they deliver harvestable, dry and easy to store biomass.

The quality of biomass plays an important role in determining the conversion efficiency and biofuel yield per tonne biomass. However, for every end use of biomass (combustion, bioethanol, biogas, biomass to liquid), the quality parameters vary. For example, high water and ash content lead to inefficient combustion and reduces the overall conversion efficiency. High lignin content decreases the fermentability of ligncellulosic biomass to biogas or ethanol.

There are four possible pathways of energetic use for the crop residues; a) solid fuel for direct combustion; b) liquid fuel such as ethanol production (Bansal et al. 2013); c) biogas production (Koçar and Civaş 2013); d) biomass to liquid (BtL). For these main residue streams the quality data about potential use of residues are collected to evaluate quality and work out the implications. For example, the use of crop biomass with high ash and mineral content for combustion will lead to combustion problems (Koçar and Civaş 2013). The quality parameters of interest are presented in Table 22 for different bioenergy routes.

Table 22: Quality parameters of different biomass conversion routes

Bioenergy route	Quality parameters	Source
Direct Combustion	Heating value and storability (Water, ash, elementary composition) Corrosion and fouling (K, Cl, ash) ash melting point (Ca, Mg, Si) Emissions (N, S)	Lewandowski and Kicherer, 1997 Baxter et al. 2014 Vassilev et al. 2010 Baxter et al. 2012
Ethanol Production	Lignin, cellulose, hemicellulose	Bansal et al. 2013
Biogas production	Lignin, cellulose, hemicellulose Specific biogas potential	Koçar and Civaş 2013
BtL	Lignin conversion, Na, Mg, Ca, K content, water content	Stöcker, 2008; Sunde et al. 2011

The quality parameters for combustion are heating value, moisture content, ash and mineral content. The water content is crucial in direct combustion; it reduces the heating value of the biomass which subsequently decreases the efficiency of power plant. Also, water reduces the storability and wet biomass may require artificial drying.

The influences of site conditions and crop management practices on the water content of crop residues is shown by the example of wheat straw. The water content of the straw varies significantly determined by year, variety and fungicide treatment. In a study of Jørgensen & Olesen (2002), the water content in straw was significantly higher after the use of strobilurins compared with untreated and EBI fungicides (ergosterol biosyntesis inhibitors). There were large differences between years in straw moisture at harvest, indicating that the weather during ripening play a major role for how much the harvest processes should be postponed. The combine effect of both fungicides on moisture content was higher than individual effect of fungicide strobilurins. The straw moisture content of different wheat cultivars under different fungicide treatments are compared in Figure 49.

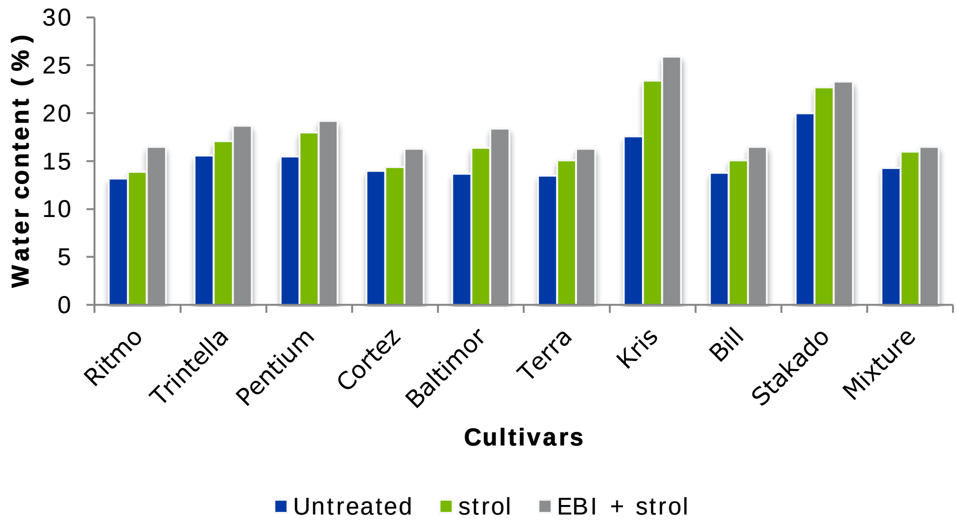

Figure 49: Water content of different wheat cultivars under different fungicide treatments in Denmark in 1999–2000.

Source: (Jørgensen und Olesen 2002), Author's own diagram

Taking water content in both grain and straw in to consideration, farmers should harvest the crop when water content in the grain has reached 15–17% regardless of the water content of the straw. If water content in the straw is high it should be left in the field for drying and weathering for 2–3 days before baling.

The other quality parameters for straw for combustion include ash melting temperature, ash content and mineral content. The high ash content lower down the combustion efficiency and increases the operational cost. In biomass composition, the Cl (Chloride), K (Potassium), Si (Silicon) content is very crucial because they have direct effect on ash melting behaviour. The high content of K and Cl will lead to corrosion, fouling and slagging problems. Therefore, the biomass with low ash content, low moisture content and low mineral content is preferred for efficient combustion process.

The time of harvesting is very crucial to optimise the biomass quality for combustion (Baxter et al. 2014). For example, if the residues are left on the field for some time, it will lead to low mineral content especially because Cl leaches down with water. Therefore, the content of Cl will lower down in the collected residue but letting the residue in field for longer could also lead to loss of biomass.

For biogas and ethanol production, contents of cellulose, hemicellulose and lignin are crucial. The high lignin content in biomass increases recalcitrance (resistance to biodegradation because of compactness and rigidness) and reduces the efficiency of conversion to ethanol. Therefore it is important to optimise it. Currently, wheat straw is being used for ethanol production but due to its high lignin content, the pre-treatment is needed to soften the biomass and make it more digestible. The common pre-treatment conditions which are being applied for straw include steam explosion or use of chemicals such as sulphuric acid under high temperature and pressure. It helps to release the cellulose and wash out the lignin content of the biomass.

However, the crop management practices have significant influence on biomass quality. For example, high N fertilisation can lead to an increase in N content of the harvested biomass which subsequently increases the chances of NOx emissions. The NOx are produced through reaction of nitrogen and oxygen gases in air during combustion, therefore if biomass with high N content is being combusted, there are high chances of emissions. All the management practices relevant to crop production have impact on biomass composition which subsequently affects the bio conversion processes to produce energy.

An overview will be provided in the final report about the qualities of the residues of the selected crops for the different energetic use routes. The formulation of best practices will also consider the optimisation of residues to enable their harvest, storage and energetic conversion.

2.6 Impact of multi-cropping

The main aim of multi-cropping is to increase the productivity per unit area. Multi-cropping is an umbrella term for all systems growing several crops consecutively or at the same time on the same plot in the same year. It is designed to intensify agricultural production while maintaining soil fertility, helping to maintain nutrients in the soil, to protect against pests and diseases, and to suppress weeds. A challenge is to select the most beneficial combination of crops where competition for light, nutrients, and water is kept to a minimum. In order to compare the efficiency of different multiple cropping systems, an index called the Multiple Cropping Index (MCI) has been developed. It is expressed as the sum of area harvested for different crops during one year, divided by the total arable land. The most common multiple cropping strategies are explained in the Figure 50.

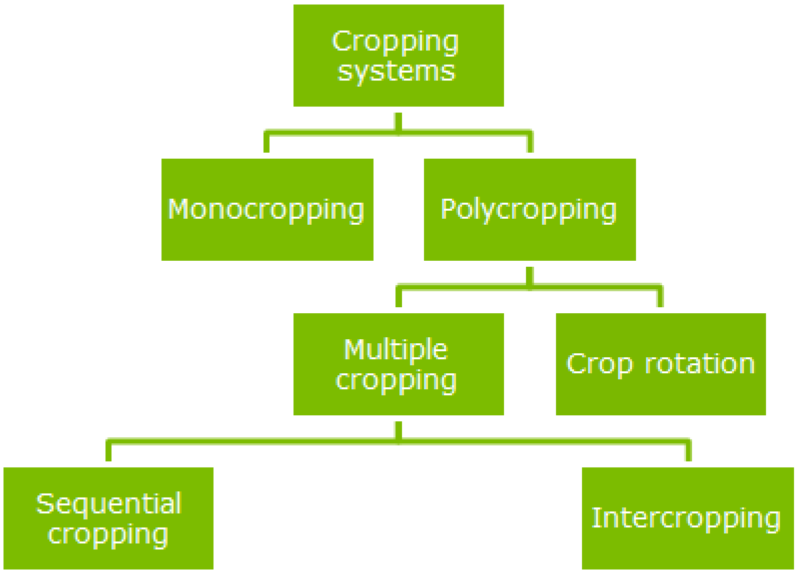

Figure 50: The systematic of cropping systems,

Sequential cropping means that a second or third crop is grown after the first has been harvested. In intercropping or relay cropping systems several crops are grown simultaneously in one field either in rows next to each other or in mixes. Inter-cropping refers to establishing two or more crops in proximity through maximizing co-operation and minimizing competition between them.

In temperate regions and in the prevailing, mechanically-managed cropping systems, multi-cropping systems are generally not performed as mixed cropping (sub-type of intercropping) and double cropping (sub-type of sequential cropping) mainly occurs in biogas. For example a project entitled "Site specific cropping systems for biogas substrate production" was funded by the German Government during 2009 to 2012 with the main focus on developing different crop rotation systems, substrate characteristics and biogas yield (FNR, 2014). The application of multi-cropping systems in the EU is limited. In the EU the main limitation is the climatic conditions because they do not allow more than one vegetation period. The main technical limitation in the EU is the trend of carrying out all field operations through machinery and large land-scale cultivation practices. In multi-cropping systems, the currently available machinery is not that useful and it is also labour-demanding. However, we will still assess the feasibility to use multi-cropping systems to increase crop residue yields.

However, still crop rotation is being used up to some extent to manage soil nutrients. Among the plant nutrients, nitrogen plays a very important role in crop productivity and its deficit is one of the major yield limiting factors for cereal production (Shafi et al. 2007). With continuous cereal cropping systems the N supplied from the decomposition of organic matter must be supplemented from other sources. Most of the times, adequate N is supplied as chemical fertiliser; however, in areas where farmers do not have sufficient resources, this is not possible due to high cost of fertilisers, low per capita income and limited credit facilities available to most farmers (Shafi et al. 2007). The ability of legumes to fix atmospheric nitrogen, their modulated roots and plant residues left after harvesting represent a valuable source of organic N. Mineral N in the root zone soil is often higher in cereal–legume cropping systems than cereal monocultures (Ladd et al. 1983). Increase in N has been attributed to both nitrate-sparing by the legume and mineralisation of the N rich residues. Cereal–legume-cropping systems also benefits the subsequent crop through non-N benefits such as:

1. Reduced incidence of root and leaf diseases in subsequent crops
2. Reduced weed populations
3. Increased P, K and S availability
4. Ameliorated soil structure
5. Release of growth substances from legume residues (Shafi et al. 2007).

Options to increase overall biomass and also residue production by applying multi-cropping systems will be researched and discussed.

2.7 Development of best practice strategies for crop residue yield increase

In this chapter the main findings for best practice strategies for agricultural crop residues yield increase are summarised. There are two main ways to increase residue yield: a) increase actual crop yield of a specific region b) increase the residue recovery and collection through use of appropriate technology.

There is a potential for increasing the agriculture production in some regions through development towards high input agricultural management which will ultimately lead to increase in residue yield. Northern and Western Europe already apply intensive agriculture and have little potential for increasing crop production. Over time, climate change may influence the potential for increased crop production and residue yield, which may counteract as well as support increased production. Lack of available data on agricultural residue production is a significant barrier for the development of accurate models on residue production (Bentsen, Felby, und Thorsen 2014). However, best practice strategies can be developed for each region to improve actual crop yield and as well as residue yield mainly through improved management practices.

Best practice strategy for agricultural crop residues yield increase is defined as follows:
Crop specific bundle of one or more different residue yield increase measures optimised to maintain or enhance the yield of the main product.

As a first step, the identification and quantification of factors affecting the crop yield are performed through a literature survey. This has helped us to categories the regions for each crop based on per hectare actual yield into three categories:

1. low yielding regions;
2. medium yielding regions;
3. high yielding regions.

The difference in per hectare actual yield between regions is explained through specific soil conditions, prevailing climate conditions, cultural practices, choice of variety, crop sequence, crop harvesting, and fertilisation and crop protection measures. Site conditions and climatic conditions have a major impact on defining actual crop yield for a specific crop in a specific region. However, the detailed assessment of these factors will not be performed as the focus of this study is on already cultivated land. This means that site and climate conditions cannot be changed, therefore the focus will be on crop management practices. The data collected about management practices including crop sequence, crop variety and crop harvesting will help to identify the best practices for crop residue yield increase.

Actual yield is defined as:
The yield being achieved under prevailing management practices for a specific region and a specific crop.

The potential for increasing actual yields is higher on low yielding regions for a specific crop than for high yielding regions, especially when the current low actual yield for a certain crop is because of poor management practices. In some cases, it could be possible that the regions which are low yielding are less suitable for crop production.
The best practice strategies are divided into two main parts:

1. **Best practice strategies to increase actual yield for a specific crop** in a specific region because actual crop yield will subsequently increase residue yield of a specific crop. For best practice strategies of part 1 the focus is mainly on:
    - Choice of variety type;
    - Crop management measures;
    - Adaptations necessary to different eco-physiological or climatic conditions.

2. **Best practice strategies specific to residue recovery rate and harvest technology**. For best practice strategies of part 2 the focus is mainly on:
    - Harvesting procedures and technologies;
    - Rate of residue recovery for a specific crop in a specific region;
    - Transport, storage and handling of residues.

A large set of literature was used for a specific crop in a specific region. Therefore, in each part the most relevant literature is listed.

Under each best practice strategy, theoretical increase in actual yield (in %) for a specific crop in a specific region will be calculated. The residue yield increase under prevailing site conditions is provided for high yielding regions, medium yielding regions and low yielding regions. The low yielding regions are further divided into low residue yield because of site condition limitations and low yield due to poor management practices.

Theoretical yield potential is defined as: ***The upper physical limit for a specific crop in a specific region, which can be achieved only under defined best practice strategies without any limitations.***

During formulation of best practice strategies, based on time duration required for implementation, best practice strategies for actual yield increase as well as residue yield increase can be divided into three main categories, which are presented in the table below.

Table 23: Categorisation of best practice strategies for agriculture crops based on time duration required for implementation

Timeline	Best practice strategy for agricultural cops
Short term strategies (0-5 years)	Improved management practices + appropriate crop variety selection
Mid-term strategies (5-10 years)	Improved management practices + appropriate crop variety selection + precision farming

Timeline	Best practice strategy for agricultural cops
Long term strategies (10-20 years)	Improved management practices + precision farming+ development of new varieties for a specific crop

For grassland, the best practice strategies are also divided into three main categories based on time required for implementation as for agriculture crops. The management practices especially cutting frequency, irrigation and fertilisation play a key role in defining the grassland actual yield for a specific region.

Table 24: Categorisation of best practice strategies for grasslands based on time duration required for implementation

Timeline	Best practice strategy for grassland
Short term strategies (0-5 years)	Improved management practices (cutting frequency, irrigation, fertilisation)
Mid-term strategies (5-10 years)	Improved management practices + optimal grassland mixtures (woody biomass + grassland)
Long term strategies (10-20 years)	Improved management practices + optimal grassland mixtures + modern breeding techniques

2.7.1 Short term strategies (0-5 years)

The focus of short term strategies is to increase actual yield of a specific crop in a specific region through selection of crop variety suitable for prevailing climatic conditions and soil type along with improved management practices. In management practices, the focus is on:

- Fertilisation
- Crop protection
- Crop rotation
- Introduction of catch crops/crop rotation
- Cultivation practices
- Irrigation

Since decades, research has been carried out in crop breeding to develop varieties with high crop yield. Selection of specific varieties depends mainly on soil and climatic conditions. The high yielding varieties for a specific crop has the potential to deliver high yield while using the available resources efficiently. Therefore, the selection of appropriate varieties for a specific region plays a key role because the inefficiency of crop varieties to use available resources is also one of the main reasons for low yield. For example, the loss of N up to 70% mainly through leaching is recorded when applied to an agriculture system (Hodge, Robinson, and Fitter 2000).
In short term strategies, the choice of crop varieties refer to the selection of better adopted varieties from already developed varieties. The selection of varieties from already developed varieties alone

can contribute 5-10% in yield increase. However, this increase can be multiplied through right combination of management practices such as fertilisation, irrigation, tillage system etc. Therefore, high yield potential of a specific variety can only be realised through combination of aforementioned factors.

2.7.2 Medium term strategies (5-10 years)

The medium term strategies for cereal crops, oil crops and sugar beet involve improved management practices, appropriate selection of crop variety and precision farming. The role of improved management practices in combination with appropriate selection of crop variety for cereal crops, oil crops and sugar beet is already described, therefore the focus in this chapter is on precision farming.

Precision farming is a farming management concept based on observing, measuring and responding to inter and intra field variability observed in crops. The precision farming system can lead to increase in crop production with minimum environmental implications (JRC, 2015).
There are two main reasons to adopt precision farming; a) to reduce input costs through increasing efficiency; b) to improve accuracy in farming operations.
There are many aspects in precision farming but the most important ones are site specific crop management and climate smart agriculture. By exploiting the variation in field through use of technology and application of appropriate amount of inputs, a substantial increase in actual crop yield can be achieved. These variations are not only limited to on field but also cover seasonal variations. Therefore, precision farming offers an opportunity to increase actual crop yield through precise crop management practices such as irrigation, fertilisation, seeding, crop protection and harvesting (JRC, 2015). For example increase in water use efficiency was achieved through different strategies such as regulated deficit irrigation. In south-west Europe due to climate change and variability in rainfall pattern, precision farming can play a key role in achieving high actual yields. Another important aspect in site specific crop management is N use efficiency. Studies were carried out in Germany where it was found that 10-15% N use efficiency can be improved through precision farming (Anselin et al. 2004, Meyer-Aurich et al. 2008; 2010).
As a part of medium term strategies, it is important to identify the regions which are suitable for precision farming. The development of precision farming calculator will make it easy for farmers to decide about precision farming in terms of productivity and profitability.

Precision farming calculator: It is a tool which helps growers to calculate the returns on investment in precision farming technology.
There is need to carry out pilot research studies to convince farmers and also to explain the benefits of precision farming in terms of economic output but also environmental benefits. It will also help the farmers to see the environmental benefits beyond farm level. Considering the current technological developments in agriculture to realise high yields, the introduction of new machines which are able to provide high resolution information and with the capability of site specific agriculture management will not be that far. It definitely needs time to come up but it’s certainly future of agriculture (JRC, 2015).

The medium term strategies for grasslands include optimisation of grassland mixtures along with improved management practices to increase productivity of grassland. The grassland mixtures include optimizing the already existing grasslands and improving these mixtures. It will help to improve the productivity of grassland system as well as economic viability.
The main aim of different grassland mixtures is to increase productivity through efficient use of available resources.

2.7.3 Long term strategies (10-20 years)

The long term strategies include choice of variety from already available crop varieties and development of new varieties and improved management practices through precision.
The development of new varieties should focus on better adaptability. The change in climate is leading to poor adaptability of varieties, which is also leading to low yields. The drought conditions and temperature is very critical for wheat yield, especially low water availability during stem elongation period and high temperature at grain filling stage. It leads to low grain yield per hectare and development of small sized grain. In past years, the annual mean temperature increased and also occurrence of drought during spring increased. Due to climate change, the per hectare decrease of wheat yield is 0.6-0.9 t/ha for leading wheat producer of Europe (France) (JRC report, 2013).
For cereal crops the other key point about development of new varieties is increase in straw length without any compromise in grain yield. The available wheat varieties can be categorised into:

a. short varieties with straw length ≤89 cm;
b. intermediate varieties with straw length 90-110 cm;
c. long varieties with straw length ≥ 111 cm (John Letts and Roger Capps 2006).

There are already long straw varieties but the problem with these varieties is lodging and low yield. This can be overcome by developing resource efficient varieties along with lodging resistance. This will not only lead to increase in grain yield but also increase in residue yield. It can be supported by the fact that during green revolution, the semi dwarf varieties played a key role in achieving high yield. It is mainly because the long straw varieties have high yield potential if managed properly (Law, Snape, and Worland 1978).
There are hybrid and line varieties with the straw length up to 146 cm but deliver low yield. The high yielding semi-dwarf rapeseed hybrids with the straw height of 107 cm are characterised by higher seed and lower straw (Feiffer, 2007). However, the actual yield of long straw varieties can be improved through breeding which will lead to high straw as well as high actual yield of main product. The actual yield of semi-dwarf hybrids can also be improved further because these varieties are less competitive to weed during establishment in autumn. Therefore, actual yield can be further improved through improving the capability of competing with weeds.

The other important considerations taken into account while developing new varieties for cereal as well as oil crops include:

- Nitrogen use efficient varieties
- Disease and pest resistance varieties

- Better adaptability to prevailing weather conditions for a specific region such as drought and high temperature

For grassland, the long term strategies involve improved management practices, optimal grassland mixtures and use of modern breeding techniques to develop better growing grassland species. Currently, there are not many breeding programs being carried out with the special focus on improvement of grassland productivity. Therefore, it is important to carry out breeding programs with the special focus on grasslands by using modern breeding techniques. For example, in hot dry regions, introduction of comparatively drought resistance grass species can contribute substantially towards improvement in grassland productivity. The breeding program should be carried out for those regions where grasslands species are in danger of vanishing due to extreme site specific conditions and without having any effect on current land use.

2.8 Theoretical potential for crop residue yield increase

The theoretical crop residue yield potential is defined as the maximum residue yield that can be obtained in a given agro-ecological zone for a specific crop type and variety. The theoretical potential is the yield that can potentially be achieved if no constraints, such as water shortage or inefficient harvest technologies are limiting.

The yields in actual production statistics reflect the actual yields. To increase the actual yield those factors that can reduce the yield, such as pest and diseases, have to be controlled by crop management measures. To further increase the yield, yield-limiting factors, such as shortages in nutrients or water, have to be encountered by yield increasing measures, such as fertilisation or irrigation.

Potential yields can be assessed by crop models that require large amounts of input data such as irrigation, soil characteristics and radiation (Folberth et al. 2014) and are combined with GIS data (Tian et al. 2008). The development of such models goes beyond the capacity of this study. Therefore, in the context of this study we define the theoretical potential for yield increase as the yield difference between the actual and the achievable yield.

The best practice strategies identified in the previous chapters are used to estimate the theoretical yield increase for each specific crop.

The estimation of the theoretical potential is displayed in Figure 3, which is included below again.

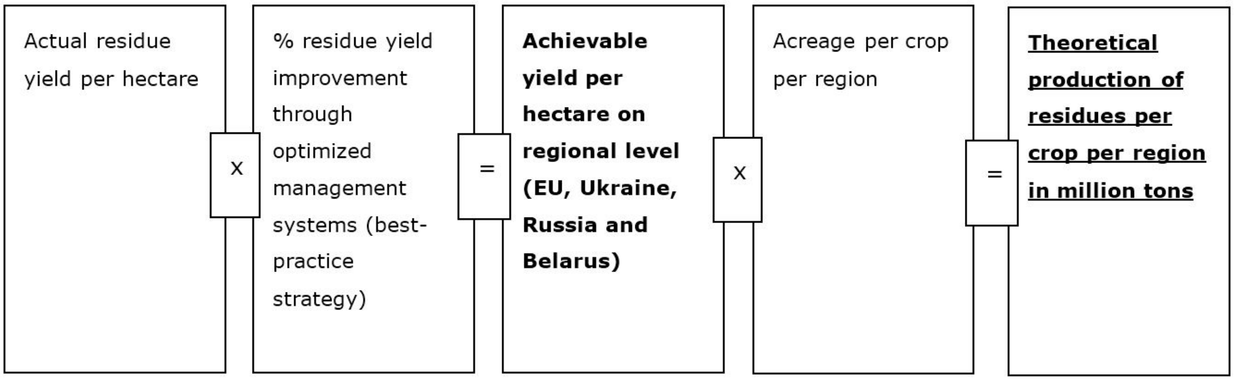

Figure 51: Approach for the calculation of the theoretical production potential for residues

2.9 Cereal crops – Best practice strategy and theoretical potential

2.9.1 Best practice strategies

The assessed cereal crops have the same growth requirements, therefore they are assessed as one group for best practice strategies. However, yield differences within cereal crops will be considered while formulating best practice strategies for a specific cereal crop for a specific region.

It was difficult to quantify the effect of each factor on actual yield for a specific crop just with literature data. Therefore, the literature based data about crop management practices was collected, arranged and fed into a statistical model to quantify the effect of each factor on actual yield for a specific crop. It was done through Proc mixed model[3] in SAS software (Statistical Analysis System). Different models were tested to figure out the relevant factors for actual yield for a specific crop.
Following key literature was used:

- Ahlemeyer, J., and W. Friedt. 2012. “Bericht Zum BDP Projekt „Züchtungsfortschritt Bei Winterweizen”.”
- Shafi, Mohammad, Jehan Bakht, Mohammad Tariq Jan, and Zahir Shah. 2007. “Soil C and N Dynamics and Maize (Zea May L.) Yield as Affected by Cropping Systems and Residue Management in North-Western Pakistan.” *Soil and Tillage Research* 94 (2): 520–29. doi:10.1016/j.still.2006.10.002.
- Thomsen, I. K., J. Djurhuus, and B. T. Christensen. 2003. “Long Continued Applications of N Fertiliser to Cereals on Sandy Loam: Grain and Straw Response to Residual N,” no. Soil Use & Management: 57–64.

[3] PROC mixed is a generalisation of the general linear model procedure in the sense that general linear model fits standard linear models, and PROC mixed fits the wider class of mixed linear models.

- Wilhelm, Wallace, J. M. F. Johnson, J. L. Hatfield, W. B. Voorhees, and D. R. Linden. 2004. “Crop and Soil Productivity Response to Corn Residue Removal: A Literature Review.” 96 (Agron. J.): 1–17.
- Sánchez-Martín, J., D. Rubiales, F. Flores, A.A. Emeran, M.J.Y. Shtaya, J.C. Sillero, M.B. Allagui, and E. Prats. 2014. “Adaptation of Oat (Avena Sativa) Cultivars to Autumn Sowings in Mediterranean Environments.” *Field Crops Research* 156 (0): 111–22.
- Mohler, C. L., and M. Liebman. 1987. “Weed Productivity and Composition in Sole Crops and Mixed Crops of Barley and Field Peas.” *Journal of Applied Ecology*, no. 24: 685–99.

Each model with all relevant factors affecting actual yield was tested and the most relevant factors, which have significant effect were selected for a final model. The variables crop variety, site effects, fertilisation, crop protection and other management practices were identified for having a significant effect for the corresponding actual yield for a specific crop and have been selected for modelling. To evaluate the effect of crop variety, site effects, fertilisation, crop protection (weeds, diseases and pests) and other management practices on actual yield of cereal crops, the following equation was developed:

Equation 1:
Actual yield = Site effects + Fertilisation + Crop protection + crop variety + other management practices

The above model is for actual crop yield under prevailing conditions. The factors stay the same for theoretical yield, only the level of inputs such as amount of fertilisation, crop protection measures, choice of variety and other management practices change. The theoretical yield will be calculated for ideal conditions without any limitations for a specific region. Therefore, improved management practices and high agriculture inputs are used to calculate the theoretical yield.

Example ‘France’: To explain the statistical model, one of the countries (France) was chosen and calculations were made for wheat for theoretical yield. France is selected because it is the largest wheat producer in the EU. Therefore, for wheat, a specific variety (medium straw length, good quality grain and high yielding) under certain fertilisation levels (NPK-150:60:80 kg/ha), crop protection measures (spring, autumn herbicide applications) and some other management practices (irrigation, reduced tillage, seed priming, narrow rows 10 cm) were included in our model to estimate the theoretical yield increase in France. The contribution of each factor considered for this model is described in the form of coefficients of variables. These coefficients of variables will change with the change in site conditions for a specific country and a specific crop.

Theoretical yield= Site effects + 0.26 × crop variety + 1.25 × Fertilisation + 0.35 × Crop protection + 0.55 × other management practices

In addition, any change in above mentioned factors will be multiplied with the corresponding coefficient of variables for each crop and each region. In the example of France the N fertilisation level is 150 kg/ha, therefore in case of any change in amount of fertilisation, it will be multiplied with 1.25 coefficient of variable for fertilisation.

It is important to state here that all factors interact with each other to reach to a specific theoretical yield level. The single factor such as increase in fertilisation will not increase the crop yield to the described level in Table 25. The site effect mainly considers the rainfall data for a specific region. Therefore, the rainfall for low, medium and high yielding regions was taken into account which led to change in site effects of a specific region. The focus of this study is not to evaluate the site effects, therefore coefficients of variables are only included for management practices. The model provides one value as coefficient of variable for 'other management practices' (cultivation practices, crop rotation, catch crop, irrigation). However, the effect of each of these factors was quantified separately before putting them together in 'other management practices'. The reason to put all these factors together under category of 'other management practices' in model is to avoid complexity. The model used in this study quantifies the effect of main factors relevant to crop yield.
All the factors quantified through this model for cereal crops are relevant for low yielding to high yielding regions. However, the potential of actual yield increase is higher in low yielding regions than in high yielding regions. In low yielding regions, the poor management practices are one of the main reasons for low actual yield.

The best practice strategy for cereal crops is described in Table 25 for low yielding, medium yielding and high yielding regions. All the measures within the best practice strategy were considered in the model by quantifying the effect of each of them for a specific region. The management practices described in Table 25, are formulated by assuming optimal soil conditions for each category. As wheat is one of the leading crops among cereal crops, therefore management practices presented here are mainly for wheat. For other cereal crops, the main components of model (site effects, crop variety, fertilisation, other management practices) stay the same with small changes in rate of inputs such as fertilisation. Although in general low yielding regions have more potential for yield increase through improved management practices, there are regions where despite improved management practice, the crop yield cannot be improved because of site specific limitations. Therefore, to provide more precise information, low yielding regions are further divided into; 1) low yield because of poor management practices; 2) low yield because of site specific limitations.

Low yield because of poor management practices

In Table 25, the best practice strategies for low yielding regions refers to regions where low yield of cereal crops is because of poor management practices. In low yielding regions such as Romania, the varieties with medium straw length with good quality grain along with drought and disease resistance characteristics can be used to increase crop yield. The increase in overall crop yield will lead to increase in residue yield. For low yielding regions, shallow seed bed preparation (narrow tines operated at shallow depth about 5-8 cm) is recommended, however for other medium and high yielding regions, reduced tillage (minimizing soil disturbance with the aim to increase soil organic matter and to control erosion) is recommended. Through reduced tillage, the rate of removal can be improved because reduced tillage helps to maintain soil carbon levels. For these low yielding regions, the yield is low because of poor management practices therefore a combination of improved management practices such as seed bed preparation for high amounts of fertilisations can lead to substantial increase in actual yield. In low yielding regions, sometimes farmers focus only on one aspect such as high fertilisation but ignore others such as appropriate crop protection measures. Therefore, crop yield potential is not realised. In Table 25, the best practice strategies provide combination of management practices to achieve theoretical maximum yield.

In medium to high yielding regions, improved management practices are being applied already. The margin to improve actual crop yield is therefore low. Cultivation practices (soil preparation, seed priming, row spacing, irrigation) and soil fertility management (crop rotation, catch crops) are part of 'other management practices'. Along with management practices, recommendations about crop varieties are also made. For example in wheat category B variety is recommended which is of medium height, good grain quality and high yielding.

Table 25: Description of management practices of the best practice strategy for cereals in regions with low, medium and high yield potentials

	Description of management practices	Low yielding (i.a. Romania)	Medium yielding (i.a. Hungary)	High yielding (i.a. France)
Crop variety	Choice of variety	• Varieties with medium straw length, good quality grain • Drought resistance • Resistance to leaf and ear diseases	• Varieties with medium straw length, good quality grain • Drought resistance • Winter hardiness • Resistance to diseases e.g. yellow rust, mildew	• Varieties with medium straw length, good quality grain • Drought resistance • Resistant to orange wheat blossom midge
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 170 kg/ha • Entec • Split application (2-3)	• 150 kg/ha • Entec • Split application (3-4)	• 150 kg/ha • Entec • Split application (3-4)
	P fertilisation	80 kg/ha P_2O_5	70 kg/ha P_2O_5	60 kg/ha P_2O_5
	K fertilisation	100 kg/ha K_2O	90 kg/ha K_2O	80 kg/ha K_2O
Crop protection	Fungicides	Dimoxystrobin, Boscalid, Epoxiconazole		
	Herbicides	Pre emergence, Post emergence 2 times application (autumn, spring), 4 kg/ha		
	Others	mechanical weeding		

Other management practices				
Cultivation practices	Soil preparation	Shallow seed bed	Reduced tillage	Reduced tillage
	Seed priming	Water, Zn-Priming*, Polyethylene glycol (PEG)		
	Row spacing	Ultra narrow (10 cm)		
	Irrigation	Under water stress conditions		
Soil fertility management	Catch crops	Mustard, Phacelia		
	Crop rotation	• Potato-Cereals • Alfalfa-Cereals • High moisture user (maize)-low moisture user (barley) • Legume-Cereals	• Maize-clover • Soybean-Cereals • Faba bean-Cereals • High root biomass (rye)-low root biomass (oats)	• Sweet clover-Cereals • Alfalfa-Cereals • High root biomass (rye)-low root biomass (oats) • Legume-Cereals
% Theoretical yield increase		75%	60%	45%

*Seed priming: it is the process to regulate the germination through controlled temperature and seed moisture content

Low yield because of site conditions

The regions with low yield because of site conditions are identified based on available soil data maps. The soil map of loess distribution in EU-27, Ukraine, Russia and Belarus was used as one of the criteria to evaluate the soil fertility level of European soils. **Loess** is the fine soil sediments of silt or clay deposited as a result of wind-blown, typically in 20-50 micrometre size range (Haase et al. 2007). The soil map with loess distribution is used as an indicator of soil fertility (Figure 52).

The loess map is a good indicator of soil fertility because the soils with high loess lead to fertile soils. Therefore, soil loess map helps to divide the soils of EU-27, Ukraine, Russia and Belarus into three main regions, soils with low fertility, soils with medium fertility and soils with high fertility. The soils of eastern Europe falls into category of high soil fertility, the soils of central Europe falls into medium to high fertility soils and soils of southern and northern Europe falls into category of low fertility.

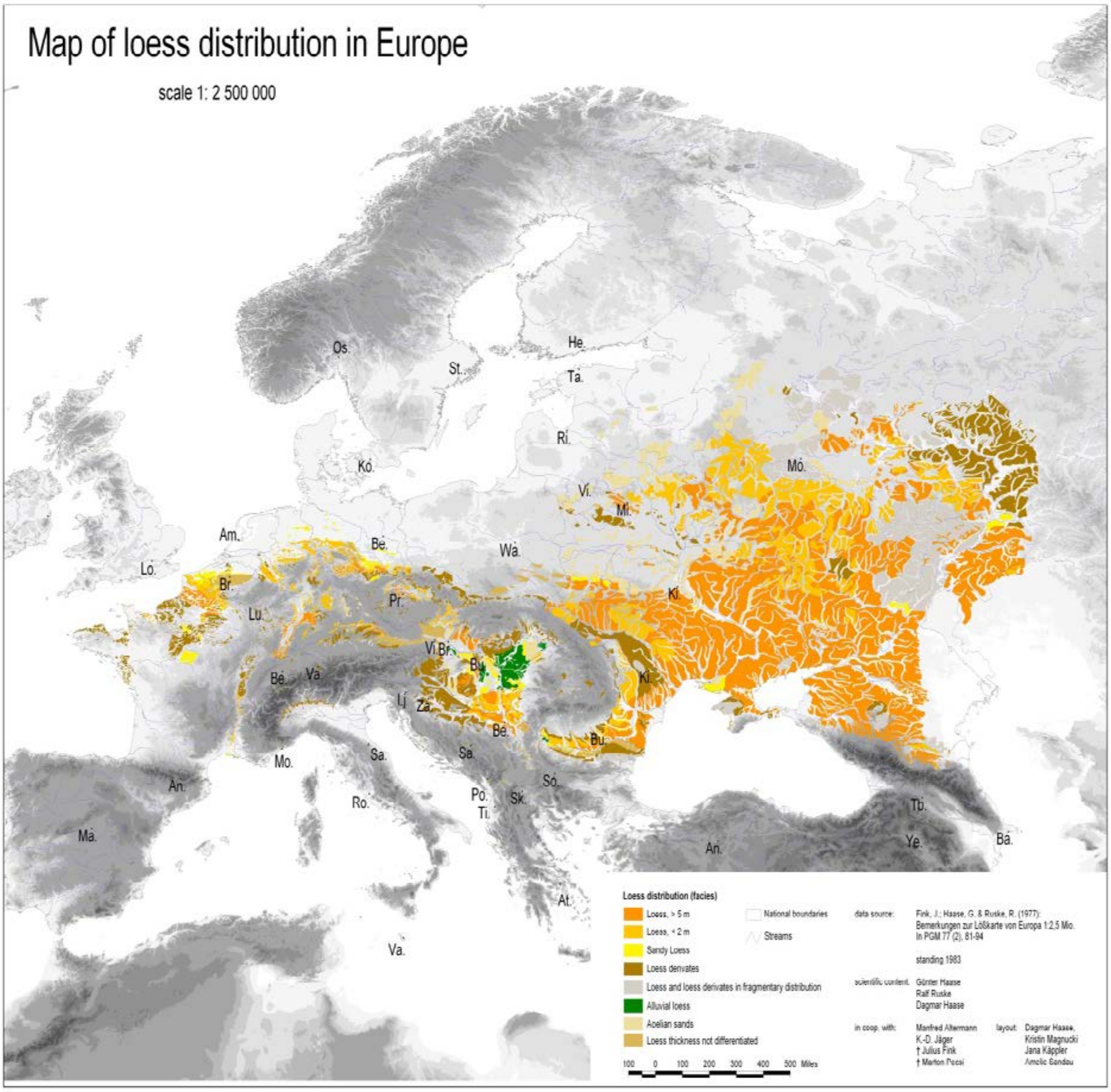

Figure 52: Loess Map of Europe 1:2,500,000. Dark orange color indicates the most fertile soils with greatest loess content (abbreviations=city names of major Eurasian cities; reference list see below) Lo.=London, Am.=Amsterdam, An=Andorra, Br.=Brussels, Lu.=Luxemburg, Be.=Bern, Va.=Vaduz, Ro=Rom, Sa=San Marino, Os.=Oslo, Ko.=Kopenhagen, St=Stockholm, He.=Helsinki, Ta.=Tallinn, Ri.=Riga, Vi.=Vilnius, Be=Berlin, Pr.=Prague, Vi.=Vienna, Lj.=Ljubljana, Za.=Zagreb, Sa.=Sarajevo, Ti.= Tirana, Po.=Podgorica, Sk.=Skopje, So.=Sofia, Be.=Beograd, Bu.=Budapest, Bu.=Bucharest, Mi.=Minsk, Mo.=Moscow, Ki.=Kiev, An.=Antalya, Ki.=Kishinev, Ye.=Yerevan, Tb.=Tbilisi, Bá.=Báku **(Haase et al. 2007). Dark grey areas represent areas with low or no loess content.**

The countries in Eastern Europe including Ukraine, Russia and Belarus have most fertile soils with great loess content. Due to the historical yields, these regions fall in the category of lowest yielding countries. The main reason of low yield in these regions is poor management. Therefore, for these regions actual yield can be improved through improved management practices as described in Table 25. The southern (Spain, Italy) and northern European countries such as Finland have low loess content compared to central (such as Germany) and eastern European countries such as Hungary. The soils of western Europe are also comparatively fertile than southern and northern Europe. Therefore, the soils of eastern, central and western Europe are more fertile compared to southern and northern Europe

Another soil map is used to illustrate the soil limitations for agriculture at EU level (Figure 53). This map shows the same trend as for soil loess distribution. The southern and northern European countries have more limitations compare to eastern and central and western Europe. It indicates that the countries in southern Europe such as Spain and Italy and northern Europe such as Finland and Sweden have more site specific limitations, therefore special management practices are needed for these countries.

In addition to soil related limitations especially in southern Europe, there is also decrease in rainfall over the past decades, which limit the agriculture production. For example in central Portugal, the rainfall is decreased up to 90 mm per decade, which is leading to lower crop yield (Royal Netherlands Meteorological Institute (KNMI)).

In some countries such as Finland and Sweden, the mechanisation is hard because of presence of stoney layers. For these countries more focus should be on soil bed preparation and selection of appropriate crops for a specific location. In spite of site specific limitations, actual yield can be improved through improved management practices. However, for low yielding regions due to site specific limitations, the main difference was low use of inputs compare to the regions where site conditions were ideal. It is mainly because high inputs will not help to improve yield considering the site limitations such as poor soil quality.

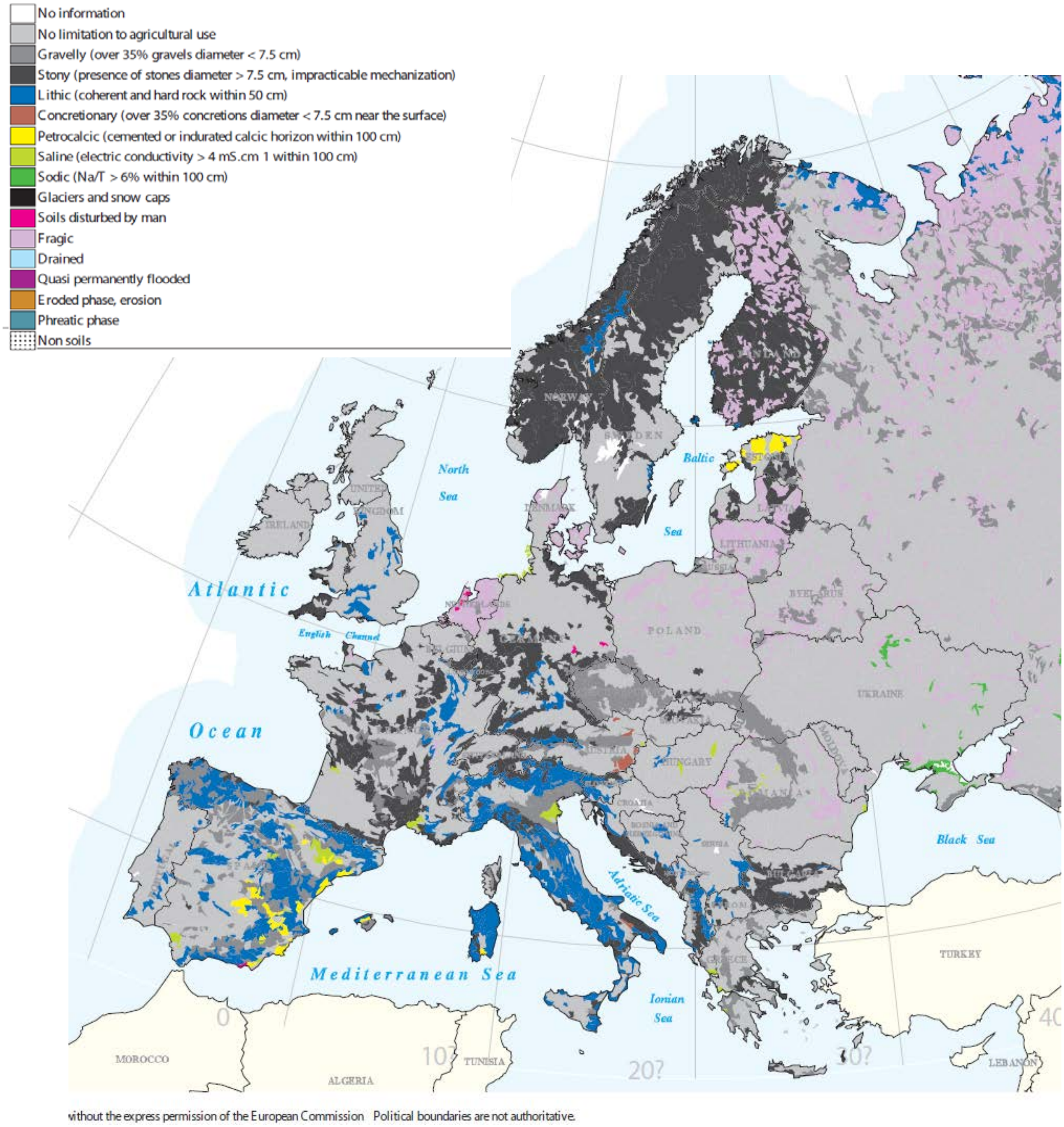

Figure 53: European soils map developed to show the soil limitations for agriculture (European soil Bureau, 2015)

The best practice strategy with special focus on management practices for the regions with site specific limitations is presented in Table 26.

Table 26: Description of management practices of the best practice strategy for wheat in region with low yield due to site conditions

	Description of management practices	Low yield due to site conditions (i.a.Spain)
Crop variety	Choice of variety	• Varieties with medium straw length, good quality grain • Drought resistance • Resistance to leaf and ear diseases
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 130 kg/ha • Entec • Split application (2-3)
	P fertilisation	60 kg/ha P_2O_5
	K fertilisation	80 kg/ha K_2O
Crop protection	Fungicides	Dimoxsystrobin, Boscalid, Epoxiconazole
	Herbicides	Pre emergence, Post emergence 2 times application (autumn, spring)
Other management practices		
Cultivation practices	Soil preparation	Shallow seed bed
	Seed priming	Water, Zn-priming, Polyethylene glycol (PEG)
Soil fertility management	Catch crops	Mustard, Phacelia
	Crop rotation	• Potato-Cereals • Alfalfa-Cereals • High moisture user (maize)-low moisture user (barley) • Legume-Cereals
	Others	• mechanical weeding, under sown crops
% theoretical yield increase		30%

2.9.2 Theoretical yield increase for cereal crops

To cover the whole EU-27, Ukraine, Russia and Belarus, the already defined regions (low yielding regions, medium yielding regions, high yielding regions) were used to estimate the theoretical yield increase. Based on the above mentioned best practice strategies for highest, medium and lowest yielding regions with the main focus on management practices, the theoretical yield increase was estimated wheat. The increase in theoretical yield is calculated following equation 1, described in detail at the beginning of this chapter. The quantification of factors is done based on the coefficients of variables (fertilisation, crop protection, other management practices).

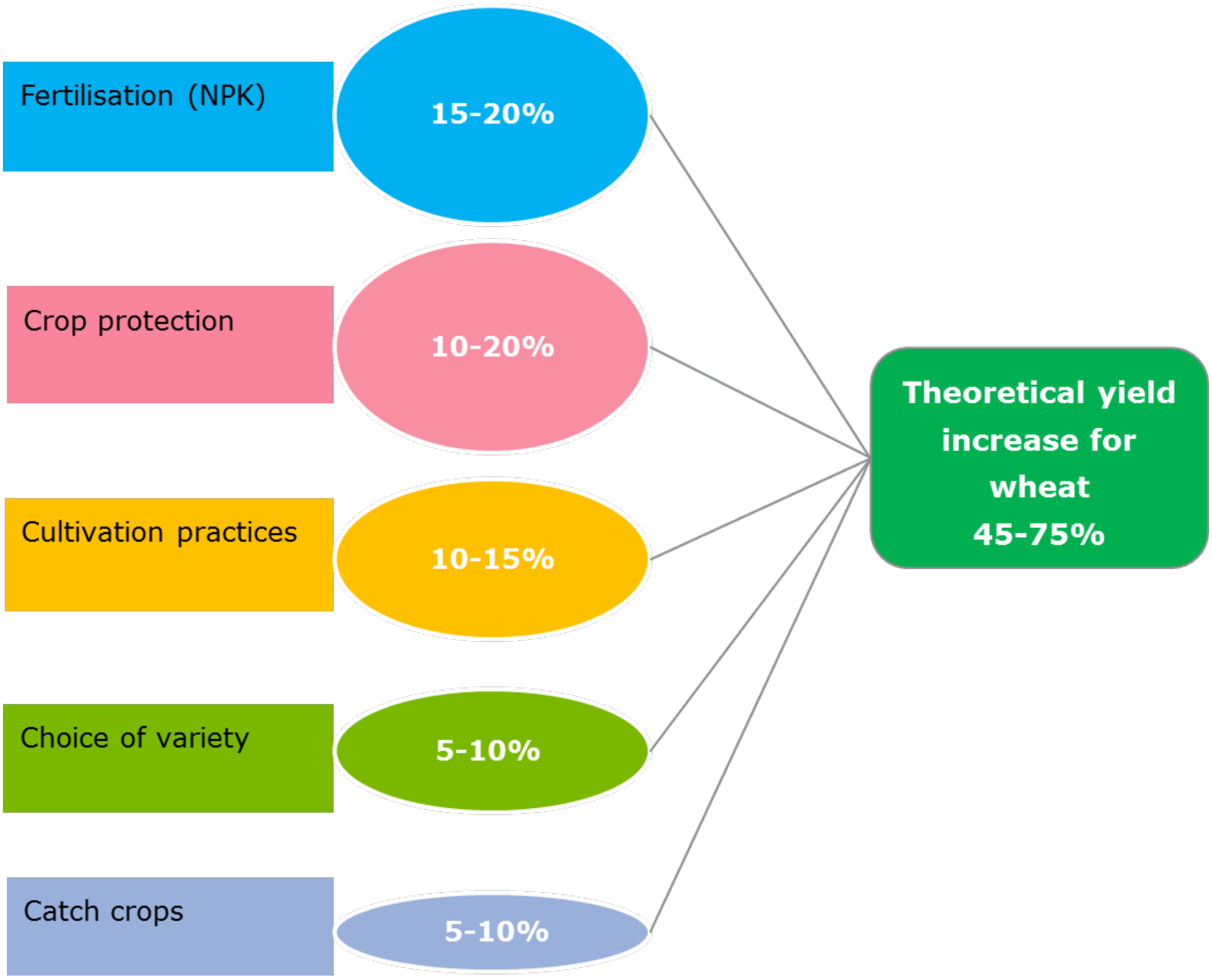

Figure 54: Effect of different factors relevant for wheat yield calculated based on data from literature and through model. The quantification of factors is made based on the coefficients of variables (site effects, fertilisation, crop protection, other management practices).

Figure 54 is prepared for wheat (as representative for cereal crops) in France, which is also used to describe the model and calculations at the beginning of this chapter. Wheat is selected as a representative because it is one of the leading cereal crops in terms of production and cultivated area.

Wheat

Since 1990 the wheat yield in the EU is stagnant or has decreased. This decrease was also recorded in other important wheat producing countries such as France, Germany. In one of the EU workshops (JRC report, 2013) about wheat yield in EU, it was detailed that the main reasons for this decline are:

- Slow genetic progress
- Selection of varieties with high quality on the expense of yield
- Low adaptability of varieties to changing climate

It was stated that the current wheat varieties are producing high quality wheat for bread production but at the expense of 1 tonne less actual yield. These varieties are covering most of the wheat production area, for example in France (largest wheat producer in EU) such varieties are being cultivated on 91% of wheat production area (JRC report, 2013). Due to a selection of varieties with the focus on both yield and quality in combination with fertilisation, suitable soil and climatic condition and proper crop protection, the theoretical yield can be increased up to 45% in France. In medium yielding regions, like Hungary, the theoretical yield can be increased by 60% under best practice strategy described in **Table 25**. In Romania, which falls in the category of low yielding regions, the theoretical yield can be increased by 75% through selection of appropriate varieties in combination with improved management practices. All the aforementioned calculations were made based on equation 1 and without any soil or climatic limitations.
As already described, in some regions the low yield is due to poor management practices, therefore such regions have greater potential to increase actual crop yield as well as residue yield.
The regions with site specific limitations were identified based on soil loess distribution map and agriculture use limitations map at EU level. For these regions another set of management practices as a part of best practice strategies was proposed and theoretical yield was calculated for these regions. For example, Spain falls in the lowest yielding category for wheat, the low actual yield in Spain is not only because of poor management practices but also because of poor soil quality. Therefore, through combination of management practices and appropriate selection of wheat varieties (described in **Table 26**), the theoretical yield increase can be reached up to 30%.

Based on the model used for wheat, the same components were used for other cereal crops with variable input levels such as different amounts of fertilisation. For other cereal crops (Barley, Maize, Oat), the detailed best practice strategies are not presented. The range for theoretical yield increase changes for the different crops and the specific range for each crop is mentioned below.

Barley

In Romania, which falls in category of lowest yielding regions, the yield increase up to 50% can be achieved through selection of high yielding varieties along with improved management practices. In medium yielding regions such as Hungary, the yield can be improved up to 35% through improved management practices and selection of appropriate varieties (AHDB 2015).
In France, which falls in highest yielding category, the yield for barley can be improved up to 20% through combination of better management practices and selection of crop varieties (AHDB 2015).

The best practice strategies for the regions with site specific limitations are proposed separately. Under aforementioned best practice strategies for low yielding regions due to site specific limitations such as Spain, the theoretical yield can be improved up to 25%. It is important to state that even in regions with site specific limitations, the poor management practices in these regions are also leading to low actual yields.

The cultivation area for barley has decreased over the years but the productivity has been increased through development of new cultivars, improved fertilisation, better pest and disease control and improved management practices. However, the yield can be increased further. There is a need to select varieties which show better adaptability to changing climatic conditions (Friedt and Ordon 2013).
As for other crops, soil and climatic conditions were assumed ideal while formulating these best practice strategies.

Maize

France and Germany are among the leading maize producers in EU-27. However based on theoretical yield calculation through different best practice strategies, there is still possibility to increase production even for leading producers of EU-27. Selecting adjusted varieties in combination with improved management practices, the crop yield in France, which falls in category of highest yielding group, can be increased up to 17%. In the category of medium yielding regions such as Hungary, the theoretical maize yield increase can be reached up to 25% through application of improved management practices. In Romania, which falls in category of low yielding regions, theoretically yield can be improved by 40%. It indicates that there is large potential to improve actual yield especially in regions with already low actual yields.
For low yielding regions with site specific limitations such as Bulgaria, through the improved management practices, the theoretical yield can be increased up to 15%.

Oat

In the category of highest actual yielding regions such as France, the theoretical yield can be reached up to 25% through application of best practice strategies. In medium yielding regions such as Hungary, the theoretical yield can be increased up to 40% under improved management practices and through selection of appropriate varieties. In lowest yielding regions such as Romania, the theoretical yield increase can be reached up to 50%.
For the regions with site specific limitations such as Spain, the theoretical yield can be increased up to 20%. The per hectare actual yield in Spain is very low, with even less than half of the highest yielding regions such as Germany (FAO, 2014).

2.10 Oil crops – Best practice strategy and theoretical potential

2.10.1 Best practice strategies

Our oil crops category includes rapeseed and sunflower. For this category, the same approach was adopted as for cereals to quantify the effect of different factors on actual crop yield subsequently on residue yield. As for cereals, wheat was taken as an example, in oil crops, rapeseed was taken as an example and explained fully from proposing best practice strategy to calculation of % theoretical yield increase.

The short term strategies for oil crops include improvement in management practices along with appropriate variety selection.
The main factors which were considered for oil crops actual yield include fertilisation, crop protection, crop variety and other management practices. The other management practices include cultivation practices, irrigation, catch crops and crop rotation. The data about aforementioned factors was collected from literature and then analysed through model as illustrated for cereals. The most important literature is sited below.

- Zhou Y, Fitt BDL, Welham SJ, Gladders P, Sansford CE *et al*. (1999): Effects of severity and timing of stem canker (*Leptosphaeria maculans*) symptoms on yield of winter oilseed rape (*Brassica napus*) in the UK. *European Journal of Plant Pathology*, 105(7), 715-728
- Wiesler F, Behrens T, Horst WJ (2001): The role of nitrogen-efficient cultivars in sustainable agriculture. In: Optimizing nitrogen management in food and energy production and environmental protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy, The Scientific World (1). In: Rathke GW, Behrens T, Diepenbrock W (2006): Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): A review. *Agriculture, Ecosystems & Environment*, 117, 80-108.
- Walton G, Si P, Bowden B (1999): Environmental impact on canola yield and oil. In: Wratten N, Salisbury PA (Eds.), New horizons for an old crop. Proceedings of the 10th International Rapeseed Congress. Canberra, Australia CD-ROM. In: Rathke GW, Behrens T, Diepenbrock W (2006): Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): A review. *Agriculture, Ecosystems & Environment*, 117, 80-108
- Sieling K, Schröder H, Hanus H (1998): Mineral and slurry nitrogen effects on yield, N uptake, and apparent N-use efficiency of oilseed rape (Brassica napus). *Journal of Agricultural Science,* 130, 165
- Sieling K, Christen O, Nemati B, Hanus H (1997): Effects of previous cropping on seed yield and yield components of oil-seed rape (Brassica napus L.). *European Journal of Agronomy,* 6, 215-223
- Rathke GW, Christen O, Diepenbrock W (2005): Effects of nitrogen source and rate on productivity and quality of winter oilseed rape (Brassica napus L.) grown in different crop rotations. *Field Crops Research,* 94, 103-113

The best practice strategies for low, medium and high yielding regions for rapeseed are described in Table 27, focuses on quality for the choice of variety as well as on selection of varieties with better resistance to diseases and pests. For sunflower, the components (crop variety, fertilisation, crop protection and other management practices) of model stay same. In terms of quality, the selection of variety depends on composition of oil. For example, the choice of rapeseed varieties depends on desired glucosinate and erucic acid contents in the vegetable oil. However, the adoption of varieties depends on climate, soil type, yield potential, date of ripening, tolerances against pests and diseases and planting time. Hybrid varieties are recommended because of high oil quality as well as yield.

With regard to cultivation practices especially soil preparation and reduced tillage is recommended for medium and high yielding regions; mainly to increase the residue removal rate through preserving carbon content by minimum soil disturbance. However, in low yielding regions, shallow seed bed is recommended because in low yielding regions the actual yield is already low due to poor management practices. For fertilisation, overall higher fertilisations need to be applied in case of low yielding regions compared to medium or high yielding regions. However, in high yielding regions, the actual yield is already high because of high inputs use, therefore the margin to improve actual yield through improved management practices is low. For crop protection, different kinds of herbicides are recommended for low yielding compared to medium and high yielding regions. The main reason is that, in low yielding regions, the crop protection measures are poor because of low awareness and economic constraints, therefore general herbicides are recommended which could kill the most prevalent weeds in those regions. However, in medium and high yielding regions, special herbicides are recommended against special weeds as in these regions the crop protection measures are already very good.

In Table 27, the low yielding category refers to the regions where low yield is mainly because of poor management practices. The best practice strategies interact with each other to reach to a certain theoretical yield level.

Table 27: Description of management practices of the best practice strategy for rapeseed in regions with low, medium and high yield potentials

	Description of management practices	Low yielding (i.a. Romania)	Medium yielding (i.a. Poland)	High yielding (i.a. France)
Crop variety	Choice of variety	• Good quality with medium straw length • Hybrid varieties • Drought resistance • Resistance to diseases	• Hybrid varieties • Drought resistance • Resistance to diseases • High erucic acid content with medium straw length	
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 200 kg/ha first year • 170 kg/ha in subsequent years • Entec • Split application (2 times)	• 170 kg/ha • Entec • Split application (2 times)	
	P fertilisation	90 kg/ha P_2O_5	80 kg/ha P_2O_5	
	K fertilisation	110 kg/ha K_2O	100 kg/ha K_2O	
	S fertilisation	30 kg/ ha	25 kg/ha	
	Mg fertilisation	25 kg/ha	20 kg/ha	
	B fertilisation	1.7 kg/ha	1 kg/ha	
Crop protection	Fungicides	Seed dressing		
	Pesticides	beta-Cyfluthrin, lambda-Cyhalothrin, Etofenprox		
	Herbicides	• Metazachlor 200 • +Quinmerac100 • +Dimethenamid-P200 • Clopyralid267 • +Picloram6 • Pre-emergence and post emergence		
Other management practices				
Cultivation practices	Soil preparation	Shallow seed bed	Reduced tillage	Reduced tillage
	Seed priming	Water, Zn- priming		
	Large working width for machinery	32 m		
	Irrigation	During water stress conditions		
Soil fertility management	Catch crops	Phacelia		
	Crop rotation	• Rapeseed / Rapeseed / Wheat / Pea • Rapeseed / Barley		
% Theoretical yield increase		65%	40%	30%

As already described for cereals in some regions the low yield mainly results from poor management practices, but in some regions they are due to site specific limitations. For the latter category, another set of measures as a part of best practice strategy was proposed (Table 28). In the regions with low yield mainly due to site specific limitations, the main change in description of management practices, is use of low inputs especially fertilisation and low chemical use for crop protection to keep it economical viable. Seed priming is recommended for these conditions mainly to enhance the initial growth (Table 28). To identify the regions where actual yield is low mainly due to poor site conditions, the same loess distribution map (Figure 52) and another map showing agriculture limitations (Figure 53) was used as for cereals.

Table 28: Description of management practices of the best practice strategy for rapeseed in regions with low yield due to site conditions

	Description of management practices	Low yield due to site conditions (i.a. Spain)
Crop variety	Choice of variety	• Good quality with medium straw length • Hybrid varieties • Drought resistance • Resistance to diseases
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 150 kg/ha • Entec • Split application (2 times)
	P fertilisation	• 70 kg/ha P2O5
	K fertilisation	• 90 kg/ha K2O
	S fertilisation	• 15 kg/ ha
	Mg fertilisation	• 10 kg/ha
	B fertilisation	• 0.5 kg/ha
Crop protection	Fungicides	• Seed dressing
	Pesticides	• Etofenprox • beta-Cyfluthrin
	Herbicides	• Pre emergence, Post emergence • 2 times application • +Quinmerac100 • +Picloram6
Other management practices		
Cultivation practices	Soil preparation	Shallow seed bed
	Large working width for machinery	32 m

	Seed priming	Water priming
Soil fertility management	Catch crops	Phacelia
	Crop rotation	• Rapeseed-legumes • Rapeseed-cereals • Rapeseed-pea-wheat
% theoretical yield increase		20%

2.10.2 Theoretical yield increase for oil crops

Based on the best practice strategies for low, medium and high yielding regions (Table 27), the theoretical yield increase was calculated for each region. For the regions with low yield because of site specific limitations (Table 28), another set of measures as a part of best practice strategy was used to calculate the theoretical yield increase.

The site factors can contribute towards yield increase from 50% to 100%. The site effects in model represents mainly rainfall data and some maps presented which depict the soil fertility levels for each region along with agriculture limitations. For fertilisation, the timing and amount of fertiliser applied fertilisation affected the actual crop yield, therefore theoretical yield increase will be achieved through improved fertilisation. The method of application plays a key role, for instance the application of Entec can reduce N losses significantly and can increase actual yield through increasing N use efficiency. The form of N fertilisation in combination with better P supply can lead to actual yield increase. For example, due to the application of solid N fertilisation along with sufficient P supply the actual rapeseed yields can be increased up to 4%. The recommended measures for fertilisation for oil crops, the fertilisation (amount, timings, form of fertilisations, way of fertilisation) can lead to a theoretical yield increase for rapeseed up to 10% in highest yielding country i.e France (Figure 55).

The other important measure to increase actual crop yield is to protect crop from diseases, pests and weeds. For France, the recommended measures as a part of crop protection (Figure 55) can contribute 10% of theoretical yield increase for rapeseed. The remaining yield increase measures include choice of variety, irrigation, cultivation practices, crop rotation and catch crops. The overall theoretical yield increase in France for rapeseed through combination of described management practices (Table 27) is up to 30% (Figure 55).

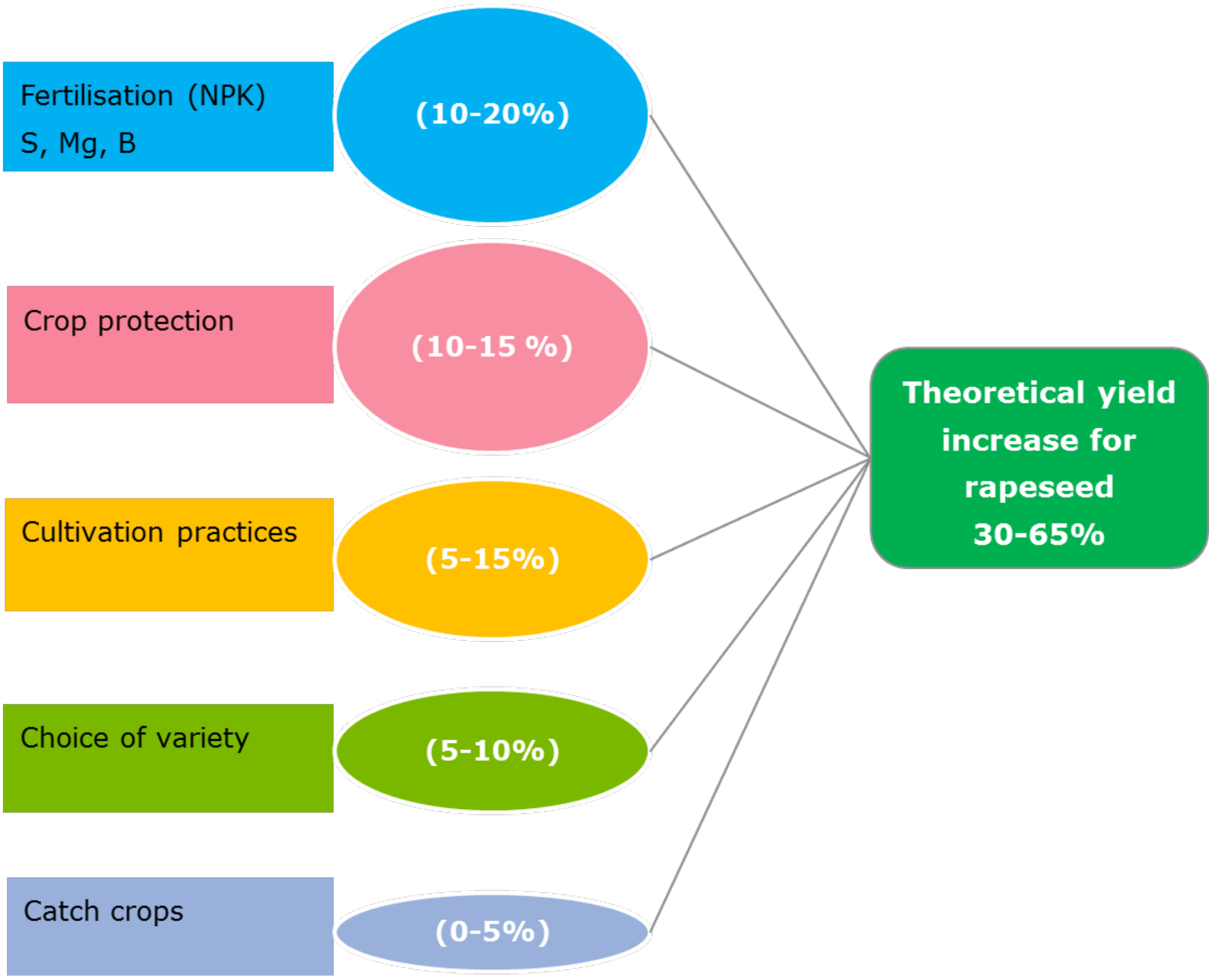

Figure 55: Effect of different factors relevant for rapeseed yield calculated based on data from literature and through model. The quantification of factors is made based on the coefficients of variables (site effects, fertilisation, crop protection, other management practices).

For medium yielding regions such as Poland, the theoretical yield can be increased by 40% under described management practices for medium yielding regions (Table 27). For the regions with low yield mainly due to poor management practices such as Romania, the theoretical yield can be increased by 65% under described management practices for low yielding regions (Table 27). The regions with low yield due to poor site conditions as identified based on soil maps with loess distribution and agriculture limitations, the theoretical yield increase can be increased by 20% under already described best practice strategies (Table 28).

Gehringer *et al.* (2007) revealed that appropriate selection of variety along with optimal soil conditions for rapeseed production can lead to significant actual yield increase. The optimal soil conditions with (50 kg N_{min} ha^{-1}; German soil classification: 70-80) and a marginal soil conditions (nutrient-poor soil; 21 kg N_{min} ha^{-1}; German soil classification: 25-35) have been identified for Hess

(Germany) in the growing season 2004/2005. The German soil classification is mainly defined based on soil profile and horizon sequence. The results by Gehringer *et al.* (2007) showed that the actual yield for rapeseed on the less suitable (marginal) site were about 42-45% lower than on the better suited site. The quality of oil on marginal locations is also low compared with better suited soils (Lewandowski and Gützloe, 2014).

The same components of model were used for sunflower as for cereals and rapeseed to calculate the % theoretical yield increase. To explain the approach, best practice strategy was only presented for rapeseed. The theoretical yield increase for sunflower in high yielding (France) through combination of management practices especially N fertilisation and selection of appropriate varieties ranges between 10-20%. In the lowest yielding country Romania the % theoretical yield increase is 20-30%.

2.11 Sugar beet – Best practice strategy and theoretical potential

2.11.1 Best practice strategies for sugar beet

The same model was used as for cereals and oil crops, to identify the most relevant factors with the main focus on sugar beet for actual yield. The most relevant factors for sugar beet include site effects, fertilisation, crop protection, crop variety, other management practices. Other management practices include row spacing, soil preparation, plant density, row spacing, sowing time, catch crops and crop rotation. The data about management practices was collected mainly from literature. The most relevant literature used here is presented below:

- Hoffmann, Christa M., Toon Huijbregts, Noud van Swaaij, and Rudolf Jansen. 2009. "Impact of Different Environments in Europe on Yield and Quality of Sugar Beet Genotypes." European Journal of Agronomy 30 (1): 17–26. doi:10.1016/j.eja.2008.06.004.
- Højland, J. G., and S. Pedersen. 1994. *Sugar Beet, Beetroot and Fodder Beet (Beta Vulgaris L. Subsp. Vulgaris): Dispersal, Establishment and Interactions with the Environment*. Vol. The Nationals Forest and Nature Agency,. Copenhagen, Denmark.
- Lacoste, E., and M.-C. Ribera. 2010. "The EU Beet and Sugar Sector: A Model of Environmental Sustainability." International Confederation of European Beet Growers; Comité Européen des Fabricants de Sucre, Brussels. www.cibe-europe.eu; www.cefs.org.
- Nichterlein, H., A. Matzk, L. Kordas, J. Kraus, and C. Stibbe. 2013. "Yield of Glyphosate-Resistant Sugar Beets and Efficiency of Weed Management Systems with Glyphosate and Conventional Herbicides under German and Polish Crop Production." *Transgenic Research* 22 (4): 725–36. doi:10.1007/s11248-012-9678-z.

For sugar beet, the choice of variety is very important because there are many different diseases which are difficult to control through chemical applications. Therefore, varieties with better disease resistance along with high sugar content are being selected.
With regard to cultivation practices early sowing is recommended to minimise the disease attack and also for better quality (high sugar content) and yield. Ideally row spacing is also narrowed down up to 17 cm to achieve higher yields. All the management practices described in **Table 29** interact with each

other to reach to a certain theoretical yield increase level. The description of management practices as a part of best practice strategies covers low, medium and high yielding regions. In Table 29 low yielding refers to the regions where yield is low mainly because of poor management practices.

Table 29: Description of management practices of the best practice strategy for sugar beet in regions with low, medium and high yield potentials

	Description of management practices	Low yielding (i.a. Romania)	Medium yielding (i.a. Poland)	High yielding (i.a. France)
Crop variety	Choice of variety	• Rhizomania tolerant varieties • Frost resistance • Resistance to spot disease		
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 150 kg/ha (First year) • Subsequent years 140 kg/ha • Entec • Split application (2)	• 140 kg/ha • Entec • Split application (2)	
	P fertilisation	100 kg/ha P_2O_5	90 kg/ha P_2O_5	
	K fertilisation	120 kg/ha K_2O	110 kg/ha K_2O	
Crop protection	Insecticides	Imidacloprid,Thiamethoxam		
	Herbicides	• Pre emergence • Post emergence • Chloridazon; • Clethodim; • Clopyralid; • Cycloxydim; • Desmedipham; • Ethofumesate • 3-6 times application		
	Others	Pellet seeds*		
Other management practices				
Cultivation practices	Soil preparation	Mulching		
	Plant density	130 (1000/ha)		
	Row spacing	Ultra narrow (17 cm)		
	Sowing time	Early sowing		
Soil fertility management	Catch crops	Mustard, Phacelia		
	Crop rotation	• Alfalfa-Sugar beet • Legume-Cereals-sugar beet		
% theoretical yield increase		80%	48%	40%

*Pellet seed is a process of coating the seeds which facilitate the handling but also protect them from diseases.

The regions where low yield is due to poor site conditions are identified based on already used loess distribution map and agriculture limitations map. For low yielding regions because of site specific limitations, low input of fertilisation is recommended (Table 30). For crop protection, herbicides and fungicides are recommended with low input amounts to keep crop production economically viable in these regions.

Table 30: Description of management practices of the best practice strategy for sugar beet in regions with low yield due to site conditions

	Description of management practices	Low yield due to site conditions (Finland)
Crop variety	Choice of variety	• Rhizomania tolerant varieties • Frost resistance • Resistance to spot disease
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 120 kg/ha • Entec • Split application (2)
	P fertilisation	70 kg/ha P_2O_5
	K fertilisation	80 kg/ha K_2O
Crop protection	Fungicides	Imidacloprid, Thiamethoxam
	Herbicides	Pre emergence, Post emergence Chloridazon; Clethodim; Clopyralid; Cycloxydim; Desmedipham; Ethofumesat 3 times application
	Others	mechanical weeding
Other management practices		
Cultivation practices	Soil preparation	Mulching
	Row spacing	17 cm
	Sowing date	Early sowing
	Plant density	130 (1000/ha)
Soil fertility management	Catch crops	Mustard, Phacelia
	Crop rotation	• Alfalfa-Sugar beet • Legume-Cereals-sugar beet
% theoretical yield increase		25-30%

2.11.2 Theoretical yield increase for sugar beet

The theoretical yield for sugar beet was calculated with the best practice strategy described in Table 29 for low, medium and high yielding regions.

In lowest yielding regions like Romania, the theoretical yield increase can be increased by 80%. The main contributors towards yield increase are fertilisation and crop protection measures. In medium yielding regions like Poland, the theoretical yield can be increased by 48% under described best practice strategy. For medium yielding regions also, the rate of fertilisation, crop protection measures along with appropriate variety selection played a key role in reaching theoretical yield increase.

In highest yielding regions like France, the theoretical yield increase can be increased by 40% under the defined best practice strategy. In all three regions (low yielding, medium yielding and high yielding), the theoretical yield increase was calculated by considering ideal site conditions without any limitations as for other crops. However, for the regions where yield is low because of poor site conditions, another set of management practices as a part of best practice strategy is recommended. For example, the map with agriculture limitations shows that southern and northern Europe has more limitations compare to central and eastern Europe. In low yielding regions due to site specific limitations like Finland, the theoretical yield can be increased by 25-30%. Here, also fertilisation and crop protection measures played a key role towards theoretical yield increase. The following figure (Figure 56) is not covering theoretical yield increase for the regions with site specific limitations.

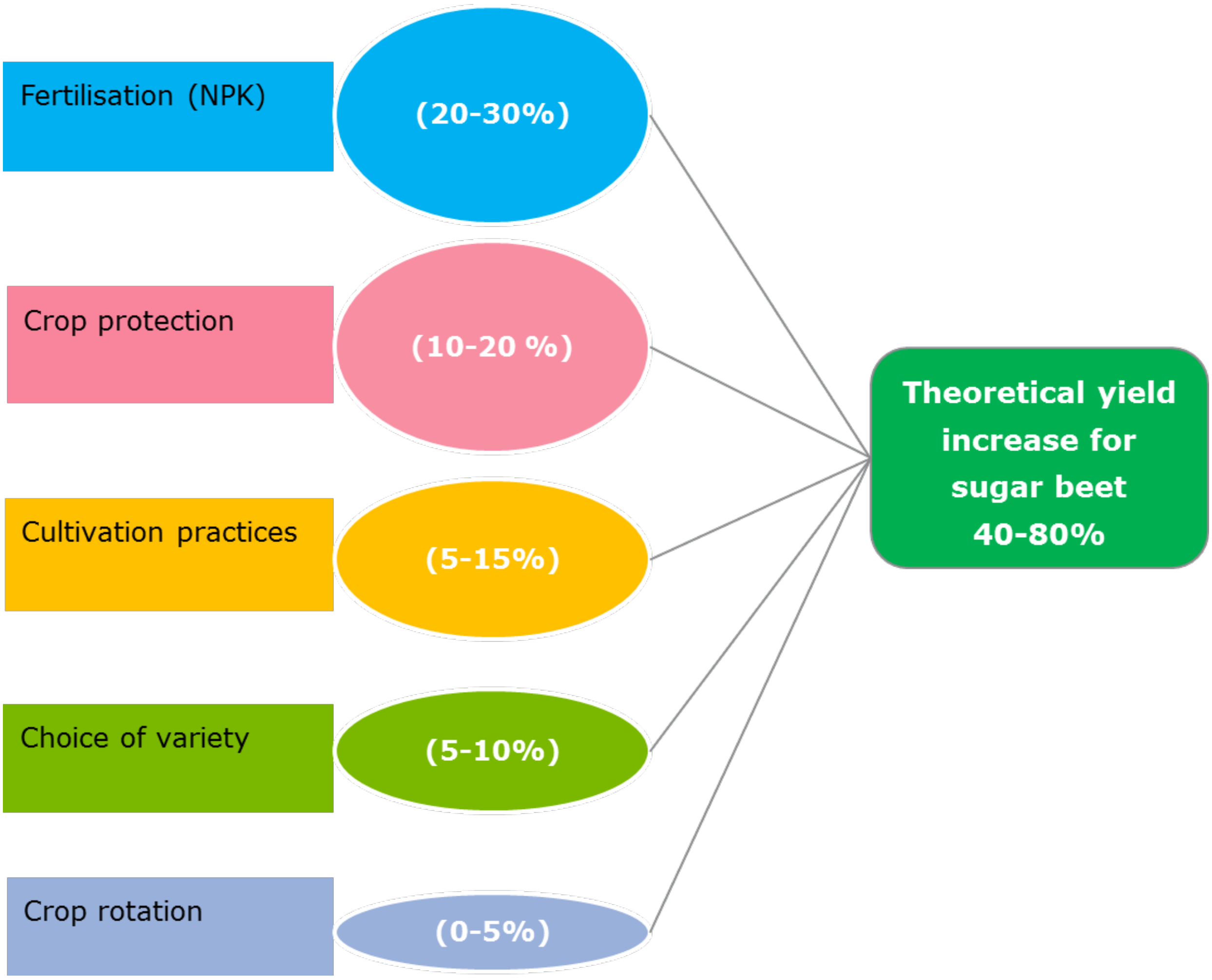

Figure 56: Effect of different factors relevant for sugar beet yield calculated based on data from literature through model. The quantification of factors is made based on the coefficients of variables (fertilisation, crop protection, other management practices)

2.12 Wine

For wine, actual yield was calculated based on residue to crop ratio, yield per hectare as presented at the beginning. However, there was not sufficient data to develop such the same calculations as the for other crops such as cereals, oil crops and sugar beet. Therefore, for wine no best practice strategy is proposed. Subsequently a theoretical yield increase for wine could not be estimated.

2.13 Grassland – Best practice strategy and theoretical potential

The short term strategies for grassland include management practices with the main focus on cutting frequency, irrigation and fertilisation. To maximise the actual yield of grassland, the focus is mainly on agriculturally improved permanent grasslands and semi-natural grasslands.

Agriculturally improved permanent grasslands: This category is characterised by good or medium quality soils, used with more frequent defoliations, higher fertilisation rates, higher stocking rates, and producing higher yields than semi-natural grasslands (Peeters et al, 2013).

Semi-natural grasslands: Low yielding permanent grasslands, dominated by indigenous, naturally occurring grass communities, other herbaceous species and in some cases shrubs and trees. These mown and grazed ecosystems are not substantially modified by fertilisation, liming, drainage, soil cultivation, herbicide use, introduction of exotic species and sowing (Peeters et al, 2013).

The highest actual yield for grassland is achieved in North Western Spain, Western France, North of Germany and Netherlands. The main reason for this are suitable climatic conditions followed by intensive pasture use (Smit, Metzger, and Ewert 2008). The suitable climatic conditions are the most important factor in defining the productivity of grassland. The highest per hectare actual yield for grassland is 10 t/ha and the lowest per hectare actual yield is about 1.5 t/ha (Smit, Metzger, and Ewert 2008). The lowest yielding countries are located in Mediterranean region and the main reason for low actual yield is water stress (Smit, Metzger, and Ewert 2008). In medium yielding regions such as Poland, Czech Republic and Slovakia, the actual yield for grassland is about 4-6 t/ha.

2.13.1 Best practice strategy

The relevant factors for increasing the yield for grassland were identified by using same approach as for agriculture crops.
The most relevant literature which was used to collect data for model is listed here:

- Smit, H.J., M.J. Metzger, and F. Ewert. 2008. "Spatial Distribution of Grassland Productivity and Land Use in Europe." *Agricultural Systems* 98 (3): 208–19. doi:10.1016/j.agsy.2008.07.004.
- Huyghe, Christian; Vliegher, Alex de; van Gils, Bert; Peeters, Alain (2014): Grasslands and herbivore production in Europe and effects of common policies. Versailles Cedex, France: Éditions Quae, zuletzt geprüft am 16.04.2014.
- Prochnow, A.; Heiermann, M.; Plöchl, M.; Amon, T.; Hobbs, P. J. (2009a): Bioenergy from permanent grassland – A review: 2. Combustion. In: *Bioresource Technology* 100 (21), S. 4945–4954. DOI: 10.1016/j.biortech.2009.05.069.
- Prochnow, A.; Heiermann, M.; Plöchl, M.; Linke, B.; Idler, C.; Amon, T.; Hobbs, P. J. (2009b): Bioenergy from permanent grassland – A review: 1. Biogas. In: *Bioresource Technology* 100 (21), S. 4931–4944. DOI: 10.1016/j.biortech.2009.05.070.

The most relevant factors were evaluated and their effect on actual yield of grassland was quantified. The factors which have significant effect on grasslands yield include irrigation, cutting frequency, optimisations of grasslands through different grass species, fertilisation mainly NPK and crop protection measures for low yielding, medium yielding and high yielding regions. Contrary to agriculture crops, low yield in grasslands is mainly due to site specific limitations. Therefore, the management practices for low yielding regions in **Table 31** refer to both poor management practices as well as site specific limitations. Irrigation is one of the main contributing factors towards theoretical yield increase because in most of the regions, the grassland yield is low because of less water availability. The other important management practice in grassland is cutting frequency, low cutting frequency is recommended for low yielding regions considering more site specific limitations in these regions. The higher the cutting frequency, the higher is the amount of harvested biomass per year if it is managed properly (fertilisation, irrigation). For optimisation of grassland mixtures, new seeds are reported with a rate of 20 kg/ha depending on regions. For high yielding regions every 1-2 years new seed broadcast (seeding method which involves the scattering of seed by hand or any other mechanical means) is recommended to make use of these high yielding regions and have high harvestable biomass per year. Fertilisation, one of the main aspects in management practices, contributes significantly towards yield increase. The recommendations are based on cutting frequency and soil conditions. The higher the cutting frequency, the more nutrients are being taken away through harvested biomass. Crop protection measures are also important but not applied as frequently as in agriculture. Herbicides are applied only when some unwanted plants are growing in grassland mixtures and can potentially affect the grassland productivity. All the aforementioned set of management practices as a part of best practice strategies interacts with each other to reach to a certain theoretical yield increase.

Table 31: Description of management practices of the best practice strategy for grasslands in regions with low, medium and high yield potentials

Description of management practices	Low yielding (i.a. Portugal)	Medium yielding (i.a. Poland)	High yielding (i.a. Netherlands)
Irrigation	During drought periods		
Cutting frequency	3-4 times	4-5 times	5-6 times
Optimisation of grassland mixtures	20 kg/ha of new seeds every 3-4 years	20 kg/ha of new seeds every 4-5 years	20 kg/ha of seeds every 1-2 years
N-application • ***Amount of application*** • ***Method of application***	• 150 kg/ha • Split application (3-4)	• 200 kg/ha • Split application (4-5)	• 250 kg/ha • Split application (5-6)
P- application (P_2O_5)	• 90 kg/ha	• 100 kg/ha	• 120 kg/ha
K- application (K_2O)	• 200 kg/ha	• 250 kg/ha	• 300 kg/ha
Crop protection	• Herbicides application when needed		
% theoretical yield increase	25%	40%	60%

2.13.2 Theoretical yield increase for Grassland

Based on the above mentioned (Table 31), the theoretical yield increase was calculated for each category (low yielding, medium yield, high yielding). The quantification of factors is based on the coefficients of variables which were obtained through model as explained at the beginning (equation 1).

The site effects include mainly soil type and climatic conditions but in this study the main focus is on management practices. The site conditions can affect the grassland actual yield from 50-100%. Within management practices, irrigation can lead to 5-15% theoretical yield increase. Fertilisation mainly NPK as described in Table 31, can contribute to 10-15% towards theoretical yield increase depending on site conditions. Under optimal conditions and through application of best practice strategies, in high yielding regions such as Netherlands, the theoretical yield increase in grasslands can be increased by 60%. In medium yielding regions such as Poland, Czech Republic, the theoretical yield can be increased by 40% through a combination of improved management practices. In lowest per hectare actual yielding regions such as Portugal, the theoretical yield increase for grassland can be increased by 25%. The following figure 57 is referring to theoretical yield increase for low yielding and high yielding regions.

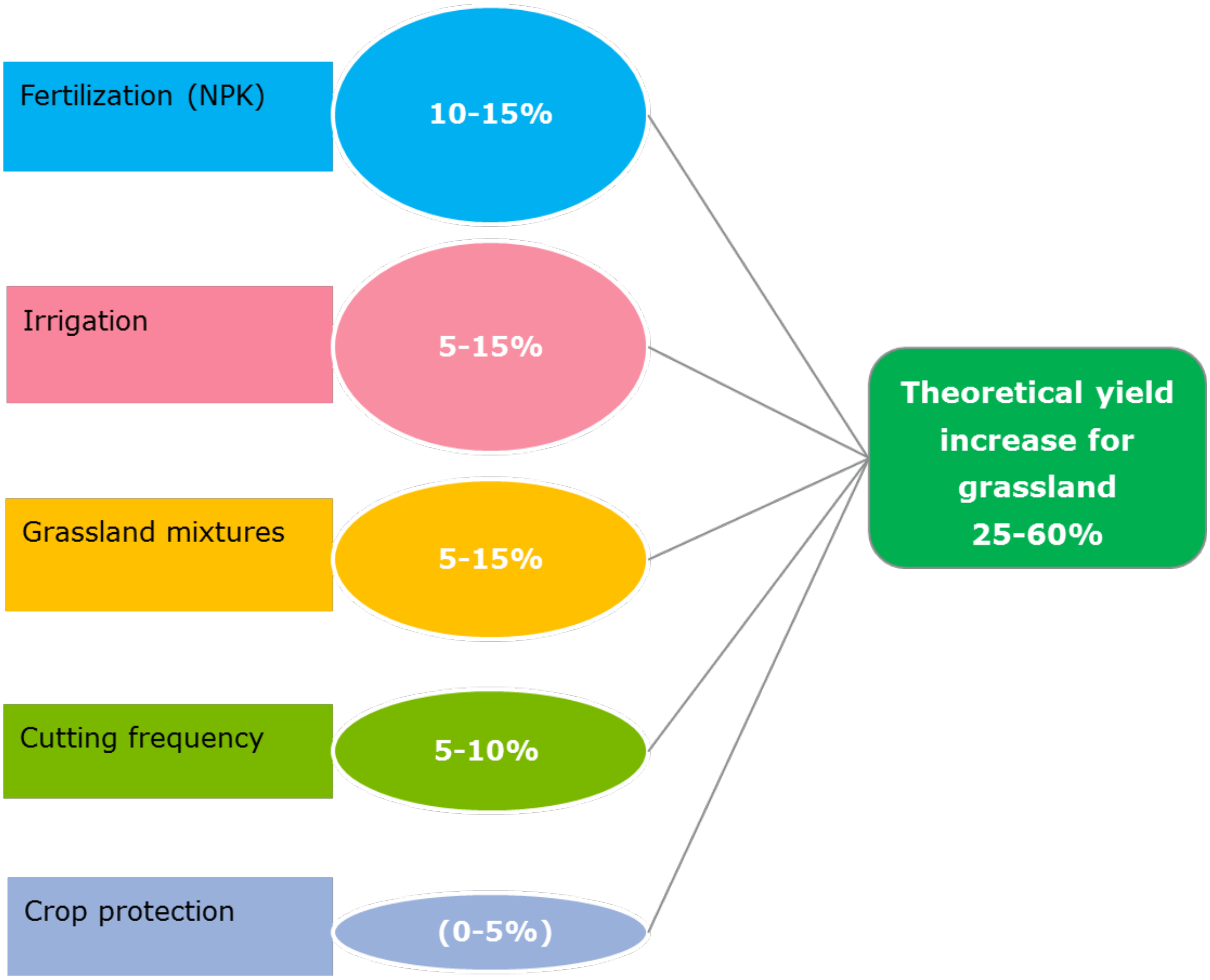

Figure 58: Effect of different factors relevant for grassland yield calculated based on data from literature and through model.

2.14 Residue-specific strategies

Large quantities of residues are generated every year, the main residue yielding crops are cereals, oil crops and sugar beets. The availability of biomass from grasslands is also one of the main biomass resources for energetic uses. Residue specific strategies refer to residue yield increase through:

- Harvesting procedures and technologies;
- Residue removal rate
- Transport, storage and handling of residues

The table below gives an overview of the residues which are covered by specific strategies.

Table 32: Overview of assessed agricultural residues

Crop	Residue
Wheat	Straw
Barley	Straw
Maize	Stover, cobs
Sugar beet	Leaves
Rape seed	Straw
Rye	Straw
Oat	Straw
Sunflower	Straw
Wine	Wood
Grassland	Grass

2.14.1 Harvesting procedures and technologies

The method and the rate of crop residue recovery from the fields are critical factors to the overall collectable residues. Within harvesting procedures, the main focus is on harvesting of main product such as grains, the residue is either left on the ground or collected if needed for the livestock use. However, the harvesting procedure varies from crop to crop and availability of machinery. For example, in case of straw, harvesting is performed by cutting the straw from 5-20 cm stubble height depending on machine being used. The straw is harvested and left on the field in the form of ridges, therefore it is still collectable. However, for some crops such as sugar beet, the harvester cuts the leaves and dig out the beets from soil. In this case beets are collected efficiently but leaves are only cut and left on field but due to high moisture level of leaves and use of heavy machinery the leaves are completely mulched into soil, therefore it is not easy to collect these leaves for further use.

Field experience indicated that in case of cereals and oil crops cutting height during harvesting of crop plays a key role. Currently, the cutting height for cereals and oil crops is more than 20 cm depending on crop variety. The main issue with residue harvesting is lack of specific machinery at farmer level which leads to greater losses. There are no efforts to harvest residue, it is simply chopped and mixed in soil to improve soil fertility or in some cases collected to use it for livestock. Although there is machinery available especially in case of straw, however, farmers are rarely using it because there is no stable market of straw and also machinery is very expensive. The following measures can be taken into account to increase the residue yield:

- Reduce cutting height up to 5 cm for cereals and oil crops
- Development of residue specific machinery to harvest and collection, which collects and bales at the same time. There are already machines available but only on pilot scales, therefore it needs to be replicated on large scale.
- For sugar beet, the machinery with the capability to collect beets and leaves at the same time, would help to increase the residue harvest at field level
- For sugar beet, development of machinery is needed which is capable of cutting and collecting leaves and simultaneously collecting beets. Currently, the leaves are cut but left on field. Cutting height is not relevant for sugar beet because leaves are already cut completely.
- For wine, the pruning procedures are state of the art, which is performed either by using machines or manually. For wine, also cutting height is not relevant, only issue is collection of pruned wood. For that it is needed to have specific machinery.
- For grassland, machinery is already available which is being used for cutting or mowing, therefore cutting height is not relevant for grassland.

The assessment of theoretical residue yield increase was made based on the optimal cutting height. For example in case of wheat, the height of wheat varieties in Europe varies from 53 cm to 124 cm depending on location, with the mean height of 76 cm (Würschum, Langer, and Longin 2015). If the stubble height is assumed 5 cm, then theoretically the rest of the straw can be harvested if there is appropriate machinery available. Contrary to it, currently 20-30 cm unharvested straw is left on field, which is almost half of the total straw height in case of short varieties. Therefore, through appropriate use of machinery, the unharvested straw can be exploited.

Within residue specific best practice strategy, we are recommending the use of residue specific machinery which means the residue harvest can be increased theoretically up to 50% in case of straw from cereals and oil crops. For sugar beet, there is no specific machinery available for collection of leaves and harvest is focussed on collection of beets. Therefore, development of new machinery specific to sugar beet residue collection can lead to theoretical increase in residue from sugar beet harvest up to 100%. It is important to state that, it is only referring to residue harvest without considering any collection losses or any other limitation. The main focus is on finding or recommending appropriate residue specific machinery which is capable of harvesting residues depending on crop type. For wine, there are pruning machines available but such machines just cut the canes. There is no harvest machine with simultaneous harvesting and collection.

2.14.2 Residue removal rate

The residue removal rate does not take into account environmental implications, which are only covered by the sustainable removal rate (see chapter 2.15.1).

The removal rate of residue depends mainly on organic matter content of soil. The soil carbon content can be a good indicator of humus balance. The organic matter contains up to 58% organic carbon (de Brogniez et al. 2015). The humus balance in soil is important because it improves the soil texture as well as soil structure. The soils with low organic matter content are more prone to wind and water erosion and are less productive. Therefore to maintain the soil productivity, it is important to maintain the soil organic matter content by maintaining the humus balance. The other important aspect in defining residue removal rate is the carbon content of residue. For example, cereals add 0.86 t/hat, sugar beet adds 0.46 t/ha, oil crops add 1.12 t/ha of humified organic carbon at EU-27 level, if all residue are left on the field (Wilhelm et al. 2004: http://ec.europa.eu). In addition, it also depends on crop productivity. It indicates that more residues can be taken away in case of oil crops than cereals and sugar beet depending on soil type and crop variety.

Based on the organic carbon content European soils can be categorised into three main categories: 1) Low (1-2% organic carbon); 2) medium (2-6% organic carbon); 3) high (more than 6% organic carbon) (Ezio Rusco, Robert Jones, and Giovanni Bidoglio 2001). Based on this classification, the soils of southern Europe fall into the category of soils with low organic carbon content, which is about 74% of the southern Europe area. Therefore, in this case more residues need to be left on soil. To get an overview about soil carbon content a map of European top soil carbon was used (Figure 60)). The soil carbon map shows that in northern and central Europe, there is high carbon content compared to southern and central Europe. The soils of central and northern Europe fall into the category of medium to high organic carbon content. However central Europe has a higher carbon content compared to southern Europe especially south-west Europe. Therefore, more crop residue can be taken away from northern and central Europe in comparison to southern Europe. However, residue removal can be increased through providing alternate sources of organic matter. For theoretical residue yield increase the following measures for removal rate can be recommended for cereal crops, oil crops and sugar beet:

- Application of manure, which is surplus and not being used for bioenergy production
- Application of composite mainly coming from kitchen gardening which include fruits, vegetables waste and green composite coming from prunings, leaf litter (http://ec.europa.eu)
- Potential recycling of nutrients through application of processed residue generated after biomass based energy production. For example recycling of ash or digestate generated as a result of combustion or biogas production, respectively.

Up to 90% of the European soils have organic carbon content between 2 to 6% (Ezio Rusco, Robert Jones, and Giovanni Bidoglio 2001). Therefore, in this study 4% organic carbon is taken as baseline value for whole Europe corresponding to sustainable removal rate for a specific crop (Nicolae Scarlat, Blujdea, and Dallemand 2011). For example in case of cereals (Wheat, barley, oat, rye) 40% sustainable removal rate is recommended in EU-27, which corresponds to 4% organic carbon and is taken as baseline value for EU-27.

Based on this, residue removal rate is calculated for the regions with low and high soil carbon. For example in southern Europe, the organic carbon is up to 2%, which is translated to 20% as sustainable removal rate for cereals except maize, which has 10% more due to its high organic carbon content in residues (Wilhelm et al. 2004). If the same cereal crop residues are harvested in north or central Europe, the sustainable removal can be up to 60% because of high carbon content of soil, which allows to take away more residue. However, in regions where soil is more prone to erosion, low amount of residues should be taken away. In northern Europe, there is less erosion problem. In southern Europe, the problem of soil erosion is more severe, therefore more residue need to be left on the field (Figure 59).

If all available manure (not used for bioenergy) and composite is applied to field, the above mentioned strategies can add up to 0.285 t/ha organic carbon (http://ec.europa.eu).

In case of cereal residues the strategies add up to 0.86 t/ha, i.e. the application of manure and composites can replace straw up to 33%. Through application of above mentioned measures, the residue removal rate for maize can be increased up to 29%, for oil crops up to 26% and for sugar beet up to 62%. These estimations are made based on soil organic carbon and added value of organic carbon through manure and composite application.

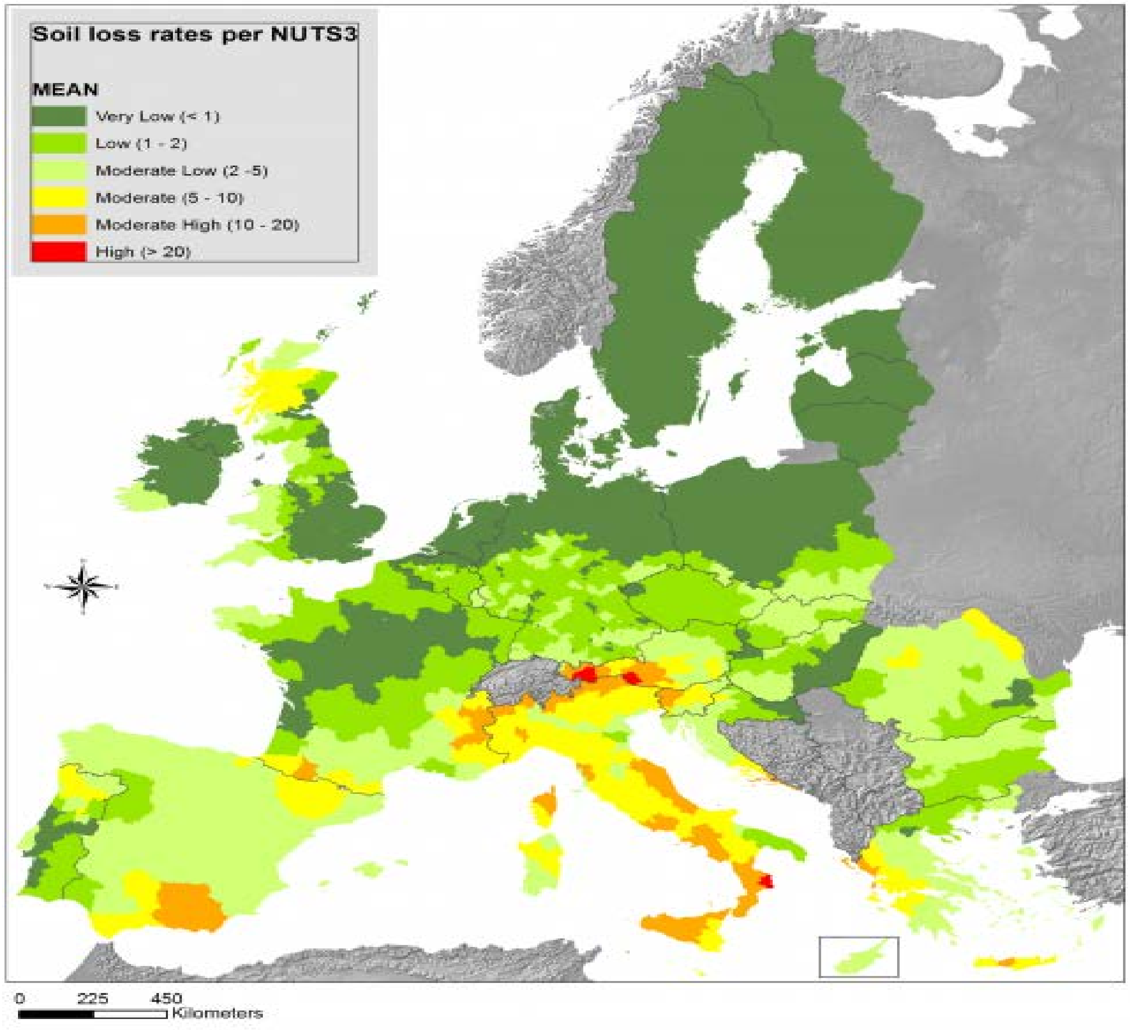

Figure 59: Soil erosion by water (tonnes per ha per year), 2010, EU 28, NUTS 3 (JRC, 2010)

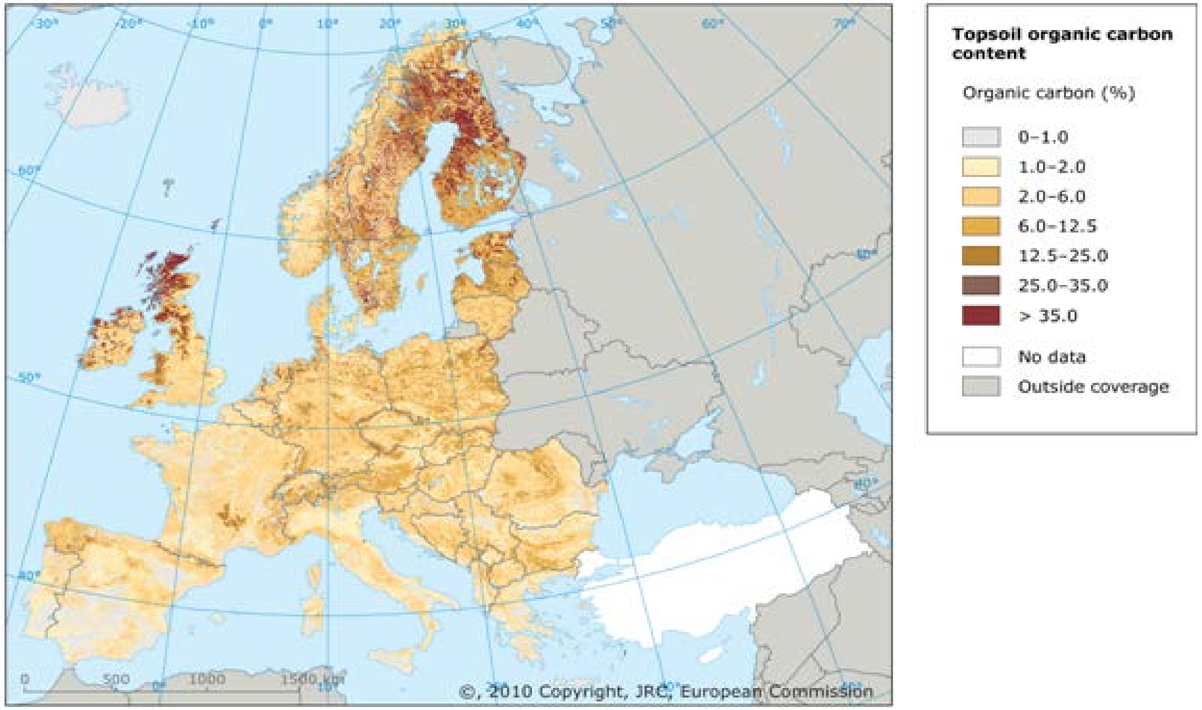

Figure 60: European topsoil organic content (JRC, 2010)

2.14.3 Transport, storage and handling

Transport costs are one of the main constraints in transportation of residues. It is mainly because the density of biomass is low in comparison to wood or other processed biomass, therefore in most of the cases the trucks cannot even carry the allowed load. As biomass based energy production, requires large quantities of biomass transportation over long distances is only economical if biomass is densified. This also facilitates the storage and converts the biomass in a ready to be used form. The use of special pressers is recommended to make more densifies bales. Such pressers can densify biomass by 5-10% (www.Dekeeble.co.uk).

In the case of straw, bales have large volume but low density, which increases the transportation cost. To increase the density and make use of allowed load for transporting trucks, the biomass can be processed on field. Straw can be densified to form some pellets, which allow to carry more biomass in one go and also ease out the storage issue because biomass is already processed and can be stored for longer time. In Austria such handling machines are being used at pilot scales. These machines have the capability to collect the straw from field, densify it and then convert it to pellets on field. This is very efficient handling. However the cost and the application of this machinery is a big issue, because it works slowly, takes time to collect and densify. This machine is called pellet harvester and is developed by the company called Krone for field straw residue handling (http://www.krone-austria.at/). Such machines can be used for cereal straw as well as for oil crops to densify biomass and transport it efficiently to longer distances.

For sugar beet, modern harvesters chop the leaves and collect beets. Leaves are mulched into soil or in some cases collected to feed animals (Bassam 2010). As leaves and tops of sugar beet have high moisture content, the handling, transport and storage is different in comparison to cereals and oil crops. The leaves and tops of sugar beet can be ensiled to produce biogas (Korres et al. 2013). The beet leaves can also be conserved in the form of stack silage. It has to be avoided that too much moisture is lost as leaves and tops will mold and decompose. The leaves should be packed air tight to exclude any air and stacked above each other. These stacks should be covered properly from top to avoid any moisture from top.

For wine, the pruned wood can be collected and directly chipped. Through chipping, it is easy to transport and store. In addition, the chipped material can be directly used for combustion purposes to produce heat and electricity. The other option is to cut the pruned material and press it to bails and transport it to farm for energy production purposes.

In case of grassland, the method of bailing is very prevalent Grassland bails are typically transported to the farm own uses such as livestock bedding.

Through use of modern machinery as described above the theoretical yield of residues, can be increased by 10-15% for cereals and oil crops, by 15-20% for sugar beet and 20% for wine.

2.14.4 Theoretical yield increase of residue specific strategies

Due to the above mentioned residue-specific strategies the theoretical yield of the residues can be increased as displayed in the table below.

Table 33: Theoretical yield increase of residue-specific strategies

Crop	Residue	Theoretical yield increase of residues
Wheat	Straw	20-40%
Barley	Straw	20-40%
Maize	Stover, cobs	30-40%
Sugar beet	Leaves	40-50%
Rape seed	Straw	30-40%
Rye	Straw	20-40%
Oat	Straw	20-40%
Sunflower	Straw	30-40%
Wine	Wood	40-50%

2.15 Constraints for best practice strategies

The best practice strategies are formulated for cereal, oil crops, sugar beet, wine and grassland to calculate the theoretical yield increase for the respective crop. However, the aforementioned theoretical yield increase cannot be achieved because of implementation limitations for best practice strategies for a specific crop. There are number of constraints which hinder the implementation of best practice strategies depending on crop type.

A *constraint* is anything that has a limiting effect on the implementation of a measure to increase (residue) yield on a general level without taking into account the regional aspects.

Identified constrains have implications on the yield increase of the specific best practice strategy. In order to come up with the technical-sustainable potential the following constraints have been assessed:

- Sustainability constraints
- Technical constraints in supply chain (i.e. harvest, collection, transport, storage and handling)

For each of the identified constraints option to mitigate the limiting effect are defined and described in detail in the specific chapter.

Despite these specific constraints some general aspects have to be considered when moving from a theoretical potential to a technical-sustainable potential (Figure 61).

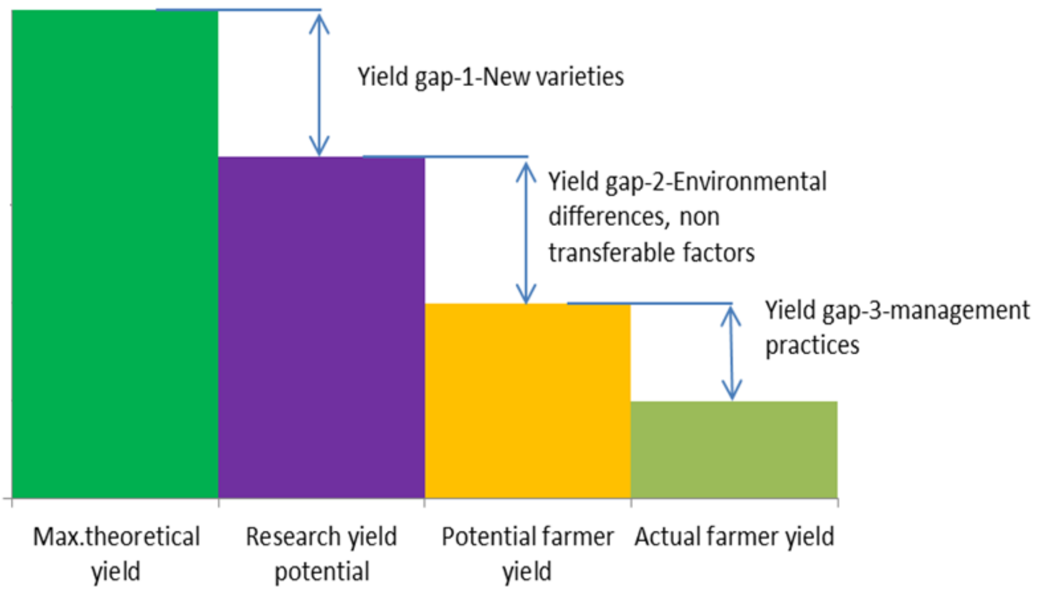

Figure 61: Different yield gap levels from maximum theoretical yield level to actual farmer yield level

The crop yield can be divided into 4 levels; 1) maximum theoretical yield; 2) research yield; 3) potential farmer yield; 4) actual farmer yield..

The yield gap level 1 is the gap between maximum theoretical yield and research yield potential which refers mainly to development of new varieties, which therefore are not yet available for cultivation. However, the genetic potential is still there to develop new varieties which could deliver high yields. Therefore, yield gap 1 involves the theoretical recommendations towards high yielding crop varieties. The yield gap level 2 is the gap between research yield potential and potential farmer yield and it mainly refers to environmental differences and other non-transferable factors (e.g. agro-chemical application in research is monitored for every single plant). The research yield potential is the yield which is being achieved at research level. Therefore, it is at small scale and every management practices can be regulated properly but when it is transferred to field, same yield increases cannot be achieved. It is mainly because at research level, it is possible to provide ideal conditions even by using a greenhouse. A farmer will not have the same opportunities in commercial production. The 3rd yield gap is the yield difference between potential farmer yield and the actual farmer yield and it is mainly the difference in management practices. This is the most crucial yield gap, as a farmer has high yield potential but cannot exploit it because of site specific constraints, poor management practices, lack of awareness, seasonal variations, economic constraints to provide sufficient inputs and even lack of access to latest technology.
As a part of best practice strategies, certain crop varieties were recommended which could potentially increase crop yield as well as residue yield. However, at field level it is not easy to implement because of socio-economic reasons. In crop management practices, some new techniques such as

seed priming were recommended to enhance the crop growth, which led to theoretical increase in actual crop yield. Seed priming is mainly used at research level and not yet large scale because it is expensive for farmers and it is also in its infancies.

The recommendations on development of new machinery to increase area under crop at field level have similar limitations. The increase in area under crop through development of new machinery refers to the use of maximum area for cropping at field level. Currently, small machines are being used which require more working lanes in the field to operate. Reduction in these tramlines and increasing the working width of machinery will lead to availability of more area for crops. However, development of new machines and such modifications requires time, capital and social acceptance to implement. Socio-economic constrains are discussed as a part of regional barriers for implementation of best practice strategies in chapter 2.17 .

2.15.1 Sustainability constraints

The increased production and use of agricultural residues can impact the environment by a) applying a more intensive agricultural production system for increasing crop yields and by b) increased removal rate of residues.

These constraints limit the theoretical yield increase. Agro-chemicals like fertilisers, pesticides, and herbicides affect air, water, and soil quality. So the increase in theoretical yield through crop based strategies or residue specific-strategies need to be optimised for the calculation of the technical-sustainable potential.

Developing a definition for “sustainable agriculture” is not within the scope of the study, but we have considered negative implications on the environment which are caused by additional measures for residue yield increase in mainstream agriculture in the EU, Russia, Belarus and the Ukraine. In an additional step we at the same developed options to mitigate the negative impacts by adjusting the best-practice strategies.

a) Applying a more intensive agricultural production – Mitigated through optimisation

Management practices to improve actual crop yield mainly focussed on amount of fertilisation, method of fertilisation such as Entec, crop protection measures such as fungicides, herbicides use and recommendation of different techniques such as seed priming to enhance plant growth. In addition, modification of existing mechanization was recommended along with crop irrigation and measures to maintain soil fertility such as adoption of specific crop rotation.

Considering the climate change and reports of drought stress for different crops at EU level, irrigation was recommended as a part of best practice strategies during drought stress periods. However, due to ecological implications and future potential water stress, irrigation cannot be recommended as a part of best practice strategies. Furthermore it has been agreed by the study consortium and the

European Commission Steering Committee to not recommend Clearfield[4] technology as a measure for technical-sustainable potential, due to the debate about its negative environmental effects and the imposed monopoly by the chemical industry.

Within crop based best practice strategies, N application is one of the focal areas, it is mainly because nitrogen is one of the key components of actual crop yield. Therefore sufficient N supply with minimum losses led to theoretical yield increase as described earlier in best practice strategies chapter. The focus was not only on application but also to ensure the efficient utilization of applied amounts of fertilisation. For example, in case of N, large amounts of applied N got wasted through leaching. As a part of best practice strategies Entec stabilized N fertilisation was recommended to minimise the losses. However, at farm level it is not being used, due to its high costs. Hence, application of high N amounts without Entec will lead to environmental concerns such as N leaching, eutrophication, GHG emissions and has negative effects on air quality and water contamination as well. The other major contributor towards theoretical yield increase are crop protection measures, which include intensive use of fungicides and herbicides. This also raises the environmental concerns if used at field level.

In order to reduce the negative effects on the environment the proposed use of agro-chemicals will be optimised to ensure a most efficient use and a reduction of the total amount used. Whereas the theoretical potential focussed on maximisation, the technical-sustainable potential will be based on optimisation, which is a smarter approach with less environmental implications. Optimisation requires a high skill set as well as sufficient resources for implementation. Regional barriers like farmers' education and financial capacities will be covered in chapter 2.17.

The optimisation of the best practice strategies is exemplary illustrated for cereals.

Table 34: Comparison of theoretical and optimised best practice strategies for cereals

	Description of management practices	Low yielding (i.a. Romania)	Medium yielding (i.a. Hungary)	High yielding (i.a. France)
Theoretical best practice strategies				
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 170 kg/ha • Entec • Split application (2-3)	• 150 kg/ha • Entec • Split application (3-4)	• 150 kg/ha • Entec • Split application (3-4)
	P fertilisation	80 kg/ha P_2O_5	70 kg/ha P_2O_5	60 kg/ha P_2O_5
	K fertilisation	100 kg/ha K_2O	90 kg/ha K_2O	80 kg/ha K_2O

[4] The heart of this technology is the resistance of crops against herbicides. These herbicides can only be used in combination with specially bred crop varieties that carry the resistance trait. Especially NGOs criticise the linkage between the herbicide and the herbicide resistant variety which forces famers to purchase them in combination.

Crop protection	Fungicides	Dimoxsystrobin, Boscalid, Epoxiconazole		
	Herbicides	Pre emergence, Post emergence 2 times application (autumn, spring) 4 kg/ha		
Optimised best practice strategies				
Fertilisation	N-application • Amount of application • Method of application • Time of application	• 140 kg/ha • Split application (2-3)	• 120 kg/ha • Split application (3-4)	• 120 kg/ha • Split application (3-4)
	P fertilisation	60 kg/ha P_2O_5	50 kg/ha P_2O_5	50 kg/ha P_2O_5
	K fertilisation	70 kg/ha K_2O	60 kg/ha K_2O	60 kg/ha K_2O
Crop protection	Fungicides	Boscalid, Epoxiconazole		
	Herbicides	Pre emergence, Post emergence 2 times application (autumn, spring) 2.5 kg/ha		

In crop production, N is one of the key yield defining factors. During optimisation of agro-chemicals, the amount of N fertilisation is decreased by about 20% and the rest of the amount is applied in the form of conventional fertilisers, not Entec. The use of conventional fertilisers can lead to more losses and inefficient use of available N. Therefore, there is chance that theoretical yield will go down significantly. Research also shows that crop yield increases linearly with increase in N fertilisation. Every 20% increase in fertilisation leads to 10% relative yield increase in wheat (Albert E 2011). Along with fertilisation, the amount of chemicals recommended in theoretical potential as a part of crop protection measures also decreased. For example the amount of herbicides application is reduced up to 48%. As there is a huge weed problem in EU-27 crop production decreases significantly. Research indicates that due to inappropriate control of weeds, cereal yield can be decreased up to 70% (Leonard Gianessi, Sujatha Sankula, and Nathan Reigner 2003). Considering the importance of fertilisation and crop protection measures, the optimisation of these measures led to significant decrease in theoretical crop yield. Based on correlation analysis between fertilisation and yield, crop protection measures and crop yield, the decrease in theoretical yield was estimated. In addition, the model as described at the beginning of chapter 2.9 was run after optimised fertilisation and crop protection measures to estimate how much theoretical yield will decrease through decreasing the fertiliser input and low doses of herbicides and fungicides.

The calculations shows that the theoretical yield decreases by 2-10% through optimisation of best practice strategy for wheat. This result was also cross checked with expert assessments.

b) Sustainable removal rate

The other important sustainability implication is caused by an increased removal rate of residues through different measures. In doing so, a set of measures was proposed with the main focus to provide alternative sources of organic matter, e.g. through application of surplus manure which is not being used for bioenergy production, through application of composite and recycling of nutrients, through application of processed residues generated as a result of biomass based energy production such as digestate from biogas production and ash from combustion. To be more precise, the site-specific constraints must be considered in order to ensure that adequate crop residues are left on the field for maintaining the soil fertility, prevention of erosion (Lal 2004), (USDA Soil Quality National Technology Development Team, 2006), (Nicolae Scarlat, Martinov, and Dallemand 2010), (Daioglou et al. 2015) and preservation of biodiversity. However this out of the scope of this project which follows a meta-level approach.

The complete removal of a specific crop residue can have negative effects on soil fertility, can affect the humus balance and in erosion prone areas it can lead to wind and water erosion. Therefore, at field level it is not possible to remove all crop residues considering sustainability constraints. In order to maintain the humus balance of the soil the sustainable removal rate has to be assessed. Ideally the humus balance has to be assessed for every cultivated area. As this study has a meta-level approach, we define a general crop-specific sustainable removal rate based on top organic carbon level of soil, soil nutrient value of crop and amount of residue generated from a specific crop. As already described soil organic content is linked with removal rate. The difference in soil nutrient value of specific crop are already taken into account while defining the baseline removal rate (based on literature), therefore increase in removal rate will be the same for all crops after optimisation of best practice strategies. For example, in maize residue, the carbon added value is high compared to other cereals, therefore in baseline removal rate 10% more are assigned compared to other cereals (Nicolae Scarlat, Martinov, and Dallemand 2010).

Supply of composite and manure in sufficient amounts to replace residue has its limitations. For example the supply of composite involves kitchen gardening, fruits, vegetables, waste, green composite, leaf and other prunings which means that it involves extra cost for collection and transport. However, in case of crop residue which are already in the field there are no extra cost except for chopping and mulching in some cases. Manure and slurries application has extra cost and also has other limitations such as N leaching in case of slurry application (Gasser et al. 2002). Considering that, it was assumed that even less than half of the proposed alternate sources for organic carbon can be supplied to replace crop residues. Therefore the decrease in removal rate proposed under best practice strategy was more than half depending on crop type. Based on these considerations, we suggest an increase in sustainable removal rate for each crop by 10%.

The values presented in table for sustainable removal rate are taken from literature and used as baseline to calculate the sustainable removal rate after optimisation of residue specific strategies for each crop (Table 35).

Table 35: Sustainable removal rate for different agriculture crop residues

Crop	Sustainble removal rate (%) from literature	Sustainable removal rate (%) after optimization of best practice strategies
Wheat	40	50
Rye	40	50
Barley	40	50
Oats	40	50
Maize	50	60
Rapeseed	50	60
Sunflower	50	60
Sugar beet	30	40
Grassland	n/a	100
Wine	50	70

Source: (Nicolae Scarlat, Martinov, and Dallemand 2010)

A number of studies had provided estimates on the sustainable removal rates of straw. For instance, (Lal 2004) reported 40-70%; USDA Soil Quality National Technology Development Team (2006) reported 30%; Nicolae Scarlat, Martinov, and Dallemand 2010 reported a crop specific rate between 40 and 50%; a sustainable removal rate of 40% for straw has also been reported by Austrian experts. (http://www.agropower.at/agro_biomass.php).

Using these scientific reports as a background, this study therefore has considered the crop type and as well the regional soil conditions especially organic carbon content of soil to estimate the residue sustainable removal rates used in this research work. The topsoil organic carbon of each region within EU-27, Belarus, Russia and Ukraine was evaluated and the results show that northern European soils especially in Finland, Sweden and the northern part of United Kingdom contain high topsoil organic carbon. Southern Europe e.g. Spain, Portugal, Greece and Cyprus contains few topsoil organic content of about 1-2%. Central Europe e.g. Germany, Austria etc. has a considerable topsoil organic content. Therefore, in areas with high top soil organic carbon and less prone to erosion, there is more chance to take away more residues.

2.15.2 Technical constraints

Technical constraints cover two main parts; a) lack of harvesting procedures and technologies; b) implications on transport, storage and handling.

a) Insufficient harvesting procedures and technologies

Within residue-specific strategies for harvesting procedures and technologies, the main focus was on using improved machines and reducing the cutting height up to 5 cm (cereals and oil crops). However, the major issue is that machines are only being used at pilot scale. It is mainly because of high costs of such harvesters, which can harvest and collect the straw (cereals and oil crops) and leaves and sugar beet tops (sugar crops). The other major constraint, is the lack of a market for agriculture crop residues, which hinders the farmer to invest high capital. It is assumed that in future the demand of crop residue mainly straw will increase, so famer will invest some capital to buy efficient machinery to harvest and collect straw simultaneously.

Due to residue-specific strategies up to 50% increase in residue harvest can be achieved. However, it depends on crop residue type, for example in case of straw, there are already some machines which are available to harvest straw but in case of sugar beet residue, currently no specific machinery is being used. Therefore, it was assumed that based on cost limitations, half of the best practice measures cannot be implemented, therefore the improvement in harvesting procedures will only result in 10-20% increase depending on crop type.

b) Implications on transport, storage and handling

Implications relevant to transport, storage and handling depend on the crop type and end use of the biomass residues. For example, straw which is comparatively dry and can be used for direct combustion or after processing can be used as pellets. Contrary to it, leaves from sugar beet have higher moisture content and are not easy to store. Farmers either dry them out or use directly after collection for biogas. For straw the collection in the form of rectangle bales is the state of the art. The rectangle bales are prepared with the length (2.2 m), width (1.2 m) and height (0.2 m) (Weiser et al. 2014). However, bales are not dense therefore it leads to increased transportation costs. Under residue-specific strategies, a pellet harvester is recommended, which is currently only being used on pilot scale and it also requires high investment cost. The use of better machinery to have more densified bails could improve the transport, handling and storage for straw (cereals, oil crops). Despite the high costs and assuming that in future a crop residue market will develop, the modification of machinery was recommended for the optimisation of best practice strategies.

Straw can be stored in the form of bales but new storage places need to be built. Currently the the farmer only crop residue which are required for his own use for instance for livestock bedding. In EU-27, Ukraine, Russia and Belarus, straw is being used mainly for cattle, pig, sheep, horses, chicken, geese, duck and turkey production (feeding, bedding). However, livestock holdings vary from region to region. For example in Bulgaria and Slovakia, the lowest livestock densities are recorded whereas in regions such as Netherlands and Belgium carry highest overall livestock densities (JRC, 2010). The use of straw for livestock production is decreasing over time. Nowadays farmers tend to use slatted flours than using straw beddings, therefore more straw is available for other purposes. In addition, the regions with high livestock densities also add up more nutrients and organic matter to soil through slurry and manures which allows removing more residues in those regions. The results from this study considers crop residues for animal bedding (Lal 2004), (Nicolae Scarlat, Martinov, and Dallemand 2010), (Daioglou et al. 2015) and mushroom production (Nicolae Scarlat, Martinov, and Dallemand 2010) as the main uses. In EU-27, up to 24 Mio. tonnes per year of the crop residue are used for such purposes whereas in Ukraine, Russia and Belarus, use of crop residues for such purposes sums up to 7 Mio. tonnes per year (FAOSTAT, 2014; (Nicolae Scarlat, Martinov, and Dallemand 2010). From grassland 74% are allocated for own use in all regions.

In case of sugar beet, storage place are required which prevent any mold and decomposition. Currently, in practice the leaves are not being stored, so extra capital for storage of residue from sugar beet is required. For wine residues the current practice is simply leaving all prunings on field and chopping it which is mostly done manually, therefore the use of recommended machinery will involve more investment for farmers.

We therefore assume that 1/3 of the residue-specific strategies for transport, storage and handling are implemented, which lead to a residue yield increase of 5-10% for cereals, 10-15% for sugar beet and 5-10% for wine.

2.16 Technical-sustainable potential

Technical sustainable potential is defined as "the harvestable biomass limited by technical and ecological constraints". It is derived from the theoretical potential taking into account all limitations for residue yield increase due to environmental constraints considering implications to define sustainable removal rate for a specific crop and technical constraints for harvesting, transport, storage and handling. In the technical sustainable potential only general economic limitations are covered, i.e. that proposed measures cannot be afforded by any farmer.

The calculation for technical-sustainable potential for crop-specific best-practice strategies was carried out in a stepwise approach as outlined below. For residue-specific strategies the sustainable removal rate was calculated based on carbon nutrient value of crops and soil carbon.

Equation 2:

$$TP = \sum (ARY + IRY_{BPS}) \times RR$$

TP= Technical potential

ARY= Actual residue yield

IRY_{BPS}= Increase in residue yield through optimisation of best practice strategies

RR= Recovery rate

Equation 3:

$$ARY = CRR * TCP \ (t/region)$$

ARY= Actual residue yield

CRR= crop to residue ratio

TCP= total crop production

Equation 4:

$$TSP = (TP * SRR)$$

TSP= Technical sustainable potential

TP= Technical potential

SRR= Sustainable removal rate

Technical potential

In a first step the technical potential was calculated including optimised best practice strategies. The technical potential was calculated based on actual residue yield data, increase in actual residue yield through optimization of best practice strategies and recovery rate. The actual residue yield here refers to the residue yield calculated based on crop yield data collected from Eurostat and residue to crop ratio (see Table 21). Increase in actual residue yield refers to the increase through optimisation of best practice strategies for crop specific strategies. The increase in residue specific strategies was covered through recovery rate. The recovery rate which was defined based on own expertise, field experience as well as literature data (Weiser et al. 2014).

Technical-sustainable potential

For technical-sustainable potential, technical potential was considered and then estimated how much of technical residue yield can be taken away without any negative impact on environment or any other ecological implication. In addition, other uses of crop residue such as own uses for livestock were also considered here for estimation of technical sustainable potential.

Considering the above mentioned sustainable removal rate the technical sustainable potential was calculated for each crop. The sustainable removal rate for a specific crop used in calculations for technical sustainable potential are already described in Table 35. The calculation for technical sustainable potential was performed by following the equation 4.

Table 36: Technical-sustainable potential (TSP) for each crop in EU-27

Crop	*Yield increase in TSP through crop specific strategies*	*Yield increase in TSP through residue specific strategies*	*High yielding (i.a. France) Mt/year*	*Medium yielding (i.a. Poland) Mt/year*	*Low yielding (i.a. Romania) Mt/year*	*Total TSP-EU-27 (Mt/year)*
Wheat	2-8%	5-10%	7.3	10.0	28.8	46.0
Barley	5-10%	5-10%	3.4	6.9	7.2	17.5
Maize	2-8%	10-15%	4.4	7.3	10.9	22.6
Rye	5-10%	5-10%	0.2	1.3	1.4	2.8
Oats	5-10%	5-10%	0.6	0.8	0.8	2.1
Sunflower	2-8%	10-15%	0.1	0.8	0.9	1.8
Rape	2-8%	10-15%	0.6	2.2	6.3	9.1
Sugar beet	2-8%	15-20%	0.001	0.3	0.4	0.7
Wine	1-4%	15-20%	0.001	0.7	0.59	1.3
Total			16.7	30.2	57.2	104

In the technical-sustainable potential, wheat and maize are largest contributors followed by barley and rapeseed. The total sustainable potential for all agriculture crops in EU-27 is 104 Mt/year excluding grasslands. However, to have more precise figure, own uses were considered and were subtracted from total. The 29% of the TSP agriculture crop residues was allocated for own use. The own use was considered mainly for cereals and maize as there is no well defined figures available for other crops. Therefore, the final amount of residues from agriculture crops is 78 Mt/year in EU-27.

Table 37 Technical-sustainable potential (TSP) for each crop in Ukraine, Russia, Belarus

Crop	*Yield increase in TSP through crop specific strategies*	*Yield increase in TSP through residue specific strategies*	*Belarus Mt/year*	*Russia Mt/year*	*Ukraine Mt/year*	*Total TSP (Mt/year)*
Wheat	2-8%	5-10%	0.6	16.5	6.4	23.4
Barley	5-10%	5-10%	0.6	4.9	2.9	8.3
Maize	2-8%	10-15%	0.2	2.0	5.1	7.3
Rye	5-10%	5-10%	0.4	1.1	0.3	1.7
Oats	5-10%	5-10%	0.2	1.5	0.2	1.8
Sunflower	2-8%	10-15%	0.0	5.9	5.7	11.6
Rape	2-8%	10-15%	0.2	0.3	0.6	1.1
Sugar beet	2-8%	15-20%	0.1	0.9	0.5	1.5
Total			2.2	33.0	21.6	56.8

The TSP for agriculture residues in Belarus, Russia and Ukraine is 56.8 Mt/year. However, in Belarus, Russia, Ukraine, 8.24 Mt/year was allocated for other uses based on literature data. Therefore, the final figure for Belarus, Russia and Ukraine for agriculture crop residues is 49 Mt/year.

For grasslands, the total biomass for EU-27 and Belarus, Russia and Ukraine is about 132.5 Mt/year, out of which 117.5 Mt/year is from the EU-27. From total biomass production in grasslands, 75% is allocated for other uses mainly livestock, therefore available biomass from grasslands is 33 Mt/year. The main challenge during allocation of grasslands for own use mainly for livestock was availability of data about grasslands. There is no data available for different categories of grasslands. For example, the grasslands which are falling out of production because of no management practices can be managed properly with the aim to enhance biodiversity but on the same time it can also deliver additional feedstock which makes management of such grasslands economically viable. The allocation of biomass from grasslands for own use could vary from region to region depending on livestock density. Therefore, further studies are needed to have better estimates about biomass availability from grasslands for bioenergy purposes without any compromise on ecosystem services.

2.17 Regional barriers for best-practice strategies

The technical-sustainable potential estimated above takes into account general constraints that occur in absence of given regional circumstances on the ground. In order to estimate the realistic potential the relevant regional barriers that hinder the deployment of the technical-sustainable potential have to be assessed. The authors have identified the following overarching barriers, which have been assessed for the EU, Ukraine, Russia and Belarus separately:

- **Political or administrative barriers**:
  - Agricultural policy
  - Unclear or unsupportive political framework
  - Targets / incentives to promote the use of residues
  - Administrative costs (lengthy procedures, many authorities involved, unclear administrative framework)
- **Social and structural barriers**
  - Societal acceptance
  - Lack of education and awareness of yield increase options
- **Economic barriers**
  - Access to and investments in residue collection equipment and infrastructure
  - Access to fertilisers
  - Lack of infrastructure

For each region (EU, Ukraine, Russia, Belarus) and for each of the identified best practice strategies), we assessed which barriers are relevant in which regional situation and give a qualitative ranking (high, medium, low impact) according to the extent to which the barrier is perceived to constrain the achievement of the estimated yield increase potential.

The relevant barriers are further specified to describe the nature of the barrier and the qualitative impact that it is likely to have.

2.17.1 European Union

The EU agricultural sector is governed by the Common Agricultural Policy (CAP), a collection of various directives and regulations that aim to ensure an economically and environmentally healthy EU agricultural sector. EU legislation does not constitute a barrier to increasing the amount of agricultural residues. Having assessed the Nitrates Directive (91/676/EEC), the Sustainable Use of Pesticides Directive (2009/128/EC), and Regulation (94/13) with regard to aspects that might prevent farmers from implementing any of the suggested best practice measures, the authors did not identify any significant obstacles.

With regard to increasing main crop yields in order to generate more residues, best practice measures have to comply with regulations specified in the Common Agricultural Policy (CAP). Annex II of the Regulation on the financing, management, and monitoring of the common agricultural policy (94/13) specifies which aspects farmers have to take into consideration in order to receive direct payments, so-called cross-compliance measures. Of these aspects, references to the Nitrates

Directive and the Sustainable Use of Pesticides Directive are of particular interest. According to the Nitrates Directive, nitrate concentrations in water may not increase and should be gradually decreased. Each Member State must monitor nitrate levels and has specified so-called nitrate vulnerable zones (NVZ), where full implementation of the suggested fertiliser increase may not be allowed. A limit of 170 kg $N*ha^{-1}*a^{-1}$ from manure applies in nitrate vulnerable zones. Similarly, no provisions in The Sustainable Use of Pesticides Directive constitutes a barrier to the use of pesticides up to the limits specified in the best-practice strategies. All pesticide products have been approved and are listed in the EU Pesticides database[5]. In the long-term, however, the Directive requires farmers to reduce pesticide use and find alternatives. In sum, nothing speaks against implementing measures to increase crop yields but farmers have to pay attention to national legislation, which may be stricter but has not been assessed in this report.

Farmers also have to comply with greening measures in order to receive 30% of payments and to avoid administrative penalties. Greening was introduced in the current CAP in order to induce more environmentally friendly farming practices. These include diversifying crops, maintaining permanent grassland and providing "Ecological Focus Areas" (EFA). EFAs are arable land without crop production and include fallow land, field margins, hedges, trees and buffer strips but also land cultivated with catch crops and other nitrogen-fixing crops. Alternatively, farmers can show that their practice is at least as beneficial to the environment as one or more of the greening requirements ("greening equivalency") such as practices under agri-environment schemes. Greening measures are no constraints to increasing residues unless they have implications on the size of cultivated land. For example, if permanent grassland or EFAs are extended, less land is available for crop production and thus less residues are available. Diversifying crops means that it is likely that different kinds of residues accrue. However, they do not affect the implementation of best practice measures.

In addition to the CAP, the EU Renewable Energy Directive (RED – 2009/EC/28) has an impact on the EU agricultural sector. The RED includes a target for 10% renewable energy in transport, which will be mainly met by the use of biofuels in road transport. Biofuels are produced from agricultural crops and advanced biofuels can be produced from agricultural residues. Although the RED includes a double counting mechanism of biofuels produced from residues and assumes zero life-cycle GHG emissions of residues up to collection (Annex V, Part C), these provisions have only resulted in a limited increase in the use of residue-based biofuels. This may change with the implementation of the ILUC-directive, which was adopted in 2015 and amends the RED by including a target of 0.5% for advanced biofuels. While this is not a mandatory target, some Member States, such as Italy and the Netherlands, have introduced or will introduce a binding target for advanced biofuels. This will most likely lead to increased demand for residues albeit at a relatively limited scale.

The lack of supportive agricultural policies may also constitute a barrier to increasing residues. For example, some countries under former communist rule have seen land privatization followed by land consolidation. Others, such as Romania, are still divided into many small, scattered plots. Small plots

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[5] (http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=activesubstance.selection&language=EN

cannot be cultivated and harvested as efficiently as continuous areas because the use of large, heavy machinery is difficult.

Several barriers exist which hamper the full implementation of best-practice strategies in the EU today. The table below shows barriers in various categories.

Table 38: Identified barriers for application of crop-specific best practice strategies in European Union

Barriers	Ranking of the impact
Political or administrative barriers	
Restricted nitrogen fertiliser use following the Nitrate Directive	**Low** **Direct** **Long term**
Social and structural barriers	
Lack of education in low yielding regions	**High** **Direct** **Long term**
Economic barriers	
Investments in residue collection equipment and infrastructure	**High** **Direct** **Long term**

Nitrate Directive

General description

A legal barrier might arise from the Nitrates Directive when increasing the amount of nitrogen fertilizer in certain areas. It specifies where and under which conditions Member States may restrict the use of fertilizer.

Impact on implementation of best-practice strategies

Because this barrier only applies to so-called nitrate vulnerable zones, it has a **low impact** in general. It is not expected that this barrier will be removed, as it is an integral part of the CAP.

Lack of education in low yielding regions

General description

In general, EU farmers are highly qualified. However in regions where agriculture is managed in a suboptimal manner without full modernisation, lack of education can be an issue. The main reason for poor agriculture is low level of education among rural work force, under developed infrastructure, shortage of necessary, research institutes and rural unemployment. Therefore farmers are not able to spend any capital for better crop production. 71% of farms in Romania fall below the threshold level defined by EU to be economical viable. This barrier applies only the low yielding regions because of poor management practices.

Impact on implementation of best-practice strategies

In regions areas where farmers are not sufficiently high trained to make full use of best-practice strategies, lack of training has a **high impact** on the implementation of the strategies. Since improving education and training requires time this barrier will probably have a **longer term** impact.

Investments in residue collection equipment and infrastructure

General description

In order to invest in residue collection machinery, farmers have to count on a residue price that compensates any additional expenses. Currently, there is no reason for them to increase residue supply because demand, and prices, are low. For example, straw prices usually cover the cost of provision, that is about 57 – 129 €/t (FNR 2014), but do not present a relevant income source. Only increases in demand, for example by bioenergy producers, will be a driver of residue prices.

Impact on implementation of best-practice strategies

The most important barrier to increasing residue supply in the EU, having a **high** and most likely **long-term** impact, is a lack of economic viable prices for residues.

Summary of barriers

There are hardly any barriers for the implementation of crop-specific best-practice strategies in the EU. Only the restricted use of nitrogen in dedicated zones applies to all farmers in the EU. Lack of education is only an issue in low yielding countries because of bad management practice.

The main barrier for the implementation of residue-specific strategies is the lack of demand and low prices for residues, providing no incentive for the farmers to invest in residue collection. This applies to all farmers, however the farmers in high yielding regions like Germany or France are already well-equipped also with machines for proper residue collection.

In the realistic potential for the implementation of crop- and residue-specific best practice strategies in the EU we assume a reduction of the yield increase of the technical-sustainable potential of 1.5% in high yielding regions, 2.5% in medium yielding regions and 5.5% in low yielding regions.

2.17.2 Ukraine

The table below shows barriers in various categories, which currently affect the implementation of crop-specific best practice strategies in Ukraine. The barriers and their scoring are explained in more detail after the table.

Table 39: Identified barriers for application of crop-specific best practice strategies in Ukraine

Barriers	Ranking of the impact
Political or administrative barriers	
Undeveloped land market	**High Indirect Long term**
Underdeveloped credit market	**High Indirect Long term**
Lack of regulation of lands use and protection	**Low Direct Long term**
Requirements for the plant materials and varieties of crops	**Low Direct Long term**
Social and structural barriers	
Conventional usage of agricultural residues as an organic fertiliser	**Medium Direct Long term**
Lack of qualified workforce in rural areas	**Medium Direct Long term**
Economic barriers	
Lack of modern equipment for main agriculture production	**High Direct Long term**
Cost of mineral fertiliser	**Low Direct Short term**

The barriers and their scoring are explained in more detail below.

Renewable Energy Directive (RED) implementation:

General description of barrier:

Ukraine as a member of the Energy Community (since 2011) is obliged to implement a number of European Union directives. Directive 2009/28/EC, the Renewable Energy Directive (RED), was to be implemented by Ukraine by January 1, 2014. The plan for the RED implementation was adopted by the Resolution of the Cabinet of Ministers of Ukraine "On the Action Plan for implementation of the European Parliament and Council Directive 2009/28/EC" (№ 791-р of 03.09.2014)[6]. One of the Resolution' points is connected with the sustainability requirements harmonization. This process is not finished yet. There are no plans to implement national targets for advanced biofuels as laid down in the ILUC directive.

In accordance with the RED requirements a National Renewable Action Plan (NREAP) has been developed and adopted. According to the NREAP[7] the main contribution of biomass is planned in the heating/cooling sector with 5000 ktoe/yr in 2020 which will be 85% of contribution of all RES. In addition, by 2020 it is planned to install 950 MWe of biomass power equipment and to use 390 ktoe/yr of biofuels (bioethanol and biodiesel) for transport. This growth in biomass consumption cannot be reached without broad involvement of agricultural residues to energy balance, as the potential of other biomass such as wood biomass types, energy crops and biogas from landfills and manure is not enough to reach the targets[8]. At the same time, there are no targets to involve agricultural residues to the energy sector in State target program of agricultural sector development for the period 2020. There is an imbalance in state policy support of agriculture residues use and targeted biomass energy share.

Impact on implementation of best practice strategies:

The impact of the RED implementation is therefore considered neither positive, nor negative with regard to the application of best practice strategies for residue yield increase and therefore has **no impact.**

Registration of pesticides and agrochemicals:

General description of barrier:

All pesticides and agrochemicals that are used in Ukraine must pass state tests and have to be registered. After that, they are included into the lists of pesticides and agrochemicals permitted for use in Ukraine[9]. Pesticides and Agrochemicals are registered for the period up to ten years. Fungicides and herbicides that contain active materials mentioned in best practice strategies for cereal, oil and other crops (Dimoxsystrobin, Boscalid, Epoxiconazole, Imidacloprid, etc.) are presented in the Register and at Ukrainian market.[10]
Therefore the registration of pesticides and agrochemicals is not a barrier for best practice strategies implementation and is considered to have **no impact.**

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[6] http://zakon2.rada.gov.ua/laws/show/791-2014-%D1%80
7 Cabinet of Ministers of Ukraine Regulation No . 902-p(2014/01/10) "National Action Plan on Renewable Energy until 2020" // Постанова КМУ No 902-р від 1.10.2014 «Про Національний план дій з відновлюваної енергетики на період до2020 року»; http://zakon4.rada.gov.ua/laws/show/902-2014-%D1%80
[8] Prospects for the development of bioenergy as an instrument for natural gas replacement in Ukraine. Position Paper N 12 of Ukrainian Bioenergy Association. http://www.uabio.org/img/files/docs/position-paper-uabio-12-en.pdf
[9] Cabinet of ministers of Ukraine Resolution No 295-96-п of 09.10.2015 "On approval of Order of the state tests, state registration and re-registration, the publication of lists of pesticides and agrochemicals permitted for use in Ukraine" http://zakon5.rada.gov.ua/laws/show/295-96-%D0%BF
[10] http://agroscience.com.ua/views/perelik-pest-all

Undeveloped land market:

General description of barrier:

There is a moratorium on agricultural land buy-and-sell transactions in Ukraine until 2016. For the first time the moratorium on sale of agricultural land was introduced on January 1, 2002, with the entry into force of the Land Code, as a temporary measure. The moratorium was to last until 2005. The law "On Amendments to the Land Code of Ukraine" that was adopted in December 2012 extended the moratorium on sale of agricultural land until January 1, 2016. Cancellation of the moratorium was planned after the enactment of the Laws “On land market” and “On the state land cadaster” (so up to 2016 two new Laws were supposed to be implemented). The first document is still being developed; the second was adopted in 2011. Experts predict that the moratorium will not be cancelled in 2016 despite the fact that it is one of the key requirements of the International Monetary Fund for financial support and mentioned in the coalition agreement[11] of the current government. Therefore, we can say that there is no fully functioning market of agricultural land sales in Ukraine – now it is based only on lease.

The Law of Ukraine “On Land lease” [12] regulates market of Land rental. Lessee (farmer) and the lessor (landowner – population, state) enter into contract that contains information on the object of lease (cadastral number, location and size of land), the term of the lease, rental fee (specifying fee size, indexing method and terms of payment, procedure of application and revision, etc.). Contract should be registered by State. Period of land lease cannot exceed 50 years. Law on Deregulation[13] determines minimum period of land lease contract – 7 years. The government set the minimum annual rental value at 3% of the normative value of land, which now is about UAH 25,773 per hectare (1073 USD) on average. This represents the floor price for rental agreements. Maximum rental value is 12% of normative value of land. There is no maximum amount and size of the land that can be rented by farmer or a company. This policy led to the consolidation of agricultural land by agriholdings: 27% of agricultural land is used by agricultural holdings.

Driving agricultural activities on leased land (typical duration of land lease agreement was 4-5 years) reduces the soil fertility and leads to humus losses (annual losses of humus due to mineralization and soil erosion reach 32-33 Mio. tonnes). Low rental value gives farmers the opportunity to have a profit without proper use of fertiliser and investing in higher yields. High dependence on agro-climate conditions, inefficient system of insurance of agricultural risks lead agricultural enterprises to reduce the costs of maintaining soil fertility. The connection of the moratorium, absence of circulating assets and high risks to lose money due to weather conditions resulted in significant reduction of soil fertility in Ukraine.

[11] http://news.finance.ua/ua/news/-/360604/zemlya-pid-moratoriyem-komu-tse-vygidno
[12] http://zakon0.rada.gov.ua/laws/show/161-14
[13] Law of Ukraine “On Amendments to Certain Legislative Acts of Ukraine on simplification of business conditions (deregulation)” No 191-19 of 12.02.2015. http://zakon2.rada.gov.ua/laws/show/191-19

Because of the moratorium on farmland sales, land plots cannot be purchased and used as a mortgage by agricultural enterprises. This leads to complicated access to financial resources, use of outdated technologies, and insufficient use of fertiliser. It also causes social problems in the countryside: the youth refuses to inherit land because of low rent values and high administrative burden at the conclusion of lease agreements, which sometimes leads to land abandonment.
According to t**he Institute for Economic Research and Policy Consulting,** cancellation of the moratorium will result in[14] increasing of production efficiency by interested landowner, increasing of the land cost and its capitalisation, the possibility of mortgage credit on security of land, concentration of lands and the establishment of rational land use size, increase of the land renting cost.

Impact on implementation of best practice strategies:

Undeveloped land market leads to other barriers: undeveloped credit market, lack of modern equipment, social problems in rural areas. Prolongation of the moratorium will have **high indirect** negative impact on the introduction of the best practice strategies. As the cancellation of the moratorium postponed at least for a year and formation of the land market will take several years, the duration of barrier considers in a **long term.**

Underdeveloped credit market:

General description of barrier:

Access to credits for farmers is very limited in Ukraine. 75% of companies in the agribusiness sector report poor access to finance as a key barrier to further expansion and investment. Ukrainian credit market is characterised by high interest rates and constrained access to credit. Raising long- and medium-term loans on the domestic market is yet limited because of high interest rates of Ukrainian commercial banks. While interest rates of loans in international currencies fluctuate around 8%, interests for loans in the national currency fluctuate around 23% (National bank of Ukraine[15]). Access to financial resources is also complicated because of limited possibilities to use mortgage by agricultural enterprises. Because of the moratorium on farmland sales, land plots cannot be purchased and used as a mortgage.

Internal self-financing in the form of retained earnings (60%) and personal savings (13%) remains the most prominent source of funding among agribusiness enterprises. External financing through bank credit (28%) and trade/supplier finance (5%) rarely appears to be a viable option for agribusinesses. About half of the producers sell 80-100% of their new harvest immediately to finance their working capital[16]. Accesses to financial resources have primarily large agro-holdings or enterprises with considerable share in the food sector. The main financial source for small and medium enterprises is retained revenues.

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[14] Policy of Ukraine in agriculture, bioenergy and food - research, conclusions and recommendations. Edited by: Strubenhoff/Movchan/Burakovsky. **The Institute for Economic Research and Policy Consulting.** http://www.ier.com.ua/files/Books/18_Policy_in_Agriculture/18_book_2009_Agrarbook_IV_ukr.pdf
[15] http://www.bank.gov.ua/control/uk/index
[16] IFC (2011). Investment Climate in Ukraine as Seen by Private Business, IFC Ukraine Investment Climate Project Report.

Especially for smallholders, cultivating 73% of the agricultural area in Ukraine, the underdeveloped credit market is a great barrier for buying new equipment or agrochemicals. Big agricultural holdings have sufficient financial capacity to invest. There is no practice in Ukraine when small or medium enterprises buy equipment by sharing the cost. In most cases, equipment is leased from neighbouring businesses and companies that provide rental services.

Impact on implementation of best practice strategies:

Lack of funding leads to significant shortage of working capital of the agriculture enterprises that reduce the medium and long-term investments (in equipment or infrastructure) and outdated agricultural production that have **negative high indirect impact** on the best practice strategies implementation. General situation with finance can be characterized as extremely difficult because additional financial resources at the Ukrainian market either are absent or directed toward other sectors that are less risky than agriculture. So the barrier is considered to have a ***long-term impact***.

Lack of regulation of lands use and protection:

General description of barrier:

Today marketable agricultural production in Ukraine is based on land lease. However, control of the land usage by the owner and the state is missing. There is also no needed agrochemical laboratory to determine the condition and fertility of the land before and after the term of its lease. Accordingly, the lease agreements do not contain these figures. In this regard, there are no penalties for unruly tenants, which degrade land as a result of their activities.

Minimum lease terms (7 years) have been recently introduced in Ukrainian legislation. This regulation primarily aimed at efficient use of agricultural land by building long-term relationships between the lessee (farmer) and the lessor (landowner – population), which allows for investments planning and efficient use of crop rotation.

Impact on implementation of best practice strategies:

Despite recent changes in the legislation, there is no strict supervision of land use and protection that creates **low direct** barrier for the implementation of best practice strategies. Because farmers lobby against state interference in their work, barrier duration will be **in a long term**.

Requirements for the plant materials and varieties of crops:

General description of barrier:

According to Ukrainian legislation, it is allowed to plant only varieties that are specified in the "State Register on plant varieties suitable for dissemination in Ukraine" (annual publication)[17]. Certification is also required for seeds and planting material of the varieties entered in

[17] Cabinet of ministers of Ukraine Resolution of 18.08,2011 N 686-2003-п "On approval of the State Register of plant varieties suitable for dissemination in Ukraine". http://zakon5.rada.gov.ua/laws/show/686-2003-%D0%BF

the abovementioned Register[18]. There is also a register of seeds producers. In order to be in the register and to get permission to produce and sell the seeds companies need to be validated by official bodies[19].

Impact on implementation of best practice strategies:

The introduction of new crop varieties leads to an increased administrative burden that is a barrier with a **low direct impact** for the implementation of best practice strategies in a **long-term** perspective (There are varieties with characteristics as specified in best practice strategies in the Register. However, the introduction of new varieties with better characteristics in a long-term perspective will have an administrative burden barrier).

Conventional use of agricultural residues as an organic fertiliser:

General description of barrier:

The "streaming" technology of agricultural residues collection is mainly applied in Ukraine. By this technology, residues are shredded by a combine harvester, scattered over the field and ploughed back into the soil later on (see the Picture below). Exceptions are cases when cereal straw is baled and used as litter and fodder for cattle. Today residues are the cheapest source of organic matter for soil fertilisation. Along with a substantial decrease in manure use as organic fertiliser (introduction of manure decreased from 8 t/ha in 1990 to 0.5 t/ha in 2012[20]) residues are the main organic fertiliser for most enterprises. Today the cost of straw is determined by the value of fertilisers that are needed to replace the straw.

Impact on implementation of best practice strategies:

Conventional or traditional farming when agriculture residues are used as an organic fertiliser is a barrier for other use of residues and **medium direct barrier** for best practice strategy implementation. The situation will change after the farmers will have enough working capital, the latest knowledge on the use of fertilisers that in the **long term.**

Straw usage leads to understated usage of mineral fertiliser (introduction of straw as a fertiliser with adding 10 kg of nitrogen per a ton of straw is 11 times cheaper than introduction of mineral fertilisers and 4-5 cheaper than the use of manure[21]). Gap between costs of fertiliser has significantly increased due to economic crisis in Ukraine and total dependence of the Ukrainian agrochemical industry on the imported raw materials and the high proportion of imported fertilisers at the market. ***Cost of imported mineral fertiliser has also a Low direct impact on the best practice strategy implementation. As a price depends on a frequent market changes, cost barrier is considered in a short perspective.***

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[18] Law of Ukraine "On seeds and propagating material" No 411-15 of 09.12.2012. http://zakon5.rada.gov.ua/laws/show/411-15
[19] Order of the Ministry of agriculture and food of Ukraine No 189 of 19.06.2015 "On approval of Order of the entities appraisal for the production and sale of seeds and planting material right, the Regulation on the State Register of producers of seeds and planting material" http://zakon5.rada.gov.ua/laws/show/z0435-13/paran112#n112
[20] Agriculture of Ukraine. Statistical publication 2012. State Statistics service of Ukraine http://www.ukrstat.gov.ua/
[21] http://www.uabio.org/img/files/docs/Position-paper-UABIO-7-EN.pdf

Furthermore conventional harvesting technology and use of the agricultural residues as a fertiliser lead to the lack of equipment for residues collection. On the other hand, agriculture enterprises do not invest in residues collection equipment because there is no demand (market) for residues.

Figure 62: View of fields after the harvest of maize for grain

Lack of qualified workforce in rural areas:

General description of barrier:

The agricultural sector of Ukraine lacks qualified workers. 63% of agricultural enterprises urgently need qualified labour in sectors such as agronomy, veterinary and machinery. As a result, 51% of agricultural enterprises are ready to employ "fresh" university graduates with little work experience and educate them on site. However, only 16% of the graduates are interested to work in rural areas while 50% prefer to work in big cities like, for instance, Kyiv, due to poor living conditions in rural areas.[22] In general, structural misbalances in agricultural employment are persisting. The number of low-qualified labour in rural areas is high because of both low level of education and non-willingness of qualified employees to work in rural areas. At the same time, agricultural enterprises need employees with at least basic knowledge of modern technologies[23].

Impact on implementation of best practice strategies:

Shortage of qualified workforce has **medium direct** impact on best practice strategies implementation due to lack of the latest knowledge on modern crop production technologies. General problems in education sector and poor living conditions in the rural areas makes it impossible to change the situation in a short term, so the impact considers in a **long-term** perspective.

[22] AgriSurvey (2014): Labour Market in Agriculture of Ukraine: Demand, Supply, and Regional Features. Kyiv: Ukrainian Agribusiness Club

[23] Productivity and Efficiency of Ukrainian Agricultural Enterprises. Agriculture Policy Report APD/APR/06/2013. The Institute for Economic Research and Policy Consulting. http://apd-ukraine.de/images/APD_APR_06-2013_Efficiency_eng.pdf

Lack of modern equipment for main agriculture production:

General description of barrier:

It is estimated that 45 to 65% of Ukrainian farms do not have sufficient access to modern farming equipment. Of existing equipment used, about 95% is operated beyond depreciation terms (used more than 10 years). Almost two thirds of the tractor fleet is aged about 20 and more years[24]. Accordingly, the degree of deterioration is high. Thus, according to the Ministry of Agrarian Policy and Food of Ukraine, the level of depreciation of machinery and equipment in agriculture of 1 May 2013 is 70% (tractors - about 78% of combine harvesters - about 72%). Backward technology and outdated equipment make increasing energy and resource expenses. Due to the fact that about 70% of agricultural machinery is outdated, Ukraine loses 5-6 million tons of grain during harvesting annually[25].

Today there is extremely low demand for new equipment in agriculture. The almost complete closure of the market of new agricultural machinery (after the growth of the market in 2008-2013) is linked to a number of factors[26]. First of all, the rapid devaluation of the UAH, the national currency, due to which new agricultural equipment (mainly imported) became virtually inaccessible to most farmers. At the same time, due to problems in the banking sector, credit institutions have reduced loans volumes to the agricultural sector that also affected sales volumes. In general, the unstable situation in the country, the economic crisis, the rapid and unpredictable devaluation of the majority of farmers forced to abandon the purchase of new equipment or postpone it until better times.

Impact on implementation of best practice strategies:

Level of equipment deterioration and low demand for new equipment in agriculture cause **high direct** impact on the best practice strategies implementation due to impossibility of introduction of better cultivation practices. Lack of modern equipment is a secondary problem that relates to the general status quo in agriculture and lack of funds, so the barrier is considered in **a long term.**

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24 Herezhenko, I.M. and Tomchuk, O.F. “Analytical evaluation of the effectiveness of fixed assets” (Accessed February 2014).
25 Institute for Economic Research and Policy Consulting, Ukraine. AGRICIS trade project. COUNTRY REPORT: UKRAINE March 2015.
26 Analytical paper of Ukrainian Agribusiness Club “Doing agribusiness in Ukraine” 2015. http://ucab.ua/en/

Figure 63: Tractor HTZ T-150 carries out ploughing activities

Summary of barriers

Ukraine's agriculture is still performing well below its potential. Given its fertile black soils and supportive climate, Ukraine is capable to reach the average yields in the EU. According to proposed best practice strategies, increasing of the yields will require more capital-intensive agriculture, financed by unleashing the potential domestic and foreign investments into the sector. At the moment, due to general situation at the agricultural sector with the moratorium on land sales, lack of funds, undeveloped credit market, total capital investments into Ukraine's agriculture is low. Another big problem is that agribusiness suffers from a glaring shortage of human capital at all levels (extension workers, skilled analysts, innovative researchers, agronomists, veterinaries etc.) thus questioning the performance of agricultural research and education system. Those two complex issues of concern have the highest impact on management practices of the best practice strategies for all crops for such factors as fertilisation and cultivation practices.

Due the assessed barriers we estimate that the yield increase of crop-specific best practice strategies in Ukraine is reduced by 4.4% in the realistic potential. Most of the reduction is caused by barriers on fertilisation and cultivation practices.

2.17.3 Russia

Table 40: Identified barriers for application of crop-specific best practice strategies in Russia

Barriers	Ranking of the impact
Political or administrative barriers	
Complexity of obtaining and insufficiency of state support for crop production	**Medium** **Indirect** **Long term**
Registration of the plant varieties	**Low** **Direct** **Long term**
Registration of pesticides and agrochemicals	**Low** **Indirect** **Short term**
Social and structural barriers	
Conventional use of agricultural residues as an organic fertiliser	**Medium** **Direct** **Long term**
Lack of qualified workforce in rural areas	**Medium** **Direct** **Long term**
Economic barriers	
Lack of working capital of agroproducers	**High** **Indirect** **Long term**
Lack of modern equipment for main agriculture production	**High** **Direct** **Long term**
Unaffordability of mineral fertiliser	**Low** **Direct** **Short term**

The barriers and their scoring are explained in more detail below.

Complexity of obtaining and insufficiency of state support for crop production

General description of barrier:

The agricultural sector of the Russian Federation significantly depends on state support. Russian Federation entered the WTO in 2012 and agreed to reduce the amount of state support to agricultural producers from $9 billion in 2013 to $4.4 billion by 2018. The state programme of agricultural development and the regulation for markets for agricultural products, raw materials and food for

2013–2020 regulates state support to agro-producers in the form of subsidies. Subsidies are allocated from the Federal budget to the budgets of Regions (Federal Subjects[27]). The Programme includes 11 sub-programs and 4 Federal Target Programs among which the following: “Development of the crop production sub-sector, processing and marketing of crop products”, “The development of melioration of agricultural lands of Russia for 2014–2020 years”, “Technical and technological modernization and innovative development”, “Support for livestock breeding, plant breeding and seed production”, “Support for small farms”. All federal programmes are linked to Regional programmes, and federal financing is only granted if and when the relevant provincial co-financing is provided in shares of 70-95% of the correspondent federal financing part[28] (i.e. if from federal budget 1 million RUB is allocated then regional share should be in range 0.7-0.95 million RUB). In cases where Regional governments cannot co-finance measures of the programme in established shares, the federal financing is reduced to the amount that suits the Regional share and the rest is returned to the Federal budget for reallocation among the remaining Regions. The results of the program are presented in annual National reports[29].

State support is carried out in the following 10 directions:

- Reimbursement of part of the costs of agricultural producers on payment of an insurance premium;
- Reimbursement of part of the interest on credits and loans;
- State support for the livestock industries;
- State support of crop production industries;
- Provision of unrelated support to agricultural commodity producers in crop production sector;
- State support for small farms;
- State support for economically important regional programs;
- Technical and technological modernization, innovative development;
- Federal Program "Sustainable Development of Rural Areas for 2014–2017 and for the period up to 2020."
- Federal Program "Development of agricultural lands reclamation in Russia for 2014–2020".

Total federal funding for all programs that benefit crop producers in 2014 amounted to $1 billion (35 billion RUB), including $412.5 million (14.44 million RUB) for subsidising (unbound support) crop producers in 2014[30]. These funds are allocated for the whole year, but farmers use most of this funding during spring field works. The top ten (among the total of 80) Regions that receive these funds are Krasnodar kray, Rostov oblast, Alta kray, Stavropol kray, Tatarstan Republic, Orenburg oblast, Saratov oblast, Voronezh oblast, Bashkortostan Republic, and Volgograd oblast, which

[27] 83 Federal subjects, that are republics, krais (territories), oblasts (provinces), cities of federal importance, an autonomous oblast, and autonomous okrugs.
[28] Information guide on the measures and directions of state support of the agro-industrial complex of Russian Federation http://www.gp.specagro.ru/
[29] http://mcx.ru/documents/document/show/22026.htm
[30] Government Order No. 45-p of January 21, 2014

altogether receive $197.1 million (6.9 billion RUB), or 48% of the total. In 2013 these top ten agricultural provinces produced 51.7% of Russia's grains and pulses.

The Russian agricultural sector significantly depends on imported seeds. In 2013 106.1 thousand tonnes of seeds were imported and in 2014 this amount rose to 122 thousand tonnes and for some crops proportion of imported seeds amounts to 43–98%. The highest import dependence is for maize – 55%, sunflower – 62% and sugar beet – 83% (95% in 2014). According to Food Security Doctrine of Russian Federation and State program on agricultural development by 2020 it is planned to provide agroproducers with 75% of domestic seeds for main agricultural crops. Within the measure of the sub-programme named *Support of elite seed production* financing is implemented through a state subsidies allocation procedure for the reimbursement of the part of expenses for the purchase of elite seeds[31] from registered sellers. General amount of subsidy in 2014 was $10.6 million (533.2 million RUB) and was determined per ton of seeds or per seed[32] to agro producers for purchasing of original and elite seeds according to list, registered by the State Commission of the Russian Federation for Selection Achievements Test and Protection[33]. According to the National report for 2014 the share of the sown areas under elite seeds was only 7.2% of the total sown area that means that majority of harvest was from low-yield varieties. For 2015 the amount of subsidy increased by $21.3 million (1.5 billion RUB) and for 2016 it is planned to allocate 3 billion RUB (it's hard to predict amount in USD due to unstable exchange rate).

For machinery in 2015 the Federal budget gives subsidies to domestic manufacturers in the amount of 25% of the machinery price[34]. In 2014 this share was 15% and under this measure domestic manufacturers provided agroproducers with 1844 units of machinery (191 tractor, 1584 combine harvesters, 69 forage harvesters).

Some Regional programs contain subsidies to agroproducers for purchasing the machinery of local production. Amount of subsidies from regional budgets is set by Decrees of the Regional Ministries of agriculture and food and differs from region to Region: in some up to 20% (Voronezh and Rostov provinces) in some up to 50% (Vologodskaya province). Some Regions compensate part of an initial fee for leasing (Ivanovskaya province). For imported machinery, for example in Voronezh, oblast there is compensation of rates on investment loans for the purchase of foreign machinery at the refinancing rate of the Central Bank, valid on the date of signing a credit agreement, and for loans in foreign currency at a rate of 10.5% per annum.

Amount of financing for "per hectare" support to agroproducers in 2014 was 19.4 billion RUB, but 5.6 million RUB (3%) was returned to the federal budget because of the inability of some agroproducers

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[31] „Elite" seeds are generation(s) from seeds of original varieties (unofficially called "super-elite"), bred by official originator (marked by "S" with number, e.g. S1, S2 etc.)
[32] List of crops is presented in Application 2 to the Order of Ministry of Agriculture N196 of 18.05.2015. http://docs.cntd.ru/document/420256206
[33] www.gossort.com
[34] Decree N1432 "On approval of rules for granting subsidies to manufacturers of agricultural machinery" from 27.12.2012 (with changes from 04.06.2015) http://docs.cntd.ru/document/902390890

for self-financing. Due to administrative barriers (such as requirements to provide documents confirming the absence of tax arrears, implementation of commitments to raise workers' wages, the presence of cattle; short deadlines for filing documents for obtaining subsidies, providing copies of reports on production, cost, prime cost, certificates of agrochemical soil examination and other non-binding documents) only 2/3 of agricultural enterprises and less than 1/3 of small farmers received this type of support in 2014.

Impact on implementation of best-practice strategies:

State support in some regions does not include subsidies for purchasing of seeds and machinery, because other agricultural directions receive support. State support is crucial for agroproducers, whose profitability without support is 6.4% (average in the country, in some regions even low). Insufficient support of crop production in some federal subjects and imperfect procedures for its obtaining is a **medium indirect** barrier for implementation of best practice strategies in a **long term**. Each year measures are improved and in 5 years this barrier can have a low indirect influence.

Registration of plant varieties

General description of barrier:

Plant varieties allowed for cultivation in Russian Federation should be registered by the State Commission of the Russian Federation for Selection, Achievements, Test and Protection and included into the State Register of Selection, Achievements, Admitted for Usage. Any new variety can be registered excluding genetically modified varieties. For testing a breeding achievement for admission to use in the next agricultural season, the application must be received for the winter sowing crops, fruit crops and grapes no later than 15 January, and on other crops and species not later than 1 December. For varieties of main agricultural crops that are included in the state register for the first time state tests are performed at small plots of State variety stations of the regions (12 regions of State register) where the variety is intended to be accessed[35]. The results of the tests are described in the corresponding report, presented not later than 6 month after tests were finished, giving the resolution on crop access to the Registry.

Impact on implementation of best-practice strategies:

New varieties of foreign producers are presented in State Register of Selection, Achievements, Admitted for Usage as well. Besides, a lot of seeds are imported (share of imported seeds are: for maize – 55%, sunflower – 62% and sugar beet – 83% (95% in 2014). Nevertheless, registration of new varieties is obligatory and though preliminary expertise lasts only 1-2 months, the expertise on newness and trials on homogeneity, distinctness, stability and economic utility can last up to 3 years[36]. That shows **low direct** impact of the Registration procedure of crop varieties on implementation of best practice strategies in a **long term**.

[35] Regulations of the decision on the application for admission to the use of a selection achievement http://old.gossort.com/docs/rus/procedure_test_ru.pdf
[36] http://www.msp-patent.ru/roslyny.html

Registration of pesticides and agrochemicals

General description of barrier:

Pesticides and agrochemicals that are sold on Russian market should be registered according to the temporary procedure of state registration of pesticides and agrochemicals[37]. Registration is carried out after the registration trials. All registered pesticides and agrochemicals are included into the correspondent Catalogue of pesticides and Catalogue of agrochemicals and are permitted to use in Russia. Registration for agrochemicals can take 1.5 years, for pesticides about 3 years[38]. Mineral fertiliser Entec is now at the stage of registration in Russia and is expected to enter the market in autumn 2016.

Cereals

Fungicides (Dimoxsystrobin, Boscalid, Epoxiconazole) that are recommended in the best practice strategies for cereals are included into the Catalogue of pesticides registered in the territory of the Russian Federation[39].

Oil crops

For oil crops (rapeseed) recommended under the best-practice strategies for oil crops pesticides beta-Cyfluthrin and lambda-Cyhalothrin and also herbicides Metazachlor, Quinmerac, Dimethenamid-P, Clopyralid and Picloram are included, but pesticide ***Etofenprox*** is not included into the Catalogue.

Sugar beet

For sugar beet insecticides Imidacloprid and Thiamethoxam and also herbicides Chloridazon, Clethodim, Clopyralid, Desmedipham and Ethofumesat and fungicides Imidacloprid and Thiamethoxam are included, but herbicide ***Cycloxydim*** is not included into the Catalogue.

Impact on implementation of best-practice strategies:

As mineral fertiliser Entec is at registration stage in Russia and is expected to become available since autumn 2016 this barrier has **low indirect** impact in a **short term**.

Conventional use of agricultural residues as an organic fertiliser

General description of barrier:

According to experts of Federal State Budget Scientific Institution All-Russian Research Institute of organic fertilisers and peat up to 20% of straw yield is used as bedding and fodder in cattle farming,

[37] Order of Ministry of Agriculture of the Russian Federation of 12.04.2013 № 26-r "On approval of the interim procedure for state registration of pesticides and agrochemicals" http://www.mcx.ru/documents/document/v7_show/23480.77.htm
[38] http://reggos.ru/en/gosudarstvennaya-registraciya-pesticidov-i-agrohimikatov.html
[39] Catalogue of pesticides registered in the territory of the Russian Federation (in Russian) http://service.mcx.ru/Registers/Register?type=1&registryType=Registry

up to 20% is used as organic fertiliser and for mulch, about 10% is used for composting and other needs and all the rest, which is about 50% of the straw yield is burnt on the fields[40].

Climatic conditions of Russia are characterized with high risk of negative factors such as droughts and floods. This significantly influences the agroproducers decision on use of agricultural residues as fertiliser instead of expensive mineral ones. Besides, collection of agro residues requires machinery and fuel that are unjustified expenses since there is no market of agro residues.

Impact on implementation of best-practice strategies:

This barrier coincides with barrier on unaffordability of mineral fertiliser, but is a social one. It has a **medium direct** impact in a **long term** due to presence of a justifying research in context of energy saving at field works and depends on further research and capacity building process in this area, as well as enough working capital.

Lack of qualified workforce in rural areas

General description of barrier:

Only about 25% of graduates from agrarian universities return to rural areas to work in the sector. According to experts of State Scientific Institution All-Russian Scientific Research Institute of Economics and norms of the RAAS[41] share of qualified personnel with higher professional education in agricultural sector for 2010 was about 8.9%[42]. This level is explained by the low wages (2 times less than average in the country), living conditions and level of development of social infrastructure at rural areas.

Impact on implementation of best-practice strategies:

Shortage of qualified workforce has **medium direct** impact on best-practice strategies implementation due to lack of the latest knowledge on modern crop production technologies. A number of state programs are aimed at improving living conditions and social infrastructure at rural areas that will attract graduates from the agrarian universities, so it can be predicted that this barrier will be removed, but only in a **long term**.

Lack of working capital of the agricultural producers

General description of barrier:

According to National Report[43] profitability of agricultural enterprises without subsidies in 2014 was 6.4% and with subsidies 16.6%. To carry out field works agrarians take short-term loans secured by future harvest. Russian agricultural credit system is featured with very high importance of the small

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[40] http://www.bellona.ru/bellona.org/files/fil_Rusakova_presentation.pdf

[41] Russian Academy of Agrarian Sciencies

[42] „Problems and Solutions of personnel maintenance of agricultural sector" (in Russian) http://cyberleninka.ru/article/n/problemy-i-puti-resheniya-kadrovogo-obespecheniya-apk

[43] Annual Report „On implementation in 2014 of the State programme of agricultural development and the regulation for markets for agricultural products, raw materials and food for 2013 – 2020" http://mcx.ru/documents/document/show/22026.htm

group of commercial banks (mainly state owned, such as Rosselkhozbank and Sberbank). These banks provide agricultural credits subsidised by the state. The procedure for obtaining subsidized agricultural credit obliges agroproducers to purchase agricultural insurance. State support compensates 50% of agricultural crop insurance (40% from federal and 10% from regional budgets) directly to insurance companies. State compensation of interest rate on credits as well as of agricultural insurance is paid only after all the payments by the agroproducers. Agricultural producers in Russia work in complex environment and though top ten Regions have conditions that are more favourable and produce half of Russian crop production the rest Regions frequently have floods and droughts and thus have problems with loan repayment (due to loss of harvest, which is a mortgage). This complicates the obtaining of next credits for the field works of following year. According to National report for 2014, total amount of agricultural credits in 2014 decreased compared to 2013 by 13% ($26.9 billion or 1011.14 billion RUB) and total amount of issued short-term loans for crop production as compared to 2013 decreased by 34% and amounted to $12 billion (450.7 billion RUB). The reason for that was inter alia an increase of interest rates for short-term credits to 22-24% (in RUB) and for investment credits to 25-28% (in RUB) per annum. Low profitability of agro-producers prevents them from obtaining credits. In 2014, the share of agricultural producers that has access to subsidized credits was slightly more than 1/10.

Another problem is that when agricultural enterprises cannot pay credits in time the Regional budgets should pay, but envisaged funds of Regional budgets to fulfil the credit guarantees are insufficient. For 2014, only $10 billion (600 billion RUB) were envisaged at Regional budgets, but actual payment can exceed 1.3 trillion RUB.

In February 1, 2015, the debt of agricultural enterprises on credits and loans reached almost $715 billion (50 trillion RUB) and has increased during the year at 18.8%.

Impact on implementation of best-practice strategies:

Lack of working capital due to low profitability of agro-producers and high debt burden has **high indirect** impact at the implementation of the best practice strategies in **a long term**.

Lack of modern equipment for main agriculture production

General description of barrier:

According to the National report “On progress and results for the implementation in 2014 the State program of agricultural development and regulation for markets of agricultural products, raw materials and food for the 2013–2020” agricultural sector is not completely provided with machinery for efficient farming. 61% of tractors, 47% of combine harvesters and 42% of forage harvesters work with exceeding average lifetime (more than 10 years).

As there is no common practice for residues collection, so the demand for such machinery is low. But this barrier can be easily removed as soon as real incentives/demand for straw collection is established.

Impact on implementation of best-practice strategies

Now within the state support to manufacturers of agricultural machinery that receive subsidy in amount of 25% of machinery price there is positive dynamics for renovation of machinery, but nevertheless lack of modern equipment will remain a **high direct barrier** to implementation of best practice strategies in a **long term**.

Unaffordability of mineral fertiliser

General description of barrier:

Since 2012 when Russia entered the WTO there have been no subsidies for purchasing of mineral fertilisers and plant protection products. Instead, farmers receive per hectare support. In 2015 amount of financing is approximately of 300 RUB/ha (4 euro/ha) and according to the National report in 2014 only 2/3 of agricultural enterprises and 1/3 of individual farmers received this support. In December 2015 an agreement was reached with manufacturers of fertilisers to provide 15-20% discount for farmers, later a new agreement of Federal Antimonopoly Service, Ministry of Agriculture and Ministry of industry and trade with producers of mineral fertilisers set a discount of 33%[44].

According to National report on agriculture farmers apply mineral fertilisers generally in amount less than 40 kg in 100% of nutrients. This indicates that mineral fertilisers are still unaffordable. Besides, because of frequent negative climatic factors such as droughts and floods agro-producers do not use expensive mineral fertilisers.

Impact on implementation of best-practice strategies:

As mineral fertiliser is an export-oriented product, its price at local market significantly depends on USD exchange rate and seasonality of demand. Unaffordability of mineral fertiliser to agro-producers has a **low direct** impact, which can influence best-practice strategies implementation in a **short term**, because positive trends of state support will likely change this situation in a medium term.

Summary of barriers

Agriculture of Russian Federation is still performing well below its potential. According to the official data, the sowing areas shrank dramatically from 118 million ha in 1990 to less than 75 million ha in second half of 2000's. Meanwhile due to such factors as agflation, and increased government spending on agriculture, one can observe stabilisation, and even some gain of sowing areas since 2009. Food Security Doctrine of Russian Federation and State program on agricultural development by 2020 are good instruments of support for Russian agricultural sector, but still implementation of best-practice strategies requires investments, which Russian agricultural sector is lacking. Another big problem is that agribusiness suffers from a glaring shortage of human capital at all levels (extension workers, skilled analysts, innovative researchers, agronomists, veterinaries etc.) thus questioning the performance of agricultural research and education system. Lack of own working

[44] http://fas.gov.ru/fas-in-press/fas-in-press_41346.html

capital as well as lack of qualified specialist are the main barriers that influence implementation of best-practise strategies for all crops for such factors as fertilization and cultivation practices.

The aggregated impact of the barriers in Russia is in the same range as for Ukraine. The project team expects that the yield increase of crop-specific best practice strategies in Russia will be reduced by 4.4% in the realistic potential. Again most of the reduction is caused by barriers on fertilisation and cultivation practices.

2.17.4 Belarus

Table 41: Identified barriers for application of crop-specific best practice strategies in Belarus

Barriers	Ranking of the impact
Political or administrative barriers	
The state regulation of output prices and setting targets on crop production	High Indirect Long term
Dependency of the agricultural sector on the state support	High Indirect Long term
State ownership of the agricultural lands	High Indirect Long term
Industry regulations and norms for the agricultural production	Medium Direct Long term
Social and structural barriers	
The lowest wages in the agricultural sector	Medium Direct Long term
Lack of specialists in the agricultural sector	Medium Direct Long term
Agricultural education does not meet to the demand of the sector	Medium Direct Long term
Economic barriers	
Extremely high level of interest rates on credits without state support	Low Direct Long term
The state support for local mechanization and equipment	Low Direct Long term

The barriers and their scoring are explained in more detail below.

Performance of the agricultural and food sector in Belarus is determined at large extent by state policy aimed at export promotion and supporting employment in rural areas. It implies that most of barriers for best-practises implementation are result of the state agricultural policy.

Registration of plant protection products, fertilizers and plant varieties:

General description of barrier:

Plant protection products and fertilizers have to be specified in the State Register of plant protection products and fertilizers[45]. It is allowed to plant only varieties that are specified in the State Register of varieties (annual publishing)[46]. The inclusion of varieties of plants in the state register, as well as their exclusion from the register is based on the results of state tests. Presence of the variety in a public register entitles the production, sale and use of seed varieties in the respective areas of Belarus.

Impact on implementation of best-practice strategies:

Fungicides and herbicides that contain active materials mentioned in best practice strategies for cereal, oil and other crops (Dimoxsystrobin, Boscalid, Epoxiconazole, Imidacloprid, etc.) are presented in the Register. There are varieties with a characteristics specified in best-practice strategies in the State Register of Varieties. Therefore, the registration of pesticides, agrochemicals and varieties is not a barrier for best practice strategies implementation.

The state regulation of output prices and setting targets on crop production:

General description of barrier:

The agricultural sector of Belarus is represented mainly by large state-owned enterprises. Private sector is represented mainly by subsistence farming (22.1% of the total agricultural output), while farm enterprises produce only about 1.5% of the total agricultural output.

Prevalence of the state ownership implies that the agricultural sector is subject to numerous regulations. On the one hand, producers are subject to direct price regulation that limit their profitability. On the other, the government provides many preferences/direct subsidies to state-owned agricultural enterprises, including: direct government spending (including financing of respective government programs); tax exemptions; loans at below credit market interest rate, government guarantees for loans to agricultural enterprises; practices of debt restructuring according to the government regulations; subsidising of compulsory insurance; cross-subsidization.

The authorities especially focus on providing agricultural enterprises with access to credits. The government adopts the plan of government programs annually, financed by Belarusian banks that include the list of investment projects and size of crediting (directed loans). Estimated average annual interest rate for preferential loans to agriculture is about 10% – far below the market rates in Belarus. Additionally, the maturity of these loans is high – up to 12 years. To compensate bank losses, the government covers interest rate gap and provides capital injections for the state banks that service government programs or provides additional subsidy for agricultural enterprises to pay

[45] http://www.ggiskzr.by/gosudarstvennyj_rees/
[46] http://sorttest.by/gosudarstvennyy-reyestr-sortov-2015

off bank loans. The practice of directed crediting of the agricultural sector creates significant market distortions and reduces the total factor productivity[47].

The Ministry of Agriculture and Food and the Executive Committees set maximum prices for agricultural products that are often below world market prices. Exports of food products is monopolised by the state. Due to the current pricing policy, total profitability of agricultural sector is 5% (2012)[48].

In addition to price and supply chain regulations, the state has an influence on production through the concern "Belgospishepro m". Belgospishcheprom is the Belarusian state food industry concern incorporating 57 food producers. It implements a coherent economic, technological and technical policy in the food industry. One of the main concern goals is to assist local authorities with agricultural zoning to ensure better supply of the food industry with raw materials. Therefore, the concern sets the targets for companies (output growth, export deliveries) and monitors their implementation. These regulations cover the activity of the state-owned enterprises. In some cases, private companies are also subordinated to the concern. On the one hand, it implies additional responsibilities for private companies, but on the other hand, they have higher possibilities of being included into state programs.

Impact on implementation of best-practice strategies:

State regulation of output prices and setting targets on crop production have **negative high indirect impact** on the best-practice strategies implementation. Agricultural enterprises are dependent from the State goals on production, are not free to set up market prices and work with the low profitability. There is no clear intentions to minimize price regulations so the barrier will affect **in the long-term perspective.**

Dependency of the agricultural sector on the state support:

General description of barrier:

Agricultural policy in Belarus is implemented though the mechanism of domestic support measures, investment policy, specific pricing, taxation and regulation of foreign trade in agricultural goods. The key document outlining agricultural policy objectives in Belarus is the Presidential Decree No. 347 from 17.07.2014 "On the state agrarian policy": The objectives are agriculture sector development and improving the mechanisms of state support for entities operating in the field of agricultural production[49].

[47] Kruk, D., Haiduk, K. (2013) The Outcome of Directed Lending in Belarus: Mitigating Recession or Dampening Long-Run Growth. *BEROC Working Paper* 22.
[48] AGRICIS Trade Project. Country report: Belarus. March 2015. Vasilina Akhramovich, Alexander Chubrik and Gleb Shymanovich
[49] http://president.gov.by/uploads/documents/347uk.pdf

There is a huge dependency of the sector on the state support, as subsidies account for 14–15% of the sectors output[50]. However, agreements within Customs Union of Belarus, Kazakhstan and Russia provide that Belarus reduces its state support to the agriculture from 16% of sector output in 2011 to 15% in 2012, 14% – 2013, 13% – 2014, 12% – 2015, 10% – 2016 and later[51].

Since 1996, the development of national agriculture has been guided by five-year state programs. Current agricultural policy was implemented within the framework of the State Program for sustainable development of rural areas in 2011–2015 (Presidential Decree No. 342 from 01.08.2011)[52]. It relies on 19 nationwide, sectoral, and regional programs for agricultural development. The program describes the budget allocations among various programs, but does not contain detailed mechanisms of funding allocation and distribution within programs. The budget process is not very transparent for agricultural producers. Selection of enterprises that could receive such support appears to contain a considerable element of discretion for government authorities.

The sector is dominated by large agricultural enterprises that lack flexibility and do not have enough incentives to increase efficiency in conditions, where state support can be viewed as granted. Furthermore, demand for their output is guaranteed through the system of product zones in which food enterprises are eligible to acquire raw agricultural products. Private farmers are more flexible but they have weak state support. To ensure profitability, private farmers produce vegetables and fruits where state interventions are marginal.

Impact on implementation of best-practice strategies:

Intransparent state support of the agricultural sector results in inefficient management and leads to **high negative impact** on best-practise strategies implementation. Due to agreements within Customs Union, state support will decline gradually so the barrier will have an impact in a **long-term**.

State ownership of the agricultural lands:

General description of barrier:

All agricultural land is owned by the state, while enterprises and farmers have to rent it. Access to the land by farmers is limited as agricultural enterprises enjoy preferential treatment by local authorities. Minimal term of agricultural land rent is 10 years[53]. Statistics reveals that the average

[50] Akhramovich V., Chubrik A. and Shymanovich G. (2015) AGRICISTRADE Belarus country report, Research Centre of the Institute for Privatization and Management, 15/03.
[51] Agreement on common rules of agriculture state support http://www.eurasiancommission.org/ru/act/prom_i_agroprom/dep_agroprom/Documents/1%20%D0%A1%D0%BE%D0%B3%D0%BB%D0%B0%D1%88%D0%B5%D0%BD%D0%B8%D0%B5%20%D0%BE%20%D0%B5%D0%B4%D0%B8%D0%BD%D1%8B%D1%85%20%D0%BF%D1%80%D0%B0%D0%B2%D0%B8%D0%BB%D0%B0%D1%85%20%D0%B3%D0%BE%D1%81%D1%83%D0%B4%D0%B0%D1%80%D1%81%D1%82%D0%B2%D0%B5%D0%BD%D0%BD%D0%BE%D0%B9%20%D0%BF%D0%BE%D0%B4%D0%B4%D0%B5%D1%80%D0%B6%D0%BA%D0%B8%20%D1%81%D0%B5%D0%BB%D1%8C%D1%81%D0%BA%D0%BE%D0%B3%D0%BE%20%D1%85%D0%BE%D0%B7%D1%8F%D0%B9%D1%81%D1%82%D0%B2%D0%B0.pdf
[52] http://mshp.minsk.by/programms/b05296a6fb2ed475.html
[53] http://kodeksy-by.com/kodeks_rb_o_zemle.htm

land area of agricultural enterprises is growing, while the number of enterprises is falling. Widespread practice of creation of holdings and affiliation of loss-making enterprises to more competitive enterprises is a result of state policy.

Impact on implementation of best-practice strategies:

State lands ownership leads to concertation of agricultural lands by agro-holdings and undeveloped sector of private farming that have **high indirect negative impact** on best-practise strategies implementation. Due to the problems with access to the agricultural land for private farmers and current minimum renting period, the barrier will have an impact in a **long-term.**

Industry regulations and norms:

General description of barrier:

The Ministry of Agriculture and Food in collaboration with the National Academy of Sciences of Belarus approved and communicated to stakeholders sectoral regulations, norms and standards to ensure the validity of the cost of production of agricultural products. The regulation allocates the costs of each input parameter and gives an estimation of the product costs. By doing so, the state knows the upper limit of the cost of production and established specific levels of profitability by a purchase price. According to the Belarusian Council of Ministers Resolution “On some issues of regulation and responsibility of leaders in the production of agricultural products"[54] No 339 of April 2014, industry regulations and norms should be fulfilled by heads of organizations. Disciplinary action will apply to the heads of the organizations in the case of non-compliance with industry regulations and standards.

Sectoral regulation and norms exist for each crop and establish requirements for soil quality, selecting predecessor, cultivation practices, fertilizer usage, seed priming, selection of the varieties, etc[55]. Value of each item that influences the cost of the main product is indicated at the Regulation. For example regulations give an amount range for N-application in 90-120 kg/ha, names of crop protection preparation with its consumption rate, etc.

Most of fertilizers are produced in Belarus and are provided to agricultural enterprises at subsidized price level. Usage of a fertilizer is strictly regulated by the State via industry regulations and norms.

The optimal level of mineral fertilizer application in Belarusian agriculture is considered to be around 1.6 million tons, including 0.6 million tons of nitrogenous fertilizers, 0.7 million tons of potash fertilizers and 0.3 million tons of phosphates[56], which is close to the actual volumes (of 2013)[57].

[54]http://kodeksy-by.com/norm_akt/source-%D0%A1%D0%9C%20%D0%A0%D0%91/type-%D0%9F%D0%BE%D1%81%D1%82%D0%B0%D0%BD%D0%BE%D0%B2%D0%BB%D0%B5%D0%BD%D0%B8%D0%B5/399-28.04.2014.htm

[55]A collection of industry regulations http://mshp.minsk.by/information/materials/zem/agriculture/efd0bdf93a4e567d.html

[56] Lapa, V., Privalov, F. (2007). Soil fertility and fertilizers application in Belarus, Soil science and agricultural chemistry, 2 (39), 7–14.

[57] Belarusian Statistical Committee.

Impact on implementation of best-practice strategies:

Industry regulations provide the producer with the guideline for selected crop production and could contain outdated technological recommendations. Nevertheless, they set up minimum amount of fertilizer usage and give information on the best catch crops. Together it has **medium direct** impact on best-practise strategies implementation in a **long-term** (there is no plans for regulation's cancelation).

Social barriers:

General description of barrier:

The agricultural sector is characterized by a lack of specialists due to human capital outflow as a result of rural-urban migration, and marginalization of rural population[58]. Furthermore, the number of students of agricultural specialties at specialized secondary educational institutions has been falling. At the same time, qualification of the specialists graduated from the universities is inadequate due to mismatch of the educational programs and needs of the agricultural sector[59]. Agriculture offers one of the lowest wages for hired personnel among sectors of the economy of Belarus (73% of the country average in 2015)[60].

Impact on implementation of best-practice strategies:

Shortage of qualified workforce and unfavourable living conditions in rural areas have a **medium direct** impact on best-practice strategies implementation due to lack of the latest knowledge on modern crop production technologies. General problems in education sector and poor living conditions make it impossible to change the situation in a short term, so the impact considers in a **long-term** perspective.

Economic barriers:

General description of barrier:

There is an extremely high level of interest rates on credits without state support (about 35% compared to subsidized credits with only 11% as of the end of 2014). The state supports only mechanization and equipment, which are produced in Belarus (credits with privileged terms, as part of the state support program to the machine-building sector). However, some types of modern equipment is not produced in Belarus at all (large square balers, self-loading trailers for large square bales, shredders, etc.).

The agriculture sector benefits from low fuel and energy prices, as Belarus imports oil and gas from Russia on privileged terms. Furthermore, acquisition of fuel by agricultural enterprises is subsidised

[58] Bobrova, A., Shakhotska, L., Shymanovich, G. (2012). Belarus Country Report: Social Impact of Emigration and Rural-Urban Migration, European Commission, DG Employment, Social Affairs and Inclusion.
[59] Nivievsky, O., Koester, U. (2012). Agricultural Research and Education System in Belarus: A Need for a Decentralized and Market-Oriented Approach, Berlin Economics Policy paper.
[60] http://belstat.gov.by/en/ofitsialnaya-statistika/otrasli-statistiki/naselenie/trud/operativnaya-informatsiya_8/gross-wages-and-salaries/gross-wages-and-salaries-in-the-republic-of-belarus-in-march-2015/

by the state. The support is provided as debt repayment for purchased petroleum products and supplies of diesel and gas at reduced prices. Low price on fuel does not encourage producers to reduce consumption and adopt new technologies.

Impact on implementation of best-practice strategies:

State support of agricultural production thought subsidized credits and reduced prices leads to **low impact barrier** for best-practice strategies implementation in a **long-term** perspective due to local equipment usage and not economical use of consumables. Barrier will have an influence until state support of agricultural production exist.

Summary of barriers

A fundamental challenge for agricultural sector development is decrease of rural population, its ageing and marginalization. This implies a lack of skilled labour force. Another problem is dependency of the sector on the state support, as subsidies account for 14–15% of the sectors output. State interventions into the sector in the form of price regulation, limiting access of food industry to raw products by resource zones, privilege treatment of the large-scale state-owned enterprises dominating the sector create distortions and hamper efficiency of the agriculture.
Moreover, the state also setting targets on crop production and regulate production technology. It makes financial stance of agricultural enterprises twice dependent on the public policy: the state regulates both costs and revenues side. Strict regulation of expenses leads and necessity of achieving targets make agricultural enterprises to follow technological norms with best practices developed by National Academy of Sciences of Belarus. For instance, according to statistical data the application of fertilisers is already optimal. Due to state subsidy, agricultural enterprises do not have problems with access to crop protection preparations and to the best crop varieties presented on the market. Usage of equipment of local production leads to outdated cultivation practises.

The experts assume that in the realistic potential for the implementation of crop-specific best practice strategies in Belarus the yield increase for the technical-sustainable potential will be reduced by 5.5%. Barriers with impact on fertilisation, crop protection and cultivation practices are the most dominant.

2.17.5 Barriers for residue-specific strategies in Ukraine, Russia and Belarus

In absence of a clear demand and low prices for residues as well as lack of access to finance we assume that residue-specific strategies are neither applied in Ukraine Russia or Belarus. The further reasoning is described below.

a) Barriers on harvesting procedures and technologies

Nowadays agricultural enterprises in Russia, Belarus and Ukraine mostly use outdated harvesting equipment and technology. On average cutting height for cereal and oil crops is 20 cm. Lack of working capital and underdeveloped credit market prevent agricultural enterprises from purchasing modern efficient machinery that allow reducing cutting height up to 5 cm (for cereal and oil crops) or to collect beets and leaves at the same time (for sugar beet). This is a barrier for implementation of best practice strategies through harvesting procedures and technologies.

b) Barriers on residue removal rate

The main barrier for measure recommended for residue removal rate increase is conventional use of agricultural residues as an organic fertiliser. Only in Belarus, where cattle farming is well developed, sufficient amount of manure is applied. In Ukraine and Russia agricultural enterprises choose straw as an organic fertiliser not only because of unavailability of manure (cattle farming is underdeveloped), but also because of the price of its application at the field in comparison with the straw. Nowadays according to expert opinion 50% of straw can be used for energy purposes in Russia[61] (see Chapter 2.17.3). In Belarus according data of energy potential assessment and survey of agricultural enterprises 20% of straw can be used for energy purposes (nowadays 19-27% of straw is not used or is burnt on field). In Ukraine according to assessment of Bioenergy Association of Ukraine 30% of straw, 40% of residues of maize for grain and sunflower production[62]. As bioenergy sector in Ukraine, Russia and Belarus is not well developed, recycling of ash or digestate generated as a result of combustion or biogas production will not be applied in a large extent in a short term.

c) Barriers on transport, storage and handling of residues

Conventional harvesting technology and use of the agricultural residues as a fertiliser lead to the lack of equipment for residues collection in Ukraine and Russia. On the other hand, agriculture enterprises do not invest in residues collection equipment because there is no demand (market) for residues. In Belarus baling of straw is more developed, but prevailing use of Belarusian baling machinery leads to small bales production. Use of modern machinery as recommended by residue-specific strategies will most likely not be applied in a long term, because of lack of working capital at agricultural enterprises in the three regions.

2.18 Realistic potential of agricultural residues

The realistic potential was calculated for EU-27, Belarus, Russia and Ukraine separately. The difference between TSP and realistic potential is mainly the reduction through regional barriers. Regional barriers vary between regions such as high yielding, medium yielding and low yielding within EU-27 and it also varies for Belarus, Russia and Ukraine. In EU-27, after considering regional barriers for agriculture crops, the realistic potential is 11.9 Mt/year for high yielding regions. In medium yielding regions, the realistic potential is 22.0 MT/year and for low yielding it is 40.6 MT/year. The total realistic potential for agriculture residues in EU-27 is 74.5 Mt/year.

[61] Federal State Budget Scientific Institution All-Russian Research Institute http://www.bellona.ru/bellona.org/files/fil_Rusakova_presentation.pdf
[62] Prospects for the use of agricultural residues for energy production in Ukraine. Position Paper N 7 of Ukrainian Bioenergy Association. http://www.uabio.org/img/files/docs/Position-paper-UABIO-7-EN.pdf

Table 42: Realistic potential (RP) for EU-27 for agriculture crops

Crop	Yield increase in RP through best practice strategies	High yielding (i.a. France) Mt/year	Medium yielding (i.a. Poland) Mt/year	Low yielding (i.a. Romania) Mt/year	Total Realistic potential (Mt/year)
Wheat	4-11%	5.095	6.891	19.298	31.285
Barley	7-13%	2.379	4.755	4.856	11.990
Maize	9-16%	3.096	5.020	7.339	15.455
Rye	7-13%	0.130	0.880	0.924	1.935
Oats	7-13%	0.388	0.568	0.504	1.460
Sunflower	9-16%	0.118	0.802	0.832	1.752
Rape	9-16%	0.614	2.113	5.933	8.661
Sugar beet	14-21%	0.047	0.321	0.333	0.701
Wine	13-17%	0.031	0.655	0.558	1.244
Total		11.9	22.0	40.6	74.5

For Belarus, Russia and Ukraine, realistic potential was calculated in same way by considering the specific regional barriers. In Belarus, the realistic potential is 1.8 Mt/year. For Russia and Ukraine, the realistic potential is 27.6 Mt/year and 18.2 Mt/year, respectively. The total realistic potential for agriculture residues for Belarus, Russia and Ukraine is 47.6 Mt/year.

Table 43: Realistic potential (RP) for Russia and Ukraine for agriculture crops

Crop	Yield increase in RP through best practice strategies	Russia (Mt/y)	Ukraine (Mt/y)	Total (Mt/y)
Wheat	1-7%	13.453	5.206	18.659
Barley	1.2-9%	3.988	2.364	6.352
Maize	1-12%	1.628	4.167	5.795
Rye	1.2-9%	0.886	0.230	1.116
Oats	1.2-9%	1.196	0.170	1.366
Sunflower	1-12%	4.833	4.636	9.469
Rape	1-12%	0.285	0.499	0.784
Sugar beet	1-17%	0.727	0.397	1.124
Wine	1-13%	0.549	0.482	1.031
Total		27.6	18.2	45.70

The realistic potential in total for EU-27, Belarus, Russia and Ukraine is 122 Mt/year. As for TSP, in realistic potential also, the grasslands were considered separately than agriculture crops.

Table 44: Realistic potential (RP) for Belarus for agriculture crops

Crop	*Yield increase in RP through best practice strategies*	*Belarus (Mt/y)*
Wheat	1-9.2%	0.448
Barley	1-11.2%	0.465
Maize	1-14.2%	0.154
Rye	1-11.2%	0.291
Oats	1-11.2%	0.128
Sunflower	1-14.2%	0.009
Rape	1-14.2%	0.136
Sugar beet	1-19.2%	0.089
Wine	1-15.2%	0.026
Total		1.8

The realistic potential for grasslands for EU-27 and Belarus, Russia, Ukraine is 31.47 Mt/y. The total realistic potential for agriculture crop residues and grasslands in EU-27 and Belarus, Russia and Ukraine is 153.57 Mt/year.

Table 45: Realistic potential for EU-27, Belarus, Russia and Ukraine for agriculture crops

Region	Agricultural crop residues (Mt/ year)
EU	74.5
Ukraine	18.2
Russia	27.6
Belarus	1.8
Total	**122.1**

3 Forestry - Realistic potential for biomass yield increase

While forests serve multiple purposes (e.g., nature conservation, recreation, wood production), there is far less competition between the production of food and the production of raw materials in forestry than in agriculture. As such, the focus of this study was clearly on maximising the total wood biomass production which was not limited to particular tree parts. Biomass residues from forestry are currently restricted to tree parts which are traditionally or, due to technical and environmental restrictions, not completely harvested (crown material such as twigs and branches, stumps and roots). In contrast to agricultural crop production, all tree parts can be utilised for bioenergy, biomaterials and biochemicals.

The aim of this chapter is to assess the theoretical potential for increasing the yield in forest production in the EU, Ukraine, Belarus and western Russia, followed by the derivation of i) a technical-sustainable potential and ii) a realistic potential. In this study, yield increases in forestry are understood as consisting of two main components:

- The total biomass yield from forest production – maximising the increment or growth of trees and forests with the primary constraint that the range and amount of assortments being harvested today is maintained or even increased.
- The yield of biomass residues from forest production – maximising the harvest rate of all different biomass compartments.

How to read the forestry chapter

Chapter 3.1 presents the methodology and includes a diagram and brief listing of tasks and sub-chapters. Chapter 3.2 presents the background of forests in Europe and develops a baseline in accordance with European forest types (EFTs). This is the *status quo* of European forests, and the values with which a potential increase in yield is compared. Chapter 3.3 presents the theoretical potential for increasing forest yield (i.e., a potential yield increase if there were no constraints) in the form of listed measures to increase yield (so-called "yield measures"). Chapter 3.4 presents the technical-sustainable potential derived from a set of suitable and applicable yield measures for the most relevant EFTs while taking into consideration constraints that exist for a particular yield measure in a given EFT (so-called “best practices”). Chapter 3.5 then presents the realistic potential of biomass yield from forestry in consideration of policy, economic and social barriers. Finally, chapter 3.6 relates the information on yield increase to the quality of forest products, especially with regard to energetic purposes.

3.1 Methodology

Sustainable forest management (SFM) implies “the stewardship and use of forests and forest lands in such a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems” (MCPFE 2005). At the social level, sustainable forest management contributes to livelihoods, income generation and employment. At the environmental level, it contributes to important services such as carbon sequestration and water, soil and biodiversity conservation (FAO 2015).

The principles of SFM, as agreed by the Ministerial Conference on the Protection of Forests in Europe (MCPFE), were always taken into consideration while developing the yield measures and applying them to various European forest types. As such, the listed yield improvements or suggested increased yield can be considered to be within “sustainable limits”.

MCPFE Criteria for Sustainable Forest Management

Maintenance, conservation and appropriate enhancement of:

- forest resources and their contribution to global carbon cycles
- forest ecosystem health and vitality
- productive functions of forests (wood and non-wood)
- biological diversity in forest ecosystems
- protective functions in forest management (notably soil and water)
- other socio-economic functions and conditions

(Forest Europe 2015b)

Figure 64 illustrates the work flow, including the subtasks and results. A stepwise approach was used to first derive a theoretical, then a technical-sustainable, and finally realistic potential to increase the biomass yield in forestry. The technical-sustainable potential takes into consideration ecological and technical constraints, whereas the realistic potential additionally considers policy, social and economic barriers.

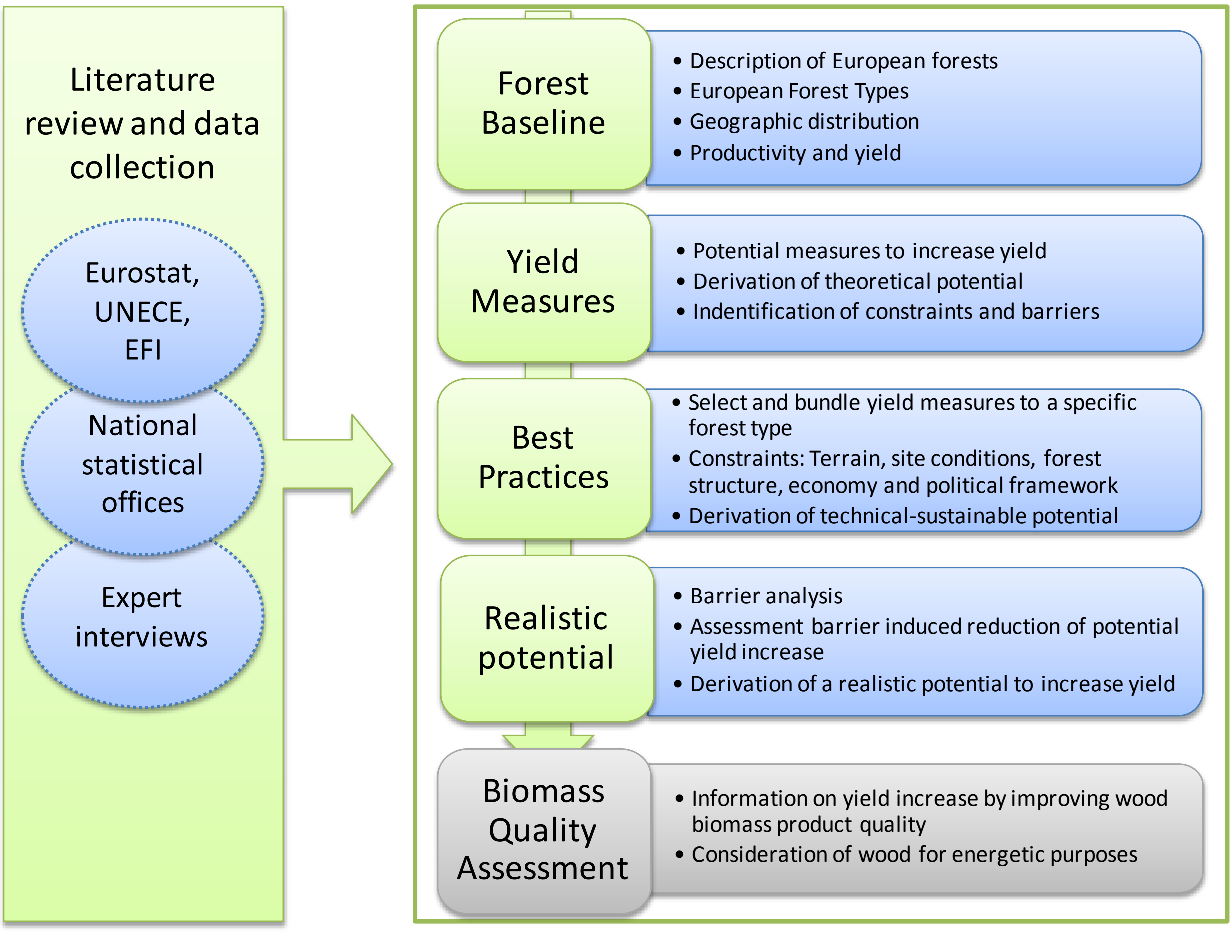


Figure 64: Work flow – analysis of potential and realistic yield increase of biomass from forestry

In a first phase, a literature review and data collection were undertaken as a basis for the following tasks:

- The description of the forest types, including standing volume, increment and potential yield
- The selection of measures to increase yield (referred to as “yield measures”)
- The development of best practices for the most relevant European forest types (EFT)
- The biomass quality assessment of forest products

The main objective of the literature study and data collection was to present an overview of existing forests in the target region in the form of a baseline. The baseline describes forest resources by forest types, which means according to the forest composition, main tree species, area, volume, productivity (increment) and yield (harvest potential). In order to develop the baseline a comprehensive collection of forest data was performed. European databases and statistics on forests provided by the UN Food and Agriculture Organisation (FAO), the United Nations Economic Commission for Europe (UNECE), the European Forest Institute (EFI) and – wherever regional data gaps exist – national forest administrative bodies and research institutions were reviewed. The central resource to derive the baseline was the EFISCEN database administered by EFI[63]. Nearly all forest studies at the European level use the EFISCEN database to describe the existing forests in Europe and apply the EFISCEN model for modelling yield potentials and prognoses of the forest resource development. The EFISCEN database relies on a diverse data pool compiled from national forest inventories (NFIs) using different methods and attributes to describe forests.

Since the EFISCEN model does not include a dataset for the western part of Russia this gap had to be filled with data provided primarily from the International Institute for Applied System Analysis (IIASA). The quality of the data for western Russia is not comparable with that obtained from EFISCEN. The Russian database was compiled from a number of sources at a later stage during the study, and the information regarding western Russian forests is not as comprehensive when compared to other regions. Furthermore, the Russian concession system has a completely different approach to forest management and leads to a different set of barriers and strategies for addressing them. For these reasons, the west Russian data was always analysed separately from the EU 28, Belarus and Ukraine.

The methodology applied for the sub-chapters deviates from the approach used for agricultural biomass residues (see chapter 2). Most notably, the differentiation between the theoretical and technical-sustainable potential yield increase is not as pronounced. A theoretical potential for yield improvement could be defined for each yield measure. When combining yield measures to form best practice strategies for the European forest types it was not possible to ignore constraints in applicability of the different measures. Moreover, the principles of a sustainable forest management were applied as general constraints in this process. The potential yield improvement by applying best practice strategies can therefore be described as the technical-sustainable potential to maximise yield from forestry.

Chapter 3.3 describes a broad selection of measures, referred to as **yield measures**, which could potentially be applied in forest management to increase the productivity and yield per area unit. This could be considered as the **theoretical potential to increase yield** per area; however, it does not include a specific quantification in absolute figures (potential x applicable area). Immediately after the qualitative description of yield measures, restrictions in applying the different yield measures in the form of constraints need to be considered and discussed in order to define and evaluate best practice strategies. In fact, it is not possible to define yield measures without considering the location, region, or forest structure where the measures are to be applied. The underlying implication is that occurring deficits in forest management are directly addressed. Each yield measure concludes with a quantification of the yield increase, which is based on a combination of literature values and

[63] EFISCEN is a forest resource database and projection model. It is used to gain insight into the future development of European forests for issues such as sustainable management regimes, wood production possibilities, nature oriented management and carbon balance issues. Through its underlying detailed forest inventory database, the projections provide these insights at varying regional scales. The bases of the EFISCEN Inventory database are individual national forest inventories of 32 European countries. Each country lists different so-called "forest types". For each forest type and age class, the forest area, the total and mean volume, the total annual increment and the current annual increment may be retrieved from the EFISCEN Inventory database. Such data are available for all countries which have an even-aged forest structure (EFISCEN 2015).

expert knowledge as theoretical potential to increase yield, wherever existing deficits, the principles of sustainable forest management and technical and economic constraints allow the application. Subsequently, chapter 0 applies the described yield measures to a specific forest context. In total, nine major EFTs were selected for the development of **best practice strategies** consisting of a selected bundle of applicable yield measures. Due to the varying climate, topography, site conditions, forest structure and political framework, not all of the yield measures will necessarily apply within each EFT. Each EFT therefore has its own specific "bundle" of yield measures. The detailed discussion of the applicable best practices leads to the derivation of a quantified, context-specific **technical-sustainable potential to increase yield**. Each EFT sub-chapter closes with a final quantification of the yield increase, subdivided into:

i. The **subtotal yield increase effect** in the narrow sense, and
ii. The **improved utilisation effect**

The yield increase effect is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures are generally medium to long-term and lead to improvements within 10 to 30 years (and more), assuming a consequent implementation.
The improved utilisation effect, on the other hand, is based on measures which do not have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The yield increase effect is applied to the basic EFISCEN model yield calculated for 2010, which provides a theoretical yield as based on the model, whereas the improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect). In general, the yield which is defined in management plans does not consider the components of an improved utilisation effect (i.e., accessibility, harvesting technologies, harvesting of all tree compartments (twigs, branches), etc.). Following this chapter, 3.5 presents policy, social and economic barriers which may prevent the implementation of the best practices. The discussion and consideration of these barriers then leads to the realistic biomass yield from forestry.
The final sub-chapter (3.6) is a qualitative evaluation of the biomass quality parameters which are required for various wood products, ranging from sawn wood to biofuels and bioenergy. The chapter also includes suggestions on how to improve the biomass quality parameters through targeted forest management activities.

3.2 Baseline - description of forest types in Europe

3.2.1 Forest types as key unit

Forest types form the key unit for which the defined measures or strategies will be applied and quantified. In the context of this study, a forest type refers to a forest which can be distinguished according to tree species, structure, site class and region. Forest types occur in certain regions, on characteristic soils and climates, show a typical tree species composition, a typical range of productivity, yield and wood assortments. Forest management strategies are typically developed on the level of forest types. For this study, forest types are used as the unit within which selected measures to maximise yields are applied, and for which the effect of the measures is assessed.

This study applies the system of the “European forest types”[64]. The European forest types were developed to improve the MCPFE reporting on sustainable forest management (SFM) in Europe, with special regard to forest types. This particular forest categorisation uses the main tree species composition, the country, region and inherent climate, the soil quality and to some extent the naturalness of forest structure or composition as criteria. For a list of the 14 main European forest types see Table 46 below.

Table 46: European forest types – short characterisation of the 14 main EEA European forest types (the nine forest types addressed in the best practices are marked in bold)

Main forest types or Categories[65]	Description
1. Boreal forests	Boreal forests are located in north and north-east Europe. They are characterised by low temperature and a short growing season. The forest composition is dominated by two conifers species – spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). Deciduous trees include birches (*Betula* spp.), aspen (*Populus tremula*), rowan (*Sorbus aucuparia*) and willows (*Salix* spp.).
2. Hemiboreal and nemoral coniferous and mixed broadleaved-coniferous forests	These mixed forests are located in between the boreal and nemoral forest zones and the anthropogenic coniferous forests of the nemoral zone[66]. The light regime and length of the growing season are the main climatic variables which control forest productivity; these factors differ considerably from the northern to the southern part of the hemiboreal zone.
3. Alpine coniferous forests	These forests are situated in the high altitudes of the European Alpine region, which is characterised by a cold, harsh climate. The climatic conditions are similar to those of the boreal zone, except for the light regime and length of day. The species composition varies with the vegetation belts (mountainous/subalpine) and site ecological conditions. Naturally dominant species include Scots pine (*Pinus sylvestris*), black pine (*P. nigra*), Swiss pine (*P. cembra*), silver fir (*Abies alba*), spruce (*Picea* spp.), and larch (*Larix decidua*).
4. Acidophilous oak and oak-birch forests	These forests are located on poor, oligotrophic soils of the nemoral forest zone. The tree species composition is poor with only 1–2 species, and is characterised by acidophilous (i.e. growing well in an acidic medium) oaks (*Q. robur*, *Q. petraea*) and birch (*Betula pendula*).
5. Mesophytic deciduous forests	Located in western and central Europe, these forests grow on medium (mesotrophic) and good (eutrophic) soils of the nemoral zone. The species composition is generally characterised by mixtures of hornbeam (*Carpinus betulus*), oaks (*Quercus petraea*, *Q.robur*), ash (*Fraxinus* spp.), maples (*Acer* spp.) and lime (*Tilia cordata*).

[64] Detailed descriptions of the European Forest types (EFTs) and the subclasses can be found in the EEA Technical report No9/2006.
[65] The name of the main forest types or so-called categories are describing the phyto-ecological zones in Europe, where the respective forest type occurs.
[66] Nemoral zone: The nemoral environmental zone covers the lowlands and undulating plains of South Scandinavia and the north-west of the Russian Plain including the Baltic countries (Bogers 2015).

Main forest types or Categories[65]	Description
6. Beech forests	This category has a very wide geographic distribution in lowland to sub-mountainous Europe. It is characterised by the dominance of European beech (*Fagus sylvatica*) or oriental beech (*Fagus orientalis*) in the eastern and southern parts of the Balkan Peninsula. Additional characteristic tree species include birch (*Betula pendula*) and mesophytic deciduous species (ash (*Fraxinus excelsior*), maple (*Acer* spp.), oak (*Quercus petraea*, *Q.robur*), cherry (*Prunus avium*), lime (*Tilia* spp.), etc.).
7. Mountainous beech forests	The forests are located in the mountainous altitudinal belt of the main European mountain ranges. In the mountainous vegetation belt coniferous species (Norway spruce (*Picea abies*), silver fir (*Abies alba*)) become as competitive as beech (*Fagus sylvatica*) and are mixed with mesophytic deciduous species (ash (*Fraxinus excelsior*), maple (*Acer* spp.)).
8. Thermophilous deciduous forests	The deciduous forests under this category mainly occur in the supra-Mediterranean vegetation belt, the altitudinal belt of Mediterranean mountains corresponding to the mountainous level of middle European mountains. Thermophilous deciduous forests are limited to the north (or upslope) by temperature and to the south (or downslope) by drought. These forests are mainly composed of oak (*Quercus* spp.), maple (*Acer* spp.), and hop hornbeam (*Ostrya carpinifolia*), and ash (*Fraxinus ornus*).
9. Broadleaved evergreen forests	These forests are located in southern Europe at low altitudes. Warm and dry climates determine the species composition, which includes holm oak (*Quercus ilex*), kermes oak (*Quercus coccifera*), olive trees (*Olea europaea*), or Maritime pine (Pinus pinaster). These forests have a very low productivity due to limited water availability.
10. Coniferous forests of the Mediterranean, Anatolian and Macaronesian regions	This category includes a large group of coniferous forests, mainly xerophytic (i.e., plants adapted to surviving with very little water) forest communities, distributed throughout Europe from coastal regions to high mountain ranges. The dominant species include pine (*Pinus nigra*, *P. halepensis*, *P. canariensis*), fir (*Abies* spp.) and juniper (*Juniperus* spp.) depending on the altitudinal belts. These forests grow on dry, often poor soils.
11. Mire and swamp forests	Waterlogged peaty soils determine these wetland forests mainly distributed in the boreal zone in North and East Europe. Spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) build up mire forests; species of alder (*Alnus* spp.), birch (*Betula* spp.), oak (*Quercus* spp.), aspen and poplar (*Populus* spp.) dominate the deciduous swamp forest.

Main forest types or Categories[65]	Description
12. Floodplain forests	These forests generally grow under a riparian or alluvial hydrological regime (high groundwater table and occasional flooding), and are distributed along the main European rivers. Floodplain forests are species-rich, often multi-layered communities characterised by different assemblages of species of alder (*Alnus*), birch (*Betula*) and poplar (*Populus*). In the Mediterranean and Macaronesian regions local species are also found (e.g. *Fraxinus angustifolia*, *Nerium oleander*, *Platanus orientalis*, *Tamarix*).
13. Non-riverine alder, birch or aspen forests	These are non-riparian, non-marshy pioneer forests of elder, birch and aspen, located in Eastern Europe. They occur under specific ecological conditions (mountain birch forests) or as pioneer stages of succession after fire or under heavy grazing.
14. Introduced tree species forests	Introduced tree species forests are found all throughout Europe. These forests have a low level of naturalness. Included in this category are forest plantations of Sitka spruce (*Picea sitchensis*) (concentrated in the UK, Ireland), Douglas fir (*Pseudotsuga menziesii*), red oak (*Quercus rubra*), nuts (*Castanea sativa*, *Juglans* spp.) (France), black locust (*Robinia pseudoacacia*) (Hungary), pine species (*Pinus* spp.) of southern Europe, eucalyptus (*Eucalyptus* spp.) (Portugal, Spain, France), and hybrid poplars (*Populus* spp.). The plantations are established and intensively managed for production or for the rehabilitation of degraded land.

3.2.2 Compiling baseline data

Baseline data for EU 28, Belarus and Ukraine

The central resource to derive the baseline was the EFISCEN database administered by EFI.
In the EFISCEN database and model the lowest level of information is called "forest type". Unfortunately the forest type in EFISCEN is not fully consistent with the EEA European forest type. In EFISCEN forest types are a synthetic combination of tree species groups of a specific region of a country (Schelhaas et al 2007). For the baseline of this study the EFISCEN tree species groups therefore had to be transferred by “label to label” bridging functions to the EEA Forest types. The method is described below.

Although the EFISCEN database is the most-cited resource on Europe’s forest, there are several data gaps and several contents lack a clear definition. It is still the most comprehensive data resource on European forested land especially in terms of key data like increment and harvesting (potential) – both are essential attributes for this study – which are not available in any other EU forest related database. Moreover, the EFISCEN database provides important information about the European forest such as forest area by tree species group, growing stock (per age class), gross increment, mortality, thinning and harvesting volume estimations derived from a management regime defined by European forest experts.

To conduct a plausibility check, the EFISCEN-model baseline database was compared with the statistics provided in the UNECE report “State of Europe’s forest” (Forest Europe, UNECE, and FAO 2011). The comparison between the EFISCEN and the UNECE data showed that there are gaps and divergences in the dataset even though EFISCEN database is based on data from national forest inventories (NFIs).

For example, the total forest area of Italy in the EFISCEN dataset is 4.7 million hectares. The UNECE report declares a total forest area of 9.2 million hectares for Italy. The EFISCEN database does not contain forests which are declared as uneven-aged[67], resulting in a gap of 50% of forest area. This data was added from the publication of results of the Italian NFI ("Documentazione E Normativa Di Riferimento" 2015).

While EFISCEN is based on data from National forest inventories, the UNECE report collected additional data based on “joint FOREST EUROPE/UNECE/FAO enquiries” on quantitative and qualitative indicators and by international data providers, namely the International Co-operative Program on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forests), the EC-Joint Research Centre, Biodiversity International, the Statistical Office of the European Communities (EUROSTAT) and the UNECE/FAO Forestry and Timber Section (Forest Europe, UNECE, and FAO 2011, 12). However, the UNECE report simply shows a snapshot of European forests at a certain point in time. Essential, detailed information on increment, age class distribution or harvest potentials is not included in this UNECE dataset; the essential information is the EEA forest type (EFT).

With the information about the EEA European forest types (area by country, growing stock, distribution) it was possible to merge the two datasets by creating label to label bridging functions (see example below) between the tree species groups from the EFISCEN dataset and the EEA European forest types (EFTS) from the UNECE report. The result is a baseline which covers the area under investigation as well as the presentation of required information about growing stock, its increment and potential yield.

Merging the datasets – example for Germany

The UNECE report contains information about the distribution and a description of the EFTs. The description always includes information about the occurring main tree species and names regions where a specific EFT usually appears. For a better understanding, the merging process will be explained through an example. In the first step, the tree species groups from the EFISCEN database were compared country by country to the appearance of the EFTs in the UNECE report and if possible a link between these two parameters was implemented.

[67] Uneven-aged forests consist of trees within two or more age classes. Generally, there will be many young trees growing in the shade of older, overtopping trees.

For Germany, EFISCEN unfortunately shows no division into regions. Nine tree species groups are derived for the whole country and the UNECE report (Forest Europe, UNECE, and FAO 2011) *discloses eight European Forest types (EFTs) for Germany. Since there are species which appear as one of the main tree species in more than one EFT, the forested area of the tree species group was divided according to the corresponding EFTs. In the case of Germany, the spruce* (Picea *spp.) can be linked to the EFT Alpine Forest or to the EFT Hemiboreal and Nemoral Coniferous and Mixed Broadleaved-coniferous Forest and beech* (Fagus *spp.) can be linked to the EFT Beech Forest and the EFT Mountainous Beech Forest (label to label bridging). For these two species the forest area available for wood supply (FAWS) has to be divided into the aforementioned two forest types using the area ration provided by the UNECE report.*
Furthermore, the tree species had to be classified into groups since the name of origin of the species differs from country to country.

Table 47: Merging datasets from the EFISCEN database and UNECE "State of European forests" – example Germany

EFISCEN - Tree Species Group*	European Forest Type (EFT)	EFT No.
Beech (*Fagus sylvatica*)	Beech forest	6
	Mountainous beech forest	7
Douglas fir (*Pseudotsuga menziesii*)	Introduced tree species	14
Fir (*Abies alba*)	Mountainous beech forest	7
Hardwoods	Mesophytic deciduous forest	5
Larch (*Larix decidua*)	Alpine forest	3
Oak (*Quercus* spp.)	Mesophytic deciduous forest	5
Pine (*Pinus* spp.)	Hemiboreal forest	2
Softwoods	Floodplain forest	12
Spruce (*Picea* spp.)	Hemiboreal forest	2
	Alpine forest	3

*This method leads to the best available information, but is only an estimation and does not meet reality to 100%.

Baseline data for western Russia

Since the EFISCEN model does not include a baseline dataset for the western part of Russia this gap had to be filled with data provided from the International Institute for Applied System Analysis (IIASA). The IIASA dataset contains official statistics on the Forest Fund of all federal agencies of state management as well as on forests which are not included in the Forest Fund (Ministry of Defence, city forests, and agricultural forests), stated by January 2003. The data are presented according to administrative regions (subjects of the Russian Federation) (IIASA 2015).

Based on this dataset, forest area, increment, and growing stock for each administrative region in the western part of Russia was calculated for groups of tree species. The forest area for wood supply (FAWS) was derived in a second step. On average, only 37% of the forest area in western Russia is said to be available for 'industrial purposes' (forestry operations). The rest is subject to technical, legal or other restrictions. A sustainable yield level comparable with the modelled yield from the EFISCEN yield model was not presented in the dataset. The potential yield and a potential utilisation rate has therefore been developed for western Russia using the mean yield calculated for Belarus, Estonia, Finland and Ukraine for the Russian tree species groups conifers, hardwood and softwood (alder, aspen, willow).

3.2.3 A baseline of European forests

The following two tables show the compilation of the European forest by EEA forest type as a result of the compromise described above, the bridging of the EFISCEN group of tree species and the EEA forest types per country and region as well as the adaptation and compilation of data for western Russia. First, data for EU 28, Ukraine and Belarus are presented, and then the data for western Russia is presented in a separate table. For each forest type the forest area, growing stock, increment per year and an estimation of a sustainable yield based on the EFISCEN model calculation is given.

Forest baseline for the EU 28, Ukraine and Belarus

Forest area for wood supply (FAWS) in EU 28, Ukraine and Belarus sums up to 142 Mio ha. It is dominated by only three forest types summing up to 55% of the forest area:

1. EFT Hemiboreal Forests (24%), featuring the coexistence of boreal coniferous species (Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*)) with temperate broadleaved tree species (oak (*Quercus robur*), ash (*Fraxinus excelsior*), lime (*Tilia cordata*));
2. EFT Boreal Forests (22%) of north and north-east Europe, where the harsh climatic conditions affect forest composition, dominated by two conifers species (spruce (*Picea abies*), Scots pine (*Pinus sylvestris*)) and deciduous trees including birches (*Betula* spp.), aspen (*Populus tremula*), rowan (*Sorbus aucuparia*) and willows (*Salix* spp.), and;
3. EFT Mesophytic Deciduous Forests (9%) of western and central Europe characterised by meso- and eutrophic soils and composed of oak (*Q. robur* and *Q. petraea*), hornbeam (*Carpinus betulus*), ash (*Fraxinus excelsior*), maple (*Acer pseudoplatanus* and *A. platanoides*) and lime tree (*Tilia cordata*).

The **growing stock** is 25,476 Mio m^3[68], the average stock per hectare results in 180 m^3/ha. The dominant forest types are characterised by large area and relatively high productivity, where the EFT Hemiboreal Forests (35%) is dominant due to its large area, followed by the less productive but even larger EFT Boreal Forests (15%), and with regard to the area followed by the EFT Mesophytic Deciduous Forests (10%) of western and central Europe. In contrast, the highest stock per hectare can be found in the EFTs Alpine Forests (286 m^3/ha), Mountainous Beech Forests (281 m^3/ha), Beech Forests (271 m^3/ha), and Hemiboreal Forests (259 m^3/ha).

[68] m^3 of standing solid wood over bark, not including branch wood below 7 cm in diameter or roots.

Table 48: Forest baseline (2010) for EU 28, Belarus and Ukraine aggregated and sorted by European forest type; forest area available for wood supply, growing stock, increment and potential yield from EFISCEN model calculation. 1) Main tree species groups by EFISCEN linked to the EEA European forest types; 2) m^3 of solid wood volume over bark; 3) m^3 of solid wood volume over bark excluding harvest losses.

Forest baseline of EU 28, Ukraine and Belarus aggregated and sorted by European forest type												
European forest type	Tree species groups[1]	Forest area for wood supply		Growing stock[2]			Increment[2]			Yield[3]		
		1000ha	*%*	*mio. m^3*	*%*	*m^3/ha*	*1000m^3/a*	*%*	*m^3/ha/a*	*1000m^3*	*%*	*m^3/ha/a*
1. Boreal forests	Norway spruce, Scots pine, Silver birch	31,660	22	3,860	15	121.9	148,937	17	4.7	124,128	22	3.9
2. Hemiboreal forests	Norway spruce, Scots pine, Silver birch	34,596	24	8,967	35	259.2	298,358	34	8.6	180,063	33	5.2
3. Alpine forests	Norway spruce, European larch, Swiss pine, black pine	5,467	4	1,561	6	285.5	44,563	5	8.2	34,393	6	6.3
4. Acidophilous oak and oak-birch forests	Sessile oak, English oak, Birch	3,093	2	577	2	186.5	17,874	2	5.8	11,148	2	3.6
5. Mesophytic deciduous forests	Acer, Ash, Hornbeam, Elm, Lime, Oak	12,316	9	2,489	10	202.1	77,497	9	6.3	38,042	7	3.1
6. Beech forests	European beech	3,743	3	1,018	4	272.0	29,034	3	7.8	21,879	4	5.8
7. Mountainous beech forests	European beech, Fir, Spruce, Acer	7,468	5	2,101	8	281.4	55,669	6	7.5	33,907	6	4.5
8. Thermophilous deciduous forests	Turkey oak, Chestnut, Oriental hornbeam	7,453	5	776	3	104.1	25,976	3	3.5	10,981	2	1.5
9. Broadleaved evergreen forests	Evergreen oak, Cork oak	9,601	7	282	1	29.4	6,454	1	0.7	4,095	1	0.4
10. Coniferous forests of the Mediterranean	Corsican pine, Aleppo pine, Maritime pine	9,729	7	941	4	96.7	44,690	5	4.6	22,380	4	2.3
11. Mire and swamp forests	Birch, Aspen, Alder, Ash, Oak, willow	2,077	1	306	1	147.4	14,911	2	7.2	6,969	1	3.4
12. Floodplain forests	Poplar, Willow, Alder, ash, oak	1,391	1	250	1	179.8	10,017	1	7.2	7,269	1	5.2
13. Non-riverine alder, birch or aspen forests	Alder, Birch, Aspen	8,212	6	1,350	5	164.5	51,594	6	6.3	31,129	6	3.8
14. Introduced tree species forests	Douglas fir, Red oak, Sitka spruce	5,398	4	998	4	184.9	51,905	6	9.6	27,482	5	5.1
Sum for 2010		**142,203**	**100**	**25,476**	**100**	**179.2**	**877,478**	**100**	**6.2**	**553,865**	**100**	**3.9**

The sum of forest trees aggregated to the above described growing stock produce 877 Mio m³ of wood[69] per year. The total **increment** is again a product of area and productivity per hectare. Dominating forest types include the EFTs Hemiboreal Forests (33%), Boreal Forests (17%) and Mesophytic Deciduous Forests (9%). In contrast to the total increment, the per hectare productivity is highest in the EFT Introduced Tree Species Forests (Douglas fir (*Pseudotsuga menziesii*), Red oak (*Quercus rubra*), Sitka spruce (*Picea sitchensis*)) with 9.6 m³/ha, then in the coniferous rich EFT Hemiboreal Forests (8.6 m³/ha), followed by the EFT Beech Forests (7.8 m³/ha).

The potential **yield** as it is calculated in the EFISCEN model is influenced by the increment and the age distribution of the forests[70] and sums up to a total harvestable timber volume of 554 Mio m³/a[71]. Here too, the EFTs Hemiboreal Forests (32%) and Boreal Forests (22%) dominate the total yield, whilst the EFTs Alpine Forests (6%) and Mesophytic Deciduous Forests (7%) contribute with almost the same amount. The yield potential per hectare is highest in the EFT Alpine Forests (6.3 m³/ha).
The yield within the EFT Hemiboreal Forests, which is dominated by conifers (pine, spruce) (5.2 m³/ha), is fairly high and comes close to the yield within the EFT Beech Forests (5.8 m³/ha). The highest yield, however, can be obtained in the EFT Alpine Forest (6.3 m³/ha). In managed forests with a homogeneous age distribution (i.e., Introduced Tree Species Forests) the harvestable yield is usually only 10-20% below the increment. Although there is some natural mortality of trees which cannot be harvested in time, when mortality occurs, almost all the increment is potential yield in age balanced or dimension balanced uneven-aged forests. As such, increment and yield should converge in the long-term. In forests with an age structure of many mature trees the yield can temporarily transcend the increment.

It is obvious that most of the forest types in Europe are not balanced in age or dimension, resulting in a much lower yield compared to the current increment. This situation can only be influenced by long-term management, but is mainly a matter of historical utilisation and/or afforestation and reforestation.

[69] m³ of standing solid wood over bark, not including branch wood below 7 cm in diameter or roots.
[70] The EFISCEN model sets a management regime for each EFISCEN forest types, defining the number of growth years until a final felling takes place (rotation), stand age for a first wood harvest as thinning, and a periodicity for thinnings. For each harvest or thinning intervention the wood volume to be removed is defined.
[71] m³ of solid wood under bark derived from felling volume over bark; a generic bark fraction of 12% detracted and excluding the amount of harvest losses, which are derived from data published in UNECE/FAO (2000) (12-20%).

Table 49: Forest baseline for western Russia (2003) aggregated and sorted by European forest type; forest area available for wood supply, growing stock, and increment from IIASA dataset, potential yield deduced from EFISCEN model calculation. Not all of the 14 EFTs occur in western Russia. 1) Main tree species groups by EFISCEN linked to the EEA European forest types; 2) m^3 of solid wood volume over bark; 3) m^3 of solid wood volume over bark excluding harvest losses.

Forest baseline for western Russia aggregated and sorted by European forest type													
European forest type	Tree species groups[1]	Forest area for wood supply		Growing stock²			Increment²			Yield³			
		1000ha	*%*	*mio. m³*	*%*	*m³/ha*	*1000m³/a*	*%*	*m³/ha/a*	*1000m³*	*%*	*m³/ha/a*	
1. Boreal forests	Norway spruce, Scots pine, Silver birch	84,828	84	3,900	65	46.0	53,558	59	0.6	32,189	61	0.4	
2. Hemiboreal forests	Norway spruce, Scots pine, Silver birch, oak, lime, acer	4,894	5	605	10	123.4	12,181	13	2.5	7,103	13	1.5	
3. Alpine forests	Norway spruce, European larch, Swiss pine	157	0	27.2	0	173.3	302	0	1.9	184	0	1.2	
5. Mesophytic deciduous forests	Acer, Ash, Hornbeam, Elm, Lime	1,384	1	203	3	146.8	4,200	5	3.0	2,520	5	1.8	
7. Mountainous beech forests	European beech, Fir, Spruce, Acer	825	1	218	4	263.8	2,240	2	2.7	1,349	3	1.6	
11. Mire and swamp forests	Birch, aspen, alder, willow, ash, oak	4,133	4	502	8	121.4	9,190	10	2.2	5,002	9	1.2	
12. Floodplain forests	Poplar, willow, alder, ash, oak	346	0	50	1	144.1	879	1	2.6	526	1	1.5	
13. Non-riverine alder, birch or aspen forests	Alder, Birch, Aspen	3,859	4	455	8	117.1	7,763	9	2.0	4,193	8	1.1	
Sum for 2003		**100,427**	**100**	**5,959**	**100**	**59.3**	**90,313**	**100**	**0.9**	**53,066**	**100**	**0.5**	

Forest baseline for western Russia

The **forest area** of western Russia sums up to 100 Mio ha. It is clearly dominated by the EFT Boreal Forests which takes up 84% of the forest area. Together with the EFTs Hemiboreal Forests (5%) and Alpine Forests (0.2%) around 90% of the forest area in western Russia is consists of forest types which are mainly formed by conifers. The EFTs Mire and Swamp Forests (4%), Non-riverine Alder, Birch or Aspen Forests' (4%), Mesophytic Deciduous Forests (1%), Mountainous Beech Forests (1%), and Floodplain Forests (0.3%) make up the remaining 10%.

The **growing stock** is 5,959 Mio m^3[72] and the average growing stock per hectare is 59 m^3/ha. The dominant EFT Boreal Forests is characterised by its enormous area and a very low productivity. The average growing stock per hectare in this EFT is only 46 m^3/ha. This low level is the result of extreme climate conditions and a relatively high proportion of degraded forests in this region. Nevertheless, 65% of the total growing stock is located in this forest type followed by the EFT Hemiboreal Forests (10%), with an average growing stock of 124m^3/ha. The highest values can be found in the EFTs Mountainous Beech Forests (264 m^3/ha) and Alpine Forests (173 m^3/ha). Both EFTs are located in the Caucasian Mountains. While the EFTs formed by conifers only have a mean growing stock of 114 m^3/ha, the EFTs formed by broadleaves show a mean gowing stock of 159 m^3/ha. Due to this fact, their share on the total growing stock with 24% is more than twice as high as their share is on the forest area.

Considering the **increment**, the biggest slice falls upon the EFT Boreal Forests again (59%) followed by the EFT Hemiboreal Forests (13%). Compared to the rest of Europe, the mean annual increment in Russian forests is twice as low, or even lower. The productivity of the Russian forest is based on its endless extent. The distribution of the increment is similar to the distribution of the growing stock. Three-quarters of the annual increment (72 Mio m^3/a) fall within the EFTs Boreal Forests (59%) and Hemiboreal Forests (13%). Together, the EFTs Mire and Swamp Forests (9%), Non-riverine Alder, Birch or Aspen Forests (8%), Mesophytic Deciduous Forests (5%), Mountainous Beech Forests (3%) and Floodplain Forests (1%) produce 26% of the annual increment. In contrast to the total increment, per hectare productivity is highest in the EFT Mesophytic Deciduous Forests (3.0 m^3/ha/a) followed by Mountainous Beech Forests (2.7 m^3/ha/a).

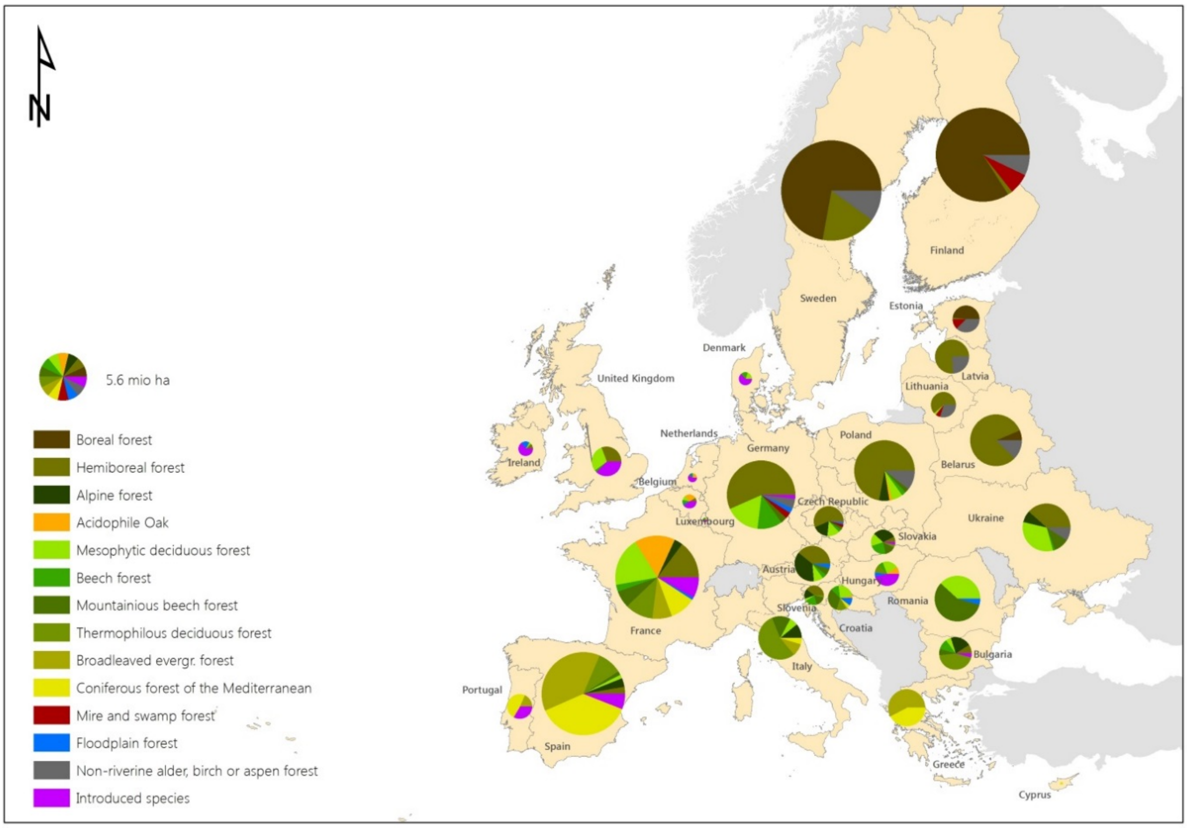
The potential **yield** for western Russia was calculated by using the mean utilisation rates from neighbouring countries and sums up to a total harvestable timber volume of 53 Mio m^3/a. Here too, the EFTs Boreal Forests (61%) and Hemiboreal Forests (13%) dominate the total yield, whilst the EFTs Mire and Swamp Forests (9%), Non-riverine Alder, Birch and Aspen Forests (8%), and Mesophytic Deciduous Forests (5%) contribute another 22%. The potential yield per hectare is highest in the EFT Mesophytic Deciduous Forests (1.8 m^3/ha).

[72] m^3 of standing solid wood over bark, not including branch wood below 7 cm in diameter or roots.

3.2.4 Geographic distribution of European forest types

The distribution of the European forest types in Europe is one of the basics to determine which regions and which forest types are most important to focus on with the measures to increase the yield. In general most of the European forest types have a geographic centre or a particular region where it occurs, as shown in the figure below, which shows the distribution of European forest types and their geographic core area.

Figure 65: Map of the project area Europe 28 plus Belarus and Ukraine – distribution of European forest types according to country; extent of the pie graphs is equal to the land area covered by forest in the respective country.



The domination for the entire European scale of the European forest types Boreal Forest and Hemiboreal Forest with their geographical localisation clearly in the Northeast is most obvious. This not only affects the value of total land covered by forests in Europe. It also strongly dominates the composition of forest types in the countries of the boreal and hemiboreal zone. The EFTs Boreal Forests and Hemiboreal Forests are expected to be affected most by yield increase measures for a surplus production of woody biomass.

Another obvious fact shown by the map is that several European forest types just occur in certain regions. This applies to the EFTs Beech Forest and Mountainous Beech Forest, which occur mainly in central Europe with a branch into the central eastern part of Europe. When sorted according to importance of forest covered land, Thermophilous Deciduous Forests, Broadleaved Evergreen Forests and Coniferous Forests of the Mediterranean are located in the southern part of Europe, particularly in the Mediterranean zone. In analogy to the Boreal Forests, the Non-riverine Alder, Birch or Aspen Forests occur just in Northeastern Europe.

Although the EFT Floodplain Forests is distributed all over Europe there is a clear core area in central Europe with branches to central western Europe and central eastern Europe. This is due in large part to the European rivers courses of the rivers Rhine and Danube. The area of Mire and Swamp Forests is not as important in terms of the land covered, but there is a clear geographic localisation in Northeastern Europe.

To get a better impression of the localisation and distribution of the 14 different European forest types, the geographic core areas and countries are listed below.

- **Boreal Forests**: as mentioned above they are localised in the Northeastern part of Europe and occur from Sweden, Finland over the Baltic states to Belarus. Core area of this European forest type is Finland.
- **Hemiboreal Forests**: this forest type builds a vast ring around the core area of the Boreal Forest. While it does not occur in Finland, it not only affects all the other countries with Boreal Forest but has the widest spread of all the European forest types. It is spreads from Sweden, the Baltic States, Belarus, Ukraine, Slovakia, Austria, Poland, Germany, Czech Republic, Benelux, United Kingdom to France in the South. The core area is located in Sweden, Poland, Germany and the Czech Republic.
- **Alpine Forests**: these are bound to the three big mountain chains of Europe – the Pyrenees, the Alps and the Carpathian Mountains. This forest type is restricted to Spain and France for the Pyrenees, France, Italy, Austria and Germany for the Alps, and Slovakia, Poland, Ukraine and Bulgaria for the Carpathian Mountains.
- **Acidophilous Oak Forests**: this EFT is less important and occurs in Bulgaria, Benelux, Croatia, Czech Republic and Austria. It is only in Bulgaria and Benelux that it covers significant parts of the respective countries.
- **Mesophytic Deciduous Forests**: these forests dominate the composition of European forest types in France. The EFT is also distributed in several countries in the temperate zone from Ireland and United Kingdom over Benelux, Germany, Denmark, Poland, Lithuania, Belarus to the Czech Republic, Slovakia, Austria, Ukraine, Romania, Bulgaria, Hungary, Croatia, Slovenia and finally Italy. It is probably the forest type with the largest amount of covered land and the widest distribution across Europe.
- **Beech Forests**: with a clear core area in central Europe with Germany, France, Benelux, Poland, Czech Republic, and Austria, this EFT also branches to Denmark and Sweden in the North, Slovakia, Hungary, Romania, Bulgaria, Croatia in the East and Slovenia and Italy in the South, with a small exclave in the United Kingdom. Together with the Mesophytic Deciduous Forest, it is presumably the most widespread forest type.
- **Mountainous Beech Forests**: bound to the mountainous zones of central and southern Europe this European forest type exists in numerous countries such as Austria, Bulgaria, Czech

Republic, Germany, Spain, France, Croatia, Hungary, Italy, Poland, Romania, Slovakia, Ukraine and the United Kingdom.

- **Thermophilous Deciduous Forest**: located further to the South, this forest type depends on the warm climate of the Mediterranean and the continental climate in South-eastern Europe. The countries which are covered by this European forest type include Spain, France, Italy, Slovenia, Croatia, Hungary and Bulgaria, with a clear core area in Italy.
- **Broadleaved Evergreen Forests**: this EFT is important on a smaller scale and dominates the forests of Spain and Greece. It mainly occurs in the Mediterranean area which includes Portugal, France and Croatia.
- **Coniferous Forests of the Mediterranean**: as the name suggests, this EFT only occurs in the Mediterranean zone in the countries Portugal, Spain, France, Italy, Croatia, Greece and Bulgaria. It dominates the forests in Portugal and Greece and constitutes a large part of the forests of Spain.
- **Mire and Swamp Forests**: this is yet another forest type with a clear geographic core area in the very Northeastern part of Europe. The EFT has been declared for Belarus, Estonia and Finland, where it has its core area and covers a significant area.
- **Floodplain Forests**: as described above, this forest type has its core area in central Europe in the countries Belgium, Netherlands, Germany, the Czech Republic and Austria and branches toward the Southeast with the river Danube, existing throughout Hungary, Romania and Bulgaria. It also occurs on smaller areas in Poland, France, Slovenia, Croatia and on a larger scale in Ireland. This European forest type is – per definition – associated with the floodplains of the temperate zone.
- **Non-riverine Alder, Birch or Aspen Forests**: this is another European forest type which is geographically clearly located in the North-eastern part of Europe. It occurs in Sweden, Finland, the Baltic States, Belarus, Ukraine, Poland and to a small degree also in the Czech Republic, Belgium and the Netherlands.
- **Introduced Tree Species Forests**: due to its artificial establishment, this European forest type is erratically spread all over Europe. It occurs in Germany, Bulgaria, the United Kingdom, Spain, France and Ukraine. It adds quite a large amount to the forested areas of Ireland, Portugal, Denmark, Benelux and Hungary. These are all countries which had vast areas of degraded forest sites or developed large-scale plantations.

Although there are clear trends in the geographical distribution of the European forest types, the merging process of the different sources for the baseline data has its weak points. In Greece, for example, there are just two different forest types named by the two main resources for the baseline. In contrast, there are ten European forests types in the dataset for France, each with a specific regional correlation.

3.3 Selection of measures and strategies to maximise yield

Within this chapter potential strategies and measures which enable the maximisation of yield derived from woody biomass per area (in the following referred to as "yield measures") are identified and described.

Potential yield measures are management strategies or measures which enable an increase in growth and respective yield of a tree, a tree species or a forest stand per area. Yield is not only referred to as biomass in tons, but also considers quality attributes of wood and bark, depending on the utilisation (sawmilling, pulp, combustion, ethanol production, etc.). Yield increase also includes measures to reduce losses during the development of a stand due to abiotic (storm, snow, fire, drought) and biotic damages (insects, fungus, game, cattle). Losses in wood biomass also occur during the harvesting process between the forest stand and the wood industry or wood consumer.

In the applied approach, the potential yield measures are subsumed under five general levels: species level, site level, stand level, forest management level and forest operations level. UNIQUE conducted literature studies (directly cited), expert interviews (see annex A), and added its internal expertise (UNIQUE 2015) to collect and select all the important measurable yield increasing factors.

The yield measures regarding the different levels are described as follows: first, a brief definition is given about the measures' background. Secondly, measures are specified, and thirdly, the regional applicability within the study area is briefly discussed. Fourth, the main constraints for an application are anticipated even though the in-depth analysis of ecological, technical and handling constraints will be carried out later. And fifth, the effect over time is evaluated according to the following five classes (see Table 50).

Table 50: Time ranges for yield increase measures to be fully effective

Yield increase effect in the time line (0 - 30 years)	
>20 years	Long term
>15-20 years	Medium-long term
>10 years	Medium term
>5 years	Short medium term
>1 year	Short term

A mid-term or long-term range for the yield increase effect does not mean that the yield potential only increases at the end of that period. Instead, it implies that the full effect as estimated can be achieved at least in the mentioned period of time. The effect will only gradually increase as the yield measure is applied.

3.3.1 Species level

At the species level, intensified breeding and the introduction of non-native species were identified as appropriate measures to improve biomass yield (Rosvall 1999).

3.3.1.1 Breeding

Definition: Tree breeding refers to the genetic improvement of tree populations in order to enhance their survival, growth and wood properties by making use of the genetic variability (diversity) of trees and their ability to inherit specific traits (Rytter et al. 2013). While the aims of tree breeding programs can be very diverse, the main objectives tend to focus on either economic traits (e.g. growth, survival, resistance to pest and diseases, stem form, branchiness and wood quality), adaptability (changing climate or environmental conditions), or gene conservation (Rosvall and Mullin 2013).

Forest tree breeding mimics natural selection through recombination and selection pressure but with two major differences: artificial selection is directional, focusing on socio-economic needs and adaptive requirements, and the selection process is faster. Tree breeding mainly addresses species of economic importance and for which artificial regeneration, by plantation or by direct sowing of improved varieties, is used for afforestation and/or reforestation (Pâques 2013). As claimed in the Annex of the Strategic Research and Innovation Agenda of the forest-based sector technology platform (Edelmann et al. 2013)[73], genetic improvement is one of the most efficient ways of changing the genetic makeup of domesticated and wild populations for increased yield and economic value and for adaptability to new environments.

Different approaches to breeding can be defined upon which concrete measures are based. The traditional method of breeding is based on the phenotypical selection of individuals with desirable characteristics to gain plants with a higher productivity (Pâques 2013). Alternatively, at stand level, the negative phenotypical selection of individuals during thinning (i.e., removal of trees with inferior quality) aims to realise better genetics in the remaining stand and following generation (Mayer 1992; see below “Forest stand level”).

Hybridisation is characterised by intentionally combining the genetic material of two related species of the same genus to create a hybrid which combines the positive characteristics of the parental species, often leading to "hybrid-effects" of improved growth (e.g., larch (*Larix* spp.), aspen or poplar (*Populus* spp.), walnut trees (*Juglans* spp.)). Hybridisation does not play much of a role in the management of forests yet. Emphasis in hybrid research has been placed on highly valuable and highly productive tree species; these are often non-native species such as larch (*Larix decidua*), Sitka spruce (*Picea sitchensis*), poplar (*Populus* spp.), willow (*Salix* spp.), eucalyptus (*Eucalyptus* spp.) or other species that are suitable for short rotation systems, where new hybrids can significantly contribute to an increase in yield in each new rotation. Furthermore, the development of vegetative clonal material has a very high impact on an increase in yield, although this is also mainly relevant for plantation forestry in south-west Europe, UK and the short rotation forestry with poplar (*Populus*

[73] Available online: http://www.forestplatform.org/files/SRA_revision/Renewed_SRA_for_2020_Annex_.pdf

spp.), willow (*Salix* spp.), black locust (*Robinia pseudoacacia*)or Paulownia species (*Paulownia* spp.) (not a topic of this study). Improved genetic material can also be applied for poplar species (*Populus* spp.).

The use of clones may greatly increase yield, as is demonstrated by a study conducted by (Routa et al. 2013), where the height and diameter of Norway spruce (*Picea abies*) clones was 30-35% above that found for non-clonal trees.

Classical breeding techniques lead to genetically *improved* tree species; in contrast, the development of genetically *modified* tree species (Genetically Modified Organisms, GMOs) focuses on adding or modifying specific genes, with the aim of creating desirable phenotypes and quality traits of a species. The use of genetically modified trees is currently prohibited outside of a pure research context (Edelmann et al. 2013), and they will not be included within this project.

Operationally, tree breeding efforts have resulted in the selection and creation of improved varieties for nearly all forest tree species at the European level. However, the most active and innovative breeding programs exist only for species which are either heavily planted or have a high timber value. In Europe these include Scots pine (*Pinus sylvestris*) and maritime pine (*Pinus pinaster*), Norway spruce (*Picea abies*) and Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), poplar (*Populus* spp.) and a few noble hardwoods (Pâques 2013).

The steady introduction of improved plant material during the regeneration phase of forest stands, which also matches the specific site conditions, can lead to 10-25% improved yield and can be applied to the whole study area. The effect can only be achieved in the long-term (>20-30 years) as the effect can only be materialised in a new generation (Ruotsalainen 2014). An average rotation of 100 years leads to 1% of newly regenerated forest area with optimally 25% improved yield potential from genetically improved material. In this rough scenario each year the yield could be improved by 0.25% or 2.5% in a ten years period. An additional effect can be gained by steady and consequent release of superior trees during tending and thinning.

Unseld (2012) lists similar gains when stating that breeding programs can improve the yield of stands of the respective species between 15-30% while also improving quality aspects such as straightness, branching, or ovality. The production value can therefore be improved by more than 30% (Pâques 2013). Improved genetic material can also be applied for poplar species (*Populus* spp.).

Species-specific tree breeding programs are still lacking for many noble hardwood species, though some initial trials have been conducted. For example, most work concerned with the improvement of European oaks is concentrated on pedunculated oak (*Quercus robur*) and sessile oak (*Q. petraea*), but there have been a number of difficulties in making improvements. Amongst them are limited knowledge on the extent and pattern of genetic variation, the long period to reproductive maturity, and the difficulties in vegetative multiplication (Savill and Kanowski 1993). Breeding programs have been initiated for sycamore maple (*Acer pseudoplatanus*) within the last few years but still need to progress further (Pâques 2013). For common ash (*Fraxinus excelsior*) there is a clear need for optimisation, especially in terms of preventing ash die-back (*Chalara fraxinea*). There has been an evident decline in the health status of mature stands in most countries of the study region in recent years. Priority should therefore be given to establishing national and international breeding programs to breed disease resistant material which can then be used for restoring damaged ash forests (Pâques 2013). Hardly any breeding information is available for common hornbeam (*Carpinus betulus*), and while the situation is similar for lime species (*Tilia* spp.), at least a few experiments have been conducted and experiences in clonal testing are available (Kobliha, Hajnala, and Janeček 2003).

Constraints: The constraints of breeding programs may be classified according to biological, economic and institutional factors (Rosvall and Mullin 2013).

Some tree species have a large distribution and a large pool of genetic diversity upon which breeding research can be based (e.g., boreal tree species). Others are more limited in their diversity, therefore limiting breeding material and approaches. Breeding implies the selection of genotypes according to a limited number of traits. Selective breeding may lead to reduced genetic diversity (Namkoong, Kang, and Brouard 1988) which is contradictory to the objectives of protecting biodiversity and preserving a wide gene-pool as source for adaptation to unknown changes of habitat conditions (climate change, new pests). Therefore, breeding programs have to keep a wide range of genotypes and provenances. A balance has to be found between forest area planted with improved material and natural regeneration.

A further constraint is linked to the introduction of improved plant material. It is restricted to regeneration phases (every 40–160 years in European forests). Compared to natural regeneration, artificial regeneration can be quite costly in terms of time and resources (breeding process, propagation, planting and protection). It therefore faces economic hurdles, research and knowledge gaps.

Measure	Breeding
Regional applicability	Entire study area
Yield increase effect	10-25%
Timeline	>20 years and more (long-term)

3.3.1.2 Introduction of non-native species

Definition: The introduction of non-native tree species aims at improving productivity by mixing non-native species into existing forests to improve the yield of high value timber products. Non-native species could be introduced stand wise, group wise or as single trees, depending on the site conditions and aim of forest management. This measure has recently received more attention due to the challenges associated with climate change. Non-native species from warmer and/or drier climate zones might match future site conditions in Europe.

Examples of non-native, non-invasive tree species include eucalyptus species (*Eucalyptus spec.*), Sitka spruce (*Picea sitchensis*), lodgepole pine (*Pinus contorta*), and Douglas fir (*Pseudotsuga menziesii*) (Forest Europe, UNECE, and FAO 2011; European Environment Agency 2007). In a large scale afforestation has been conducted with Sitka spruce (*Picea sitchensis*) in the UK and Ireland (Moore 2011), Douglas fir (*Pseudotsuga menziesii*) and red oak (*Quercus rubra*) (Kölling 2013) in Western Europe, as well as spruce (*Picea* spp.) and larch (*Larix decidua*) far outside of their native range in western and central Europe. Medium-term experiences exist, for example, with the introduction of eucalyptus species (*Eucalyptus* spp.), more than 1 Mio ha exists in Portugal, Spain

and south-west of France (Grupo Empresarial ENCE 2009) or the Kiri-tree (*Paulownia tomentosa*) in Bulgaria, Romania, UK, Portugal, Spain and recently also in Germany (Stimm et al. 2013). Grand fir (*Abies grandis*) in Western Europe has been identified as a well-adapted and highly productive mix into beech forests (Geb et al. 2008). An additional wide spread species, commonly used is black locust (*Robinia pseudoacacia*) (European Environment Agency 2007; Mayer 1992). Examples for the successful integration of non-native species include Douglas fir (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Lodgepole pine (*Pinus contorta*) and red oak (*Quercus rubra*), all of which are now well-adapted to specific site ranges in European forests.
In regional terms, improvements in yield can be achieved on medium to better soils in the southern, western and central part of Europe. The effect on yield improvement through the introduction of non-native species is depending on the site specific growth performance of the non-native compared to the native species. If admixture of the high productive species not exceeding 30% is the target, not a monoculture and if the species and site is carefully selected and genetically improved material is used an increase in yield of 5–30% is possible. The effect can be gained by promoting high-productive species during tending and thinning but mainly during the regeneration process, overall it has an medium-term effect, (>10 years).

A major **constraint** for the further promotion of new species is that the management has to cope with tendencies to be invasive on specific forest sites, meaning that these species are outcompeting natural forest species resulting in loss of biodiversity. Some introduced tree species have become problematic due to their ecological characteristics. Their competitiveness may change the dynamics of forest ecosystems and influence site characteristics, species composition, structure and functional diversity. These non-native tree species are termed invasive species. Conifers are generally not considered invasive but some of the introduced broadleaved species are black locust (*Robinia pseudoacacia*), tree of heaven (*Ailanthus altissima*), boxelder (*Acer negundo*) and black cherry (*Prunus serotina*) (Forest Europe, UNECE, and FAO 2011).
To minimise the risks from invasive tendencies ecological research and a permanent monitoring system need to be in place. A sustainable, multifunctional forest management aims to maintain and use forests so that their productivity, regeneration capacity, and vitality are preserved, while also taking into account measures to safeguard forest biodiversity (Vor et al. 2014). The general opinion in the forestry sector today is that biodiversity cannot be achieved only by management of forests for wood production. Nature conservation, in contrast, is also unable to fulfil all forest functions adequately (Vor et al. 2014; Ammer and Puettmann 2009; Otto 1991). The integration of imported tree species into a silviculture based on ecological principles therefore requires compromises which can be derived from scientific findings. Specifically, this means that the cultivation of non-native tree species is accepted as part of sustainable forest management as long as the interests and restrictions of nature conservation are also taken into account (Vor et al. 2014).

Clear legal **barriers** to cope with the risks posed by invasive species are defined by the EU regulation No 1143/2014 “On the prevention and management of the introduction and spread of invasive alien species” (EU Law 2014) and respective national norms. The lists of invasive species being developed on national levels classify some forest species as invasive. An intensive scientific discussion between the nature conservation sector and the forestry sector is ongoing regarding which species can accurately be considered invasive as well as about their management, specifically on sites with conservation status (Natura 2000) (Vor et al. 2014).

Measure	Introduction of non-native species
Regional applicability	On nearly all sites of entire study area
Yield increase effect	10-30%
Timeline	>10 years and more (medium-term)

3.3.2 Site level

Trees have their own optimal growth rate within a certain range of site conditions (Kozlowski, Kramer, and Pallardy 1991; Oliver and Larson 1996). Improvements of the productivity and yield are possible by selecting the optimal sites for each species (species-site matching), by improving water and soil oxygen availability (water management) mainly on groundwater influenced sites (floodplains, swamps, mires) and soil improvement by fertilisation or improvement of humus content.

3.3.2.1 Optimised species-site matching

Definition: due to soil conditions, site exposition, climate conditions, etc. forest species have their own optimal growth rate if the conditions offered by the forest site meet the specific needs. Hence, applying an optimised species-site matching has a strong impact on biomass yield. The approach of this measure is to maximise the yield by choosing species which fully utilise the site potential.

Site mapping is an important pre-requisite for appropriate species-site matching. With this procedure, the composition of soils is examined and suggestions for site-specific tree species selection can be made. Site adapted tree species (Forstliche Bildungsstätten der Bundesrepublik Deutschland 2011):

- Are well-adapted to the climatic conditions of a growing area
- Exploit the full potential of forest soils, leading to good/optimal growth
- Fully utilise the soil with their roots (well-developed root system)
- Maintain and improve soil fertility
- Enable a healthy development of plant communities which occur on the site

Even though this measure is intensively discussed in plantation forestry (e.g., introduction of high-value native timber (Manson et al. 2012)), it is just as relevant for Europe's forests. An optimised species-site matching could, for example, improve afforestation on the Iberian Peninsula (Pemán Garcia, Navarro Cerrillo, and Serrada Hierro 2006), or huge monocultures of pine and spruce in central Europe located on sites which are appropriate for mixed forests or mesophytic deciduous forests (Mayer 1992). Improvements could also be achieved in pure beech forests in south-eastern Europe which suffer from the exploitation of admixed firs. Beyond improvements in these historically suboptimal species-site combinations, climate change tends to change site conditions to a high degree (Spiecker et al. 1996). As a consequence, forest site mapping has to be completely revised. New decision support systems are being developed which are able to integrate changes in climate and soil when evaluating the productivity of and risks for forest trees species and stands (Albert et al. 2015; Rammer et al. 2013; Nothdurft et al. 2012; Albert and Schmidt 2009). Recently, specific maps have been developed which aim to support the selection of appropriate species in accordance with changing site conditions (Zimmermann, Schmatz, and Psomas 2013). Nevertheless, most site suitability guidelines compiled for forest management do not provide sufficient information on the growth potential of the different “suitable” tree species (Joyce et al. 1998).

Even if the origin of species-site improvements can be manifold, the mentioned measures are valid for the entire study area. The potential to contribute to a sustainable higher yield of woody biomass is very difficult to estimate. Studies showing systematic comparisons between site conditions and in-situ tree species composition, or even the evaluation of selected provenances of a tree species could not been detected.

In conclusion, the yield increase effect of an improved and systematic species-site matching is estimated very conservatively to be 2-3% (UNIQUE 2015). One example of how the potential effect can be estimated is provided by the decision support system “DSS WUK”, which allows the comparison of different tree species on the same soil and under the same climate, including a prognosis of climate change effects (DSS-WuK 2010) – see table below.

Table 51: Potential yield increase from species site matching - comparison of productivity and risk evaluation of two species on two examples of site conditions (soil and climate)

Potential yield increase from species site matching				
Region	Western Black Forest		Upper Palatinate (north-east Bavaria)	
Soil type	Secondary podsole, medium rich		Secondary podsole, poor	
Characteristic	Sandy loam on mixed acid metamorphic weathering rock		Quarzitic sands with insufficient base nutrients	
Climate ***- MAT (°C)*** ***- MAP (mm)***	6.1 °C 463 mm		8.2 °C 645 mm	
Tree species	**Beech**	**Norway Spruce**	**Beech**	**Norway Spruce**
Productivity class - mean annual production in 100 years (m³/ha)	**700**	**1300**	**600**	**800**
Relative advantage in productivity	100%	180%	100%	130%
Risk classification	low	medium	low	high

The differences in growth rates are substantial. An improved yield increase effect could be gained from an admixture of the highly productive spruce into a pure stand of beech. As growth rate is not the only criteria for an improved yield, the risk of damages (bark beetle and storm) is also evaluated.

While the measure can be applied during tending and thinning of foster tree species with a better species-site matching, it is mainly conducted during the regeneration of stands (after a 40–160 year rotation). As a result, this effect is considered to be long-term.

There are no known implementation **constraints**. The **barriers**, however, include the lack of research, non-existing site surveys and respective guidelines for the selection of tree species.

Measure	Optimised species-site matching
Regional applicability	Entire study area
Yield increase effect	2-3% - conservative estimate due to the lack of studies
Timeline	>20 years and more (long-term)

3.3.2.2 Water management

Definition: water is essential for plant physiology and its availability has a direct impact on forest growth and vitality. Water management aims to improve the water availability for forests. Measures applied can range from artificial irrigation, to groundwater management in swampy areas or in floodplain forests, to humus content improvement in mountainous forests to improve water retention. This measure can be sub-divided into i) drainage, ii) irrigation, and iii) indirect influences on the water household, such as humus improvement or considerations in constructing forest roads.

i) Drainage

In the past, drainage systems were established in order to change site conditions for more productive species and to increase yield. Drainage of swampland and moors was used to create or improve productive agricultural and forest sites (Stoeckeler 1963). Specifically in the boreal zone, the effect of drainage on forest production was high, with peaks in the 19th and 20th century (Hesmer 1986). Drainage is widespread in Scandinavian countries, but also applied to a lesser extent in western and central Europe (UK, Netherlands, Flanders, France, north-west Germany), and on some floodplains in south European countries (Hungary, Romania). In most Scandinavian countries, the development of new drainage systems is restricted, as in most other countries, due to its influence on natural soil and habitat conditions. The maintenance of existing drains is relevant in order to sustain a high productivity and to control the (ground) water level for optimal growth. For example, extensive drainage in the boreal peatlands has had a striking effect on forest productivity; increases of 50% to over 300% in mean annual increment were recorded for slash pine (*Pinus elliottii*) plantations after drainage (Duncan and Terry, 1983 in Gholz, Ewel, and Teskey 1990). Drainage can shift the conditions of water-influenced sites with low growth rates to sites with higher growth rates. The

resulting effect is that more productive species can be grown (e.g., transition from alder (*Alnus* spp.) to spruce (*Picea* spp.) in Scandinavia).
As a yield measure, drainage areas should be maintained in northern Europe, and former drainage areas which have become overgrown can be restored in western and central Europe. The effect on yield is estimated to be 2-10%, depending on the quality of the drainage system and its potential to have constant control over the water levels. The measure can be applied in the EFTs floodplain forests, mire and swamp forests, and more generally in lowlands with a high percentage of organic soils, where drainage systems often already exist.

ii) Irrigation
For the time being, irrigation in forest areas is not applicable due to the large areas in question. However, on particularly dry sites, temporary irrigation can be applied during the establishment (planting) phase of new forest stands to improve the survival rate and stocking of saplings. Weeding and mulching are further methods to reduce plant competition (Davies 1985) for water during the early tree generation stages (Coll et al. 2003). Therefore, a yield increase effect is not taken into consideration.

iii) Indirect influences on water availability
Water drainage effects of forest roads on dry or mountainous areas should be taken into consideration. Skidding/access roads need to be carefully planned and equipped with facilities to redistribute water from the road system back to the forest stands. The outline of the road network should avoid high in-slopes (Dietz, Knigge, and Löffler 2011).
Improvement and restoration of the humus content can be achieved in dry and mountainous terrain by erosion control, selection of an adapted management regime, and adapted harvest operations (i.e., cable yarder instead of skidding roads[74] and fire prevention[75] are indirect measures to retain water in the soil and to improve water availability for trees, therefore resulting in improved growth, vitality and yield). Unfortunately, it is not possible to estimate a yield increase effect for this measure as studies quantifying these known effects are not available.

Constraints:
i) Drainage is widely applied but critically regarded due to its negative impact on natural soils and the respective habitat changes, especially where swamps, mires and wetlands are rare; this is true for many parts of the study area. As such, creating new drainage systems as well as maintaining existing systems is a matter of environmental assessment procedures, or in some cases, prohibited in forests underlying a particular nature conservation status.
A further constraint is that draining organic and peat soils leads to the release of greenhouse gases and a reduced below-ground carbon storage (humus and peat losses) in the soil (Gelman et al. 2013; Ojanen, Minkkinen, and Penttilä 2013; Tiemeyer et al. 2013). Whereas in some soil and climate conditions, growth rates of the forest seem to overcompensate and lead to a carbon sink of the total

[74] See yield measure “Forest operations” in chapter 3.3.6.
[75] See yield measure “Fire management” in chapter 3.3.5.1.

ecosystem, forests are turned into a GHG source if drainage is newly established or drastically maintained and too deep (> -25 cm water level). As most of the drainage systems are already in place, it is recommended to control the water level close to a constant so as to avoid fast mineralisation of humus and peat, and to maintain a high carbon sink effect through high growth rates of the forest stands.

Where drainage systems exist on water-logged soils and peatlands, climatically sustainable forestry seems to be possible if the harvested biomass is later stored, for example, in wooden buildings, biofuels or as biochar on agricultural soils ("product storage") (Ojanen et al 2012).

Even though the positive influence of forests towards the landscape water household is remarkable (reduction of dry-season flows, mitigation of small and local floods, protection of drinking water), the simple formula "the more trees, the more water" must be viewed critically nowadays (Calder et al. 2007). Groundwater supply or recharge under forests is not optimal, meaning that in the drier climate of southern Europe drinking water preservation or water management on a landscape level requires special management regimes (open forests, intensive thinnings, and broadleaved instead of conifer forests). Forest management is therefore a compromise between optimised yield and ground water supply.

Constraints for ii) irrigation are mainly economic in nature. Without economic constraints, the major limitation would arise from the question of water origin, which would be used for irrigation. For this reason, systematic irrigation is not applied in sustainable forest management throughout all of the regions.

Constraints for iii) indirect influences on water availability do not exist.

Barriers include the lack of knowledge about the effects of drainage, as well as on the effect and optimal maintenance of older systems. With exception of northern Europe, UK and Ireland, the maintenance of traditional drainage systems in forests is no longer contemporary and is usually neglected.

In general there is also not enough knowledge on the potentials of water management and therefore low acceptance of related costs in the forestry sector and also not in the politics. These barriers exist mainly in central and western Europe, where active water management is only be accepted for agricultural purposes.

Measure	Water management
Regional applicability	EFT floodplain forests, swamp and mires (in the boreal and hemiboreal zone)
Yield increase effect	+ 2-10% - the effect is only considered for water management through i) drainage
Timeline	>5 years and more (Short to medium-term)

3.3.2.3 Soil improvement

Definition: Soil improvement can be defined as activities not only to protect forest soils from degradation (e.g., erosion) but to improve its performance as rooting medium, and source of water and nutrients for forest ecosystems. In the 19^{th} and 20^{th} century, forests were often overused due to

inadequate extraction of wood, overgrazing and extraction of foliage. Additionally, so-called "acid rain" (NOx and SOx immissions) led to acidification of forest soils, decreasing the provision of essential nutrients for the trees. Intensive use of young forests (industrial purposes) and harvesting of wood, bark, crown material, branches (firewood) and stumps results in high nutrient extraction through the removal harvested material. Moreover, the ongoing immission of anthropogenically caused nitrogen worsens the situation by causing an imbalance in nutrients and trace elements.
The application of fertiliser to influence the nutrient level of forest soils in forestry can be divided into the following measures:

i) Fertilisation, to improve nutrient content and improve tree vitality and growth where a naturally given poverty/certain lack of nutrients exists;
ii) Restoration, to compensate massive nutrient removal caused by overusing or degradation of sites;
iii) Melioration, to compensate for depletion caused by the acidic emissions (i.e., nitrogen and sulfuric acid) and harvested biomass or a combination of both.

i) Fertilisation
In the temperate regions of central Europe, soil acidification and lack of calcium, magnesium and potassium are the main problem, whereas in the boreal zone the soils tend to have a nitrogen deficiency. As such, classical fertilisation tends to be applied mainly in the boreal zone, rather than in the temperate zone. The yield increase effect of fertilisation has been examined in various studies. Simonsen et al. (2010) demonstrated that applying multiple fertilisation treatments in boreal forests – the first one at least 20 years before the trees are harvested – can lead to an 8% (Norway spruce; *Picea abies*) to 12% (Scots pine; *Pinus sylvestris*) increase in growth. In a fertilisation experiment in temperate forests conducted by the German Federal Forest Research Centre, an increased growth of 0.7 to 3.9 m^3 per year and ha was documented over a period of 15 years. The fertilisation effect, however, was only fully effective as of the 2nd or even the 3rd five-year period in some cases. For coniferous forests of the temperate zone it can therefore be said that the effects of fertilisation only have a noticeable impact on growth after 5-10 years and the effect will last for roughly 5 years (Mayer 1992). Furthermore, improvements in German forests due to combined fertilisation and melioration have been recorded in the form of an MAI increase of 19-29% in two Scots pine stands (Prietzel et al. 2008) and a 9-40% increase in annual volume increment in a formerly highly degraded Scots pine stand (Klemmt et al. 2007).
The effect of fertilisation is only applicable in boreal forests and is estimated to lead to a yield increase of 5-25%, although this figure is highly dependent on site conditions.

ii) Restoration
Soil degradation is mainly a problem in mountainous or karst-rich areas of southern Europe and is caused by erosion and overgrazing by cattle combined with periodic forest fires. There is a deficit of humus and fine soil, which means that the nutrient availability and water storage capacity are reduced. Forest management can react to this situation with a combination of measures:

a) Keeping crown and branch material in the stand, promoting a multi-storey stand structure and a dense ground vegetation layer help to reduce erosion and lead to an increase in the humus content. A higher humus content improves the water storage capacity as well as the amount and availability of nutrients.

b) Continuous cover forest management to avoid blank soil situations.

c) Fire prevention (see chapter 3.3.5.1).

d) In terms of forest operations, erosion control in sloping terrain can be improved if cable yarders are used instead of mountain harvesters, and if yarding lines are not installed parallel to the slope direction. Preference should be given to diagonal lines and shorter distances between the cable extraction lines.

The yield measure is related to the area with degraded sites, which are mainly concentrated in southern Europe. The measure will have an effect in the medium-term and can only be estimated to increase forest yield by 5-10%.

iii) Melioration

As mentioned above, in the temperate regions of west and central Europe, soil acidification and lack of calcium, magnesium and potassium are the main problem. For this reason, tree growth is usually determined by the scarcity of these elements, rather than by nitrogen which tends to be available in excess due to anthropogenically caused atmospheric deposition. In fact, tree growth stimulation becomes unbalanced by a nitrogen surplus, since it leads to a higher demand for other nutrients which cannot be met due to soil acidification/degradation. An increase in growth due to higher levels of nitrogen is therefore limited in time. An imbalance in the nutrient supply triggered by an N-surplus can, for example, lead to an acute potassium deficiency, particularly after and in combination with dry years (von Wilpert 2015). Given this situation, melioration with basic cations is essential in order to balance the nutrient levels. This approach may lead to a long-term increase in forest productivity.

Natural and industrial limes can be applied on acidic sites according to the individual requirements of the sites. Limes are applied either by air (helicopter) or by specific machines which blow the material from forest roads into the stand. Both techniques are practiced in central and northern Europe.

Melioration is practiced mainly in western and central Europe. For example, the German federal state of Baden-Württemberg recommended soil improvement (melioration with lime and wood ash) for about 5% of its forest area (600,000 ha) to regain the original state of forest soils (Schäffer 2006). It is difficult to estimate a growth effect due to the multivariate conditionality and the spatial-temporal dynamics of the problem. Nevertheless, the combined effect of nitrogen immissions and melioration is estimated to lead to a 3-5% increase in yield.

Constraints:

i) Fertilisation of forest stands with the aim of increasing growth is applied on specific soils in Scandinavia due to its remarkable growth effect as nitrogen is generally the limiting factor. It is also applied in the Eucalyptus plantations of south western Europe and partly in Sitka spruce management in north-western Europe. Nevertheless, even in regions where fertilisation is applied, the primary operational factors limiting this yield measure include the prohibitive cost of purchasing and applying fertilisers in forests and the potential need for application on vast land areas. Due to these considerations and a lower yield increase effect, the use of fertilisers in most other parts of the region is rare (Ellsworth and Oleksyn 1997). Since forest soils are the most natural type of soils in Europe,

sustainable forestry practice (Forest Europe, UNECE, and FAO 2011) aims to protect the properties and biocenosis of particularly these soils; both aspects are altered if fertilisation is applied. Soil improvement measures are therefore not applied in protected forest areas. The risk of raising GHG levels from fertilised soils also increases costs due to complex planning and application, and lowers public acceptance (Hemström, Mahapatra, and Gustavsson 2014).
ii) Restoration is hardly discussed in forestry and iii) melioration is practiced where industrial or agricultural immissions have caused soil acidification and nutrient depletion (west- and central Europe). Constraints include the high cost of application and the impact on natural forest soils under nature conservation.

Barriers are considered to be the lack of diagnostic guidelines for the type of fertiliser mixture needed and lack of knowledge of the efficiency of single or multiple fertiliser applications to a variety of sites, especially if negative impacts to the soil and habitats shall be minimised.
For fertilisation and melioration research, soil surveys and analyses, training measures for proper implementation are time consuming and costly. The long term positive effect in the future does not lead to investment decisions today in many regions of the study area with exception of Scandinavia as improved yield on stable forest soil are not a widely accepted or noted management objective.

Measure	Soil improvement
Regional applicability	i) Fertilisation: boreal zone ii) Restoration: mainly mountainous areas of southern Europe iii) Melioration: entire region
Yield increase effect	i) Fertilisation: > 5-25%, highly dependent on site conditions ii) Restoration: 5-10% iii) Melioration: 2-5% in areas where nitrogen immissions exist
Timeline	i) Fertilisation and ii) melioration: >5 years (Short-term to medium-term) ii) Restoration: >10 years (medium-term)

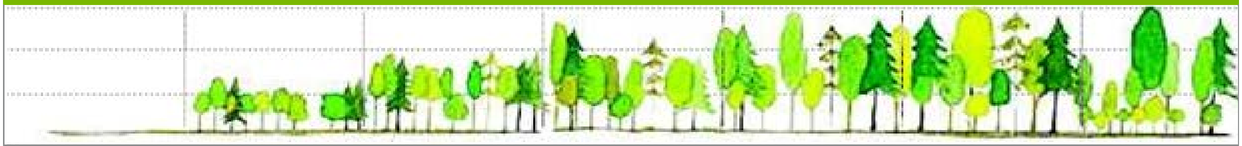
3.3.3 Forest stand level

A "forest stand" is the uniform operational unit designed to make forest management efficient. It is defined as a contiguous group of trees sufficiently uniform in age, species composition and structure, and growing on a site of sufficiently uniform quality, to be a distinguishable and manageable unit. A forest stand is generally described by its location, area, species composition, tree density, standing volume, increment etc. Forest stands are the key unit within which forest planning and forest operations take place.
There are two broad classifications of forests stands (Forest Europe 2015a):

- Even-aged stand – a stand or forest type, in which no or relatively small age differences exist among individual trees within it, usually less than 20% of the rotation length
- Uneven-aged stand – a stand consisting of trees of a range of age classes, with age differences which are significant in relation to the stand structure management and rotation length

In each stand of the different forest types, a management approach or "management regime" can be applied, which is defined as a range of silvicultural operations during the life cycle of a forest stand.

Forest growth stages



Undeveloped area	Thicket	Differentiation stage	Dimensioning stage	Ageing stage	Mature stage	Regeneration stage
Cutting, browsing protection, fencing…		Clearing	Tending	Thinning	Harvesting	

Figure 66: Forest growth stages; Source: Hessian Forest Service, Silvicultural Guidelines

The informed selection of a management regime as a silvicultural system is a crucial step in forest planning which has major consequences for growth, vitality, yield and sustainability. The selection can only partially be influenced by a forest manager; given and therefore uncontrollable variables include site conditions, the current tree species composition, climate, but also economic and market circumstances. The management regime is controlled by forest management through the selection of silvicultural operations at the stand level, such as site preparation, tree species selection and tree species composition, regeneration, planting and spacing, tending, thinning, final harvest and further regeneration strategies.

We have distinguished two yield measures, which are both closely related to the idea of the management regime. The first, trees species composition and mixture, is regarded as a central decision for stand level management and has a huge potential for optimizing yield. The second, optimised management regime, deals with the other set of silvicultural operations such as spacing, tending, thinning, the final harvest and regeneration strategy.

3.3.3.1 Tree species composition and mixture

Definition: The yield measure tree species composition and mixture refers to the definition and selection of an optimal set of tree species and the form of their mixture in a forest stand, so that it results in optimal growth and vitality on the specific site.

The tree species composition in a forest is affected both by natural factors (climate, edaphic and hydrological site conditions, stage of stand development) and by past and present human activity (grazing, agro-forestry, forestry). In Europe at high latitudes, altitudes, or under certain ecologically limiting conditions (e.g., peatland, poor soils) single-species, mainly coniferous, forests naturally dominate. Mixed forests of the boreal zone are associated only with the early stages of stand development or overly rich soils, and are naturally more frequent in central and southern Europe, in broadleaved deciduous and in mixed evergreen forest zones (Leikola, 1999 in European Environment Agency 2007).

Within a given forest area the edaphic variation, from poor to rich soils, and hydrological site conditions, from wet to dry soils, are further key factors explaining the variation in tree species composition. Forests in Europe are highly influenced by human management, and their composition has changed drastically over the years. Naturally occurring uneven-aged, mixed forests or those with a similar structured due to exploitation were converted into even-aged, homogeneous forests. Large afforestations were carried out in western and central Europe on areas that were devastated or that had been logged during or shortly after the First and Second World Wars; in the same period many national reforestation programs were carried out in southern European countries to recover degraded lands and protect soil from erosion.

This yield measure aims to add suitable tree species to pure stands or stands of only two species to improve their overall growth, vitality and yield.
The mixture of different site-appropriate species results in several effects when compared to pure stands:

- Higher productivity
- Higher biodiversity levels
- Greater resistance and resilience to human or non-human disturbances
- Higher carbon storage capacity and thus higher potential for mitigation strategies

Several studies in temperate and boreal forests found over-yielding of mixed versus pure stands of 20-30% in terms of stand volume productivity, due to the niche complementarity of associated species (Bielak, Dudzińska, and Pretzsch 2014).
Tree species mixtures in single-storey forests (fir-beech, spruce-beech) can be combined with a mixture in two-storey or even multi-storey stand structures. This is possible if shade tolerant species are mixed (i.e., fir-spruce-beech in typical plenter forests (Schütz 2003)), or if shade tolerant species are mixed with light demanding species (e.g., pine-beech, pine-oak, pine-spruce (Bielak, Dudzińska, and Pretzsch 2014)).
Moreover, temporary mixtures of fast and slow growing species can be promoted (e.g., cherry-beech, larch-beech, birch/aspen-spruce, poplar-oak, poplar-fir), which temporarily increase yield and synergy effects by nursing the slower growing species (Unseld 2012).
In general, an intensive mixture of species in small groups which take into consideration micro site differences improves stand growth and lowers the risk of losses through storms, fires or fungus and insect pests.
This yield measure can be applied on all sites. Rare exceptions include the situation where the natural vegetation consists of only a single species (mountain pine (*Pinus mugo*) at the treeline; Scots pine (*Pinus sylvestris*) at the boreal tree line). A given species mixture can be changed gradually by tending and thinning in a short period or underplanting, but mainly during regeneration phases, which results in a medium to long-term effect (> 10–20 years).
The yield increase effect for intensive mixtures in single-storey stands can be estimated to be 20-30% (see above), multi-storey mixtures might add up 20-30% (see Bielak, Dudzińska, and Pretzsch (2014) for pine-spruce). Temporary mixtures can add 5-15% (Weinreich et al. 2012 in Unseld 2012). In general, the effect increases with the evenness of the mixture, heterogeneity of shade tolerance

and species richness (Zhang, Chen, and Reich 2012). The effect is more pronounced in dense stand conditions, on poor sites and in years with bad growth conditions (Pretzsch 2013).

Constraints for the application of the yield measure do not exist.

Barriers include the necessity for a higher intensity of forest management (e.g., thinning and pruning). There is also an evident lack of knowledge regarding the optimal set of species, the effect of the mixture and the management. Harvest operations are more complicated and tend to be more costly, especially in multi-layered mixed stands. For well-managed forests the application of these measures is quite realistic, whereas for private smallholders the implementation seems less probable.

Measure	Tree species composition
Regional applicability	Entire study area, where monocultures or stands with only single-storey and only 1-2 species occur.
Yield increase effect	20-30% compared to single species, even-aged stands
Timeline	>15-20 years and more (medium to long-term)

3.3.3.2 Optimised management regime

Definition: An optimised management regime combines a set of silvicultural operations such as planting and spacing, tending, thinning, the final harvest and regeneration strategy to optimise the yield which can be achieved on a specific site. The selection and application of certain tree species mixture (see chapter 3.3.3.1 above) is part of an optimised management regime.
To be able to harvest high amounts of woody biomass and valuable timber products, the following measures are recommended for the different silvicultural operations.

- *Spacing:* starting with a dense young stand from a combination of artificially planted or naturally regenerated site-appropriate set of tree species and a dense matrix of other species from natural regeneration (e.g., oak-beech as target species; dense matrix of spruce, pine, aspen, and/or birch). During the establishment of a new tree generation genetically improved plant material should be used. The yield increase effect is a high number of trees, high volume and increment, early harvesting of biomass during tending and early thinnings. There is also a vertical mixture effect due to different height growth.
- *Tending:* early tending with first harvest of biomass (energy wood) and facilitation of the target species by securing their competitiveness and stability, while maintaining a very high tree density.
- *Thinning:* regular thinning controlled by tree height (thinning measures in Europe are site dependent and usually conducted every 5–10 years) combined with the selection and facilitation of potential crop trees (PCTs) mainly from the target species. Harvest of industrial timber (particle board, pulp) in early thinnings. Most of the biomass harvested during the 40–140 years of rotation of a stand results from thinning. Thinning can improve

the growth rate and increase structural diversity. Increasing the canopy complexity by selecting trees with different heights promotes more efficient use of light and nutrients, and improves the overall yield and wood quality as well as health and resilience of the stand.

- *Final harvest and regeneration strategy:* the point of final harvest will be species dependent and needs to consider the typical growth dynamics, the highest quality of the main product and minimizing age dependent damages (e.g., heart rot, colored heartwood, storm, etc.). Thinnings allow for a dense natural regeneration layer to develop, which is the basis for advanced regeneration leading to overlapping generations of trees and an increase in growth rate and yield. Depending on the potential tree species composition in the forest type, a two-storey vertical structure or a multi-storey structure (e.g., through group selection or single tree selection strategy) can be recommended. This will have an impact on yield optimisation through improved growth rates, but will mainly contribute through a healthier, more diverse and resilient stand structure.

By applying the described measures, the rotation of a tree generation can be reduced in many cases while also increasing the quantity and quality of biomass and wood products (Burschel and Huss 2003; Schütz 2003; Otto 1994; Mayer 1992; Kramer 1988).

The yield measure can be applied throughout the entire study area. The yield increase effect is based on the comparison with unmanaged or unsystematically managed forest stands. In Europe, extensively managed forests exist:

- Mainly in small private forests[76] but also in smaller community forests.
- Where markets for woody biomass do not exist or only for very small assortment ranges, such as conifer saw logs (Russia).
- Where other management objectives exist, which do not target yield optimisation (urban forests, hunting as objective).

The overall yield increase effect against the described extensively managed forest is estimated to be 10-20% depending on the previous management intensity (Jari Hynynen et al. 2014; Jonsson et al. 2013; Spellmann 2010; Normark et al. 2007; Nagel 2006). As the effect is based on a series of silvicultural operations, it will only have a medium to long-term effect (> 15–20 years).

The **constraints** are mostly economic in nature and are relevant on steep slopes and on wet sites, where intensive management is costly. Moreover, the described form of intensive management is not recommended in mountain protection forests and urban forests.

Most of the measures and strategies are well known and scientifically approved, and best practice guidelines exist for several forest types, countries and regions (see for example Ireland, Nisbet, and

[76] In 2008, the share in area of forest and other wooded land in Europe was evenly divided between private ownership (49.55%, 68.5 million ha) and public ownership (50.09%, 70 million ha) (Schmithüsen et al. 2008). According to more recent figures from the the FAO Global Forest Resources Assessment, private forest ownership in Europe excluding Russia accounts for more than half the forest area (ca. 52%) (FAO 2010).

Broadmeadow 2006; Irland and Collins 2000). Mainly large-scale private forest enterprises in western and northern Europe define their forest management strategies according to this approach, but the essential information is generally only available from state forest administration bodies or research institutes. As such, the **barriers** for this yield measure include knowledge-gaps concerning the actual implementation of the measures. A further barrier is the increasingly complex management of multi-layered forests, which will require well-trained staff or training of forest owners. Moreover, harvest operations require more professional skills and adapted techniques.

Measure	Optimised management regime
Regional applicability	Entire study area, mainly focused on deficit areas in private and community forests
Yield increase effect	10-20%
Timeline	>15-20 years and more (medium to long-term)

3.3.3.3 Coppice improvement

Definition: Coppicing is a method traditionally used in stands where tree species re-grow after cutting by developing coppice shoots from the stump or roots. Production cycles vary from short rotation (5 years or even less, mainly for energetic uses) practiced on agricultural land, to coppice forests with long production cycles (20-60 years). Typical coppice tree species include numerous oaks (*Quercus* spp.), chestnut (*Castanea sativa*), hornbeam (*Carpinus betulus*) and beech (*Fagus sylvatica*). In Portugal and north-western Spain eucalyptus (*Eucalyptus* spp.) plantations are also managed as coppice forests.

As the demand for products from managed coppice forests has drastically decreased or does not even exist anymore, formerly coppiced forests remain less managed. The management is neglected; wood is harvested, but the stand quality is not maintained. Root systems are over-mature and rotten, and the stand density is poor. In many south European forests cattle browsing is also diminishing stand regeneration (Kirby and Watkins 2015; Ciancio et al. 2006).

Measures to gain higher yield from coppiced forests can be divided into two strategies:

i) Restoration of coppice
ii) Conversion into high forest

i) Restoration of coppice

Measures which attempt to improve biomass production by aiming at the continuation of coppice forests. Optimisation could be reached by regulating the shoots/number of stems per hectare, by adding regeneration from seeds or by optimizing the tree species composition.

ii) Conversion into high forest

Measures which aim to convert coppice forests into high forests (Kneifl et al 2011). This could be realised either through enrichment planting, using natural regeneration or even increasing the production cycle combined with tending and thinning activities. A dense regeneration from seeds can replace sparse, over-mature trees and root systems. Conversion approaches also including planting and promoting a mixture of highly productive conifer species (i.e., artificial planting of highly productive and site adapted species). The newly established stands should be treated as described under "Optimised management regime".

Due to the regional distribution of coppice forests, measures are mostly concentrated in southern Europe (Portugal, Spain, southern France, Italy) and south-eastern to eastern Europe (Croatia, Romania, Bulgaria and Ukraine). Coppice forest which is actively managed as coppice or only originated from coppice harvest sums up to ca. 9 Mio ha of the FAWS of the study area (ca. 12%) (calculated based on data of Kirby and Watkins 2015, p. 81). The latest official data from 'State of European Forests' are much too low and implausible (Forest Europe, UNECE, and FAO 2011).
The yield increase effect is high and estimated to be 10-30%, depending on the previous management intensity, the degree of degradation and the admixture of highly productive conifers in the conversion. The effect is medium to long-term (> 10-30 years).

There are no **constraints** in the application of this yield measure.

The traditional use of coppiced forests for grazing can be regarded as a major **barrier** to the improvement of this forest type. Moreover, there is a lack of investments and know-how when it comes to implementing mid- to long-term measures for improving coppice stands.

Measure	Coppicing
Regional applicability	Mainly in south western and south-eastern Europe, including Ukraine
Yield increase effect	10-30% depending on the previous management intensity and the admixture of highly productive conifers
Timeline	>15-20 years and more (medium to long-term)

3.3.3.4 Improving degraded forests

Definition: FAO defines forest degradation as "a quality decrease in its condition [...], to the interactions between these components (e.g., vegetation layer, fauna, soil), and more generally to its functioning" (Lanly 2003). Degraded forests stock on degraded soils (erosion, fire damaged, grazing) and/or have a reduced stocking, low quality of trees and unfavorable species-site matching.
In order to reduce forest degradation through concrete measures, the main causes of degradation must first be identified. Degradation can be caused by natural phenomena (e.g., diseases and pests, storms, fire, drought and other climatic stresses) or human-induced ones (e.g., air pollution, fire, economic overexploitation, overgrazing), or by the interaction of human impacts and natural causes (European Environment Agency 1995).
In the case of degraded soils, the growth rate is reduced and only a very long-term adapted management to prevent soil erosion and to accumulate humus combined with melioration (bio-char, wood ash) can improve the soil condition and resulting growth potential. Where forest stocks are

degraded, the appropriate measures will depend on the age of the degraded forest stands. For young stands, re-construction by establishment of optimally stocked stands through regeneration with a dense stand of site-appropriate tree species mixture is a suitable option. When dealing with older degraded forests, recommended conversion measures include selective tending and thinning, closing the gaps in the canopy through natural or artificial regeneration, and an admixture of highly productive conifers species (see also "Optimised management regime").

Degraded forests are found mainly in eastern Europe (western Russia, Ukraine) and south-eastern Europe (Romania, to a lesser extent Bulgaria), where uncontrolled exploitation instead of sustainable forest management leads to degradation, or where investments in "repairing" forest structures after damages (e.g., insects, fire) are missing. There is no reliable data about the amount of degraded forests in Europe; in many cases, they are neglected coppice forests and should be treated as such (see chapter 3.3.3.3). In this case, mainly western Russia, Ukraine and conifer forest types of south-eastern Europe are locations where the described yield measures can be applied. The yield increase effect cannot be estimated in the case of soil restoration, but for degraded forest stocks a yield increase of 15-40% can be achieved. The effect is a medium to long-term one (> 10–20 years).

There are no existing **constraints** for the application of the measure.

Major **barriers** include the lack of investments and know-how to implement measures for the improvement of degraded stands.

Measure	Improving degraded forests
Regional applicability	Eastern Europe (western Russia, Ukraine) and conifer forest types in south-eastern Europe
Yield increase effect	15-40%
Timeline	>15-20 years and more (medium to long-term)

3.3.4 Forest management level

Forest management covers a large variety of steering activities within a forest enterprise, comprising technical, economic, legal, and social aspects. Most of the management activities are indirectly influenced by the guidance of the implementation of the concrete measures (see measures discussed above). Nevertheless, three measures have been identified which have a strong, direct relationship between forest management and yield, namely the prevention of biotic and abiotic damages, fire management and forest accessibility. These measures contribute to yield increase mainly by preventing negative effects.

3.3.5 Preventing biotic and abiotic damages

Definition: This measure incorporates all actions to reduce or prevent damages caused by biotic (insects such as beetles or moths, fungus, invasive plant species, wildlife (browsing, fraying, debarking), or livestock (browsing)) or abiotic (storm, wind-throw, snow-break, frost, flooding and erosion, drought) factors. In order to combat insect pests, the FAO recommends the implementation of integrated pest management (IPM; FAO 2013) as part of the forest management strategy. Within the IPM, both prevention and control play a leading role at the enterprise level. Phytosanitary measures are more relevant within the context of national and international legislations.

The following specific measures have been identified:

i) Prevention and control of damages caused by insects, fungus or invasive plant species:
The Temperate & Boreal Forest Resources Assessment (Forest Europe, UNECE, and FAO 2011) identified biotic factors and grazing as main causes for forest damage in the EU. Other major factors affecting forests are air pollution, storms and forest fires. Abiotic factors such as flooding, landslides, and storms are not considered within the pest management but are discussed in the silvicultural topics above.
Different forest types and species have different degrees of vulnerability when it comes to damages caused by insects or fungus (bark beetles, cockchafers, *Armillaria* spp., etc.). For example, spruce trees planted on a clearing are sensitive to infestation with the large pine weevil (*Hylobius abietis*; Örlander and Nordlander 2003). Concrete measures are risk reduction (e.g., species mixture (Kelty 2006); species-site matching), the monitoring of pest populations, pest control and finally, the application of pesticides. Monitoring pest infected stands based on satellite images will allow for low-cost improvements in pest management (Rullan-Silva et al. 2013) in future, especially since an early reaction to the occurrence of a loss of vitality of tree crowns allows for the control of infection rates.
The aim of this yield measure is to reduce losses in forest stands and it needs to be applied within the entire study area. The yield increase effect is highly dependent on the deficits in the prevention and control of damages, which is mainly related to the management intensity and investment in staff and techniques. The measure will lead to a reduction in wood production losses mainly in those areas, where a deficit in the prevention measures is known. However, it is not easy to estimate the yield increase effect. Data as well as case studies are missing on a European level. The estimation could be based on data regarding the proportion of damaged wood recorded in the countries of the study area. Unfortunately, data differentiated according to the causes of pest damages does not exist. Moreoever, where the highest deficits in prevention exist, the statistical data is not comprehensive. This is mainly the case in eastern and south-eastern Europe. The yield increase effect under these conditions is within a range of 5-15%.

Certain **constraints** regarding the application of pesticides in forests exist. This is especially the case in the densely populated western countries of Europe, where nature protection and biodiversity regulations prohibit the application of pesticides. In the dry Rhine-valley between Frankfurt and Karlsruhe in Germany, the May bug population is a massive barrier for any plan able regeneration of forest stands. To use of pesticides at the same time hasn't been allowed (Ahner et al. 2013).

ii) Prevention and control of damages caused by wildlife populations:
Overpopulation of wildlife is one of the main factors hindering the establishment of new forests and of the devaluation of young forests. Damages caused include browsing, fraying and debarking (Reimoser, Armstrong, and Suchant 1999). Browsing leads to reduced growth rates due to a lack of regeneration, as well as to reduced tree species diversity (Apollonio, Andersen, and Putman 2010). Furthermore, debarking in pole stands leads to reduced growth and quality, mortality and stem rot. The lack of predators and, in particular, conflicting interests (Reimoser 2003) prevent the reduction of damages and biomass losses. Counteractive measures include first and foremost the management of wildlife populations through adapted hunting systems (lease contracts, incentives with combined yield improvement and hunting targets). Further improvements can be expected through the inclusion of predators in the management scheme. Another measure is the fencing of young stands to protect them from browsing; this, however, can be a rather costly option depending on the size and accessibility of the forest area to be protected (Trout and Pepper 2006).

Optimal management of wildlife populations allows for the early development of a diverse layer of advance regeneration in forest stands (Harmer and Gill 2000), building a second storey after some decades, diminishing risks and allow the overlapping of tree generations.
Browsing of roe deer and red deer can reduce the biomass growth rate of this advance regeneration layer in the range of 1-2 m^3/ha/year (Prietzel and Ammer 2008; Bobek et al. 1979), which results in a loss of ca. 10% of growth, and in the medium-term also yield[77]. High browsing damages are currently recorded for many of the western and central European countries (Belgium, Netherlands, Luxemburg, France, Germany, Austria, Poland etc.), where this yield measure should be applied.

There are no known **constraints**.

Considerable **barriers** are hunting traditions and hunting legislation. Traditional systems of hunting and grazing remain very rigid despite legal adaptations, scientific research and public discussions.

[77] The assumption is that in an average 100-year rotation, an optimised thinning regime allows for advance regeneration to develop in stands older than 60 years.

Advance regeneration in a spruce forest

Figure 67: Profile strip of a sub-alpine spruce forest, demonstrating the beginning phases of advance regeneration on the left-hand side (adapted from Schütz 2003).

iii) Prevention and control of damages caused by livestock pasture:

In some European regions, livestock pastures are common in the forests, specifically in Mediterranean countries and south-east Europe. As with game, it hinders the establishment of new forests, devalues young forests and reduces growth. Measures to avoid damages can be in the form of a strict separation of forests and pasture land. Fences, a clear definition of land use forms and strong capacity building to improve the awareness of grazing impacts on forests are further measures to be taken into account. Specifically in south-east Europe, where forests are mainly state-owned, local forest administrations are poorly equipped and it is quite difficult to implement control or monitoring systems. The first steps which should be carried out include regional inventories and the implementation of land use programs, supported by monitoring.

Livestock grazing still exists in many southern countries, for example, Greece, Croatia, Portugal or Spain. The forest area which is also used for grazing can be estimated only roughly. We assume that up to 30% of some of the relevant EFTs are used for extensive, uncontrolled grazing, most of which is concentrated in the broadleaved dominated EFT.

The amount of biomass yield losses is estimated to be at a similar level (ca. 10%) as for game browsing. This is a conservative value considering that sheep and goat grazing is more destructive than damages caused by roe deer or red deer.

The main **barriers** arise due to traditional land use systems and lack of control and herd management (i.e., temporary exclusion from vulnerable area).

Measure	Preventing biotic and abiotic damages
Regional applicability	Entire study region for pest prevention and game damages, south-eastern Europe and Ukraine for grazing damages
Yield increase effect	Pest damages: 10% Game damages: 10% Grazing damages: 10%
Timeline	>5 years and more (short to medium-term)

3.3.5.1 Fire management

As most fires are caused by people, fire management that is dedicated to prevention has a strong impact on forest development, growth and yield. Fires destroy biomass, reduce the possibility to harvest, destroy the humus cover and therefore reduce growth conditions. On the other hand, forest fires are a natural force in some of the EFTs, mainly in the boreal and Mediterranean zone (Pyne et al. 2013), and are a relevant ecological factor for the habitat of the respective EFT. The FAO defines integrated fire management (IFM) as a holistic approach to consider biological, environmental, cultural, social, economic and political interactions (FAO 2012). Both damaging and beneficial fires have to be regarded within this context.

Specific measures of fire management can be differentiated according to organisational levels; measures which focus on frameworks exist on a national and even international level, whereas measures designed for direct implementation tend to exist on an enterprise level. In general, fire management aims to develop or improve adapted legislation, policy and institutional frameworks. The FAO has coordinated the elaboration of *Fire Management Voluntary Guidelines*. The guidelines intend to help "… countries develop an integrated approach to fire management, from prevention and preparedness to suppression and restoration."
The goal at the enterprise level is to develop a fire management strategy and implement it. Knowledge, and to a certain degree investments in infrastructure are necessary to implement and improve the strategy. Following aspects are essential for the fire management system:

- Fire prevention
- Use of fire
- Preparedness for fire events
- Response to fire events
- Restoration and recovery after fire events

As for its regional importance, fire is one of the main antagonists to regular forest production in certain regions of southern (Spain, Greece, Portugal, Italy) and north-eastern Europe (western Russia). The effect is local but has a rather high impact. It is therefore important to develop a European satellite system for fire detection – similar to the one used in southern Africa where satellite images/data are updated twice a day (AFIS User Guide, Global Fire Monitoring Center, n.d.). This type of fire monitoring is recommended for earliest fire detection even in remote, low populated areas. Satellite monitoring can be supported by fire towers equipped with cameras to also allow for fire detection on cloudy days. Furthermore, the firefighting capacity by planes and helicopters is lacking; investing in these options is another means of yield improvement. Smaller preventative measures include mulching (see images below) crown material and the removal of woody debris from dry forests stands (to be used for energetic purposes). Controlled grazing by cattle or controlled burning can be used to remove highly flammable fuel from the understorey (Pyne et al. 2013).

Source: Forest mulchers, copyright 2014 Prinoth AG

Regarding the timeframe, short-term improvements can be expected in regions where national laws exist, a general awareness of forest fire is given and measures are discussed. However, a quick implementation at the enterprise-level, specifically for small-scale forest units is not realistic. The first noticeable improvements with an impact on yield should not be expected before 10 to 20 years.

Forest fire prevention can be intensified and improved in all south-eastern European countries and western Russia. This yield measure leads to reduced losses of forest biomass, forest products and will improve site conditions in the long-term. Data for estimating a yield increase effect are not explicitly available and the European fire statistics do not differentiate between fires causing total loss of the forest stock or only damages to the understorey. Therefore, the yield increase effect was estimated very conservatively as a 5 years loss of forest growth after each fire, resulting in 5% loss of yield. Figures from fire statistics for southern Europe indicate that 1.5% of the forest area is damaged each year; statistically this means that a forest stand with a 100 year rotation period is damaged 1.5 times in its life cycle, resulting in losses of 15% of the yield.

We further assume that improved fire management can reduce losses to a certain degree. We have compared annual forest area damaged by fire in the boreal zone for Finland/Sweden (0.01%) and western Russia (0.75%) (Csiszar, Justice, and MCGuire 2004), considering that Scandinavian countries have an optimal fire management. An 80% reduction seems possible in this extreme setting. We therefore concluded that 40% for south-eastern Europe and 80% for western Russia are possible, resulting in yield improvement of ca. 6% and 12% respectively.

Economic **constraints** exist in terms of acquiring monitoring and firefighting equipment.

Barriers include the lack of investments in fire prevention measures.

Measure	Fire management
Regional applicability	South-eastern Europe and western Russia
Yield increase effect	Ca. 3% for south-eastern Europe Ca. 6% for western Russia
Timeline	>5 years and more (short to medium-term)

3.3.5.2 Improving Forest accessibility

Improving forest accessibility is a measure which has an indirect impact on yield. The measure includes planning and construction of forest roads, skidding roads as well as skidding trails. Forest accessibility is the main prerequisite for opening forest stands for any kind of economic utilisation. An optimised access road system helps to avoid damages and losses during harvesting operations, and is an important aspect for worker's safety (Pinnard and Putz 1996).
Improvements can be achieved if forest areas are accessed, which were not accessible before or where the hauling distance and respective costs were too high for an economically viable harvest operation. In the study area, deficits can be found on difficult site conditions (e.g., wet or steep terrain) where road construction is expensive and planning and maintenance complex. This is particularly true in private forests, mainly in Eastern Europe.
Deficits are identified by comparing recommended road densities (meters of road per ha forest), which are available for different terrain conditions with the existing road density on country level (Dietz, Knigge, and Löffler 2011; Styranivsky, Hromyak, and Styranivsky 2011; Ghaffariyan et al. 2010). Data on the road networks, road classes and road densities are not fully available on a European level by countries, nor by regions. Standards for low productivity boreal forests or high alpine conditions are ca. 12 m/ha, for flat or hilly terrain ca. 20 m/ha, and for highly productive mountain forests 25-30 m/ha. Countries like Romania (6 m/ha), Bulgaria (8 m/ha), Ukraine (11 m/ha) or Russia (5 m/ha) still show a clear deficit in forest accessibility. To estimate a yield increase effect, the simplified assumption is that 50% of the deficit against the standards can be compensated without the occurrence of inaccessible forest area for wood supply. If the deficit is higher, 50% of the area cannot be accessed and harvested.

As a result, 10-15% of the FAWS of western Russia, Belarus, Romania, Bulgaria and mountainous forests of the Ukraine can be estimated as unused because the area is currently inaccessible.
The yield increase effect is that, at least for eastern Europe, the yield can be improved by 10-15%, if forest road networks are complete. The measure could immediately result in improved yield.

Technical **constraints** exist in wet and steep terrain and economic constraints (i.e., the cost of road construction machinery and labor) are prevalent in certain regions of Europe (south-eastern and eastern Europe), if the productivity of the forest is low. On the other hand, low productive forests (extreme steep or wet terrain) are mostly not included in the forest area for wood supply (FAWS) and therefore not evaluated here.

Barriers are the political framework leading to a lack of investments in forest road infrastructure in eastern Europe.

Measure	Improving Forest Accessibility
Regional applicability	Eastern and south-eastern Europe
Yield increase effect	10-15%
Timeline	More than 1 year (short-term)

3.3.6 Forest operations level

Forest operations are **defined** as all value chain activities, namely harvesting, transport, and storage. These activities are interrelated in many ways. Measures aim to reduce losses as well as gaining extra yield (e.g., use of additional tree compartments).

A large variety of concrete measures can be mentioned and were discussed by mentioning constraints and the regional application.

3.3.6.1 Optimised harvesting techniques

Choosing the appropriate felling/harvesting technique according to the respective terrain is relevant for harvesting and hauling all the trees selected for harvest in a stand (no area is inaccessible). Appropriate equipment and special training of forest workers is particularly required in wet and very steep terrain (e.g. application of different cable yarding systems). This measure is also relevant in terms of harvesting trees without damaging the harvested material (e.g., breaking the stem when felled), remaining stand (i.e., felling damages), or soil (e.g., compaction).
Adapted harvesting techniques result in reduced biomass losses and fewer damages to harvested timber and the environment. Locations with deficits are mainly eastern and parts of south-eastern Europe, and to a lesser extent mostly well-managed forests in other parts of Europe. Optimised harvesting techniques will lead to an increase in yield through:

- Fewer losses in the quality and quantity of harvested trees
- Fewer damages to trees remaining in the stand
- Entire harvestable area is can be accessed via skidding trails, skidding roads or cable systems

While skidding-trails and skidding roads generally reduce the production area (Jäger 2012), they are essential for harvesting operations. Well-structured skidding trails which are established during tending balance the production site losses with the requirement to have access to the timber during subsequent thinnings and harvesting.

Table 52: Appropriate harvesting techniques/machinery according to terrain

Wet area	Flat area (0-20% slope)	Semi steep area (20-35% slope)	Steep area (> 35% slope)
Tracked felling/processing	Manual systems	Manual systems	Manual systems
Cable yarder	Tractor and trailer	Tractor with winch	Cable yarder
	Forwarder	Ground cable systems	Aerial systems
	Skidder	Skidder	
	Wheeled felling/processing	Wheeled felling/processing	
	Tracked felling/processing	Tracked felling/processing	

Source: adapted from Sappi Tree Farming Guidelines (2004)

The yield increase effect in areas with a deficit is estimated to lead to a gain of 5-20%, mainly due to the improved accessibility, selectivity and reduction of damages from harvest. The effect is a short-term one (> 1 year).

There are only economic **constraints**. In difficult terrain (i.e., wet and steep terrain) and in low productive forest areas the utilisation of modern harvest technologies does not pay off. However, most of these forests are excluded from the total forest area for wood supply (FAWS).

Barriers include the lack of investment in technology and missing know-how.

Measure	Optimised harvesting techniques
Regional applicability	Eastern and south-eastern Europe
Yield increase effect	5-20%
Timeline	More than 1 year (short-term)

3.3.6.2 Use of previously unexploited tree compartments

Particularly deciduous broadleaved tree species are characterised by a high volume of crown material (i.e., branches, twigs). Depending on the age of the stand and silvicultural treatments, up to 70% of the biomass is fixed in the crown. Currently, the upper stem in the tree crown and branch material classified as harvest residues is not yet systematically utilised. Therefore, maximizing the harvested stem and crown volume during forest operations by including the branches will result in an increased utilisation of woody material. However, special techniques to haul a full tree including the crown or to collect branch material need to be established and trained. Recent studies show that the extraction of small, young trees during energy thinnings, the utilisation of branch material in final fellings, and the harvesting of stumps and roots could be increased on sites where this measure does not have a negative impact on sustainable forest management (Rytter et al. 2014).
For economic reasons, if the wood processing industry is located far from the forests, only the main products are used whilst smaller dimensions (e.g., upper stem in a tree) or by-products (branches) remain in the forest. The effects on yield by utilizing the entire tree in these cases are remarkably high. In conifer forests, where the full stem is already used, 10% can be gained; in broadleaved forests, where only the best part of the stem is used, more than 50% can be gained. The effect is a short-term one (1 year and longer).

A major **constraint** arises when nutrients are scarce, whether caused by former overuse or naturally poor site conditions. The impact of using a higher biomass percentage in those cases causes increment losses if no compensatory measures are applied (e.g., melioration to maintain the nutrient balance).

Measure	Use of unexploited tree compartments
Regional applicability	Central, south-eastern and eastern Europe (western Russia, Belarus and Ukraine)
Yield increase effect	10-50%, depending on the previously harvested assortments and whether all species are harvested
Timeline	More than 1 year (short-term)

3.4 Development of best practice strategies for forest yield increase

Chapter 3.3 presented a list of yield measures which could potentially be applied to increase forest productivity and yield. The following chapter addresses the yield measures in the specific context of selected European forest types (EFTs). Since the EFTs vary according to location, topography and climate (therefore resulting in different tree species compositions), not all of the yield measures will apply for each EFT. As such, only the relevant measures are discussed while the irrelevant ones are omitted.

A best practice strategy for forest residue yield increase is defined as "… a specific bundle of different measures to increase growth rates, improve yield, and reduce losses enhancing the overall yield of all wood products."

Best practice strategies are formulated for the most relevant forest types by bundling single yield measures in appropriate combinations. As explained in chapter 3.1, the formulation of best practice considers the principles of sustainable forest management. Their application will therefore minimise the disturbances to the environment (soil, water, biodiversity). For example, recommended improved utilisation rates will not lead to significant nutrient imbalances in the forest ecosystem. The identified best practice strategies are based on the literature review, expert interviews and UNIQUE's forest management expertise.

The resulting effects of the applied yield measures are summarised in a table at the end of each sub-chapter. The table lists a sub-total yield increase effect and an improved utilisation effect. The sub-total of yield increase effects is based on measures which have a direct impact on the growth of forest stands. These measures are generally medium to long-term. The improved utilisation effect, on the other hand, is based on measures which do not have an impact on forest growth *per se*, but which lead to a more efficient and therefore increased biomass removal from forest stands. These measures are generally short to medium-term.
The yield increase which is given at the end of each presented EFT is already the "technical-sustainable" potential. This means that it is the amount/percentage of biomass which can additionally be harvested from the forest if the best practice strategy is applied.

Show cases: studies on optimising yield for forests of Northern Europe

One show case and very comprehensive study aiming to optimise yield in a similar approach in bundling several measures to increase forest growth and yield was conducted for Holmen Skog, a Swedish forest company (Simonsen et al. 2010). In the study, the following measures were examined:

- Use of genetically improved materials
- Planting with cloned seedlings
- Fertilisation
- Maintenance of ditches

- Improved seedling quality
- Treatment against beetles
- Introduction of non-native species (lodgepole pine, *Pinus contorta*)

Results

The overall result of a previous production assessment was that the productivity of Holmen Skog can be increased by 25% (Rosvall and Normark 2006 in Simonsen et al. 2010). Based on this study, the previously listed measures seemed most promising and therefore were chosen for an economic analysis, considering different site qualities as well as the applicability and profitability of the various measures.

Depending on the given site and stand conditions, the following maximum improvements can be achieved within a period of 30 years.

Results of Applied Measures	
Measure	**Max. increase in forest growth**
Use of genetically improved materials	14.2%
Planting with cloned seedlings	26.0%
Fertilisation	13.5%
Maintenance of ditches	20.0%
Improved seedling quality	3.9%
Treatment against beetles	3.3%
Introduction of non-native species	40.0%

In consideration of investment costs and potential area of application, especially the introductions of lodgepole pine as well as the use of genetically improved regeneration materials provide possibilities to efficiently increase forest growth.

Question of transferability

Since the mentioned study was conducted in Sweden, it can be seen as a good reference for boreal and hemiboreal forests. Unfortunately, no comparable study exists for other parts of Europe or respective European Forest Types.

The current study for DG Energy of the European Commission aims to provide similar information about measures to optimise forest growth and its utilisation, though on a geographically broader level including the EU, eastern Europe and western Russia.

In another study conducted by Hynynen et al. (2014) the potential, cost-efficiency and impacts of intensified management of Finnish forests for the next 100 years were assessed. The findings were summarised as follows:

"In the intensity of forest management will remain at the current level, the growing stock will increase. Increasing amount of high quality raw material for forest industry can be produced but it necessitates also increase in annual management practices. For example, treatment areas of young stand management should be doubled compared to current areas in order to maintain or increase cutting removals of hight quality wood. It is possible to increase annual removals in a sustainable manner by applying more intensive forest management that also improves profitability nearly 50%. The annual removals can be ca. 40% higher than the current level, and the annual energy wood removal can be over 10 million m^3. Despite increased removals, sustainable wood and biomass production during the next 100 years can be achieved."

3.4.1 Best practice strategy for EFT 1: Boreal Forests

3.4.1.1 General description

In Europe, boreal forests cover most of Fennoscandia and Russia and the region is characterised by low temperatures and a short growing season. Coniferous and mixed coniferous-broadleaved forests dominate this EFT. The northern and middle boreal forests experience a dominance of conifer species (Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*)), with birch (*Betula* spp.) being the main broadleaved species. In the southern boreal forests, conifers still dominate, but scattered occurrences of the temperate broadleaved trees of the hemiboreal zone are also found. Boreal forests can broadly be categorised into pine-dominated (*Pinus sylvestris*) boreal forests and spruce-dominated (*Picea abies*) boreal forests. Both Scots pine and Norway spruce have quite broad habitat amplitudes and may grow from very dry to wet habitats. Pine generally prevails on drier soils, in areas with a more continental climate and with a high fire frequency. Spruce, on the other hand, prevails on more nutrient-rich, mesic-moist soils, in areas with a more oceanic climate and on sites with a low fire frequency. Birch species (*Betula pubescens, B. pendula*) as well as other deciduous trees, such as aspen (*Populus tremula*), rowan (*Sorbus aucuparia*) and grey alder (*Alnus incana*) can be frequently found growing amongst the conifers. Admixtures of spruce or pine with birch species are also typical of the pioneer stages of the forest succession (European Environment Agency 2007).


Source: K. Rantanen, 2013 (www.flickr.com)


Source: C. Wasserfallen, 2014 (www.flickr.com)

Under natural conditions, forest fires ignited by lightning and repeated with cyclical frequency regulate the dynamics of boreal coniferous forests. Nowadays, these wildfires have been almost completely prevented through forest management (Niklasson and Granstrom 2000). Most of the boreal forests are managed as even-aged forest for commercial forestry; the management intensity increased in Scandinavia during the 20th century and has also recently been increasing in Russia (European Environment Agency 2007).

Table 53: Key Data for EFT Boreal Forests

Key Data – Boreal Forests					
		EU 28	**Belarus and Ukraine**	**Western Russia**	**Total**
Total forest area	1000 ha	31,262	399	84,826	116,487
Total growing stock	mio. m³	3,755	105	3,900	7760
Growing stock per ha	m³/ha/year	120.0	263.1	46.0	66.6
Total increment	1000 m³/year	145,482	3,455	53,558	202.495
Increment per ha	m³/ha/year	4,7	8.7	0.6	1.7
Total yield	1000 m³	123,194	933.7	32,189	156,317
Yield per ha	m³/ha/year	3.9	2.3	0.4	1.3

3.4.1.2 Species level

Breeding

There is an excellent opportunity to introduce genetically improved trees due to the large-scale clear-cut approach applied in boreal forests (Mattsson 2005). Scandinavian countries already have well-developed tree breeding programs for all wide spread and commercial species (especially Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), birch (*Betula* spp.), and aspen (*Populus* spp.)). Spruce and pine breeding programs tend to focus on improving the volume and quality of wood produced, and in recent years there has been an increasing focus on optimising tree species with regard to their adaptability to climate change (Pâques 2013). Experiments in Sweden indicated that the use of seedlings originating from the third round of Norway spruce seed orchards can increase the growth by up to 25% relative to non-bred material (Rytter et al. 2013). Breeding improvements of Scots pine have resulted in a 10% increase in genetic gains in Sweden, 15-20% faster growth (stem volume) in Finland, an increased growth of 10-20% in the British breeding program, and a volume increase of 15-30% in Germany (Pâques 2013). The yield and stem quality of silver birch (*Betula pendula*) have been significantly improved through targeted breeding (J. Hynynen et al. 2010); long-term birch breeding experiments in Sweden have demonstrated a growth increase of over 15% in birch trees when compared to specimen that were not bred in any way (Unseld 2012).

Introduction of non-native species

The Siberian larch (*Larix sibirica*) has already been introduced in Scandinavian countries and been adapted to the area through breeding. The lodgepole pine (*Pinus contorta*) was introduced in mid and northern parts of Sweden starting in the 1970s (Rytter et al. 2013) due to its superior growth when compared to Scots pine (*Pinus sylvestris*) and resistance to moose browsing. Breeding programs exist for this species and suitable site conditions are known. The growing area of both species can be enlarged (mostly in Russia) by using improved plant material.

3.4.1.3 Site level

Optimised species-site matching

East European countries can profit from the developments in Scandinavian countries, where site mapping systems are well-established and decision support systems (DSS)[78] for species-site matching exist. Other than that, not many species occur in this region, so the potential impact is quite limited (de Vos, 2015).

Water Management

Throughout most of the region, wetlands such as mires, bogs and fens form characteristic landscape elements in mosaics with various forest types. For example, in parts of northern Finland, mires cover almost 50% of the surface area. Since the development of new drainage systems is restricted in most Scandinavian countries, existing systems should be maintained in order to regulate the water level in accordance with the seasons. This is especially true for drainage systems which have become overgrown.

[78] Many DSS tools exist (http://forestdss.org/wiki/index.php?title=Category:DSS) which help in analyzing the environmental, economic and social impacts of changes in silvicultural measures and/or in the forestry-wood production chain. Austria provides an example of an implemented DSS for species-site matching tools (http://waldbauberater.at/).

Soil improvement

Fertilisation is regarded as a very effective means to increase yields in boreal forests. Nitrogen-lime mixtures are applied on poor to medium mineral soils, and basic cations in the form of wood ashes are applied on peat soils. The application of fertilisers is cost efficient, and most of the terrain of the boreal region can be easily accessed by vehicles.

3.4.1.4 Forest stand level

Tree species composition and mixture

On medium to good soils, a mixture of light demanding and shade tolerant species could, for example, be Siberian larch (*Larix sibirica*) and Scots pine (*Pinus sylvestris*) in the upper layer and spruce (*Picea* spp.) in the lower layer (two-storey forests).

Optimised management regime

Opting for a higher tree density during artificial regeneration, and the use of dense direct seeding to imitate dense natural regeneration, results in a higher volume in young stands. A higher density also allows for early thinnings for energy wood and a higher number of trees from which to select high quality future crops trees.

Improving degraded forests

While Scandinavian forests are well managed, Russian boreal forests partly suffer from degradation caused by fire, neglected clear-cut areas or pest damaged areas. These areas can be improved through soil preparation and planting, weeding tending and thinning.

3.4.1.5 Forest Management level

Preventing biotic and abiotic damages

The forests of Norway, Sweden, Finland and Denmark have suffered from damages caused by the European spruce bark beetle (*Ips typographus*) and Dutch elm disease (caused by *Ceratocystis ulmi*) in the past (Austarå et al. 1983). Prevention and control of damages caused by insects (mainly bark beetles) and fungus (spruce heart rot) is therefore a key element of best practice strategies in Scandinavian boreal forests. Improvements in preventing these biotic damages can mainly be achieved in western Russia, where thorough pest monitoring systems still need to be installed (Rullan-Silva et al. 2013).

It is only the southern most productive parts of this EFT whose yield is influenced by moose populations browsing in young stands (Heikkilä and Tuominen 2009; Ball and Dahlgren 2002; Crête, Ouellet, and Lesage 2001). Developing hunting plans is important to reduce damages caused by these animals, and hunting activities should be intensified and focused on young stands.

Fire management

Fire as a natural disturbance has been and still is shaping the structure of dry boreal forest types dominated by Scots pine (*Pinus sylvestris*). These fires may occur as frequently as every 40 years and range over as much as 1,000 ha, though most fires are of a limited extent. Areas of wet and

moist forest types rarely burn, effectively constituting fire refuges on nearly 30-40% of the forest area.
Prevention of large scale damages in Scandinavia is made possible by a dense access road network, prescribed burning, as well as early fire detection and fighting; these aspects are lacking for western Russia and therefore points to be improved on (Hovi et al. 2008; Johann Georg Goldammer and Furyaev 1996).

Forest accessibility
Certain parts of the Russian boreal forests experience a lack of accessibility. In this case, developing an improved road network is essential for applying the best practice strategies described above.

3.4.1.6 Forest operations level

Optimised harvesting technique
Highly mechanised systems are applied all over Scandinavia which helps in minimising harvesting losses in felling and hauling. Russia could apply similar mechanised systems in order to reduce its harvest losses and unused tree compartments, tree species.

The use of previously unexploited tree compartments
Significant potentials to remove young trees, branch material, stumps and roots exit in the well-managed forests of Scandinavia. Estimates in Sweden showed that less than 20% of the total annual forest fuel potential is currently utilised and it is dominated by logging residues from final felling (Nordfjell, Athanassiadis, and Lundström 2010). This biomass removal should be combined with forest fertilisation to maintain the nutrient content of the soil.
The potentials for increased biomass removals are much higher in Russia and can be estimated as an additional 32% (Petrov 2011 cited in Krismann 2012). This is applicable in areas where branch and crown material is not being harvested, but also for tree species which are of lower economic interest and which are currently excluded from hauling (mainly broadleaved species such as birch and aspen).

3.4.1.7 Technical-sustainable potential

Summary of Key Data – EFT 1 Boreal Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[79]	1000 ha	31,262	398	84,828	116,487
Increment per ha	m³/ha/year	4.7	8.7	0.6	1.7
Current utilisation rate	m³/ha/year	3.9	2.3	0.4	1.3

Quantification of Yield Increase by Applying Best Practices – EFT 1 Boreal Forests – EU 28, Belarus and Ukraine								
Selected yield measure		Timeline – full effect in years	Yield increase (per ha)	Specific yield increase effect (per ha)	Applicability of the measure according to location and site conditions			
					% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Species	Breeding	>20	10-25%	10%	100%	31,660	10%	
Site	Optimised species-site matching	>20	2-3%	2%	100%	0	0%	N/A
	Water management	>5	2-10%	5%	25%	8,587	1%	Only applicable in mires and in swamps; assumption is that 25% of the EFT area are mires or swamps.
	Soil improvement: fertilisation	>5	5-25%	10%	60%	18,863	6%	Fertilisation is only applicable on poor to medium soils and peatlands.

[79] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 1 Boreal Forests – EU 28, Belarus and Ukraine								
Forest stand	Tree species composition	>15-20	20-30%	25%	18%	5,657	4%	Applicable to pure stands only, not considering the far north, where pure stands exist naturally.
	Optimised management regime	>15-20	10-20%	10%	100%	31,660	10%	Interactions with tree species composition.
	Improving degraded forests	>5	15-40%	20%	0%	0	0%	N/A
	Preventing biotic and abiotic damages: - pest damages	>5	10%	10%	0%	0	0%	N/A
Forest manage -ment	Fire management	>5	0%	0%	0%	0	0%	N/A
Subtotal of yield increase effects[80]							**31%**	

i. For the EFT Boreal Forests in EU 28, Belarus and Ukraine a potential yield improvement of 31% can be achieved when compared to the modelled EFISCEN yield[81], taking into consideration short-term to long-term improvements. The improved yield increase effect is realised mainly through improved breeding, an optimized management regime, and soil fertilization. In > 5-10 years (medium-term) a yield improvement of 7% can be achieved, whereas in > 20-30 years (long-term) the yield can be increased by an additional 24%.

ii. There is no improved utilization effect for this country grouping since the Scandinavian countries already have a high level of optimization in forest management and operations.

[80] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[81] EFISCEN model for 2010

Quantification of Yield Increase by Applying Best Practices – EFT 1 Boreal Forests – Western Russia								
Selected yield measure		Timeline - full effect in years	Yield increase (per ha)	Specific yield increase effect (per ha)	Applicability of the measure according to location and site conditions			
					% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Species	Breeding	>20	10-25%	10%	100%	84,828	10%	
Site	Optimised species-site matching	>20	2-3%	0%	100%	84,828	2%	Measure applicable in western Russia.
	Water management	>5	2-10%	5%	27%	22,903	1%	Only applicable in mires and swampy areas (27% for Scandinavia applied for western Russia in analogy).
	Soil improvement: fertilisation	>5	5-25%	10%	60%	50,897	6%	Fertilisation will only be applied on poor to medium soils and peatlands (60% for Scandinavia applied for western Russia in analogy).
Forest stand	Tree species composition	>15-20	20-30%	25%	18%	15,157	4%	Not considered for the far north of the boreal zone, where pure stands exist naturally. As a result, applicable for 19% of FAWS in Scandinavia and also western Russia in analogy.
	Optimised management regime	>15-20	10-20%	10%	61%	51,745	6%	Applicable on non-degraded forests; interactions with tree species composition.
	Improving degraded forests	>5	15-40%	20%	39%	16,967	20%	Measure applicable in western Russia; interaction with optimised management regime; ratio of FAWS calculated as degraded is the area with a low relative stocking < 0.5.
	Preventing biotic and abiotic damages: - pest damages	>5	10%	10%	100%	84,828	10%	Measure applicable in western Russia.

Quantification of Yield Increase by Applying Best Practices – EFT 1 Boreal Forests – Western Russia								
Forest manage-ment	Fire management	>5	6%	6%	4%	84,828	6%	Measure applicable in western Russia.
Subtotal of yield increase effects[82]							**65%**	
Forest management	Improving forest accessibility	>1	10-15%	10%	100%	84,828	10%	Measure applicable in western Russia.
	Optimised harvesting technique	>1	5-20%	20%	100%	84,828	20%	Measure applicable in western Russia.
Forest operations	Use of previously unexploited tree compartments	>1	10-50%	32%	19%	84,828	32%	Measure applicable in western Russia.
Improved utilisation effect[83]							**62%**	

i. For western Russia, a potential yield improvement of 65% can be achieved when compared to the modelled EFISCEN yield[84], taking into consideration short-term to long-term improvements. The main contributing yield measures are improving degraded forests, breeding and preventing biotic and abiotic damages (i.e., preventing pest damages). Mid to long-term improvements account for a yield increase of 22%, whereas short to mid-term improvements amount to 43%.

ii. The improved utilisation effect for western Russia is 62% and encompasses all the yield measures relevant for this effect. The most significant of the three yield measures is the use of previously unexploited tree compartments.

[82] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[83] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

[84] EFISCEN model for 2010

3.4.2 Best practice strategy for EFT 2: Hemiboreal and nemoral coniferous and mixed broadleaved-coniferous forests

3.4.2.1 General description

The hemiboreal zone is a transitional zone between the boreal zone and the temperate forests of nemoral Europe. The light regime and length of the growing season are the main climatic variables controlling forest productivity. This is the second largest EFT in terms of area and is typical for southern Sweden, Norway and Finland – where this forest region is represented only as narrow bands in the southernmost parts of the countries – the United Kingdom, southern France, northeast Germany, Poland, Czech Republic, lower regions of Slovakia and Austria, the Baltic States, Belarus, northern Ukraine, stretching with an eastern wing to Urals across the Russian Federation. This forest type is characterised by the coexistence of coniferous species (Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*)) on poor soils with mixtures of broadleaved deciduous tree species such as birch (*Betula* spp.), aspen (*Populus tremula*), Alder (*Alnus* spp.), and rowan (*Sorbus aucuparia*). The broadleaved trees generally characterise early-to-mid-successional stages; with increasing stand age, the dominance of coniferous species increases. Two main types of hemiboreal forest can be distinguished:

- Natural hemiboreal forest with large conifers and southern deciduous trees, occurring almost only in forest reserves (e.g., Bialowieza National Park in eastern Poland)
- Culturally originated woodlands, i.e., mixed forest stands originating from abandoned wooded meadows with broadleaved trees (ash (Fraxinus excelsior), oak (Quercus spp.), hazel (Corylus spp.)) invaded by conifers, particularly spruce (Picea spp.).

Source: R. Moss, 2009 (www.flickr.com)

Source: J. Allen, 2014 (www.flickr.com)

An important feature of the hemiboreal forest is that its structural and compositional diversity is shaped by a complicated mixture of natural (fires, windbreaks) and cultural (grazing, pollarding, lopping) disturbances which actually maintain a continuous presence of large old trees and deadwood. Agricultural use has greatly reduced the extent of hemiboreal forest and altered its original tree species composition (European Environment Agency 2007).

Table 54: Key Data for EFT Hemiboreal Forests

Key Data – Hemiboreal Forests					
		EU 28	**Belarus and Ukraine**	**Western Russia**	**Total**
Total forest area	1000 ha	27,246	7,350	4894	39,489
Total growing stock	mio. m^3	7,233	1,735	604,784	9,572
Growing stock per ha	m^3/ha/year	265.5	236.0	123.6	242.4
Total increment	1000 m^3/year	251,550	46,809	12,181	310,540
Increment per ha	m^3/ha/year	9.2	6.4	2.5	7.9
Total yield	1000 m^3	159,445	20,618	7103	187,166
Yield per ha	m^3/ha/year	5.9	2.8	1.5	4.7

3.4.2.2 Species level

Breeding

There is a good opportunity to introduce genetically improved trees (especially Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*)) during stand regeneration which is often practiced in the form of artificial regeneration (i.e., direct seeding or planting seedlings; Mattsson 2005; Duryea 2000). Tree breeding programs mainly exist for the conifer species (Jensen 2000), but not in the same intensity and region-specific manner as in the boreal region. There is still a lack of breeding programs for a number of conifer and broadleaved species, and therefore also a significant potential to intensify breeding for such species. For example, the breeding potential of grey alder (*Alnus incana*) is high due to early flowering, high seed production and easy vegetative propagation, but very limited genetic improvements have been obtained to date (Rytter et al. 2013). If existing improved tree material is applied in practice, similar gains as in boreal forests can be achieved for Scots pine, Norway spruce and birch species (*Betula* spp.). Advances as in Scandinavia with up to a 15-30% increase in growth are known for black pine (*Pinus nigra*) or spruce (*Picea* spp.). Both Norway and Luxembourg have conducted breeding research on *Sorbus* species, but the information obtained through the experiments has yet to be used for breeding programs (Turok et al. 2002).

Introduction of non-native species

The introduction of non-native species is not yet applied for most of this wide spread EFT (Rytter et al. 2013), which covers a wide range of climatic conditions, site conditions, and tree species. It is only in Scotland that Scots pine (*Pinus sylvestris*) forests are widely replaced or mixed with highly productive Sitka spruce (*Picea sitchensis*) (Mason and Perks 2011).

A well-known and adapted suitable species to improve growth and yield in the western part of central Europe is Douglas fir (*Pseudotsuga menziesii*). In the Scots pine-beech forest of south-west Germany (Pfälzerwald), an admixture with 20% Douglas fir would result in a 10-15% higher yield and a 40% increase in the net present value per rotation (Chini 2012).

3.4.2.3 Forest stand level

Tree species composition and mixture

Many of the pine and spruce forests have less than 10% of other species. As such, it is recommended to increase the species mixtures to include, for example, a higher proportion of broadleaved species. A similar species mixture as in the boreal zone could be aimed for (i.e., light demanding Scots pine (*Pinus sylvestris*) or Birch (*Betula pendula*) with shade tolerant *Picea abies*).

Optimised management regime

There are a wide range of tree species available for intensive mixture of light demanding and fast growing species (e.g., pine (*Pinus* spp.), birch (*Betula* spp.), aspen (*Populus* spp.), larch (*Larix decidua*)) and shade tolerant slower growing species (e.g., spruce (*Picea* spp.), oak (*Quercus* spp.), hornbeam (*Carpinus betulus*), lime (*Tilia* spp.)). In young stands of initially slow growing species such as spruce or oak, fast growing aspen and birch can be used in mixture to be harvested as energy or pulp wood in one of the first thinnings after 20-30 years (Unseld 2012).

3.4.2.4 Forest Management level

Preventing biotic and abiotic damages

Prevention and control of damages caused by insects (mainly bark beetles and pine related pests) and fungus (spruce heart rot) is a key element for the best practice strategy of these forests. Improvements can mainly be achieved in areas with large pure conifer stands, and are even more pronounced on dry and acidic sites.

Prevention and control of damage caused by wildlife populations has a significant yield increasing potential in this EFT. Overpopulation of red deer and roe deer are a large problem; Combating browsing and debarking can be achieved through the inclusion of a rigorous hunting plan in the management plan, and by providing for very dense natural regeneration.

In terms of abiotic damages, silvicultural systems should be applied which are adapted to the risks associated with specific tree species (e.g., shorter rotation for Norway spruce (*Picea abies*), more focus on tending and thinning).

Forest accessibility

Certain parts of the Russian hemiboreal forests experience a lack of accessibility. In this case, developing an improved road network is essential for applying the best practice strategies described above.

3.4.2.5 Forest operations level

The use of previously unexploited tree compartments

The extraction of small, young trees during tending/early thinnings, and the utilisation of branch material from thinnings and harvest operations especially of broadleaved species are not applied throughout the entire region of this EFT. The reasons for this are dry and acidic soils (Scots pine-birch, Scots pine-oak), where the removal of additional trees and tree compartments can have a negative influence on nutrients. Melioration can be used to compensate for the intensified use of biomass and should be included in the management approach. This is specially recommended in all regions of western and central Europe, where Nitrogen immission still are high, which have lead to a growth effect in the past, but also to an imbalance in nutrients.

3.4.2.6 Technical-sustainable potential

Summary of Key Data – EFT 2 Hemiboreal Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[85]	1000 ha	27,246	7,350	4,894	39,489.2
Increment per ha	m^3/ha/year	9.2	6.4	2.5	7.9
Current utilisation rate	m^3/ha/year	5.9	2.8	1.5	4.7

Quantification of Yield Increase by Applying Best Practices – EFT 2 Hemiboreal Forests – EU 28, Belarus and Ukraine								
Selected yield measure		Timeline - full effect in years	Yield increase (per ha)	Specific yield increase effect (per ha)	Applicability of the measure according to location and site conditions			
					% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Species	Breeding	>20	10-25%	10%	100%	33,957	10%	
	Introduction of non-native species	>10	10-30%	5%	100%	33,957	5%	Interactions with tree species composition.
Forest stand	Tree species composition	>15-20	20-30%	20%	40%	13,583	8%	Only applicable on areas with pure stands; interactions with the introduction of non-native species.

[85] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 2 Hemiboreal Forests – EU 28, Belarus and Ukraine								
	Optimised management regime	>15-20	10-20%	10%	61%	33,957	6%	Applicable on non-degraded forests; interactions with tree species composition.
Forest manage-ment	Preventing biotic and abiotic damages - pest damages - game damages	>5	10% 10%	10% 10%	0.7% 29.0%	235 3,038	0.1% 0.9%	Preventing pest damages is applicable in south-eastern and eastern Europe, whereas preventing game damages is applicable in central and western Europe; assumption: severe biomass losses occur on 30% of the area.
Subtotal of yield increase effects[86]							**30%**	
Forest operations	Use of previously unexploited tree compartments	>1	10-50%	20%	19%	6,736	4%	Applicable in eastern Europe; improvements are based on the existing yield.
Improved utilisation effect[87]							**4%**	

i. For the EFT Hemiboreal Forests, when the weighting of the applicable area is applied, the potential yield improvement for EU 28, Belarus and Ukraine could be 30%, when compared to the modelled EFISCEN yield[88], taking into consideration short-term to long-term improvements. This comparatively high improved yield increase effect is mainly attributed to improving degraded forests, tree breeding and tree species composition. Mid to long-term yield measures lead to an improvement of 24%, whereas short to mid-term yield measures lead to an improvement of 12%.

ii. The improved utilisation effect is quite low with 4% and is based on only one yield measure – the use of previously unexploited tree compartments.

[86] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[87] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

[88] EFISCEN model for 2010

Quantification of Yield Increase by Applying Best Practices – EFT 2 Hemiboreal Forests – Western Russia								
Selected yield measure		Timeline - full effect in years	Improved yield increase effect (per ha)	Specific yield increase effect (per ha)	Applicability of the measure according to location and site conditions			
					% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Species	Breeding	>20	10-25%	10%	100%	4,894	10%	
	Introduction of non-native species	>10	10-30%	5%	100%	4,894	5%	Interactions with tree species composition.
Forest stand	Tree species composition	>15-20	20-30%	20%	40%	1,691	7%	Only applicable on areas with pure stands; interactions with the introduction of non-native species.
	Optimised management regime	>15-20	10-20%	10%	100%	4,894	10%	Interactions with tree species composition.
Forest manage-ment	Preventing biotic and abiotic damages - pest damages	>5	10%	10%	100%	4,894	10%	Preventing pest damages is applicable in western Russia.
Subtotal of yield increase effects[89]							**42%**	
Forest manage-ment	Improving forest accessibility	>1	10-15%	10%	100%	4,894	10%	Measure is applicable in western Russia.

[89] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

Quantification of Yield Increase by Applying Best Practices – EFT 2 Hemiboreal Forests – Western Russia								
Forest operations	Use of previously unexploited tree compartments	>1	10-50%	20%	19%	930	4%	Measure applicable in western Russia
Improved utilisation effect[90]							**14%**	

i. For western Russia a subtotal of yield increase effects of 42% can be achieved when compared to the modelled EFISCEN yield[91], taking into consideration short-term to long-term improvements. The most relevant yield measures are quite similar to those of the Russian boreal forests and include breeding, an optimised management regime and preventing biotic and abiotic damages (i.e., prevention of pest damages). Mid to long-term improvements can achieve a yield increase of 27%, whereas short to mid-term improvements account for a yield increase of 15%.

ii. The improved utilisation effect for western Russia is 14% and is based on the implementation of two yield measures, namely improving forest accessibility and the use of previously unexploited tree compartments.

[90] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

[91] EFISCEN model for 2010

3.4.3 Best practice strategy EFT 3: Alpine Forests

3.4.3.1 General description

Bound to the major mountain ranges of Europe, the Pyrenees, the Alps, the Apennine and the Carpathian Mountains, this forest type is restricted to Spain and France for the Pyrenees, France, Italy, Austria and Germany for the Alps, and Slovakia, Poland, Ukraine and Bulgaria for the Carpathian Mountains. These forests are situated in the high altitudes of the European Alpine region, which is characterised by a cold, harsh climate. The climatic conditions are similar to those of the boreal zone, except for the light regime and length of day. The species composition varies with the vegetation belts (mountainous/subalpine) and site ecological conditions. Naturally dominant species include spruce (*Picea* spp.), pine (*Pinus* spp.), fir (*Abies* spp.), European larch (*Larix decidua*), Swiss pine (*Pinus cembra*) and black pine (*P. nigra*).
The Alpine forest type can be further classified into three sub-types.

1. **Subalpine larch-arolla pine and dwarf pine forest:**
   On a European scale, these forests are highly divided and have a small-scaled distribution due to their occurrence at the highest elevations of European mountain ranges.
2. **Subalpine and mountainous spruce and mountainous mixed spruce-silver fir-forest:**
   These forests are present both in the Alpine region and in the mountainous regions of central Europe and in the Carpathian and Balkan ranges. Due to paleoecological reasons, spruce is not present in the Pyrenees, in the Apennine range and the mountainous altitudinal belt of Corsica. These potential spruce sites are covered by pure silver fir (*Abies alba*) forests.
3. **Alpine Scots pine and black pine forest:**
   In most cases, these are pure pine forests occurring on sites where climax tree species cannot withstand because of specific site conditions (mainly caused by dry and poor limestone, dolomite or serpentine substratum) (European Environment Agency 2007).

Source: L. Hempelmann, 2013 (Unique)

Source: Brewbooks, 2015 (www.flickr.com)

The main purpose of the first sub-type is protective functions; they have a very low growth rate. Of the three sub-types, only the second category (subalpine and mountainous forests) is considered to be relevant in terms of commercial productivity. Therefore, this is the group for which most of the following best practice measures apply. The natural range of distribution of this forest type originally covered a larger area. However, due to human activities (e.g., pasturing) over hundreds of years the majority of its distribution has been converted to alpine meadows.

Table 55: Key Data for EFT Alpine Forests

Key Data – Alpine Forests					
		EU 28	**Belarus and Ukraine**	**Western Russia**	**Total**
Total forest area	1000 ha	5,008	459	157	5,624
Total growing stock	mio. m^3	1,425	136	27	1,588
Growing stock per ha	m^3/ha/year	284.4	296.7	173.3	282.3
Total increment	1000 m^3/year	41,520	3,043	302	44,864
Increment per ha	m^3/ha/year	8.3	6.6	1.9	8.0
Total yield	1000 m^3	32,357	2,036	184	34,614
Yield per ha	m^3/ha/year	6.5	4.4	1.2	6.2

3.4.3.2 Species level

Breeding

Advanced breeding programs already exist for major spruce (*Picea* spp.) and pine species (*Pinus* spp.) (see EFT Boreal Forests). According to Wolf (2003), since silver fir (*Abies alba*) was and is mainly regenerated naturally, the species is not considered a high-priority species in tree-breeding programs in most European countries where it occurs.[92] Considering this information, there is great potential for genetically improving silver fir and therefore for increasing the yield from subalpine and mountainous spruce-silver fir forests. One of the prominent breeding methods possibly leading to a higher general resistance of fir is intra-specific/inter-specific hybridisation (Kobliha and Stejskal 2009). However, since hardly any breeding trials have been conducted so far, it will take a minimum of 20-30 years to optimise the breeding of this tree species. The hybrid larch (*Larix decidua x L. kaempferi*) has received some attention in breeding in Denmark and southern Sweden. In breeding, the growth and straightness of stem have been the major selection criteria (Rytter et al. 2013). Choosing the correct genetic origin of larch species has represented positive results in terms of growth traits, canker resistance and broader adaptability in many countries. For example, in Germany, an expected gain of about 10% was estimated for height and of about 25% for volume

[92] Wolf, H. 2003. EUFORGEN Technical Guidelines for genetic conservation and use for silver fir (Abies alba). International Plant Genetic Resources Institute, Rome, Italy. 6 pages.

growth based on appropriate provenance selection (Pâques 2013). Similar results could be achieved in breeding of Larix for alpine conditions.

Introduction of non-native species

The Douglas fir (*Pseudotsuga menziesii*) could be introduced as a non-native species in subalpine and sub- and mountainous forests. However, since the mixed spruce and fir forests already have a fairly high increment, it is assumed that the Douglas fir might only lead to an estimated 5% increase in productivity (UNIQUE 2015, estimation based on results presented by Chini 2012). A further positive effect of Douglas fir is its drought resistance compared with spruce (*Picea* spp.). Introduction of Douglas fir will have a positive effect on the resilience of this EFT with respect to climate change.

3.4.3.3 Site level

Water Management

Water could potentially be a limiting factor in the third forest sub-type consisting of alpine Scots pine and black pine forests. The establishment of new forest stands should therefore be supported by weeding and mulching and erosion control to prevent humus losses. Forest roads need to be carefully constructed in the steep terrain conditions so that water is redistributed from the road system back into the forest stands.

3.4.3.4 Forest stand level

Tree species composition and mixture

The tree species composition for the second sub-type is linked to increasing the amount of fir and the inclusion of Douglas fir (*Pseudotsuga menziesii*) to make the stands more resilient. The composition is also strongly linked to the amount of browsing (see also “Prevention of biotic and abiotic damages”) occurring in a given stand. If there is strong browsing then intensive hunting should be conducted and single trees can be protected through fencing; this will allow for species diversification.

3.4.3.5 Forest Management level

Preventing biotic and abiotic damages

The application of Integrated Pest Management (IPM) depends on accessibility, tree species composition and hunting. As mentioned above, one of the main causes of damage is from browsing by wildlife populations. Controlling the wildlife population through hunting will reduce browsing and lead to better natural regeneration and a different tree species composition.

Fire management

Fire management is mostly relevant for the third forest sub-type: Alpine Scots pine and black pine (*Pinus nigra*) forest, especially where particularly dry pine stands are located. The risk of fire can be reduced by mulching crown material and the removal of woody debris for energetic purposes; these preventative measures, however, are only possible in passable terrain. Improved fire monitoring and firefighting capacities should also be constituents of a fire management plan.

Improving forest accessibility

The main aim here is to promote the construction of forest roads to increase the permanent accessibility to forest stands on steep slopes. Especially in the Carpathians and in western Russia (Caucasus), a denser road network and improved accessibility will allow for the implementation of optimised harvesting technologies and therefore also increase the harvestable area and yield.

3.4.3.6 Forest operations level

Optimised harvesting technique

At the moment, harvesting is problematic mainly due to lacking accessibility and high costs of harvesting. It is possible to increase the amount of harvested timber through the utilisation of appropriate harvesters (those able to cope with steep slopes), and/or cable yarding systems. This measure can improve yield in south western, south-eastern and Russian mountain ranges.

The use of previously unexploited tree compartments

In this case, this yield measure is linked with optimised harvesting techniques. Small diameter wood located on steep slopes could be harvested if suitable harvesting technologies are made available. This wood dimension could then be used for energetic purposes. This measure can improve harvest potential in south western, south-eastern and Russian mountain ranges.

3.4.3.7 Technical-sustainable potential

Summary of Key Data – EFT 3 Alpine Forests						
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[93]	1000 ha	5,008	459	157	5,624
Increment per ha	m^3/ha/year	8.3	6.6	1.9	8.0
Current utilisation rate	m^3/ha/year	6.5	4.4	1.2	6.2

Quantification of Yield Increase by Applying Best Practices – EFT 3 Alpine Forests – EU 28, Belarus and Ukraine									
Selected yield measure by level		**Timeline - full effect in years**	**Yield increase (per ha)**	**Specific yield increase effect (per ha)**	**Applicability of the measure according to location and site conditions**				
					% of FAWS	**Area of FAWS**	**Weighted yield increase effect**	**Explanation of approach and application area, assessment of interactions**
Species	Breeding	>20	10-25%	10%	100%	5,467	10%	
	Introduction of non-native species	>10	10-30%	5%	100%	5,467	5%	Interactions with tree species composition and optimised management regime; there is a reduced yield increase effect since artificial regeneration is very costly.
Site	Water management	>5	2-10%	2%	20%	1,093	0.4%	Only applicable on the dry sites of Scots pine and black pine (third forest sub-type).
Forest stand	Tree species composition	>15-20	20-30%	20%	25%	1,367	5%	Only applicable in areas with pure stands; based on data from the SEF study (Forest Europe, UNECE, and FAO 2011).

[93] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 3 Alpine Forests – EU 28, Belarus and Ukraine								
Forest management	Preventing biotic and abiotic damages - pest damages - game damages - grazing damages	>5	10% 10% 10%	10% 10% 10%	11% 62% 11%	601 3,390 601	1% 6% 1%	Pest management is applicable in south-eastern and eastern Europe; preventing game damages is relevant in central and western Europe; assumption: biomass losses occur on 100% of the area; preventing grazing damages is applicable in south-eastern Europe.
	Fire management	>5	3%	3%	11%	601	0,3%	Only applicable in the drier forest type (sub-type 'Alpine Scots pine and black pine forest'); percentage of FAWS is estimated to be 11%.
Subtotal of yield increase effects[94]							**28.7%**	
Forest manage -ment	Improving forest accessibility	>1	10-15%	15%	19%	1,039	3%	Applicable in south-eastern Europe (e.g., Carpathians); effect is based on the existing utilisation rate.
Forest operations	Optimised forest accessibility	>1	5-20%	10%	29%	1,586	3%	Only applicable for south western and south-eastern mountain ranges; effect is based on the existing utilisation rate.
	Use of previously unexploited tree compartments	>1	10-50%	10%	29%	1,586	3%	Only applicable for south western and south-eastern mountain ranges; effect is based on the existing utilisation rate.
Improved utilisation effect[95]							**9%**	

[94] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[95] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

i. For the EFT Alpine Forests in EU 28, Belarus and Ukrain, a potential yield improvement of 28.7% can be achieved when compared to the modelled EFISCEN yield[96], taking into consideration short-term to long-term improvements. This yield increase is realised mainly through the yield measures breeding, prevention of game damages and the introduction of non-native species. The mid to long-term effects result in a yield increase of 15%, whereas the short to mid-term effects lead to an increase of 13.7%.

ii. For this EFT an improved utilisation effect of 9% can be achieved. Unlike the two previous EFTs, all relevant measures for an improved utilisation are applicable in this case, and all are equally important according to their weighting.

[96] EFISCEN model for 2010

Quantification of Yield Increase by Applying Best Practices – EFT 3 Alpine Forests – Western Russia								
Selected yield measure		**Timeline - full effect in years**	**Yield increase effect (per ha)**	**Specific yield increase effect (per ha)**	**Applicability of the measure according to location and site conditions**			
					% of FAWS	**Area of FAWS**	**Weighted yield increase effect**	**Explanation of approach and application area, assessment of interactions**
Species	Breeding	>20	10-25%	10%	100%	157	10%	
	Introduction of non-native species	>10	10-30%	5%	100%	157	5%	Interactions with tree species composition and optimised management regime.
Site	Water management	>5	2-10%	2%	20%	85	1.1%	Only applicable on the dry sites of Scots pine and black pine (third forest sub-type).
Forest stand	Tree species composition	>15-20	20-30%	20%	25%	39	6%	Only applicable in areas with pure stands; based on data from the SEF study (Forest Europe, UNECE, and FAO 2011); the same proportion was used for western Russia.
Forest management	Preventing biotic and abiotic damages - Pest damages grazing damages	>5	10% 10%	10% 10%	100% 100%	157 157	10% 10%	Pest management is applicable in south-eastern Europe and western Russia, whereas the prevention of game damages is applicable in central and western Europe; biomass losses occur on 100% of the area; preventing grazing damages is also applicable in the EFT located in western Russia.
	Fire management - Russia	>5	Ca. 6%	6%	11%	17	1%	Only applicable in the drier forest type (sub-type 'Alpine Scots pine and black pine forest'); percentage of FAWS is estimated to be 11% - this figure is from EFISCEN data and applicable for western Russia in analogy.

Quantification of Yield Increase by Applying Best Practices – EFT 3 Alpine Forests – Western Russia								
Subtotal of yield increase effects[97]							**43.1%**	
Forest manage -ment	Improving forest accessibility	>1	10-15%	15%	100%	157	15%	Applicable in western Russia (e.g. Carpathians
Forest ope-rations	Optimised forest accessibility	>1	5-20%	10%	100%	157	10%	Applicable in the mountain ranges of western Russia
	Use of previously unexploited tree compartments	>1	10-50%	10%	100%	157	10%	Applicable in the mountain ranges of western Russia
Improved utilisation effect[98]							**35%**	

i. For western Russia, the subtotal yield increase effect amounts to 43.1% and the most significant yield measures are breeding, the prevention of pest damages and the prevention of grazing damages, each with an equal weighted yield increase of 10%. The mid to long-term effects lead to a 16% yield increase, whereas the short to mid-term effects lead to an increase of 27.1%.

ii. As with the previous country grouping, all relevant yield measures to improve the utilisation effect are applicable in this EFT and region. Therefore, an improved utilisation effect of 35% can be achieved, and the yield measure with the highest contribution is improving forest accessibility.

[97] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[98] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

3.4.4 Best practice strategy EFT 5: Mesophytic deciduous forest

3.4.4.1 General description

Located in western and central Europe, these forests grow on medium (mesotrophic) and good (eutrophic) soils of the nemoral zone. The species composition is characterised by mixtures of European hornbeam (*Carpinus betulus*), sessile oak (*Quercus petraea*), pedunculated oak (*Quercus robur*), species of ash (*Fraxinus excelsior*, *F. angustifolia*), maple (*Acer campestre*, *A. pseudoplatanus*), and small-leaved lime (*Tilia cordata*). Five main groups of forest types are separated under this category.

1. **Oak-hornbeam forests:**
   Generally found on clay to lime-clay substrates in plain, colline to submountainous levels, in sub-atlantic to continental climates. The geographical distribution of mixed oak-hornbeam forests is extremely wide from west France to the region of Kiev in the Ukraine, and from southern Lithuania to the flatlands of the River Po. Mixed oak-hornbeam forests replace beech forests in areas, where beech cannot grow as a result of special local climatic conditions (sites with frequent frost periods in early spring, basins with temperature inversion) as well as macroclimatic areas with too low precipitation rates.
2. **Ashwood and oak-ash forests:**
   These included forests dominated by common ash (*Fraxinus excelsior*), characteristic of limestone districts and growing in basic and moist soils in wet, cool and windy climates. Atlantic ashwoods are found mainly on the British islands, on the foothills and in the inner western Pyrenees, and the Cantabrian mountains.
3. **Eastern European broadleaved forests:**
   This forest sub-type grows in the continental climate of east European Plain out of the natural range of European beech (*Fagus sylvatica*). Pedunculate oak (*Quercus robur*) and lime (*Tilia cordata*) play a dominant role in this zone. The other components of plant communities have the same patterns as in the beech forest. However, the pre-Ural broadleaved forest has a significant proportion of Siberian cold-resistant species in ground cover.
4. **Ravine and slope forests:**
   Cool, moist forests with a multispecific tree layer of variable dominance (sycamore malpe (*Acer pseudoplatanus), ash (Fraxinus excelsior), elm (Ulmus glabra), lime (Tilia cordata, Tilia platyphyllos)*), most often on more or less abrupt slopes.
5. **Other mesophytic deciduous forests:**
   These include forests of the western Palaearctic region dominated by hornbeam (*Carpinus betulus*), elm (*Ulmus* spp.), or maple (*Acer* spp.) (European Environment Agency 2007).

Source: G. Frank (EEA Report, 2006)

Source: H. Städtler and P. Küchler (Google images)

Table 56: Key Data for EFT Mesophytic Deciduous Forests

Key Data – Mesophytic Deciduous Forests					
		EU 28	**Belarus and Ukraine**	**Western Russia**	**Total**
Total forest area	1000 ha	10,410	1,906	1,384	13,700
Total growing stock	mio. m^3	2,074	416	203	2,693
Growing stock per ha	m^3/ha/year	199.2	218.2	146.8	196.5
Total increment	1000 m^3/year	68,438	9,059	4,200	81,697
Increment per ha	m^3/ha/year	6.6	4.8	3.0	6.0
Total yield	1000 m^3	34,226	3,816	2,520	40,321
Yield per ha	m^3/ha/year	3.3	2.0	1.8	2.9

3.4.4.2 Species level

Breeding

One of the main tree species of which the lack of breeding measures is most evident is oak (*Quercus* spp.; Savill and Kanowski 1993). Research on oak breeding should therefore be promoted. In a few European countries, some breeding programs have been initiated for sycamore maple (*Acer pseudoplatanus*). In this case, the existing breeding programs need to be strengthened and implemented for a wider area (Pâques 2013). For common ash (*Fraxinus excelsior*) there is a clear need for optimisation, especially in terms of preventing ash die-back (*Chalara fraxinea*). Priority should be given to establishing breeding programs to breed disease resistant material which can then be used for restoring damaged ash forests (Pâques 2013). Further studies should also be conducted

for hornbeam (*Carpinus betulus*) and lime species (*Tilia* spp.) (Kobliha, Hajnala, and Janeček 2003) in order to develop appropriate breeding programs which will lead to increased growth and yield.
In summary, tree breeding programs for broadleaved species should be intensified, especially since many species have not yet been improved through breeding measures.

Introduction of non-native species

Douglas fir (*Pseudotsuga menziesii*), black pine (*Pinus nigra*), red oak (*Quercus rubra*), walnut (*Juglans regia*), black walnut (*Juglans nigra*) and mixed nut hybrids and larch (*Larix decidua*) are all species which can be introduced in mixed deciduous forests. The most suitable approach is to include these species as temporary mixtures or long term mixture to up to 20%-30%.

3.4.4.3 Forest stand level

Tree species composition and mixture

Potential tree species' combinations include mixtures of shade tolerant species (e.g., sycamore maple (*Acer pseudoplatanus*), beech (*Fagus sylvatica*), spruce (*Picea* spp.)) with light demanding species (e.g., oak (*Quercus* spp.), ash (*Fraxinus* spp.)), and mixtures with highly productive conifers (e.g., Douglas fir (*Pseudotsuga menziesii*), black pine (*Pinus nigra*), etc.) and/or high productive broadleaved species (e.g., red oak (*Quercus rubra*), walnut (*Juglans regia*), black walnut (*Juglans nigra*), etc.) (see above Introduction of non-native species).

Optimised management regime

Optimal silvicultural regimes are known and need to be applied in a wider manner. The main strategy is to optimise yield through high initial spacing, intensification of tending and thinning, and a shelterwood or group selection system (leading to overlapping generations during regeneration).

Coppice improvement and improving degraded forests

Since these forests were frequently managed as coppice with standards, yield can be improved by converting old coppice stands into mixed high forest. Conversion approaches include enrichment planting and promoting a mixture of highly productive non-native species. The newly established stands should be treated as described under "Optimised management regime" (see above).

3.4.4.4 Forest Management level

Preventing biotic and abiotic damages

Intensive mixtures of tree species prevent the infection rate of pests and diseases and reduce the risk of losses. Monitoring, especially of insect populations is required. The timely removal/transport of harvested stems out of the forest is a further measure to prevent damages caused by biotic factors (e.g., longhorn beetles and fungus). This can be combined with the chemical treatment of sawn logs to prevent spread of infestations.
Management of wildlife populations to reduce browsing is also a very important measure in this forest type. Direct approaches include hunting and fencing; reduced browsing by wildlife allows for improved advance regeneration and overlapping tree generations.

3.4.4.5 Forest operations level

The use of previously unexploited tree compartments

Deciduous broadleaved tree species are characterised by a high volume of crown material (i.e., branches, twigs). Depending on the age of the stand and silvicultural treatments, up to 70% of the biomass is fixed in the crown. However, collecting the small sized material is costly, especially if it is not used as fuel wood for households and directly sold in the forest. The utilisation of branch material is therefore concentrated in densely populated regions of Europe (Germany, France, Benelux, Denmark) and in easily accessible terrain.

3.4.4.6 Technical-sustainable potential

Summary of Key Data – EFT 5 Mesophytic Deciduous Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[99]	1000 ha	10,410	1,906	1,384	13,700
Increment per ha	m^3/ha/year	6.6	4.8	3.0	6.0
Current utilisation rate	m^3/ha/year	3.3	2.0	1.8	2.9

Quantification of Yield Increase by Applying Best Practices – EFT 5 Mesophytic Deciduous Forests – EU 28, Belarus and Ukraine

Selected yield measure		Timeline - full effect in years	Yield increase (per ha)	Specific yield increase effect (per ha)	Applicability of the measure according to location and site conditions			
					% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Species	Breeding	>20	10-25%	15%	100%	12,316	15%	
	Introduction of non-native species	>15-20	10-30%	5%	75%	9,237	4%	Only applicable in high forests, not in coppice forests; interactions with tree species composition.
Forest stand	Tree species composition	>15-20	20-30%	20%	29%	3,572	6%	Only applicable in pure stands.
	Optimised management regime	>15-20	10-20%	5%	75%	9,237	4%	Only applicable in high forests, not in coppice forests; interactions with the introduction of non-native species and tree species composition.
	Coppice	>15-20	10-30%	20%	25%	3,079	5%	Applicable in coppice forests of Bulgaria, Croatia, Romania, Ukraine, Spain, Italy, and France.

[99] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 5 Mesophytic Deciduous Forests – EU 28, Belarus and Ukraine								
	Improving degraded forests	>15-20	15-40%	0%	0%	0.0	0%	This measure is related to degraded coppice forests and the yield increase effect can therefore not be separated.
Forest management	Preventing biotic and abiotic damages - pest damages - game damages - grazing damages	>5	10% 10% 10%	5% 5% 3%	39% 56% 39%	4,786 3,428 4,786	1.9% 1.4% 1.2%	Pest management can be improved in eastern and south-eastern Europe (e.g., Ukraine); preventing game damages is applicable in western and central Europe, while preventing grazing damages is applicable in eastern and south-eastern Europe.
Subtotal of yield increase effects[100]							**38.5%**	
Forest opera-tions	Use of previously unexploited tree compartments	>1	10-50%	25%	48%	2,838	23%	Deficits occur mainly in central, eastern and south-eastern Europe, with the exception of Germany and Austria.
Improved utilisation effect[101]							**23%**	

i. For the EFT Mesophytic Deciduous Forests in EU 28, Belarus and Ukraine a potential yield improvement of 38.5% can be achieved when compared to the modelled EFISCEN yield[102], taking into consideration short-term to long-term improvements. The yield measures with the highest contribution include breeding, tree species composition, and coppice. Mid to long-term effects amount to an increased yield of 34% and short to mid-term effects amount to 45%.

ii. An improved utilisation effect of 23% can be achieved for this EFT and region. This is a fairly high value, especially when considering that it is only based on a single yield meaure – the use of previously unexploited tree compartments.

[100] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[101] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

[102] EFISCEN model for 2010

Quantification of Yield Increase by Applying Best Practices – EFT 5 Mesophytic Deciduous Forests – Western Russia								
Selected yield measure		**Timeline - full effect in years**	**Yield increase (per ha)**	**Specific yield increase effect (per ha)**	**Applicability of the measure according to location and site conditions**			
					% of FAWS	**Area of FAWS**	**Weighted yield increase effect**	**Explanation of approach and application area, assessment of interactions**
Species	Breeding	>20	10-25%	15%	100%	1,384	15%	
	Introduction of non-native species	>15-20	10-30%	5%	75%	1,384	4%	Only applicable in high forests, not in coppice forests; interactions with tree species composition.
Forest stand	Tree species composition	>15-20	20-30%	20%	29%	401	6%	Only applicable in pure stands; percentage of pure stands from SEF study (Forest Europe, UNECE, and FAO 2011) also used for western Russia.
	Optimised management regime	>15-20	10-20%	5%	75%	1,038	4%	Only applicable in high forests, not in coppice forests; percentage of high forests for western Russia based on EU 28; interactions with the introduction of non-native species and tree species composition.
	Coppice	>15-20	10-30%	20%	25%	346	5%	Applicable in coppice forests of western Russia; percentage of coppice as calculated for EU 28 in analogy.
	Improving degraded forests	>15-20	15-40%	0%	0%	0.0	0%	This measure is related to degraded coppice forests and the yield increase effect can therefore not be separated.
Forest manage-ment	Preventing biotic and abiotic damages – pest damages	>5	10%	5%	100%	1,384	5%	Pest management can be improved in western Russia.

Quantification of Yield Increase by Applying Best Practices – EFT 5 Mesophytic Deciduous Forests – Western Russia								
Subtotal of yield increase effects[103]							**39%**	
Forest ope-rations	Use of previously unexploited tree compartments	>1	10-50%	25%	100%	1,384	25%	Deficits occur in western Russia.
Improved utilisation effect[104]							**25%**	

i. For western Russia a subtotal yield increase effect of 39% can be achieved. The most significant contributing yield measures include breeding, tree species composition, coppice improvments and preventing pest damages. When considering the timeframe of effects, a similar pattern to the prior country region is evident – most yield measures are mid to long-term with an overall improvement of 34%. Short to mid-term effects amount to a yield increase of 5%.

ii. The improved utilisation effect for western Russia is 25% in this particular EFT. As was the case with EU 28, Belarus and Ukraine, the effect is based on a only one yield measure, namely the use of previously unexploited tree compartments. This yield measure can therefore be considered to be particularly effective in maximising yield from this EFT.

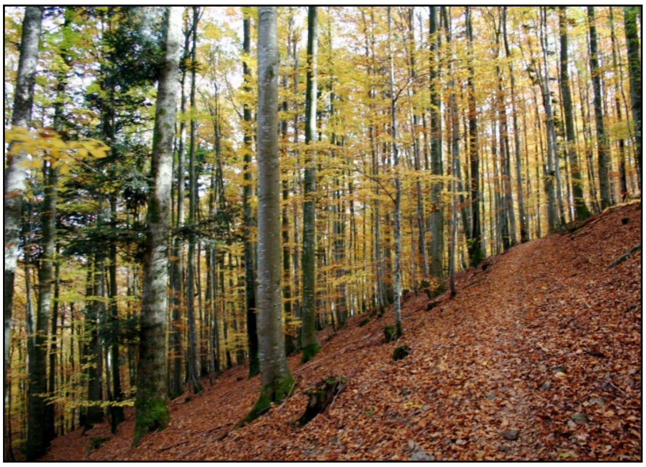
[103] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[104] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

3.4.5 Best practice strategy EFT 6: Beech forest

3.4.5.1 General description

Beech (*Fagus sylvatica*) has extremely wide climatic and edaphic amplitudes, which explains its wide geographic distribution, ranging from southern Norway to Sicily and from Southern England, to Brittany in France and the Cantabrians in Spain, to the lowlands in north-eastern Poland, east of the Carpathians in Moldavia. More eastern locations are restricted to the mountains of the Crimean peninsula. The competitive strength of beech is explained by its high shade tolerance, the dense shadow it casts and its longevity. Beech forests are characterised by the dominance of the European beech (*Fagus sylvatica*) or its transitional hybrids with oriental beech (*Fagus orientalis)* in the eastern and southern parts of the Balkan Peninsula, and along the eastern periphery of the Carpathians. Other locally important trees species include birch (*Betula pendula*) and mesophytic deciduous species such as maples (*Acer* spp.), ash (*Fraxinus europeus*), hornbeam (*Carpinus betulus*), sweet chestnut (*Castanea sativa*), wild cherry (*Prunus avium*), oak species (*Quercus petreae* and *Q. robur*) or lime (*Tilia* spp.).[105] Beech is limited by low winter temperatures causing either direct damage (extreme winter cold or late frosts in spring) or shortened growing seasons. To the south and at lower altitudes water deficiency can limit beech distribution. Beech forests are generally intensively managed in an even-aged structure. In the southern and south-eastern parts of its distribution it frequently occurs as coppice of differing quality, with the tendency to bad quality coppice (European Environment Agency 2007).



Source: L. Hempelmann, 2014 (Unique)

Source: R. Viček, 2012 (www.flickr.com)

[105] EEA Technical report No9/2006. EEA 2006

Table 57: Key Data for EFT Beech Forests

Key Data – Beech Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total forest area	1000 ha	3,675	68	0	3,743
Total growing stock	mio. m^3	996	22	0	1,018
Growing stock per ha	m^3/ha/year	271.1	321.0	0	272.0
Total increment	1000 m^3/year	28,648	386	0	29,034
Increment per ha	m^3/ha/year	7.8	5.7	0	7.8
Total yield	1000 m^3	21,671	209	0	21,879
Yield per ha	m^3/ha/year	5.9	3.1	0	5.8

3.4.5.2 Species level

Breeding

Traditionally, beech forests are regenerated via natural regeneration, even if stands are characterised by phenotypically bad qualities and suboptimal growth. The introduction of planting material with documented origins and species can lead to higher growth rates (approx. 15-20% (FAO 1995)). There is no tradition in planting beech forests since this method of regeneration is cost-intensive and is rare; hence, the introduction of genetically improved plants has to first pass these hurdles. Superior plant material can be introduced once per rotation cycle (100 – 140 years).

3.4.5.3 Site level

Soil improvement

For this EFT, fertilisation is the main aspect of soil improvement. In addition to dolomite and lime, wood ashes can be used for melioration (von Wilpert et al. 2011; Glatzel, Kazda, and Sieghardt 1986). The existing nitrogen immissions in western and central Europe can be regarded as another, steady melioration or fertilisation which is relevant for beech forests.

3.4.5.4 Forest stand level

Tree species composition and mixture

Beech forests are dominated by the very shade tolerant and competitive beech (*Fagus sylvatica*). For this reason, beech forests mainly have a single-storey structure. Artificial planting and tending of highly productive, often light demanding and site adapted species (cherry (*Prunus avium*), chestnut (*Castanea sativa*), Douglas fir (*Pseudotsuga menziesii*), fir (*Abies* spp.), and larch (*Larix decidua*)) can lead to higher growth rates and reduced risks. Without changing the main characteristics of beech forests (<30% non-native conifers), a yield increase of 10-20% due to the inclusion of these highly productive species can be seen as a realistic target (Becker, Prof. Dr. and Huss, Prof. Dr. 2015). Even if the introduction of these alternate species already has some tradition in beech forest management, it is not implemented systematically and does not apply to all regions. The potential impact is very high, but only visible in the medium-term. Introduction requires skillful silvicultural management because beech tends to outcompete other species (Schütz 2003).

Optimised management regime

As beech (*Fagus sylvatica*) has a slow height growth rate in the first 20-30 years and does not perform well on open sites, a second storey of fast growing pioneer species (e.g., poplar and aspen (*Populus* spp.), and/or birch (*Betula* spp.)) is an adequate measure to improve yield, whenever the regeneration is on an open site (after small clear-cuts, storm or snow-damage). While the pioneer species act as a protective cover for beech in its early developmental stages, they can be harvested after 20-40 years, mainly for energetic purposes (Unseld et al. 2010); this adds ca. 10% to the yield.

The rotation cycle of beech ranges from 100 to 140 years. Due to bad market conditions in the past, as well as high felling and transportation costs (e.g., caused by a lack of access in mountainous regions), the rotation cycle of beech forests was even longer in many cases (Klädtke 2001; Peters 1997). Intensification of thinning regimes allows for shortening the rotation period for a similar target diameter and associated wood products. Beech growth and value can be raised effectively; beech is harvested before age-related heart rot and other age-related risks reduce its value. The rotation period can additionally be shortened by a longer regeneration period in group selection systems with overlapping generations – instead of wide-spread short-term shelter-wood systems – combining natural regeneration and planting (Mitscherlich 1970).

Coppice improvement

Beech forests traditionally managed as coppice forests are wide spread in southeast and southern Europe. Currently, these forests are often not regularly and professionally managed (steep slopes, firewood not relevant, less rural population). Another important reason is the low market potential of the products (Kollert 2014). The yield and value potential can be drastically raised in the medium-term if conversion or reconstruction into a high mixed forest stand is conducted (Kneifl et al 2011). A dense regeneration from seeds can replace sparse, over-mature trees and root systems. In addition to this, artificial planting of highly productive and site adapted species (e.g., black pine (*Pinus nigra*), fir (*Abies alba*), cherry (*Prunus avium*)) could be combined. For regions in southern Europe the impact can be high with a potential yield increase of 20-60%.

3.4.5.5 Forest management level

Preventing biotic and abiotic damages

Management of wildlife populations to reduce browsing is a very important measure in this forest type. Direct approaches include hunting and fencing; management of wildlife populations leads to advance regeneration and an overlapping of tree generations.

3.4.5.6 Forest operations level

The use of previously unexploited tree compartments

Beech (*Fagus sylvatica*), similar to tree species of the mesophytic deciduous forests, is characterised by a high volume of crown material (i.e., branches, twigs). Depending on the age of the stand and silvicultural treatments, up to 70% of the biomass is fixed in the crown. Branch material classified as harvest residues is not yet systematically utilised. Collection of the small sized material is costly, if it is not used as fuel wood for households and directly sold in the forest. Branch material is therefore concentrated in densely populated regions of Europe (Germany, France, Benelux, Denmark) and in easily accessible terrain. In remote or steep areas, where crown material is not harvested as firewood 10-40% more wood volume can be gained.

3.4.5.7 Technical-sustainable potential

Summary of Key Data – EFT 6 Beech Forests					
		EU 28	**Belarus and Ukraine**	**Western Russia**	**Total**
Total FAWS[106]	1000 ha	3,675	68	0	3,743
Increment per ha	m^3/ha/year	7.8	5.7	0	7.8
Current utilisation rate	m^3/ha/year	5.9	3.1	0	5.8

Quantification of Yield Increase by Applying Best Practices – EFT 6 Beech Forests– EU 28, Belarus and Ukraine									
Selected yield measure by level		**Timeline - full effect in years**	**Yield increase (per ha)**	**Specific yield increase effect (per ha)**	**Applicability of the measure according to location and site conditions**				
					% of FAWS	**Area of FAWS**	**Weighted yield increase effect**	**Explanation of approach and application area, assessment of interactions**
Species	Breeding	>20	10-25%	10%	100%	3,743	10%	
Site	Soil improvement - melioration	>15-20	2-5%	3%	77%	2,882	2%	Nitrogen immissions exist throughout almost the entire area of this EFT, melioration has to balance the nutrient deficits; applicable in central and western Europe.

[106] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 6 Beech Forests– EU 28, Belarus and Ukraine								
Forest stand	Tree species composition	>15-20	20-30%	20%	22%	807	4%	Only applicable in pure beech high forests; interactions with the introduction of non-native tree species.
	Optimised management regime	>15-20	10-20%	10%	55%	2,059	6%	Applicable in private forests of western and central Europe, and in eastern and south-eastern Europe; applicable only in beech high forest; interactions with tree species composition.
	Coppice – south-eastern Europe south western Europe	>15-20	10-30%	30% 10%	1% 5%	22 186	0.2% 0.7%	Applicable in south western (10%) and south-eastern Europe (30%).
Forest Manage-ment	Preventing biotic and abiotic damages - game damages - grazing damages	>5	10% 10%	10% 10%	77% 17%	1,441 636	4% 2%	Preventing game damages is relevant in western and central Europe; assumption: 50% of the area shows severe biomass losses; preventing grazing damages is relevant in south-eastern Europe.
Subtotal of yield increase effects[107]							**28.9%**	
Forest operations	Use of previously unexploited tree compartments - Central Europe - South-eastern Europe	>1	10-50%	5% 15%	25% 18%	931 688	1% 3%	Relevant for eastern and south-eastern Europe (+15%), and central Europe (+5%) with the exception of Germany and Austria.
Improved utilisation effect[108]							**4%**	

[107] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[108] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

i. The subtotal yield increase effect for this EFT is 28.9%, with the main contributing yield measures being breeding, optimised management regime, tree species composition and the prevention of game damages. Most of the applicable measures are mid to long-term and amount to an increased yiled effect of 28.9%, whereas the short to mid-term measures amount to a 6% increase in yield.

ii. Once again, the improved utilisation effect of 4% is based on a single yield measure. This value, however, is differentiated according to two particular regions in Europe, that is central Europe (1%) and south-eastern Europe (3%).

3.4.6 Best practice strategy EFT 7: Mountainous beech forests

3.4.6.1 General description

The center of distribution of this EFT is in the central European mountains, but they also occur in higher mountains in the Pyrenees, Alps, Carpathians and central Balkans, and penetrate via the Apennines as far south as Sicily. In general, progressing in a southward direction, beech forests are able to occupy increasingly higher mountain zones. Mountainous beech forests are defined by the altitudinal range of distribution, by the dominance of beech (*Fagus* spp.) and, in most cases, by the presence of coniferous species (*Abies alba* and/or *Picea abies*) as important components. As with beech forests, locally important additional tree species include sycamore maple (*Acer pseudoplatanus*), silver birch (*Betula pendula*), common hornbeam (*Carpinus betulus*), sweet chestnut (*Castanea sativa*), common ash (*Fraxinus excelsior*), aspen (*Populus tremula*), wild cherry (*Prunus avium*), sessile oak (*Quercus petraea*), pedunculated oak (*Quercus robur*), roawn (*Sorbus aucuparia*), lime species (*Tilia cordata*, *T. platyphyllos*), and wych elm (*Ulmus glabra*) depending on trophic status and/or successional phase. In the northern Apennines to southern Alps, human use has been intensive for more than a millennium, while in parts of the Dinaric Alps, the Balkans and the Carpathians large tracks of more or less semi-natural forests with smaller natural remnants exist. Intensive forest use for fuelwood purposes was typical of mining areas, and in many mountain areas (e.g., in the Apennines and partly in the Alps) beech (*Fagus sylvatica*) was used as coppice for firewood and charcoal. Most of these stands were turned into high forest in the 20th century. In other parts of Europe, beech exploitation was severe and large regions became heavily deforested. In some of these areas systematic programmes of reforestation began. Reforestation has changed the composition of natural forest in these areas, supporting the spread of spruce and fir, both pushing back beech (European Environment Agency 2007).

Source: L. Hempelmann, 2014 (Unique)

Source: P. Beranek, 2010 (www.flickr.com)

Table 58: Key Data for EFT Mountainous Beech Forests

Key Data – Mountainous Beech Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total forest area	1000 ha	6,868	600	825	8,292
Total growing stock	mio. m^3	1,908	193	218	2,319
Growing stock per ha	m^3/ha/year	277.8	322.4	263.8	279.6
Total increment	1000 m^3/year	52,073	3,596	2,240	57,909
Increment per ha	m^3/ha/year	7.6	6.0	2.7	7.0
Total yield	1000 m^3	31,490	2,417	1,349	34,792
Yield per ha	m^3/ha/year	4.6	4.0	1.6	4.2

3.4.6.2 Species level

Breeding

Well-developed breeding material already exists for Norway spruce (*Picea abies*; Pâques 2013), but breeding programs for beech (*Fagus sylvatica*) and fir (*Abies alba*; Wolf 2003) are still lacking. Both beech and fir stands tend to be regenerated via natural regeneration. As a best practice, breeding material for spruce could be applied within a larger area, and further research and breeding improvements need to be made for beech and fir. Once genetically modified material is more easily available, it needs to be applied throughout this EFT in order to lead to higher growth rates and increased yield (approx. 15-20% for beech (FAO 1995)). There is also potential to increase the use of modified plant material for birch (*Betula* spp.), ash (*Fraxinus excelsior*) and poplar (*Populus* spp.)(Pâques 2013; J. Hynynen et al. 2010; Stanton, Neale, and Li 2010) since this will also lead to yield increases in the mixed mountainous beech forests. However, considering that the percentage of these additional broadleaved species is rather low – in Slovenia beech makes up more than 90% of the forest due to its competitiveness (Diaci et al. 2013) – the resulting impact of this measure will also be limited.

Introduction of non-native species

Larch (*Larix* spp.) is a suitable pioneer species which has been used in central and Eastern Europe for temporal mixtures. The hybrids of European larch (*Larix decidua*) and Japanese larch (*L. kaempferi*) are very effective for increasing productivity (Pâques 2013). Douglas fir (*Pseudotsuga menziesii*) can be implemented in Western Europe (positive experiences have already been made), and should also be promoted further in central Europe. A positive argument for the inclusion of Douglas fir in mountainous beech stands is that it has a high potential with regard to climate change (i.e., a high drought tolerance; Fischer 2008). If an admixture of up to 30% is considered for yield improvement, the added increment will be between 5-15% (depending on the percentage of beech (*Fagus sylvatica)*, since it is the tree species with the lowest productivity in this species mixture) (UNIQUE

2015). Other positive effects to be expected are in terms of climate change risk reduction and higher value timber.

3.4.6.3 Site level

Soil improvement

For mountainous beech forests, approaches similar to those in beech forests should be applied. Soil melioration can be achieved by applying dolomite, lime or wood ash fertilisers. The existing nitrogen immission in western and central Europe can be regarded as another, steady melioration or fertilisation which is relevant for mountainous beech forests. Since the range of nutrient availability is quite high, the rate of melioration can vary considerably (frequencies of 10-50 or even 60 years could be relevant to compensate the nutritional losses and imbalances).

3.4.6.4 Forest stand level

Optimised management regime

If traditional forest management approaches (i.e., group selection and selection forest) are recommended to maximise the productivity of this EFT. The aim is to work toward a well-managed and well-structured group selection or plenter forest (Schütz 2003; Duchiron 2000). In areas where this is not the case, forest management plans could be revised to include group selection and work toward selection forest.

Improving degraded forests

Degraded forests exist mainly in south-eastern Europe (Romania, Bulgaria, and Greece). There is a high potential for improvements in these forests. The degradation is frequently caused by prioritizing spruce (*Picea abies*) and fir (*Abies alba*) for harvests, therefore gradually leading to an increase in the proportion of beech (*Fagus sylvatica*). In general, lower quality trees are often left in the forest stands. In this case, there is a need to work toward optimal tree species mixture and stock density, resulting in 15-25% higher productivity and a 20-40% increased wood value.

3.4.6.5 Forest Management level

Preventing biotic and abiotic damages

Severe browsing damages are concentrated in the Alpine region. The subsequent impact on forests is high due to the steep terrain and high altitude which make it difficult to regenerate forests through planting and to maintain young stands. The lack of regeneration layers below the canopy reduces the increment and yield. Wildlife browsing damages therefore need to be reduced through hunting to avoid costly fencing of young stands.

Improving forest accessibility

The main focal area for this measure is south-east Europe, and there is some overlap with the forest operations level. The key to increasing yield in this area is to improve the overall forest accessibility in mountainous terrain.

3.4.6.6 Forest operations level

Optimised harvesting technique

A deficit in optimised harvesting techniques is a wide-spread issue in south-eastern Europe which leads to potential harvestable areas being left unharvested. There is a need to improve the technical equipment for harvesting in mountainous areas (e.g., implementation of cable yarding systems). The implementation of cable yarding systems combined with a systematic skidding trail network will lead to an estimated 10-15% more harvestable area (UNIQUE 2015).

The use of previously unexploited tree compartments

The focal area for this measure is east and south-east Europe, where branch and crown material is currently not being used on a regular basis. A big potential is to mobilise the utilisation of low quality beech stem wood, branch and crown material for energetic purposes.

3.4.6.7 Technical-sustainable potential

Summary of Key Data – EFT 7 Mountainous Beech Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[109]	1000 ha	6,868	600	825	8,292
Increment per ha	m^3/ha/year	7.6	6.0	2.7	7.0
Current utilisation rate	m^3/ha/year	4.5	4.0	1.6	4.2

Quantification of Yield Increase by Applying Best Practices – EFT 7 Mountainous Beech Forests – EU 28, Belarus and Ukraine					Applicability of the measure according to location and site conditions				
Selected yield measure by level		Timeline - full effect in years	Yield increase (per ha)	Specific yield increase effect (per ha)	% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Species	Breeding	>20	10-25%	10%	100%	7,468	10%	
Site	Introduction of non-native species	>15-20	10-30%	5%	100%	7,468	5%	Interactions and combined effect with tree species composition.
	Soil improvement - melioration	>5	2-5%	3%	31%	2,281	1%	Nitrogen immissions exist throughout almost the entire area of this EFT, melioration has to balance the nutrient deficits; relevant in central and western Europe.

[109] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 7 Mountainous Beech Forests – EU 28, Belarus and Ukraine								
Forest stand	Optimised management regime	>15-20	10-20%	10%	81%	6,018	8%	Applicable to private forests in western and central Europe, and the remaining EFT area minus the degraded forests of south-eastern and eastern Europe.
	Improving degraded forests	>15-20	15-40%	25%	9%	646	2%	Measure is only applicable in south-eastern and eastern Europe; assumption is that 15% of forests are degraded.
Forest management	Preventing biotic and abiotic damages - pest damages - game damages - grazing damages	>5	10% 10% 10%	10% 10% 10%	58% 42% 50%	4306 1581 3706	6% 2% 5%	Improvements in pest management can be applied in south-eastern and eastern Europe; preventing game damages is relevant for western and central Europe; assumption: 50% of the area shows severe biomass losses; preventing grazing is relevant in south-eastern and eastern Europe.
Subtotal of yield increase effects[110]							**39%**	
Forest manage-ment	Improving forest accessibility	>1	10-15%	10%	58%	4,306	6%	Applicable in south-eastern and eastern Europe.
Forest operations	Optimised forest accessibility	>1	5-20%	10%	58%	4,306	12%	Applicable in south-eastern and eastern Europe.
	Use of previously unexploited tree compartments	>1	10-50%	20%	58%	4,306	6%	Applicable in south-eastern and eastern Europe.
Improved utilisation effect[111]							**24%**	

[110] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[111] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

i. For the EFT Mountainous Beech Forest in EU 28, Belarus and Ukraine a potential yield improvement of 39% can be achieved when compared to the modelled EFISCEN yield[112], taking into consideration short-term to long-term improvements. The improved yield increase effect is realised mainly through breeding, an optimised management regime, and the prevention of pest damages. Mid to long-term effects can be achieved through the majority of listed measures and amount to 25%. Short to mid-term measures on the other hand lead to a yield increase of 14%.

ii. The improved utilisation effect is 24% and is based on all yield measures which are relevant for increasing the utilisation of forest biomass. The most significant of the three yield measures is optimised forest accessibility.

[112] EFISCEN model for 2010

Quantification of Yield Increase by Applying Best Practices – EFT 7 Mountainous Beech Forests – Western Russia									
	Selected yield measure	**Timeline – full effect in years**	**Yield increase effect (per ha)**	**Specific yield increase effect (per ha)**	**Applicability of the measure according to location and site conditions**				
					% of FAWS	**Area of FAWS**	**Weighted yield increase effect**	**Explanation of approach and application area, assessment of interactions**
Species	Breeding	>20	10-25%	10%	100%	825	10%	
Site	Introduction of non-native species	>15-20	10-30%	5%	100%	825	5%	Interactions and combined effect with tree species composition.
Forest stand	Soil improvement - fertilisation	>5	2-5%	3%	100%	825	3%	Nitrogen immissions exist throughout almost the entire area of this EFT, melioration has to balance the nutrient deficits; applicable western Russia.
	Optimised management regime	>15-20	10-20%	10%	71%	586	7%	Applicable in private forests in western and central Europe, and the remaining EFT area minus the degraded forests of south-eastern and eastern Europe.
	Improving degraded forests	>15-20	15-40%	25%	29%	239	7%	Measure is applicable in western Russia; interactions with optimised management regime; assumption for western Russia: ratio of FAWS counted as degraded has a relative stocking <0.5.
Forest manage-ment	Preventing biotic and abiotic damages - pest damages - grazing damages	>5	10% 10%	10% 10%	100% 100%	825 825	10% 10%	Improvements in pest management and the prevention of grazing damages are applicable in western Russia.

Quantification of Yield Increase by Applying Best Practices – EFT 7 Mountainous Beech Forests – Western Russia								
Selected yield measure		Timeline – full effect in years	Yield increase effect (per ha)	Specific yield increase effect (per ha)	Applicability of the measure according to location and site conditions			
					% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Subtotal of yield increase effects[113]							**52%**	
Forest manage-ment	Improving forest accessibility	>1	10-15%	10%	100%	825	10%	Relevant for western Russia.
Forest operations	Optimised harvesting techniques	>1	5-20%	10%	100%	825	10%	Relevant for western Russia.
	Use of previously unexploited tree compartments	>1	10-50%	20%	100%	825	20%	Relevant for western Russia.
Improved utilisation effect[114]							**40%**	

i. The subtotal of yield increase effects for western Russia is 52%. The biggest contribution to this improvement can be made by the yield measures breeding, the prevention of pest damages and the prevention of grazing damages. Mid to long-term effects account for an increase of 29%, whereas short to mid-term effects amount to an increase of 23%.

ii. For this EFT in western Russia, an improved utilisation effect of 40% can be achieved. This value is based on all relevant utilisation yield measures, but most importantly on the use of previously unexploited tree compartments.

[113] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[114] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

3.4.7 Best practice strategy EFT 8: Thermophilous deciduous forests

3.4.7.1 General description

The main area of distribution of this forest type is the biogeographical Mediterranean region, namely the climatic zone referred as supra-Mediterranean. Forest types under this class are also found in other distinct biogeographical areas, namely the warmest sector of the Atlantic region (south-western France, north and north-western coast of the Iberian Peninsula), the Alpine region in the lowest altitudinal levels of the Pyrenees, Massif central, Jura, and Alps, the periphery and hills surrounding the Pannonic depression, as well as the sub-continental sector of the Continental Region. Thermophilous deciduous forests are limited to the north (or upslope) by temperature and to the south (or downslope) by drought; at these limits they are replaced by, respectively, coniferous forests and broadleaved sclerophyllous vegetation. This forest type is dominated by deciduous or semideciduous thermophilous species, mainly downy oak (*Quercus pubescens*). Other oaks associate with or replace downy oak in sub-mediterranean woods: Portuguese oak (*Quercus faginea*), Pyrenean oak (*Q. pyrenaica*) and Algerian oak (*Q. canariensis*) (Spain), Turkey oak (*Q. cerris*) (Italy), Hungarian oak (*Q. frainetto*), and Macedonian oak (*Q. trojana*) (Greece). Other species typically associated with these oak woods are maples (*Acer monspessulanus*, *A. opalus*, *A. obtusatum*) and, in eastern areas, hop hornbeam (*Ostrya carpinifolia*), manna ash (*Fraxinus ornus*), and Oriental hornbeam (*Carpinus orientalis*). Most thermophilous deciduous forests are dominated by assemblages of one or two dominant native (or naturalised) tree species accompanied by secondary species and/or an understory. Anthropogenic exploitation has modified the natural composition of thermophilous deciduous forests, leading in most cases to the elimination of natural species without a commercial interest or with poor resprouting capacity or, conversely, the introduction of other forest species that would not occur naturally (e.g., sweet chestnut (*Castanea sativa*)) (European Environment Agency 2007).

Source: P. Regato (EEA Report, 2006)

Source: R. Haveman, 2015 (www.flickr.com)

Table 59: Key Data for EFT Thermophilous Deciduous Forests

Key Data – Thermophilous Deciduous Forests					
		EU 28	**Belarus and Ukraine**	**Western Russia**	**Total**
Total forest area	1000 ha	7,453	0	0	7,453
Total growing stock	mio. m^3	776	0	0	776
Growing stock per ha	m^3/ha/year	104.1	0	0	104.1
Total increment	1000 m^3/year	25,976	0	0	25,976
Increment per ha	m^3/ha/year	3.5	0	0	3.5
Total yield	1000 m^3	10,981	0	0	10,674
Yield per ha	m^3/ha/year	1.5	0	0	1.4

3.4.7.2 Species level

Breeding

Currently, very little information is available for potential oak breeding programs. According to Savill and Kanowski (1993), and Hubert and Savill (1999) a genetic improvement program for only the European oaks *Quercus robur* and *Quercus petraea* began in the mid to late 1990s, however these are not the main oak species for this particular EFT. In Turkey, some research has been conducted on *Quercus* species through the Noble Hardwoods Network (Alan 2002), but here too, the research has not yet developed into a full breeding program for selected oak species. With sufficient information and testing, breeding programs have the potential to lead to substantial increases in growth and yield and secure the genetic potential of the wide range of tree species included in this EFT.

Introduction of non-native species

Eucalyptus (*Eucalyptus* spp.) is already a genus which is being planted in mixture with oak species (*Quercus* spp.) in north-west Portugal, Spain (Grupo Empresarial ENCE 2009) and south-west France since it has a high drought tolerance (Shvaleva et al. 2006). Eucalyptus could play a wider role in areas with an Atlantic climate. Its range is limited by low winter temperatures and frost.

3.4.7.3 Site level

Water Management

Water is a limiting factor in this EFT. The establishment of new forest stands should therefore be supported by temporary irrigation, weeding and mulching. Forest roads need to be carefully constructed so that water is redistributed from the road system back into the forest stands.

Soil improvement
Since water is the limiting factor for growth, increasing the humus content would lead to a better water storage capacity (Morris 2004). With regard to erosion on sloping terrain, the ground vegetation cover needs to be managed and appropriate cable yarding lines should implemented to reduce the pressure on soils; skyline cable techniques are far less damaging than other yarding techniques (Greulich et al. 1997) An increase in ground vegetation will decrease the amount of erosion while also adding to the humus layer. Also, crown and branch material should at least partially be left in the stand.

3.4.7.4 Forest stand level

Tree species composition and mixture
The thermophilous forests already have a high mixture of tree species (see general description). Nevertheless, there is potential to introduce pine species (*Pinus halepensis*, *P. nigra*, *P. pinnea*, *P. pinaster*, *P. brutia*) which also occur in the coniferous forests of the Mediterranean EFT. Site and regional specific mixtures with these pines are possible in a wide range of climatic conditions. A 20-40% admixture of pine could lead to a substantial increase in yield (ca. 10-15%) and value.

Coppice improvement and improving degraded forests
Similar to the mesophytic deciduous forests and beech forests, these forests were frequently managed as coppice with standards, but have been neglected in recent years. The yield and value potential can be drastically raised in the medium-term if conversion or reconstruction into a high mixed forest stand is conducted (Kneifl et al 2011). A dense regeneration from seeds can replace sparse, over-mature trees and root systems. In addition to this, artificial planting of highly productive and site adapted species (e.g., pine species (*Pinus* spp.)) could be combined. The potential yield increase of this combination of measures could be between 20-60% (UNIQUE 2015; see also section on “Tree species composition”).
In this case, the improvement of degraded forests refers to active management of the timeworn coppice stands.

3.4.7.5 Forest Management level

Fire management
The risk of fire in particularly dry areas can be reduced by mulching crown material and the removal of woody debris for energetic purposes; these preventative measures, however, are only possible in accessible areas. Improved fire monitoring and firefighting capacities should also be constituents of a fire management plan.

Improving forest accessibility
Access road networks need to be improved in many regions of this EFT, mainly in south-east Europe. The consequence of lacking road infrastructure is that parts of the forests are completely underutilised and cannot be accessed to conduct measures pertaining to fire management.

3.4.7.6 Forest operations level

Optimised harvesting technique

There is a need to adapt the harvesting system to mountainous areas since a large part of thermophilous forests are located on sloping terrain. At the moment, harvesting is problematic mainly due to lacking accessibility and high costs of harvesting. It is possible to increase the amount of harvested timber through the utilisation of appropriate harvesters (those able to cope with steep slopes), and/or cable yarding systems (Greulich et al. 1997).

3.4.7.7 Technical-sustainable potential

Summary of Key Data – EFT 8 Thermophilous Deciduous Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[115]	1000 ha	7,453	0	0	7,453
Increment per ha	m^3/ha/year	3.4	0	0	7.5
Current utilisation rate	m^3/ha/year	1.4	0	0	4.5

Quantification of Yield Increase by Applying Best Practices – EFT 8 Thermophilous Deciduous Forests – EU 28, Belarus and Ukraine								
Selected yield measure		Timeline – full effect in years	Yield increase (per ha)	Specific yield increase effect (per ha)	Applicability of the measure according to location and site conditions			
					% of FAWS	Area of FAWS	Weighted yield increase effect	Explanation of approach and application area, assessment of interactions
Species	Breeding	>20	10-25%	15%	100%	7,453	15%	
Site	Introduction of non-native species	>15-20	10-30%	5%	76%	5,664	4%	Applicable in western and south western Europe, as an admixture (less than 30%); interactions with the tree species composition.
Forest stand	Soil improvement - restoration	>10	5-25%	5%	20%	1,491	1%	Mainly relevant for steep mountainous terrain, where water erosion causes humus losses.

115 Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 8 Thermophilous Deciduous Forests – EU 28, Belarus and Ukraine								
	Tree species composition	>15-20	20-30%	15%	70%	5,217	11%	Admixture of coniferous species (up to 30%); applicable to high forests; interactions with the introduction of non-native species.
	Coppice	>15-20	10-30%	20%	38%	2,851	8%	Coppice of better quality (not degraded).
	Improving degraded forests	>15-20	15-40%	40%	7%	503	3%	Assumption: 15% of coppice is degraded.
Subtotal of yield increase effects[116]							**42%**	
Forest manage-ment	Improving forest accessibility	>1	10-15%	10%	23%	1,691	2%	Relevant in south-eastern and eastern Europe.
Forest operations	Optimised harvesting techniques	>1	5-20%	20%	5%	338	1%	Relevant in south-eastern and eastern Europe.
Improved utilisation effect[117]							**3%**	

i. For the EFT Thermophilous Deciduous Forests in EU 28, Belarus and Ukraine a potential yield improvement of 42% can be achieved when compared to the modelled EFISCEN yield[118], taking into consideration short-term to long-term improvements. The improved yield increase is realised mainly through the application of breeding, tree species composition and coppice improvement. Mid to long-term effects amount to a yield increase of 41%, whereas mid-term effects amount to a yield increase of 1%.

[116] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.
[117] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).
[118] EFISCEN model for 2010

ii. The improved utilisation effect for this EFT and region is 2%. This is a fairly low value; nevertheless, it is based on two yield measures, namely improving forest accessibility and optimised harvesting techniques. The first yield measures makes a slightly larger contribution to the yield increase.

3.4.8 Best practice strategy EFT 10: Coniferous forests of the Mediterranean

3.4.8.1 General description

This category includes a large group of coniferous forests, mainly xerophytic (i.e., plants adapted to surviving with very little water) forest communities, distributed throughout Europe from coastal regions to high mountain ranges. The dominant species include pine (*Pinus nigra*, *P. halepensis*, *P. canariensis*), fir (*Abies* spp.), juniper (*Juniperus* spp.), cypress (*Cupressus* spp.) and cedar (*Cedrus* spp.) depending on the altitudinal belts. These forests grow on dry, often poor soils. As indicated by the name, this forest type only occurs in the Mediterranean zone in the countries Portugal, Spain, France, Italy, Croatia, Greece and Bulgaria. It dominates the forests of Portugal and Greece and plays a large role in the forest type composition of Spain. The geographical distribution of this forest type and its main relevant compositional and structural features are specific to the forest sub-types listed below (European Environment Agency 2007).

1. Thermophilous pine forest
2. Mediterranean and Anatolian Black pine forest
3. Canarian pine forest
4. Mediterranean and Anatolian Scots pine forest
5. Alti-Mediterranean pine forest
6. Mediterranean and Anatolian fir forest
7. Juniper forest
8. Cypress sempervirens forest
9. Cedar forest
10. Tetraclinis articulata stands
11. Mediterranean yew stands

Source: www.wikimedia.org

Source: P. Regato (EEA Report, 2006)

Table 60: Key Data for EFT Coniferous Forests of the Mediterranean

Key Data – Coniferous Forests of the Mediterranean					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total forest area	1000 ha	9,729	0	0	9,729
Total growing stock	mio. m^3	941	0	0	941
Growing stock per ha	m^3/ha/year	96.7	0	0	96.7
Total increment	1000 m^3/year	44,690	0	0	44,690
Increment per ha	m^3/ha/year	4.6	0	0	4.6
Total yield	1000 m^3	22,381	0	0	22,381
Yield per ha	m^3/ha/year	2.3	0	0	2.3

3.4.8.2 Species level

Breeding

Optimised pine breeding material already exists for western countries (e.g., Spain, Portugal, and especially France), although it is more developed for Scots pine (*Pinus sylvestris*) than for Aleppo pine (*Pinus halepensis*). For Aleppo pine, standard breeding programs have been developed in Spain and particularly in Greece (Pâques 2013). Italian cypress (*Cupressus sempervirens*) is the cypress species with the most intensive tree improvement program in Europe, and it has both cultural and economic importance (T.J. Mullin et al. 2011). In all these cases, it is important that existing optimised plant material be applied on a larger scale in order to increase yield. Further research in and development of breeding programs could be conducted not only for pine, but also for cedar (*Cedrus* spp.) and juniper (*Juniperus* spp.) species.

Introduction of non-native species

Eucalypts (*Eucalyptus* spp.) are partially established in the coastal zone of this forest type in Portugal, Spain and France. As such, eucalyptus could be a potential species to be planted in mixture with pine (*Pinus* spp.). Since eucalyptus is limited by low winter temperatures and frost, it would only play a wider role in areas with an Atlantic climate. It is also important that the eucalypts be monitored and managed continuously to avoid any undesired self-propagation. Paulownia (*Paulownia tomentosa*) can be introduced as broadleaved mixture in lower altitudes and warmer climates in south western as in south-eastern Europe.

3.4.8.3 Site level

Water Management

Water is a limiting factor in the Mediterranean region. The establishment of new forest stands should therefore be supported by temporary irrigation, weeding and mulching (Coello, Piqué, and Fuentes

2015). In mountainous areas of this forest type, forest roads need to be carefully constructed so that water is redistributed from the road system back into the forest stands.

Soil improvement

One of the main issues in this area is erosion. It is important to allow for ample ground vegetation. This will also lead to an improved humus layer in the soil, which will in turn improve the overall water storage capacity of the soil; both of these aspects are directly related to yield, especially where the soil is being prepared for the next tree generation.

3.4.8.4 Forest stand level

Tree species composition and mixture

The mostly pure coniferous stands where pine species (*Pinus* spp.) are dominating should be mixed with shade tolerant broadleaved species (beech, hornbeam, oak, lime) and/or fir (*Abies* spp.) in higher altitudes. This will lead to a surplus in yield, improved erosion prevention, reduced fire risk, and reduced risks of pest attacks.

Optimised management regime

An optimised management regime is linked to the vertical and horizontal mixtures described above. There is a need to focus more on weeding during the establishment phase, and stands should be regenerated with a higher number of trees per hectare and with a mix of species. Early thinnings result in improved yield for energy purposes and help in controlling water availability for the remaining stand. Where shade tolerant species are part of the forest stand, advance regeneration and a second storey increases growth and yield.

Improving degraded forests

In this particular forest type, degradation is mainly caused by fire, pests (insects) (FAO 2013) and lack of weeding during the establishment phase (poor stocking). In order to improve yield, active forest regeneration should be conducted after severe fires or losses due to pests – even on small forest patches. Furthermore, weeding and mulching should be intensified during the establishment phase.

3.4.8.5 Forest Management level

Preventing biotic and abiotic damages

Intensive mixtures of tree species prevent the infection rate of pests and diseases and reduce the risk of losses. Monitoring, especially of insect populations is required. Monitoring the vitality of trees or infection based on satellite images will allow for low-cost improvements in the future. The timely removal/transport of harvested stems out of the forest is a further measure to prevent damages caused by biotic factors (e.g., longhorn beetles (*Cerambycidae)* and fungi).

A reduction of pressure from livestock pasture, especially occurring in the eastern part of the Mediterranean and mountainous areas, will improve the yield; less browsing leads to an improved stocking of young stands. Targeted herding strategies can also be included as a component of forest management plans to help minimise browsing damages in young stands.

Fire management

The risk of fire in particularly dry areas can be reduced by mulching (Ryan et al. 2011) crown material and the removal of woody debris (Brown et al. 2003) for energetic purposes; these preventative measures, however, are only possible in accessible areas. Improved fire monitoring and firefighting capacities (especially in eastern countries) should also be constituents of a fire management plan.

Improving forest accessibility

As was mentioned above, yield improving measures are linked with the careful planning of forest road networks in mountainous areas and the development/application suitable of cable yarding systems.

3.4.8.6 Forest operations level

Optimised harvesting technique

As a first step, the basic forest road network needs to be improved in mountainous areas of this EFT. In addition to this, there is a need to improve the technical equipment for harvesting in mountainous areas (e.g., implementation of cable yarding systems). The use of suitable cable yarding systems (Greulich et al. 1997) leads to improved accessibility and reduced water disturbances which might otherwise be associated with forest road networks.

3.4.8.7 Technical-sustainable potential

Summary of Key Data – EFT 10 Coniferous Forests of the Mediterranean						
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[119]	1000 ha	9,729	0	0	9,729
Increment per ha	m^3/ha/year	4.6	0	0	4.6
Current utilisation rate	m^3/ha/year	2.3	0	0	2.3

Quantification of Yield Increase by Applying Best Practices – EFT 10 Coniferous Forests of the Mediterranean – EU 28, Belarus and Ukraine					Applicability of the measure according to location and site conditions			
Selected yield measure by level		**Timeline - full effect in years**	**Yield increase (per ha)**	**Specific yield increase effect (per ha)**	**% of FAWS**	**Area of FAWS**	**Weighted yield increase effect**	**Explanation of approach and application area, assessment of interactions**
Species	Breeding	>20	10-25%	10%	100%	9,729	10%	Breeding is well developed and applicable in western part of the EFT; there are deficits in private forests and in south-eastern Europe.
	Introduction of non-native species	>15-20	10-30%	10%	25%	2,469	2.5%	Applicable in coastal regions and warmer climates of south western and south-eastern Europe; assumption: 30% (Eucalyptus and Paulownia).
Site	Water management	>5	2-10%	0%	0%	0	0%	Difficult to estimate the effect of irrigation, weeding and mulching (water management during artificial regeneration).
	Soil improvement - restoration	>10	5-10%	5%	41%	1,946	1%	Relevant for steep terrain.

[119] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 10 Coniferous Forests of the Mediterranean – EU 28, Belarus and Ukraine								
Forest stand	Tree species composition	>15-20	20-30%	10%	60%	5,838	6%	Applicable in pure stands.
	Optimised management regime	>15-20	10-20%	15%	78%	7,589	12%	Relevant for private forests and south-eastern Europe.
	Improving degraded forests	>15-20	15-40%	30%	10%	973	3%	Applicable in south-eastern Europe; assumption of 10% degraded forest; interactions with tree species composition.
Forest management	Preventing biotic and abiotic damages - pest damages	>5	10%	10%	17%	1,654	2%	Applicable in private forests of the EFT.
	Fire management	>5	ca. 3%	3%	17%	1,654	1%	Relevant for south-eastern and south western Europe.
Subtotal of yield increase effects[120]							**37.5%**	
Forest manage-ment	Improving forest accessibility	>1	10-15%	5%	23%	1,691	0.9%	Applicable in south-eastern Europe.
Forest operations	Optimised harvesting techniques	>1	5-20%	20%	5%	338	0.9%	Applicable on steep terrain in south-eastern Europe.
Improved utilisation effect[121]							**1.8%**	

[120] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[121] The improved utilisation effect is based on measures which don't have an impact on forest growth, but which lead to a more complete and therefore increased biomass harvest in forest stands. The improved utilisation effect can only be applied to the real utilisation rate from national harvesting statistics (it is a surplus short-term effect).

i. For the EFT Coniferous Forests of the Mediterranean in EU 28, Belarus and Ukraine, a potential yield improvement of 37.5% can be achieved when compared to the modelled EFISCEN yield[122], taking into consideration short-term to long-term improvements. This is based primarily on the contribution of the yield measures optimised management regime, breeding and tree species composition. Mid to long-term effects lead to a yield increase of 33.5%, whereas short to mid-term effects lead to a yield increase of 4%.

ii. The improved utilisation effect for this EFT and region is 1.8%. As with the previous EFT, this is a fairly low value which is nevertheless based on the combination of two yield measures, namely improving forest accessibility and optimised harvesting techniques. Both are equally important in terms of their contribution to an increased yield.

[122] EFISCEN model for 2010

3.4.9 Best practice strategy EFT 14: Introduced tree species forests

3.4.9.1 General description

This class covers forest plantations and self-sown stands of non-native species. Forest plantations are stands established by planting and/or seeding in the process of afforestation or reforestation; they are intensively managed stands (e.g., short rotation forestry) that meet all the following criteria – one or two species at plantation, even aged, regular spacing, systematic thinning regimes. There are two sub-types of introduced tree species forests (European Environment Agency 2007):

1. Plantations of site-native species
2. Plantations of non-site-native and self-sown exotic forests

Source: www.wikimedia.org

Source: Intl. Forestry Resources and Institutions (IFRI)

Table 61: Key Data for EFT Introduced Tree Species Forests

Key Data – Introduced Tree Species Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total forest area	1000 ha	6,029	8.1	0	6,037
Total growing stock	mio. m^3	1,117	0.7	0	1,118
Growing stock per ha	m^3/ha/year	185.3	81.3	0	185.2
Total increment	1000 m^3/year	58,371	15	0	58,386
Increment per ha	m^3/ha/year	9.7	1.8	0	9.7
Total yield	1000 m^3	30,085	15	0	30,100
Yield per ha	m^3/ha/year	5.0	1.8	0	5.0

3.4.9.2 Species level

Breeding

Breeding programs have already been developed for most intensively managed plantation tree species, but they still need to be implemented consequently. Genetically improved material already exists on a high level. This means that further improvements can be made within a short amount of time, due to the application of new technologies such as genome analysis and vegetative propagation.

Example of breeding in plantation species

Tree breeding in Britain: Sitka spruce

Genetic background

Tree improvement takes advantage of the natural genetic variation which exists within a species. It is often convenient to recognise 3 main stages in tree-breeding work; i) selection – choosing and archiving potential breeding material, ii) testing – validating the actual genetic worth of individual selections, iii) production – making the products of tree breeding available to the user in commercial quantities. A number of improvement techniques are available which exploit this variation at different levels:

- Seed origin or provenance testing
- Tree breeding
- Using plus trees
- Vegetative propagation
- Creating an untested orchard
- Seedling seed orchards
- Clone banks
- Family-mixtures
- Potential genetic gain

Sitka Spruce

The first open-pollinated Sitka spruce progeny-test series planted with the objectives of ranking parent trees for genetic quality relative to unimproved material of the species was planted over eight sites in 1967. To start with, only height and stem straightness assessments were carried out in progeny tests. Wood density was not measured until around 1986 after which the Pilodyn®*) was used. In 1993 it was decided that the first generation of Sitka spruce progeny testing should come to an end. Parent trees which did not have progeny in test by this time would be discarded; there remained in fact only 22. Between 1967 and 1993 nearly 300 Sitka spruce progeny tests had been established. Nearly 100 different series of experiments (involving the same families planted at a range of sites) had been planted; an average of 12 progeny tests or four series per year. Assuming each series contained 50 families, this equated to 200 families per year. The British genetic improvement programme for Sitka spruce was the largest in the world, the improvement programme had been active for 30 years and yet, by the early 1990s, the amount of improved material reaching the forest manager was minimal.

*) This machine measures wood density indirectly as the distance penetration at breast height of a blunt pin fired into the tree with a fixed force of six joules.

(Forestry Commission 2015)

Introduction of non-native species

By definition, the second category of this EFT already includes a wide spectrum of non-native tree species. Non-site native species plantations include a number of industrial plantations providing the raw material for wood processing; these are mostly managed through short-rotation forestry. The species most commonly used in plantations include eucalyptus species (*Eucalyptus* spp.), poplar clones (*Populus* spp.), Sitka spruce (*Picea sitchensis*), Monterey/radiata pine (*Pinus radiata*), lodgepole pine (*Pinus contorta*), Douglas fir (*Pseudotsuga menziesii*), and the western hemlock (*Tsuga heterophylla*) (European Environment Agency 2007).

3.4.9.3 Site level

Water Management

For dry pine plantations located in mountainous terrain water is frequently a limiting factor. The establishment of new forest stands should therefore be supported by temporary irrigation, weeding and mulching. In mountainous areas of this forest type, forest roads need to be carefully constructed so that water is redistributed from the road system back into the forest stands.

For poplar plantations which are mostly located on groundwater influenced floodplain sites it is important to control an optimal groundwater level (change in groundwater levels should correspond to seasons). In plantations where drainage ditches exist, they should be used to control the water level and not simply for draining the soil. This type of water regulation is also an important point when considering climate change and prolonged periods of drought.

Soil improvement

Fertilisation is regarded as a very effective means for increasing yield in plantations. The fertilisation with nitrogen-lime mixtures, however, is less important in this forest type than for boreal forests. Since basic cation deficits are brought about due to the extraction of timber, higher relevance is given to the application of basic cations in the form of wood ashes. The application of fertilisers is usually cost efficient (Mead 2013; Moore 2011; Dickens et al. 2004).

3.4.9.4 Forest stand level

Tree species composition and mixture

Although these forests are by definition low in species diversity, there is a clear need to work toward a combination of several species and multiple tree layers; this can be achieved by combining shade tolerant species with light demanding tree (e.g., Sitka spruce-hornbeam, Douglas fir-beech, poplar-other broadleaved species). Higher tree species diversity is essential for reducing the risk of pests and damages (Kelty 2006).

Improving degraded forests

It is known that degraded forest plantations exist in some countries, for example, Spain. Even though most plantations are managed intensively, there are still areas where efforts to reforest and afforest stands is not accompanied by consequent forest management (e.g., poplar plantations of the 1960s, to some extent eucalyptus in smallholder plantations in northern Spain). Initial stages of forest management were evident (plantations were established), but the following stages (tending, thinning) were neglected due to changes in the wood prices, markets and/or forest policies. In these cases, there is a need to return to optimal forest management; this could substantially increase yield and reduce losses caused by abiotic (storm, fire) and biotic (bark beetles) factors.

3.4.9.5 Forest Management level

Preventing biotic and abiotic damages

The prevention of damages is highly relevant in plantation forests. Monitoring of insect populations and the outbreak of diseases should be a fixed component of forest management. Furthermore, "clean management" should be conducted, i.e., the removal of infected trees, as well as promoting mixed stands to reduce the infection potential and to reduce the risk of losses.

In terms of abiotic damages, silvicultural systems should be applied which are adapted to the risks associated with specific tree species (e.g., shorter rotation for Norway and Sitka spruce (*Picea abies* and *P. sitchensis*) in western parts of Europe, more focus on tending and thinning).

Fire management

Fire management is particularly relevant for plantations of pine (*Pinus* spp.) and eucalyptus (*Eucalyptus* spp.). Similar issues and approaches as for the boreal forests and the coniferous forests of the Mediterranean will apply. Prevention of large-scale damages is made possible by a dense access road network, prescribed burning (FAO 2002), as well as early fire detection and fighting. The risk of fire can be further reduced by mulching crown material and the removal of woody debris for energetic purposes. Improved fire monitoring and firefighting capacities should also be constituents of a fire management plan.

3.4.9.6 Technical-sustainable potential

Summary of Key Data – EFT 14 Introduced Tree Species Forests					
		EU 28	Belarus and Ukraine	Western Russia	Total
Total FAWS[123]	1000 ha	5,390	8.0	0	5,398
Increment per ha	m³/ha/year	9.6	1.8	0	9,6
Current utilisation rate	m³/ha/year	5.1	1.8	0	5,1

Quantification of Yield Increase by Applying Best Practices – EFT 14 Introduced Tree Species Forests – EU 28, Belarus and Ukraine								
Selected yield measure by level		**Timeline - full effect in years**	**Yield increase (per ha)**	**Specific yield increase effect (per ha)**	**Applicability of the measure according to location and site conditions**			
					% of FAWS	**Area of FAWS**	**Weighted yield increase effect**	**Explanation of approach and application area, assessment of interactions**
Species	Breeding	>20	10-25%	5%	100%	6,037	5%	There is a high level of breeding for many of the introduced species; it reduces the increase in future yield, but secures fast implementation.
	Introduction of non-native species	>15-20	10-30%	0	0	0	0%	Most of these stands are already made up of non-native species.
Site	Water management	>5	2-10%	0	0	0	0%	Water management is limited to pine forests on dry sites and poplar forests on wet sites; the effect is not quantifiable.

[123] Forest area available for wood supply; harvestable forest area.

Quantification of Yield Increase by Applying Best Practices – EFT 14 Introduced Tree Species Forests – EU 28, Belarus and Ukraine								
	Soil improvement - fertilisation	>1	5-25%	5%	41%	2,475	2%	Applicable to plantations in the coastal zone of western and south western Europe (Eucalyptus, Radiata pine, Sitka spruce).
Forest stand	Tree species composition	>15-20	20-30%	5%	100%	6,037	5%	Assumption: most stands are pure; effect of 20% admixture and a second layer.
	Improving degraded forests	>15-20	15-40%	20%	4%	241	0.8%	Private forests of south western and south-eastern Europe; assumption: 20% of plantations are degraded.
Forest management	Preventing biotic and abiotic damages - pest damages	>5	10%	10%	64%	3,455	6%	Relevant for private forests of the EFT; interactions with tree species composition and optimised management regimes.
	Fire management	>5	ca. 3%	3%	17%	915	0.5%	Applicable in south-eastern Europe.
Subtotal of yield increase effects[124]							**19.3%**	

i. For the EFT Introduced Tree Species Forests in EU 28, Belarus and Ukraine, a potential yield improvement of 19.3% can be achieved when compared to the modelled EFISCEN yield[125], taking into consideration short-term to long-term improvements. This is based primarily on the contribution of the yield measures preventing pest damages, tree species compostion and breeding. Mid to long-term effects can lead to a yield increase of 10%, whereas short to mid-term effects can lead to a yield increase of 8.5%.

ii. There is no improved utilisation effect for this EFT and country grouping since the majority of plantation forests area already being fully utilised.

[124] The subtotal of yield increase effects is based on measures which have a direct impact on the growth, vitality and productivity of forest stands and species. These measures generally lead to medium to long-term improvements. The yield increase effect is applied to the basic EFISCEN data from 2010 which provides a theoretical yield as based on the model. It is a sum of the yield increasing effects of the listed yield measures.

[125] EFISCEN model for 2010

3.4.10 Summary of constraints for application of yield measures

Chapter 3.3 describes a broad selection of measures, referred to as **yield measures**, which could potentially be applied in forest management to increase the productivity and yield per area unit. This could be considered as the **theoretical potential to increase yield** per area. Immediately after the qualitative description of yield measures, restrictions in applying the different yield measures in the form of constraints need to be considered and discussed in order to define and evaluate best practice strategies.

Following on, chapter 3.4 then applies the described yield measures to a specific forest context. A best practice strategy for forest residue yield increase is defined as "… a specific bundle of different measures to increase growth rates, improve yield, and reduce losses enhancing the overall yield of all wood products."

Due to the varying, climate, topography, site conditions and forest structure not all of the yield measures will necessarily apply within each EFT. The detailed discussion of the applicable best practices leads to the derivation of a quantified, context-specific **technical-sustainable potential to increase yield**.

This chapter presents an overview of most relevant constraints identified, when defining yield measures as well as bundling yield measures for concrete EFT. Constraints cause that yield measures are excluded from application in certain locations or regions and in special site and terrain conditions. Constraints also implied that the yield measure cannot be applied to full extend, which lead to a reduction in the estimated maximal yield increase effect.

3.4.10.1 Species level

Constraints Breeding

The constraints of breeding programs may be classified according to biological, economic and institutional factors (Rosvall and Mullin 2013).

Breeding implies the selection of genotypes according to a limited number of traits. Selective breeding may lead to reduced genetic diversity (Namkoong, Kang, and Brouard 1988). Therefore, breeding programs have to keep a wide range of genotypes and provenances. A balance has to be found between forest area planted with improved material and natural regeneration.

A further constraint is linked to the introduction of improved plant material. Compared to natural regeneration, artificial regeneration can be quite costly in terms of time and resources (breeding process, propagation, planting and protection).

Introduction of non-native species

A major **constraint** for the further promotion of new species is that the management has to cope with tendencies to be invasive on specific forest sites, meaning that these species are outcompeting natural forest species resulting in loss of biodiversity. The non-native conifers are generally not

considered invasive at the moment[126] but some of the introduced broadleaved species are black locust (*Robinia pseudoacacia*), tree of heaven (*Ailanthus altissima*), boxelder (*Acer negundo*) and black cherry (*Prunus serotina*) (Forest Europe, UNECE, and FAO 2011).
The integration of non-native tree species into a silviculture system based on ecological principles therefore requires compromises which can be derived from scientific findings. Specifically, this means that the cultivation of non-native tree species is accepted as part of sustainable forest management as long as the interests and restrictions of nature conservation are also taken into account (Vor et al. 2014).

3.4.10.2 Site level

Optimised species-site matching

There are no known implementation constraints for applying optimised species-site matching application.

Water management

Drainage was widely applied in the past but critically regarded now due to its negative impact on naturalness of soils and the respective habitat changes, especially where intact swamps, mires and wetlands are rare; this is true for many parts of the study area. As such, creating new drainage systems as well as maintaining existing systems is a matter of environmental assessment procedures, or in some cases, prohibited in forests underlying a particular nature conservation status. Existing drainage systems should be maintained in order to regulate the water level in accordance with the seasons. This is especially true for drainage systems which have become overgrown.
A further constraint is that draining organic and peat soils leads to the release of greenhouse gases and a reduced below-ground carbon storage (humus and peat losses) in the soil (Gelman et al. 2013; Ojanen, Minkkinen, and Penttilä 2013; Tiemeyer et al. 2013). Where drainage systems exist on water-logged soils and peatlands, climatically sustainable forestry seems to be possible if the harvested biomass is later stored, for example, in wooden buildings, biofuels or as biochar on agricultural soils ("product storage") (Ojanen et al 2012).
Groundwater supply or recharge under forests is not optimal (Calder et al. 2007), meaning that in the drier climate of southern Europe drinking water preservation or water management on a landscape level requires special management regimes (open forests, intensive thinnings, and broadleaved instead of conifer forests). Forest management under these conditions is therefore a compromise between optimised yield and ground water supply.
Constraints for ii) irrigation are mainly economic in nature. Without economic constraints, the major limitation would arise from the question of water origin, which would be used for irrigation. For both reasons, systematic irrigation is not applied in sustainable forest management throughout all of the regions.

[126] Not on European level. In Germany a debate exists if Douglas fir is invasive.

Soil improvement

i) Even in regions where fertilisation is applied, the primary operational factors limiting this yield measure include the prohibitive cost of purchasing and applying fertilisers in forests and the potential need for application on vast land areas. Moreover the risk of raising GHG levels from fertilised soils also increases costs due to complex planning and application, and lowers public acceptance (Hemström, Mahapatra, and Gustavsson 2014).

Fertilisation is also restricted in protected forest areas.

iii) Melioration is practiced where industrial or agricultural immissions have caused soil acidification and nutrient depletion (west- and central Europe). Constraints include the high cost of application and the impact on natural forest soils under nature conservation.

3.4.10.3 Forest stand level

3.4.10.4 Optimised management regime

Constraints are mostly economic and are relevant on steep slopes and on wet sites, where intensive management is costly. Moreover, the described form of intensive management is not recommended in mountain protection forests and urban forests.

3.4.10.5 Forest management level

Preventing biotic and abiotic damages

Constraints regarding the application of pesticides in forests exist. This is especially the case in the densely populated western countries of Europe, where nature protection and biodiversity regulations prohibit the application of pesticides.

Fire management

Economic constraints exist in terms of acquiring monitoring and firefighting equipment.

Improving forest accessibility

Technical constraints exist in wet and steep terrain and economic constraints (i.e., the cost of road construction machinery and labor) are prevalent in certain regions of Europe (south-eastern and eastern Europe), if the productivity of the forest is low.

3.4.10.6 Forest operations level

Optimised harvesting techniques

There are only economic **constraints**. In difficult terrain (i.e., wet and steep terrain) and in low productive forest areas the utilisation of modern harvest technologies does not pay off.

Use of previously unexploited tree compartments

A constraint arises when nutrients are scarce, whether caused by former overuse or naturally poor site conditions. The impact of using a higher biomass percentage in those cases causes increment losses if no compensatory melioration to maintain the nutrient balance is applied.

3.4.11 Technical-sustainable potential of biomass yield

In the case that the best practice strategies are applied in all recommended regions and conditions, the following yield increase effect and additional harvesting potential can be achieved. This technical-sustainable potential is derived assuming that the measures can be fully be applied “as of tomorrow” in all regions, which is not realistic, but presents a potential of increased biomass yield, that can be achieved considering economic, environmental and logistical constraints as summarised in chapter 3.6.9 and consider the principles of a sustainable forest management (see chapter 3.1).

The three following table show results for EU 28, Belarus and Ukraine, secondly for western Russia and finally for the whole study area. Whereas best practice strategies to increase biomass yield are only developed and evaluated for the eight most relevant EFT by area and potential yield, representing 87% of FAWS and 88% of the baseline yield potential, the data are presented for all 14 EFT meaning the total FAWS. It allows to present a full overview of all forest in the study area assuming that for the 6 not selected EFT -representing 13% of the FAWS and 12% of the baseline yield potential, the yield cannot be improved, which is a conservative assumption.

For the region EU 28, Belarus and Ukraine a potential yield increase effect of 29% has been estimated by analysing 8 of the 14 European forest types and defining best practice strategies to increase yield. It sums up to an increase in annual yield of 162 Mio m³/a. Highest absolute increase in yield can be achieved in the EFT Hemiboreal forest (61 Mio m³/a), the highest effect per hectare in the EFT Mountain Beech forest (1.8 m³/ha/a).
In a short term additional 5% or 28 Mio m³/a can be utilised if the additional harvest potential mainly in broadleaved dominated EFT can be mobilised. For the mobilisation improved harvesting technique, improved forest accessibility and the consequent utilisation of all wood assortments (branch wood, crown material, bad qualities, small dimensions, etc[127]) need to be applied.

[127] Not considering stumps, roots, twigs below 7 cm diameter, needles or leaves

Total Yield increase effects by Forest Type – EU 28, Belarus and Ukraine												
No	**European Forest Type**	**FAWS**	**Yield** (EFISCEN)		**Utilisation 2005-2010**		**Yield increase effect**	**Yield increase**		**Improved utilisation rate**	**Additional harvest potential**	
	(EFT)	1,000 ha	1,000 m³/a	m³/ha/a	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a
1.	Boreal Forests	31,660	124,128	3.9	110,025	3.5	**32%**	39,721	1.3	**0%**	0	0.0
2.	Hemiboreal Forests	34,596	180,063	5.2	167,103	4.8	**34%**	61,221	1.8	**4%**	7,203	0.2
3.	Alpine Forests	5,467	34,393	6.3	27,938	5.1	**29%**	9,974	1.8	**9%**	3,095	0.6
4.	Acidophilous oak and oak-birch forests	3,093	11,148	3.6	13,323	4.3	**n/a**					
5.	Mesophytic Deciduous Forests	12,316	38,042	3.1	41,622	3.4	**38%**	14,456	1.2	**23%**	8,750	0.7
6.	Beech Forests	3,743	21,879	5.8	19,249	5.1	**29%**	6,345	1.7	**4%**	875	0.2
7.	Mountainous Beech Forests	7,468	33,907	4.5	28,643	3.8	**39%**	13,224	1.8	**23%**	7,799	1.0
8.	Thermophilous deciduous Forests	7,453	10,981	1.5	13,044	1.8	**41%**	4,502	0.6	**3%**	329	0.0
9.	Broadleaved evergreen forests	9,601	4,095	0.4	4,923	0.5	**n/a**					
10.	Coniferous forests of the Mediterranean	9,729	22,380	2.3	22,183	2.3	**36%**	8,057	0.8	**2%**	380	0.0
11.	Mire and swamp forests	2,077	6,969	3.4	7,828	3.8	**n/a**					
12.	Floodplain forests	1,391	7,269	5.2	4,811	3.5	**n/a**					
13.	Non-riverine alder, birch or aspen forests	8,212	31,129	3.8	28,458	3.5	**n/a**					
14.	Introduced tree species Forests	5,398	27,482	5.1	28,321	5.2	**20%**	5,496	1.0	**0%**	0	0.0
	Total	142,203	553,865	3.9	517,473	3.6	**29%**	162,996	1.1	**5%**	28,431	0.2

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Total Yield increase effects by Forest Type – Western Russia												
No	**European Forest Type**	**FAWS**	**Yield**		**Utilisation 2005-2010**		**Yield increase effect**	**Yield increase**		**Improved utilisation rate**	**Additional harvest potential**	
	(EFT)	1,000 ha	1,000 m³/a	m³/ha/a	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a
1.	Boreal Forests	84,828	32,189	0.4	8,516	0.1	**66%**	21,245	0.3	**62%**	19,957	0.06
2.	Hemiboreal Forests	4,894	7,103	1.5	1,321	0.3	**42%**	2,983	0.6	**14%**	994	0.04
3.	Alpine Forests	157	184	1.2	59	0.4	**43%**	79	0.5	**35%**	64	0.13
5.	Mesophytic Deciduous Forests	1,384	2,520	1.8	444	0.3	**40%**	1,008	0.7	**25%**	630	0.08
7.	Mountainous Beech Forests	825	1,349	1.6	475	0.6	**49%**	661	0.8	**40%**	539	0.23
11.	Mire and swamp forests	4,133	5,002	1.2	1,096	0.3	**n/a**					
12.	Floodplain forests	346	526	1.5	109	0.3	**n/a**					
13.	Non-riverine alder, birch or aspen forests	3,860	4,193	1.1	992	0.3	**n/a**					
		100,427	**53,066**	**0.5**	**13,012**	**0.1**	49%	**25,976**	**0.3**	54%	**22,185**	**0.06**

For western Russia a potential yield increase effect of 49% has been estimated by analyzing 8 of the 14 European forest types and defining best practice strategies to increase yield. It sums up to an increase in annual yield of 12 Mio m³/a. Highest absolute increase in yield can be achieved in the EFT Boreal Forest due to its outstanding area (10 Mio m³/a), the highest effect per hectare in the EFT Hemiboreal Forest (0.6 m³/ha/a).

In a short term additional 54% or 22 Mio m³/a can be harvested if the additional harvest potential, which can be found in nearly the entire analysed EFT can be mobilised.

No	European Forest Type	FAWS	Yield		Utilisation 2005-2010		Yield increase effect	Yield increase		Improved utilisation rate	Additional harvest potential	
	(EFT)	1,000 ha	1,000 m³/a	m³/ha/a	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a
1.	Boreal Forests	116,487	156,317	1.3	118,542	1.0	**39%**	60,966	0.5	**3%**	5,280	0.05
2.	Hemiboreal Forests	39,489	187,166	4.7	168,424	4.3	**34%**	64,205	1.6	**4%**	6,869	0.17
3.	Alpine Forests	5,624	34,577	6.1	27,997	5.0	**29%**	10,053	1.8	**7%**	2,535	0.45
4.	Acidophilous oak and oak-birch forests	3,093	11,148	3.6	13,323	4.3	**n/a**					
5.	Mesophytic Deciduous Forests	13,700	40,562	3.0	42,066	3.1	**38%**	15,464	1.1	**24%**	9,684	0.71
6.	Beech Forests	3,743	21,879	5.8	19,249	5.1	**29%**	6,345	1.7	**4%**	770	0.21
7.	Mountainous Beech Forests	8,292	35,255	4.3	29,118	3.5	**39%**	13,884	1.7	**19%**	6,778	0.82
8.	Thermophilous deciduous Forests	7,453	10,981	1.5	13,044	1.8	**41%**	4,502	0.6	**4%**	391	0.05
9.	Broadleaved evergreen forests	9,601	4,095	0.4	4,923	0.5	**n/a**					
10.	Coniferous forests of the Mediterranean	9,729	22,380	2.3	22,183	2.3	**36%**	8,057	0.8	**2%**	377	0.04
11.	Mire and swamp forests	6,210	11,972	1.9	8,923	1.4	**n/a**					
12.	Floodplain forests	1,737	7,795	4.5	4,920	2.8	**n/a**					
13.	Non-riverine alder, birch or aspen forests	12,072	35,322	2.9	29,451	2.4	**n/a**					
14.	Introduced tree species Forests	5,398	27,482	5.1	28,321	5.2	**20%**	5,496	1.0	**0%**	0	0.00
	Total	**242,630**	**606,931**	**2.5**	**530,485**	**2.2**	**31%**	**188,972**	**0.8**	**5%**	**32,685**	**0.13**

Table: Total Yield increase effects by Forest Type – EU 28, Belarus, Ukraine and western Russia

For the total study area of 242 Mio ha of forest for wood supply (FAWS) a potential yield increase effect of 31% has been estimated by analyzing 8 of the 14 European forest types and defining best practice strategies to increase yield. It sums up to an increase in annual yield of 189 Mio m^3/a or 0.8 $m^3/ha/a$. Highest absolute increase in yield can be achieved in the EFT Hemiboreal Forest (64 Mio m^3/a), the highest effect per hectare in the EFT Alpine Forest (1.8 $m^3/ha/a$).

In a short term additional 5% or 32 Mio m^3/a can be harvested if the additional harvest potential, which can be found in nearly the entire analysed EFT can be mobilised.

3.5 Realistic potential of biomass yield from forestry

A number of barriers limit the application of best practice strategies to all recommended regions. As a result, the yield increase and the additional harvesting potential cannot be achieved completely within the timeline of 20-30 years presented above.

Hence, in a final step, the influence of barriers which reduce the technical-sustainable potential for biomass yield increase and additional harvest potential are evaluated and quantified. This estimation leads to a more realistic potential; a potential yield which could be obtained under given regional circumstances without changes in forest and environmental policy, economic conditions, research strategies, forest sector organisation and capacity building among forest managers and forest owners.

The following tables provide an overview of the policy, social and economic barriers which have been identified for EU 28, Belarus, Ukraine and western Russia. While this report attempts to present a clear differentiation between the three groups, it is important to bear in mind that some barriers might contain elements of all groupings (e.g., lack of research may be a social *and* an economic barrier). The listed barriers are different in each country and region and also vary for each yield measure. Depending on the specific EFT in the region, they affect the implementation of the best practice strategies very individually, leading to marginal or severe implications for the increase of biomass yield from forestry.
The ranking of impacts is based on the region in which the barrier applies (e.g., only south-eastern countries in the EU) as well as on the overall impact which a yield measure may have. For example, a lack of funding in tree breeding can have a high impact due to the fact that the yield measure breeding may result in an improved yield of 10-25%. This stands in contrast to the barrier “hunting legislation” and “social acceptance of intensified hunting” where the underlying yield measure of preventing game damages can only lead to yield improvements of 8-10%.

3.5.1 Policy and legal barriers

Barriers	Ranking of the impact			
Policy and legal barriers	**EU 28**	**Belarus**	**Ukraine**	**Western Russia**
Unsupportive policy and legal framework for • State forest management • Private forest management	Low	High	High	High
	Indirect	Indirect	Indirect	Indirect
	Short-term	Long-term	Long-term	Short-term
Lack of active policy to foster forest-wood cluster and wood industry	Medium	High	High	Medium
	Indirect	Indirect	Indirect	Indirect
	Short-term	Short-term	Long-term	Short-term
Forest management in concession systems in Russia	--	--	--	High
				Indirect
				Long-term

Barriers	Ranking of the impact			
Hunting legislation	Medium Indirect Long-term	--	--	--
Traditional grazing rights/systems	Low Indirect Long-term	--	Low Indirect Long-term	Low Indirect Long-term

Unsupportive policy and legal framework

This barrier is subdivided into i) unclear and ii) restrictive policy and legal frameworks. Unclear frameworks imply that it is difficult for state or private forest users to understand which long-term forest management strategies can actually be implemented. Restrictive policy and legal frameworks, on the other hand, imply that policies deliberately intervene in particular aspects of forest management, therefore preventing state and private forest users from following a particular line of action (restricted freedom in decision-making, e.g., some state forest administrations restrict the amount of harvesting volume and quality for private forest owners). In both cases it is important for forest policies to have a long-term perspective and management decisions must incorporate and respect forest ownership (stable, transparent forest policies which promote secure tenureship). Unsupportive policy and legal frameworks exist for both state (south-eastern Europe, Belarus, Ukraine and western Russia) and private (south-eastern Europe) forest management.

The production and use of wood for energy is the most rapidly growing sector driven by stringent and ambitious EU and national energy and climate policies. The current EU policy and legal framework is also focused on nature conservation (EU Biodiversity Strategy, EU Habitats and Birds Directives) which potentially implies constraints for more intensive forest management. The new non-legally binding EU Bioeconomy Strategy can be used to support forest management in the development of rural economies, employment, energy security, climate change mitigation and the environment through the substitution of non-renewable resources and securing a sustainable economic development. However, the EU Bioeconomy Strategy is still too general and mainly based on innovation and research measures. This implies that the EU Bioeconomy Strategy cannot be directly implemented as a policy framework to support intensive forest management in the 28 EU member states. The new EU rural development regulation provides EU funds for forestry measures including *inter alia* investments in forest area development and improvement of the viability of forests, afforestation and creation of woodland, establishment of agroforestry systems and production of wood for energy. The EU rural development funding for forestry-related measures are increasingly dependent on Member States priorities', which can focus on either economic or ecological aspects of forest management. This means that the use of wood for bioenergy is at the intersection of many different sectoral EU and national policies and laws which leads to a complex and incoherent governance framework affecting forest management. In the face of an increasing demand for renewable energy driven by policies and markets, the forest sector will have to resolve fundamental policy inconsistencies as well as material and ideological conflicts toward growing competition between material and energetic use of wood in several regions and countries in Europe.

Lack of active policy

Active policy implies an active perception of and support for the forest-wood cluster. The connection between forest management and forest industry and their interdependencies are not actively recognised. There is a lack of active policies in several regions, including south-eastern Europe, Belarus, Ukraine, and western Russia. While this is predominantly a policy issue, there are underlying social and economic aspects which need to be addressed as well.

Forest management in concession systems in western Russia

The following citation by the World Bank's discussion paper on "Key Challenges of the Russian Forest Policy Reform" fully encapsulates the situation at hand:

> In Russia, "the private forest sector is struggling for secure and long-term access to raw materials, a key factor for sound investment decisions. Still, many leasing arrangements are based on a shared responsibility between the forest service (management planning and reforestation) and the private sector (harvesting) which does not create the necessary incentive for applying sustainable forest management. The Russian Forest Agency is currently not well prepared to face the challenges of market economy and competition. Under current leasing practices technical capacities are not sufficient to assure forward-looking landscape-based forest management planning, post-harvest reforestation and supervision of forest operations."
>
> (World Bank 2004)

Hunting legislation

There is an inherent conflict between the interest of hunters to maintain high population densities of hoofed-game and the interests of forest production to reduce the influence of wildlife and therefore minimise costs from browsing, rubbing and debarking. The hunting legislation does not clearly address the tension between these interests; in many countries there is no clear support for production-oriented forest management and a lack of financial compensation of damages and no adequate consequences regarding overpopulation. This is mainly a barrier in western and central Europe. The issues associated with the hunting legislation are deeply rooted in the social understanding of hunting and forest production. Therefore, potential changes in the legal framework can only be achieved through changes in the public perception of hunting (i.e., social barrier).

Traditional grazing rights/systems

Browsing damages caused by livestock (e.g., goats, sheep, cattle) cannot be excluded from forest areas due to existing traditional grazing rights. Grazing systems with negative impacts on forest yield remain in place despite legal adaptations, scientific research and public discussions. Traditional grazing rights are an issue in all mountainous regions of Europe; this pertains mainly to south-eastern Europe in EU 28, as well as to the Ukraine (Carpathians) and Russia (Caucasus, Ural).

3.5.2 Social and structural barriers

Barriers	Ranking of the impact			
Social and structural barriers	**EU 28**	**Belarus**	**Ukraine**	**Western Russia**
Lack of perception on the positive impacts of forests and forestry	Medium Indirect Short-term	Medium Indirect Short-term	High Indirect Short-term	Medium Indirect Short-term
Lack of societal acceptance regarding • The introduction of non-native species • Active water management (drainage) • Fertilisation in forestry • Intensified hunting	Medium Direct Long-term	--	Low Direct Long-term	--
Lack of knowledge and education on options to increase yield	Medium Direct Long-term	Medium Direct Long-term	High Direct Long-term	Medium Direct Long-term
Structural deficits in private forests	Medium Direct Long-term	--	--	--

Lack of perception on the positive impacts of forests and forestry

There is still a lack of perception on the positive aspects of forests and their products. The use of forests as a natural resource has positive impacts on the national economy, employment and rural development. Currently, there is insufficient awareness raising regarding the positive effects of improving forest structures to achieve i) a yield increase and ii) to improve the quality of forest resources. This is a barrier throughout the entire study area; it is more pronounced in western and central Europe and less of an issue in Scandinavia, where there is a different perception of intensive forest management and utilisation. There is a need for more concerted efforts toward explaining the benefits of sustainable forest management and the recognition of wood as a renewable natural resource (e.g., targeted education, campaigns and lobbying).

Lack of societal acceptance

The lack of societal acceptance is, at least to some degree, associated with a conflict of interests between the forestry sector and the nature conservation sector (mainly represented by NGOs). Quite frequently it is believed that alterations to the “natural forest” will threaten or lower the existing biodiversity. The lack of societal acceptance is found with regards to:

- ***The introduction of non-native species***

  The introduction of non-native species is challenged by the lack of acceptance even within the forestry sector. There is a conflict between nature conservation targets and the production interests of forestry. The introduction of non-native species requires greater efforts in research and monitoring to avoid the introduction and spread of invasive species, and/or the displacement of natural fauna and flora. This is a barrier mainly in the EU.

- ***Active water management (drainage)***
  An important barrier for water management is that it has not (yet) been recognised as an important management measure in lowlands, resulting in a lack of acceptance in forestry. Barriers for water management include the absence of knowledge on the effects of drainage, as well as on the effects and optimal maintenance of older systems. There is insufficient knowledge on the potentials of water management and therefore low acceptance of related costs in the forestry sector and in politics. These barriers occur mainly in western and central Europe where active water management through drainage and irrigation is only accepted for agricultural purposes.
- ***Fertilisation in forestry***
  Similarly to the introduction of non-native species, fertilisation is challenged by the lack of acceptance even within the forestry sector. There is a conflict between nature conservation targets and the production interests of forestry. Barriers for fertilisation and melioration include the lack of diagnostic guidelines for the type of fertiliser mixture needed, and the lack of knowledge on the efficiency of single or multiple fertiliser applications to a variety of sites. Fertilisation and melioration research, soil surveys and analyses, and training measures for the proper implementation of fertilisers are costly and time consuming. Considerations on long-term positive effects do not lead to investment decisions in many regions of the study area (with the exception of Scandinavia), especially since an improved yield on stable forest soils is not a widely accepted or noted management option. This is a barrier throughout the entire study area, besides for Scandinavia and where plantations exist (e.g., Sitka spruce, eucalyptus and pine).
- ***Intensified hunting***
  The prevention and control of damages caused by wildlife populations is closely linked to intensified hunting. However, there is a clear conflict of interests between the goal of forest production and the hunting sector (see also hunting legislation barrier). Game damages are mainly relevant in western and central Europe.

Lack of knowledge and education on options to increase yield

In general, these deficits are high in private smallholder forestry, but also exist among professionals due to a lack of know-how transfer from research into practice. The lack of knowledge and education is prevalent throughout south-eastern Europe, Belarus, Ukraine and western Russia, and primarily includes the following aspects:

- ***Introduction of non-native species***
  In addition to the points mentioned under “lack of societal acceptance”, know-how on species’ potential and management is missing. Non-native species are still widely unknown and/or their potential remains unrecognized, there is little research and therefore an insecure basis for further developments.

- ***Species-site matching***
  Species-site matching is not applied due to a lack of research (also linked to economic barriers), non-existing site surveys, and respective guidelines for the selection of tree species.
- ***Tree species composition***
  Although there is already wide acceptance of this measure in terms of improving the growth and vitality of forest stands, there is limited know-how among private forest owners concerning the development of mixed stands and the selection of optimal species mixtures. The implementation of this measure requires intensive information/training of forest owners, more funding of private forests (economic barrier) and a better understanding in the forestry sector regarding the benefits. The introduction of a new tree species composition is often regarded sceptically since there is little experience with benefits and risks.
- ***Optimised management regimes***
  There is an evident lack of research and concepts in south-eastern Europe regarding this measure – especially in broadleaf dominated EFTs. Since knowledge on the proper implementation of forest management regimes is missing mainly among private smallholder forests, intensive training of forest staff and forest owners is required.

Structural deficits in private forests

Private forest areas are frequently too small to be regarded as manageable entities. These forest areas are often unutilised or underutilised and the yield is far from optimal. As a result, these areas experience missing management capacities brought about by the lack of economic incentives to manage forests, as well as a general lack of investment in the forest resource (economic barriers). This barrier is prevalent throughout the entire study area where private forests exist (exceptions: Belarus, Ukraine, western Russia). Approaches to overcome these structural deficits include:

- Education, information and training
- Land consolidation
  Traditional land consolidation refers to legal procedures to create manageable forest units in regions with highly fragmented ownership. Experiences show that these officially initiated procedures are generally difficult to implement and can be very lengthy. Interfering in land property rights tends to be highly conflict-prone and expensive. Hence, the corresponding benefits for the owners such as improved access due to new forest roads, easier bundling of harvesting activities and lower costs of operations should be clearly pointed out from the very beginning. In some countries simplified forms of land consolidation exist, for example, voluntary land exchange or accelerated land merging procedures. In regions where forest commons (*not* community forests) have historical roots, these kinds of forest enterprises with ideal shares can be established more easily. It is also worth focusing on the extension of existing forest commons, whether through the inclusion of private or public forests. Clear rules and a sound legal basis would foster forest commons. In most cases, success will depend on efforts provided by forest administrations in convincing forest owners to give up real ownership for ideal ownership.

- Wood mobilisation
  This is the generic term for all activities to strengthen forest use in areas characterised by small and fragmented forest ownership. Activities could be developed by the regional forest administration, owners associations or even private, benefit-orientated organisations. Aiming at efficient harvesting operations and a value-oriented sorting of timber, at least 500 to 1,000 m^3 should be brought together by each harvesting operation in preferably closely connected areas. In order to obtain permission from forest owners, establishing confidence through transparent information is crucial. For reasons of data protection, cadastre agencies are restricted in the provision of owners' addresses to private organisations or even to owners associations. Hence, access to the data about owners is a key factor for wood mobilization.
- Bundling of management activities by forest associations or cooperatives
  Strengthening of forest owners associations/cooperatives and encouraging these organisations to become responsible for bundling activities has become one of the major topics of forest policy in recent years. The withdrawal of state forest administration tends to leave a gap in providing technical advice for private forest owners. Combined with a decline of agricultural enterprises (traditionally combined with forest activities) and a generation-turnover, abandoned private forests are currently increasing. Strong forest cooperatives could assume the future role of information, advice and forest management. Therefore, forest policy could make a significant contribute by offering success-based subsidies in the initial phase of newly established forest owners' enterprises.

3.5.3 Economic barriers

Barriers	Ranking of the impact			
Economic barriers	**EU 28**	**Belarus**	**Ukraine**	**Western Russia**
Lack of long-term investments (public/private) to improve forest structure, including • Breeding and artificial regeneration • Restructuring coppice and improving degraded forests • Forest accessibility • Harvesting techniques and technology	Medium	High	High	High
	Indirect	Indirect	Indirect	Indirect
	Short-term	Long-term	Long-term	Long-term
Lack of private investments in wood processing industry	--	Medium	High	Medium
		Indirect	Indirect	Indirect
		Long-term	Long-term	Long-term

Lack of long-term investments (public/private) to improve forest structure

As was already addressed in the best practices, the yield measures only fully become effective in the long-term, beyond 10-20 years. Improvement in forest profits can only be expected in this timeframe; however, it is out of the scope of many forest enterprises, even in state forest enterprises (no long-term political or budgetary perspective). In western Russia, the forest concession system with its mid-term leases leads to a lack of ownership and investments in the forest resource. Where long-term investments are missing, forest management has an exploitative character, aiming at fast profits without considering a sustainable optimisation of forest structures and yield. These deficits are mainly an issue in south-eastern Europe, Belarus, Ukraine and western Russia. There is a pronounced lack of funding or investments in the following areas:

- ***Breeding and artificial regeneration***
  Breeding could be considered a high-potential yield measure in the forestry sector. However, long-term investments in breeding programmes and research are needed. The implementation of breeding is directly connected to artificial regeneration, a measure which is missing for several EFTs. Deficits are particularly high for broadleaf dominated EFTs in western, central and south-eastern Europe, Belarus, Ukraine and western Russia. One reason why active artificial regeneration is currently being avoided is the high costs associated with the prevention of browsing. This barrier can be addressed through an improvement in the research budget for breeding, and a general change in perception (see social barriers).
- ***Restructuring coppice and improving degraded forests***
  There are considerable deficits in restructuring coppice forests and improving degraded forests throughout the entire study area. The deficits are most pronounced in south-eastern and eastern Europe. This is strongly linked to the absence of appropriate forest management concepts, insufficient training of forest owners (see social barriers) and the lack of investments in measures to improve stand structure and implement artificial regeneration.
- ***Forest accessibility***
  Accessibility to forests is a precondition not only for operational activities but also for the monitoring and control of biotic and abiotic damages. The evident lack of investments in forest road infrastructure (mainly in private forest areas) has substantial implications for the prevention of pests and diseases as well as for fire management (i.e., difficult to reach and mitigate the damage). This is especially the case in south-eastern Europe, Belarus, Ukraine and western Russia.
- ***Harvesting techniques and technology***
  The lack of harvesting techniques and technology is a barrier with regards to fully utilising the potential yield in a sustainable manner. Deficits are concentrated in difficult terrain (steep slopes or wet soils). As a result, it is not possible to harvest the full potential area, and not all potential assortments can be hauled to the forest roadside. This barrier occurs mainly in south-eastern Europe, Belarus, Ukraine and western Russia.

In all the examples mentioned above, it is important to improve investments in research and the development and dissemination of best practice strategies for all forest owners. Funding deficits in state forests are a budgetary constraint which can only be altered on a political level. For private forests, more incentives need to be created to attract investments (e.g., access to loans). More stringent laws to support the process of structural improvement of forest resource can support this in parallel.

3.5.4 Realistic potential for yield increase

In the following tables, the application of best practice strategies is evaluated in the context of the identified barriers. Since the effects of the best practice strategies are twofold (firstly, the yield increase and secondly, the additional harvesting potential) the barriers are considered with respect to whether they influence the targeted yield increase and/or the harvesting potential. The valid time frame embraces the coming 20-30 years.

Method

The applied and rather complex method is shortly described below:

- Regions were differentiated between a) EU 28, Belarus and Ukraine and b) western Russia (separately) and c) all countries merged together by weighted values (see the three tables below).
- Each forest type was considered separately.
- For each yield measure (fertilization, water management etc.) within a given forest type, the identified yield effect (mostly a value range, seldom a single value) was discussed with experts (see Annex A for list of interviewed experts) for that specific case (e.g., fertilization for boreal forests EU 28, Belarus and Ukraine), and the result was a single value.
- The yield effect was weighted according to the area for which the measure tends be applied (e.g., for EU 28, Belarus and Ukraine, fertilization results in increased yield effects for only 60% of the area, since 40% of the area has fertile soils).
- Following this, the weighted yield effect was considered with regard to the identified barriers. The entire bundle of identified barriers and their effects were discussed and quantified in expert discussions. As a result, a reduction factor was generated (e.g., due to the lack of techniques and missing public acceptance, fertilization could only unfold half of its effectiveness). This led to the derivation of a realistic yield effect for each yield measure.
- Finally, the impact of the bundle of yield measures on each forest type, reduced by the effects of the barriers on each measure was quantitatively developed.

Results

For EU 28, Belarus and Ukraine an area of 142,203,000 ha has been identified. According to EFISCEN, the total annual yield is 553,865,000 m^3 or 3.9 m^3/ha/a. The wood utilization in the period from 2005–2010 adds up to a total of 517,473,000 or 3.6 m^3/ha/a. A realistic outcome, when applying all yield measures and under consideration of the barriers, would increase the yield by 15% or 0.6 m^3/ha/a, whereas the improved utilization rate only results in an improvement of 2% or 0.09 m^3/ha/a.

About 80% of the absolute yield effect can be obtained in the four forest types Boreal Forests, Hemiboreal Forests, Mesophytic Deciduous Forests and Mountainous Beech Forests. These forest types are dominant due to the area and yield within the nine forest types under consideration.

In the case of western Russia, the forest area is 100,427,000 ha. The annual yield is 53,066,000 m^3 or only 0.5 m^3/ha/a. The wood utilization in the period from 2005–2010 was 13,012 m^3 or 0.1 m^3/ha/a. A realistic outcome, when applying all yield measures and under consideration of the barriers, would increase the yield by 10% or 0.05 m^3/ha/a, whereas the improved utilization rate

results in an improvement of 26% or 0.03 m³/ha/a. The Boreal Forests are the dominant forest type which contains about 80% of the area and 60% of the yield.
In the case of western Russia, the overall yield effect is far below the effect of the country group EU 28, Belarus and Ukraine whereas for the improvement of the utilization rate it's vice versa.

In the table below the two country groups were merged to one group (EU 28, Belarus, Ukraine and western Russia) by weighting the values.

Table 62: Realistic potential by forest type – EU28, Belarus and Ukraine

No	European Forest Type	FAWS	Yield (EFISCEN)		Utilisation 2005-2010		Realistic Yield increase	Realistic Yield increase		Realistic utilisation rate	Realistic additional harvest potential	
	(EFT)	1,000 ha	1,000 m³/a	m³/ha/a	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a
1.	Boreal Forests	31,660	124,128	3.9	110,025	3.5	**21%**	26,067	0.8	**0%**	0	0.00
2.	Hemiboreal Forests	34,596	180,063	5.2	167,103	4.8	**15%**	27,009	0.8	**2%**	3,342	0.10
3.	Alpine Forests	5,467	34,393	6.3	27,938	5.1	**12%**	4127	0.8	**4%**	1,118	0.20
4.	Acidophilous oak and oak-birch forests	3,093	11,148	3.6	13,323	4.3	**n/a**			**n/a**		
5.	Mesophytic Deciduous Forests	12,316	38,042	3.1	41,622	3.4	**19%**	7,228	0.6	**10%**	4,162	0.34
6.	Beech Forests	3,743	21,879	5.8	19,249	5.1	**13%**	2,844	0.8	**3%**	481	0.13
7.	Mountainous Beech Forests	7,468	33,907	4.5	28,643	3.8	**20%**	6,781	0.9	**13%**	3,724	0.50
8.	Thermophilous deciduous Forests	7,453	10,981	1.5	13,044	1.8	**15%**	1,647	0.2	**2%**	196	0.03
9.	Broadleaved evergreen forests	9,601	4,095	0.4	4,923	0.5	**n/a**			**n/a**		
10.	Coniferous forests of the Mediterranean	9,729	22,380	2.3	22,183	2.3	**17%**	3,805	0.4	**1%**	222	0.02
11.	Mire and swamp forests	2,077	6,969	3.4	7,828	3.8	**n/a**			**n/a**		
12.	Floodplain forests	1,391	7,269	5.2	4,811	3.5	**n/a**			**n/a**		
13.	Non-riverine alder, birch or aspen forests	8,212	31,129	3.8	28,458	3.5	**n/a**			**n/a**		
14.	Introduced tree species Forests	5,398	27,482	5.1	28,321	5.2	**11%**	3,023	0.6	**0%**	0	0.00
	Total	142,203	553,865	3.9	517,473	3.6	**15%**	82,532	0.6	**2%**	13,244	0.09

Table 63: Realistic potential by forest type - Western Russia

Realistic yield increase and additional harvest potential by forest type – Western Russia													
No	European Forest Type	FAWS	Yield		Utilisation 2005-2010		Realistic Yield increase	Realistic Yield increase		Realistic utilisation rate	Realistic additional harvest potential		
	(EFT)	1,000 ha	1,000 m³/a	m³/ha/a	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a	
1.	Boreal Forests	84,828	32,189	0.4	8,516	0.1	**13%**	4,185	0.0	**30%**	2,555	0.03	
2.	Hemiboreal Forests	4,894	7,103	1.5	1,321	0.3	**8%**	568	0.1	**7%**	92	0.02	
3.	Alpine Forests	157	184	1.2	59	0.4	**7%**	13	0.1	**17%**	10	0.06	
5.	Mesophytic Deciduous Forests	1,384	2,520	1.8	444	0.3	**10%**	252	0.2	**5%**	22	0.02	
7.	Mountainous Beech Forests	825	1,349	1.6	475	0.6	**10%**	135	0.2	**11%**	52	0.06	
11.	Mire and swamp forests	4,133	5,002	1.2	1,096	0.3	**n/a**			**n/a**			
12.	Floodplain forests	346	526	1.5	109	0.3	**n/a**			**n/a**			
13.	Non-riverine alder, birch or aspen forests	3,860	4,193	1.1	992	0.3	**n/a**			**n/a**			
		100,427	**53,066**	**0.5**	**13,012**	**0.1**	**10%**	**5,153**	**0.05**	**26%**	**2,732**	**0.03**	

Table 64: Realistic potential by forest type - EU28, Belarus, Ukraine and Western Russia

Realistic yield increase and additional harvest potential by forest type – EU 28, Belarus, Ukraine and Western Russia												
No	**European Forest Type**	**FAWS**	**Yield**		**Utilisation 2005-2010**		**Realistic Yield increase**	**Realistic Yield increase**		**Realistic utilisation rate**	**Realistic additional harvest potential**	
	(EFT)	1,000 ha	1,000 m³/a	m³/ha/a	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a	in %	1,000 m³/a	m³/ha/a
1.	Boreal Forests	116,487	156,317	1.3	118,542	1.0	**19%**	30.251	0.3	**2%**	2,555	0.0
2.	Hemiboreal Forests	39,489	187,166	4.7	168,424	4.3	**15%**	27.578	0.7	**2%**	3,435	0.1
3.	Alpine Forests	5,624	34,577	6.1	27,997	5.0	**12%**	4.140	0.7	**3%**	1,128	0.2
4.	Acidophilous oak and oak-birch forests	3,093	11,148	3.6	13,323	4.3	**n/a**					
5.	Mesophytic Deciduous Forests	13,700	40,562	3.0	42,066	3.1	**18%**	7.480	0.5	**10%**	4,184	0.3
6.	Beech Forests	3,743	21,879	5.8	19,249	5.1	**13%**	2.844	0.8	**2%**	481	0.1
7.	Mountainous Beech Forests	8,292	35,255	4.3	29,118	3.5	**20%**	6.916	0.8	**11%**	3,776	0.5
8.	Thermophilous deciduous Forests	7,453	10,981	1.5	13,044	1.8	**15%**	1.647	0.2	**2%**	196	0.0
9.	Broadleaved evergreen forests	9,601	4,095	0.4	4,923	0.5	**n/a**					
10.	Coniferous forests of the Mediterranean	9,729	22,380	2.3	22,183	2.3	**17%**	3.805	0.4	**1%**	222	0.0
11.	Mire and swamp forests	6,210	11,972	1.9	8,923	1.4	**n/a**					
12.	Floodplain forests	1,737	7,795	4.5	4,920	2.8	**n/a**					
13.	Non-riverine alder, birch or aspen forests	12,072	35,322	2.9	29,451	2.4	**n/a**					
14.	Introduced tree species Forests	5,398	27,482	5.1	28,321	5.2	**11%**	3.023	0.6	**0%**	0	0.0
	Total	**242,630**	**606,931**	**2.5**	**530,485**	**2.2**	**14%**	**87.684**	**0.4**	**2%**	**15,976**	**0.07**

3.6 Biomass quality assessment of forest yield

The objective of this section of the forestry chapter is to describe biomass quality attributes relevant for biomass conversion routes to produce biomaterials, biochemicals or biofuels. In addition to this, the determinants influencing the quality attributes will be presented.

Background

Once trees have been harvested from forest stands they are transported to sawmills and/or biorefineries for further processing. As already mentioned in the introduction of the forestry chapter, the focus is on wood as a main raw material, rather than on so-called "biomass residues" in forestry. In contrast to agricultural crops, there are three possible pathways of energetic use for wood and bark as the main biomass compartments of trees. The main conversion routes for wood are mechanical processing, chemical processing and thermo-chemical processing. These conversion routes lead to a myriad of products which can be sub-divided into the categories biomaterials, biochemicals and biofuels. The use of wood for energetic purposes is relevant in each of the aforementioned categories. For example, in mechanical processing, the use of solid wood fuel for direct combustion is by far the most relevant conventional path. In thermo-chemical processing, solid wood plays an increasing role in gasification (Hasler and Nussbaumer 1999). However, new conversion routes also exist, such as biomass to liquid (Sunde, Brekke, and Solberg 2011), hydro-pyrolysis (Mohan, Pittman, and Steele 2006; Rocha et al. 1997) and ethanol synthesis from cellulose (Bansal et al. 2013). These fall mainly under the category of chemical processing and enable the advanced production of biofuels from woody biomass.
Most industrial sawmills have already optimised their processes so that any residues from their operations remain within the system and are used to generate heat and/or energy. In this respect, biorefineries play a particular role in that they attempt to maximise the efficiency in the use of raw materials which include, amongst others, wood, bark and branches. New biomaterials and biochemicals produced in biorefinery processes (Demirbas 2009) will play a role in the future.

The following sub-chapters present the main conversion routes and associated products. Each sub-chapter includes a brief description of the most important quality attributes of the products and how forest management could influence these parameters or be optimised to meet the stated quality requirements.

Remark:
Volume (m^3) is a yield target only for mechanical conversion routes.
For energetic purposes or chemical use, mass (kg, t) is the more relevant yield factor.

3.6.1 Mechanical processing

The main parameter which influences wood variation is its density or “specific gravity”. This varies from species to species and is determined, in part, by the ratio of earlywood (less dense) to latewood (more dense), the cell size and cell wall thickness, as well as the size and amount of vessel elements (Zobel and van Buijtenen 1989).

Wood which is processed mechanically (particularly sawn wood) is classified either according to optical or strength/durability quality parameters. The five main factors which influence the latter quality parameters include branchiness, taper, reaction wood (compression wood in conifers and tension wood in hardwoods), juvenile wood and the spacing/distribution of annual growth rings (UNIQUE 2015). These five factors can be addressed through forest management activities to produce more desirable wood for further processing steps. However, there are further criteria which are listed in DIN-norms (e.g. DIN 4074) and may include stem straightness, discolouration, direction of fibres, the dimension of the core, and tears or splits in the wood. All of these criteria can be influenced to some extent by forest management

Table 65: Quality parameters of products derived through mechanical processing

Wood assortment (input)	Products (output)	Target quality attributes	Interfering attributes	Influencing measures	Source
Round wood	Sawn wood	Strength and density; stiffness, stability	Spiral grain, knot size and distribution, compression wood, cracks or tears, rot	Tree species selection, breeding, silvicultural system (e.g., tree spacing, pruning)	Hannrup et al. 2004; Zobel and van Buijtenen 1989
	Veneer, plywood	Veneer: log form, growth-ring consistency, heartwood/sapwood proportion, wood colour Plywood: density, colour, ease of peeling or slicing, drying without wrinkling, bondability	Uneven growth, irregularities of wood structure, cracks or tears, water sprouts	Tree species selection, breeding, silvicultural system	Shi and Walker 2006; Alderman et al. 2004
Chips, saw dust	Particle boards, MDF	Long cells with steep fibril angles make stronger and more stable boards; thin particles and fibres are desired, good bonding properties; in addition, extractive properties and adhesives need to be considered	Wood extractives (secondary metabolites)	Tree species selection, breeding, tree improvement	Chapman 2006; Zobel and van Buijtenen 1989
Round wood	Mechanical pulp	Long, uniform fibres	Coloured heartwood	Tree species selection, breeding	

3.6.2 Chemical processing

In chemical processing, the chemical properties of wood are more significant than the factors listed under mechanical processing. Above of all, this includes the amount of cellulose, hemicellulose and lignin in wood.

> "Wood contains up to 40-50% cellulose by mass, and around 95% of cellulose production is used in papermaking, derived from wood-pulping operations. Hemicellulose, also a key component of plant cell walls, comprises up to 25-30% of woody plant tissues. Hemicelluloses can be hydrolysed into their component sugars and used as fermentation feedstock for the production of ethanol and other alcohols, organic acids, acetone and gases. Lignin is the third most abundant structural polymeric material found in plant cell walls and typically comprises 20-30% of woody biomass. Most lignin is sourced as a by-product of papermaking. Lignin binds hemicellulose and cellulose together in plant cell walls and shields them from enzymatic and chemical degradation."
>
> (Turley 2008)

Contrary to the products derived through mechanical processing, the aim in chemical processing is to optimise the industrial manufacturing processes, rather than the optimisation of forest management activities (Laborie, 2015). For example, it would be impossible to modify trees so that they no longer produce lignin. Considering that the focus is on optimising the utilisation of the given resource, the yield measures described in chapter 3.3 are less applicable in influencing the quality parameters of the products listed below.

Of the products listed in Table 62, the quality of pulp and paper can be influenced most directly through forest management activities or measures. In the production of pulp and paper, dense wood and long cells with thin cell walls are preferred since this enhances the tear strength of paper (i.e., more resistant to tearing). Secondary cell contents such as phenols and tannins are considered as interfering attributes because they reduce the "purity"/homogeneity of the pulp. In order to produce longer cell walls the only forest management activity which could have an impact is tree breeding; this is, the selection of individual trees which naturally have denser wood with longer cells and/or thinner cell walls.

Table 66: Quality parameters of products derived through chemical processing

Wood assortment (input)	Conversion routes	Products (output)	Target quality attributes	Interfering attributes	Influencing measures	Source
Chips, cellulose	Chemical extraction	Pulp and paper	Wood density determines pulp yield and quality; cell length (long cells); often necessary to add 15-20% long fibers (tracheids) to manufacture papers that have a satisfactory tear strength; thin cell walls	Secondary cell content (heartwood) such as phenols, tannins, etc.; lignin; fibre dimensions	Cell length is genetically controlled; tree species selection and breeding	Zobel and van Buijtenen 1989
Lignocellulose in different assortments (chips, pellets, briquettes, firewood)	Biomass to liquid	Liquid biofuel	Heating value, high carbon content	Lignin conversion, Na, Mg, Ca, K content, water content	Tree species selection, breeding	Anton and Steinicke 2012; Sunde, Brekke, and Solberg 2011; Stöcker 2008
	Ethanol production	Liquid biofuel	Heating value, high cellulose content; high biomass per hectare	Hemicelluloses xylose, lignin; high crystallinity of cellulose	Tree species selection, breeding, land use system	Bansal et al. 2013; Rudie 2007
	Biorefinery	Biomaterials, biochemical, bioenergy		Lignin, cellulose, hemicelluloses		Kretschmer et al. 2013

3.6.3 Thermo-chemical processing

The most important target quality attributes in thermo-chemical processing include the heating value of the input material (i.e., lignocellulose in different forms), the density, and water content. A high bark and mineral content lead to a high ash content (e.g., in direct combustion; Biedermann and Obernberger 2005). A low water content and high density of wood imply a lower heating value (Rosillo Callé 2007); therefore, less energy is required in the conversion process. Most wood conversion processes will produce some form of waste material (e.g., lignin in the production of pulp and paper), and the concept of biorefineries is to work toward a complete utilisation of the input material. As such, all major components of wood (cellulose, hemicellulose, and lignin) may be considered as useful or as waste products, depending on which end-product is desired. Nevertheless, biorefineries are a suitable, viable and lucrative option for optimising the utilisation of biomass derived from forests.

Table 67: Quality parameters of products derived through thermal processing

Wood assortment (input)	Conversion routes	Products (output)	Target quality attributes	Interfering attributes	Influencing measures	Source
Lignocellulose in different assortments (chips, pellets, briquettes, firewood)	Direct combustion	Bioenergy	Heating value, low water and ash contents, high specific gravity, high H:C & low O:C, low ash; lignins increase heating value	High mineral content, high ash content, high water content, high corrosion and sintering effects (K, Cl, ash), low ash melting point (influencing elements: Ca, Mg, Si), high emissions (N, S)	Fertilisation, silvicultural system (influences N, S and K contents)	Tanger et al. 2013; Vassilev et al. 2010; Kaltschmitt, Hartmann, and Hofbauer 2009; Ragland and Aerts 1991
	Wood gasicfication	Bioenergy	Heating value, high content of nutrients and trace elements, high specific gravity, high H:C ratio and low O:C ratio, low ash content	High bark content, high water content, high ash content	Tree species selection, breeding, fertilisation	Tanger et al. 2013; Kaltschmitt, Hartmann, and Hofbauer 2009
	Hydro-pyrolysis	Liquid biofuel	Heating value, low water content, high specific gravity, high H:C ratio, low O:C ratio, low ash content	Cellulose, hemicellulose, xylose	Tree species selection, breeding	Tanger et al. 2013; Kaltschmitt, Hartmann, and Hofbauer 2009; Mohan, Pittman, and Steele 2006
	Biorefinery	Biomaterials, biochemicals, bioenergy				Kretschmer et al. 2013

4 Policy recommendations to overcome identified barriers in the EU

Due to regional barriers the realistic potential for both agricultural crop residues as well as for forest biomass is significantly lower than the technical-sustainable potential. How can these barriers be lifted? This chapter discusses various options to overcome them in order to potentially make the full agricultural residue potential available. All of the measures discussed here should be applied for a sufficiently long period of time to allow market actors the time to react to improved market conditions.

4.1 Agricultural residues

The policy recommendations are formulated for the European Commission and therefore the focus is on overcoming the barriers in the EU. A full description of each barrier is provided in chapter 2.17.1

Two main barriers have been identified that can prevent the realistic potential of agricultural residues to be achieved. The main barrier is the fact that currently no mature market for residues exist and therefore no sufficient incentive exists to invest in residue collection equipment and infrastructure. While this is mainly due to lack of market, in less developed agricultural regions an additional barrier is lack of education among farmers that prevents them from running farms in the most optimal manner.

4.2 Stimulate investments in residue collection equipment and infrastructure

The most important barrier to increasing residue supply in the EU, having a **high** and most likely **long-term** impact, is a lack of economic viable prices for residues.

Prices for agricultural residues vary quite significantly across the EU. Prices in Central and Southern Europe are rather low whereas prices in countries such as Denmark, the Netherlands and the UK can be up to €100/tonne or even higher. It is estimated that across the EU prices for straw vary from €57 to €129 (FRN, 2014). Prices for energy crops such as miscanthus will in most cases be lower, around €45 to €60, taking into account that lower quality land will be used for miscanthus production with relatively low resulting yields.[128] In order for farmers to invest in residue collection machinery, farmers have to count on a residue price that compensates any additional expenses. Currently, in many parts of the EU the price incentive is insufficient to increase residue supply.

[128] Compare this with prices for a crop such as maize which during 2015 trades for around €250/tonne.

Options to overcome the barrier

Several options exist to create a more attractive market for agricultural residues in the EU, leading to increased efforts to harvest residues.

1. **Stimulating the residue market by incentivising demand**

The amendments to the EU RED and FQD directives as laid down in the 'ILUC directive' as passed in 2015 include an indicative mandate of 0.5% advanced biofuels. Member States could opt to introduce a binding target for advanced biofuels, as Italy did in 2014 and other Member States might do as well. Such a binding mandate for advanced biofuels could lead to an increased uptake of cellulosic ethanol produced from agricultural residues. NER300 funds could be used to co-fund the construction of such biofuel installations. The 2030 policy framework for renewables in transport could be used to provide a stable regulatory outlook for biofuels produced from agricultural residues.

In addition to stimulating residue use for biofuels, the use of residues for other purposes could be further developed as well. One example is the use of straw for electricity and heat production, as happens in Denmark. Straw has been used since 1976 mainly in small scale farm boilers. Starting in the 1980s it was used for district heating (now about 65 medium scale boilers) and since 1990 straw is used for combined heat and power (CHP, now 12 installations) in Denmark. Currently there is 1 co-firing plant using straw and 1 power plant, which together use about 1.5 million tonnes of straw (out of a total of 6 million tonnes), generating 20 PJ in 2013.[129] This development was mainly triggered by the Danish Energy Agreement of 1993 in which the Danish government and utilities agreed to use 1 million tonnes of straw biomass. In 2012, Denmark extended its Energy Agreement foreseeing a share of 35% renewable energy in final energy consumption by 2020.

The EC could highlight residue use for heat in power as happens in Denmark as a best practice for residue use and encourage Member States to follow the Danish example.

2. **Stimulating residue harvesting by adding more value on-farm**

Low market prices for residues lead to suboptimal residue collection in many parts of the EU. In addition to market stimulation measures as outlined above, it could be possible to make residue collection more interesting economically for farmers if more value would be added on-farm. Residues could be upgraded to products such as pyrolysis oil in small-scale installations on-site. This may involve external investments in such installations by external investors. The EC could promote showcases on farm levels for instance within the Horizon 2020 funding programme.

[129] http://www.ens.dk/node/2228

3. Monetary incentive to reduce residue supply costs

In 2008 the USA implemented the Biomass Crop Assistance Program (BCAP) which provides financial assistance ("matching payments") to owners and operators of agricultural and non-industrial private forest land for delivery (collection, harvest, storage, transportation) of agriculture and forestry residues to qualified biomass conversion facilities for heat, power, biobased products, or advanced biofuels. For 2014 the budget for matching payments was up to $12.5 million, with no more than $20 per tonne for more than 2 years.[130] Most of the funding was for woody biomass. The EC could replicate and improve the US approach by clearly defining which biomass and conversion facilities are eligible for subsidies and could also perhaps cap the budget for financial support.

4. Improving harvest logistics

In some areas farmers harvest agricultural residues themselves. It is possible to rationalise residue collection by outsourcing collection. Regional structures for harvesting and logistics could be introduced for the sharing of harvesting equipment, defining a unified format for straw bales and outsource harvesting and residue collections by specialised companies or vertically-integrated processing companies. For instance Verbio AG offers to do the straw harvest at the farm with their own bailing machines to facilitate straw supply for their straw to methane plant in Schwedt. This would lead to lower overall costs, standardised quality of residues and higher yields due to the use of higher quality machinery.

5. Improving transport links and using niches of current transport inefficiencies

Agricultural residues are relatively high in moisture content which makes transport from field to end users or processing facilities relatively costly. This means that it is difficult to connect available supply in Central Europe with demand in Western Europe. One way to deal with this is to reduce the moisture content by pelletisation. This however is costly and not logical for many end uses. Increased efforts could therefore focus on making it easier and cheaper to transport straw over longer distances. For example by using empty long-haul trucks or empty ship loads by organising a better exchange of transport supply and demand information across Europe. Also, in areas where efficient transport is hampered by inadequate transport links, EU TEN-T funding could help to create better connections.

4.2.1 Counter lack of education in low yielding regions

In regions areas where farmers are not sufficiently high trained to make full use of best-practice strategies, lack of training has a **high impact** on the implementation of the strategies. Since improving education and training requires time this barrier will probably have a **longer term** impact. This barrier applies only the low yielding regions because of poor management practices.

[130] http://www.fsa.usda.gov/programs-and-services/energy-programs/BCAP/index

Options to overcome the barrier

Several options exist to improve the level of education among farmers in the EU, leading to more successful residues harvesting.

- **Capacity building projects:** Farmers could be supported by external parties by setting up showcase examples of residue collection and trade and by developing demonstration fields. Such efforts are usually undertaken by crop breeding companies. The goal of such efforts is to enable farmers to improve their farming practices.
- **Consultancy provided by authorities or private organisations:** Local, regional or national authorities could involve consultants or agro-chemical companies to deploy improved farming practices. This is a very common practice in central Europe, where for instance the Raiffeisen cooperative provides support on crop management. The EC could trigger the establishment of such organisations or partnerships in south-eastern Europe.

4.3 Forestry

Several barriers in the EU have been identified in chapter 0 which hamper the deployment of the technical-sustainable potential for forest biomass yield increase. There are more barriers for deploying forest biomass than for deploying agricultural crop residues. In absence of a harmonised forest policy within the EU the impact of the EC is limited. However the EC could encourage Member States to apply the proposed measures.

4.3.1 Create supportive policy framework

As stated in chapter 3.5.1 there are barriers due to unclear and restrictive policies. Unclear frameworks imply that it is difficult for state or private forest users to understand which long-term forest management strategies can actually be implemented. Restrictive policy and legal frameworks, on the other hand, imply that policies deliberately intervene in particular aspects of forest management, therefore preventing state and private forest users from following a particular line of action. In both cases it is important for forest policies to have a long-term perspective and management decisions must incorporate and respect forest ownership (stable, transparent forest policies which promote secure tenureship).

Options to overcome the barrier

The following measures would contribute to create a supportive policy framework for forest biomass yield increase:

- Reorganisation of state forest administration and further support toward market-oriented state forest enterprises (e.g., ÖBF, ONF, BaySF, Hessen-Forst) in all EU member states.
  - Develop and implement incentives for forest managers or staff of forest enterprises.
  - Instead of covering the deficit of state forest administration by a state budget price for ecosystem services should be negotiated between ministry and state forest administration.

  - Creation of a forest financial fund (obtained as a certain percent of timber sale revenues) to allow long-term investments in infrastructure improvements and improvement of forest resources (e.g., artificial regeneration, coppice improvements).
- Provide a policy and legal framework which allows both state and private forest owners and enterprises to manage forests and market wood according to economic-based performance (market incentives).
- Strengthen the demand side and wood value chains for low-grade biomass through supportive policy framework for the wood industry and wood energy.
- The application of best practice strategies to maximise yield should be directly linked through national and EU policy measures to support climate mitigation (higher resilience) and adaptation (e.g., carbon sequestration in forests and wood products)
- Provide for an integrated policy approach to address the imbalance between the use of timber as a raw material for construction and as a source of bioenergy on the one hand, and between timber use and nature conservation and other forest ecosystem goods and services on the other hand.

4.3.2 Active perception and support for forest-wood cluster

The connection between forest management and forest industry and their interdependencies are not actively recognised. There is a lack of active policies in several regions, including south-eastern Europe, Belarus, Ukraine, and western Russia. While this is predominantly a policy issue, there are underlying social and economic aspects which need to be addressed as well.

Options to overcome the barrier

Active policy could entail the following:

- Promoting leading-edge innovation through research and development
- Providing business stability for the forest and wood products industry (e.g., creating standards in forest management and chain-of-custody)
- Ensuring the sector is underpinned by suitable infrastructure (e.g., forest roads) and a skilled and safe workforce (requirements in capacity building)
  (Labour New Zealand 2014)

4.3.3 Clear separation of land use and tenure

Browsing damages caused by livestock (e.g., goats, sheep, and cattle) cannot be excluded from forest areas due to existing traditional grazing rights. There is an urgent need for clear specification and separation of land use and tenure.

Options to overcome the barrier

This process lasted some decades (or is still ongoing) in central Europe. In addition to this, long-term changes in livestock pasture (i.e., less grazing) will only be achieved with the necessary financial support and intensive capacity building for villagers. Alternative grazing concepts need to be promoted and implemented (i.e., temporary exclusion from vulnerable areas).

4.3.4 Awareness raising on the positive impact of forests and forestry

There is insufficient awareness raising as well as lack of knowledge and educations in south-eastern Europe regarding the positive effects of improving forest structures to achieve i) a yield increase and ii) to improve the quality of forest resources. In addition there is a lack of social acceptance, at least to some degree, associated with a conflict of interests between the forestry sector and the nature conservation sector (mainly represented by NGOs). Quite frequently it is believed that alterations to the "natural forest" will threaten or lower the existing biodiversity (see chapter 3.5.2).

Options to overcome the barrier

Long-term exchange possibilities for young professionals in south-eastern Europe and opportunities for international networking (participation in task forces, conferences etc.) for forest management staff could be a means for knowledge transfer. Overall, options to overcome the lack of knowledge and education on options to increase yield will include a combination of education training, and research, concentrated on private forest owners. The Commission could support this capacity-building by launching conferences or workshops on forest biomass yield increase or by funding show-case projects.

4.3.5 Remove structural deficits in private forests

Private forest areas are frequently too small to be regarded as manageable entities. These forest areas are often unutilised or underutilised and the yield is far from optimal. As a result, these areas experience missing management capacities brought about by the lack of economic incentives to manage forests, as well as a general lack of investment in the forest resource (economic barriers). This barrier is prevalent throughout the entire study area where private forests exist.

Options to overcome the barrier

Approaches to overcome these structural deficits include:

- **Land consolidation:** Traditional land consolidation refers to legal procedures to create manageable forest units in regions with highly fragmented ownership. Experiences show that these officially initiated procedures are generally difficult to implement and can be very lengthy. Interfering in land property rights tends to be highly conflict-prone and expensive. Hence, the corresponding benefits for the owners such as improved access due to new forest roads, easier bundling of harvesting activities and lower costs of operations should be clearly pointed out from the very beginning. In some countries simplified forms of land consolidation exist, for example, voluntary land exchange or accelerated land merging procedures. In regions where forest commons (*not* community forests) have historical roots, these kinds of forest enterprises with ideal shares can be established more easily. It is also worth focusing on the extension of existing forest commons, whether through the inclusion of private or public forests. Clear rules and a sound legal basis would foster forest commons. In most cases, success will depend on efforts provided by forest administrations in convincing forest owners to give up real ownership for ideal ownership.

- **Wood mobilisation:** This is the generic term for all activities to strengthen forest use in areas characterised by small and fragmented forest ownership. Activities could be developed by the regional forest administration, owners associations or even private, benefit-orientated organisations. Aiming at efficient harvesting operations and a value-oriented sorting of timber, at least 500 to 1,000 m^3 should be brought together by each harvesting operation in preferably closely connected areas. In order to obtain permission from forest owners, establishing confidence through transparent information is crucial. For reasons of data protection, cadastre agencies are restricted in the provision of owners' addresses to private organisations or even to owners associations. Hence, access to the data about owners is a key factor for wood mobilization.
- **Bundling of management activities by forest associations or cooperatives:** Strengthening of forest owners associations/cooperatives and encouraging these organisations to become responsible for bundling activities has become one of the major topics of forest policy in recent years. The withdrawal of state forest administration tends to leave a gap in providing technical advice for private forest owners. Combined with a decline of agricultural enterprises (traditionally combined with forest activities) and a generation-turnover, abandoned private forests are currently increasing. Strong forest cooperatives could assume the future role of information, advice and forest management. Therefore, forest policy could make a significant contribute by offering success-based subsidies in the initial phase of newly established forest owners' enterprises.

4.3.6 Stimulate investments to improve forest structure

The yield increase measures become fully effective in 10 to 20 years. However a long-term perspective is missing in many forest enterprises or even in state forest enterprises. Where long-term investments are missing, forest management has an exploitative character, aiming at fast profits without considering a sustainable optimisation of forest structures and yield. Within the EU this is mainly an issue in south-eastern Europe.

Options to overcome the barrier

The Commission could suggest to EU Member states to strengthen the demand side by attracting international investors by a free capital transfer, reliable/transparent tax-system, and promote towards south-eastern Member States that international investors are allowed to possess land and industrial installations.

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6 Annex A – List of experts interviewed by UNIQUE

Table 68: List of experts interviewed by UNIQUE

Related topic	Expert	Institution	Interview
UNIQUE Expertise			
Forest management	Dr. Markus Grulke	UNIQUE forestry and landuse GmbH	02.02.2015
Biomass quality assessment; mechanical processing	Dr. Carsten Merforth	Head of the Forest Economics Division, UNIQUE forestry and land use GmbH, Germany	30.09.2015
Optimized management regime	Martin Redmann	UNIQUE forestry and landuse GmbH	02.02.2015
Silviculture, forest management	Dr. Axel Weinreich	UNIQUE forestry and landuse GmbH	Input throughout the study
Forest management	Dr. Bernd Wippel	UNIQUE forestry and landuse GmbH	Input throughout the study
External Expertise			
Breeding	Dr. Jean-Michel Carnus	Institute for Agricultural Research; Centre of Bordeaux ; IUFRO Division 8 – Forest Environment	12.03.2015
Silviculture	Prof. Dr. Jürgen Huss	University of Freiburg	05.03.2015
Forest operations	Prof. Dr. Dr. Gero Becker	University of Freiburg	05.03.2015
Species site matching	Prof. Dr. Karl Stahr	University of Hohenheim	11.03.2015
Site level; species site matching	Dr. Bruno de Vos	Research Institute for Nature and Forest, Geraardsbergen, Belgium	01.06.2015
Forest stand level; silvicultural management	Dr. Palle Madsen	University of Copenhagen, Denmark; IUFRO Division 1 – Silviculture	29.05.2015
Forest stand level; silvicultural management	Dr. Jiři Remeš	University of Life Sciences, Prague, Czech Republic	05.06.2015
Forest operations level	Prof. Dr. Hans R. Heinimann	Future Resilient Systems, Singapore-ETH Centre; IUFRO Division 3 – Forest Operations Engineering and Management	11.06.2015
Forest management level; fire management	Prof. Dr. Johann Goldammer	Global Fire Monitoring Center (GFMC), Fire Ecology Research Group, Max Planck Institute for Chemistry	24.05.2015
Biomass quality assessment; chemical processing	Prof. Dr. Marie-Pierre Laborie	Chair of Biobased Materials, University of Freiburg, Germany	30.09.2015

7 Annex B - Overview of crop data used

Wheat

Table 69: Residue yield for wheat (low, medium, high)

Country	RCR[a]	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Portugal)	0.8	1.64	0.79	0.11
Medium (Poland)	1.2	4.03	2.90	10.8
Highest (Ireland)	1.6	8.78	8.43	1.26

[a] Residue to crop ratio

Barley

Table 70: Residue yield for Barley (low, medium, high)

Country	*RCR[a]*	*Crop yield (t/ha)*	*Residue yield (t/ha)*	*Residue yield (per state) (mt)*
Lowest (Cyprus)	0.8	1.6	0.77	0.046
Medium (Denmark)	1.05	5.27	3.32	3.65
Highest (Belgium)	1.3	7.96	6.21	0.48

[a] Residue to crop ratio

Rye

Table 71: Residue yield for Rye (low, medium, high)

Country	RCRa	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Portugal)	0.9	0.94	0.51	0.02
Medium (Luxembourg)	1.25	6.25	4.69	0.009
Highest (UK)	1.6	9.6	9.17	0.09

[a] Residue to crop ratio

Oat

Table 72: Residue yield for Oats (low, medium, high)

Country	RCRa	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Cyprus)	0.9	0.96	0,52	0.00072
Medium (Denmark)	1.15	4.7	3,25	0.31
Highest (Ireland)	1.4	7.4	6,17	0.22

[a] Residue to crop ratio

Maize

Table 73: Residue yield for Maize (low, medium, high)

Country	RCRa	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Romania)	0.9	3.6	3.24	8.5
Medium (Luxembourg)	1.05	7.86	8.26	0.0025
Highest (Netherland)	1.2	11.75	14.10	0.27

[a] Residue to crop ratio

Rapeseed

Table 74: Residue yield for Rapeseed (low, medium, high)

Country	RCRa	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Russia)	1.4	1.9	1.21	1.02
Medium (Poland)	1.7	2.72	3.37	3.34
Highest (Belgium)	2	4	5.79	0.07

[a] Residue to crop ratio

Sunflower

Table 75: Residue yield for Sunflower (low, medium, high)

Country	RCRa	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Portugal)	2.2	0.56	0.90	0.023
Medium (Poland)	2.7	1.7	3.27	0.014
Highest (Austria)	3.2	2.6	6.02	0.22

[a] Residue to crop ratio

Sugar beet

Table 76: Residue yield for Sugar beet (low, medium, high)

Country	RCRa	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Bulgaria)	0.2	18.7	1.49	0.004
Medium (Lithuania)	0.23	37.4	6.13	1.8
Highest (France)	0.25	85.3	12.79	8.2

[a] Residue to crop ratio

Wine

Table 77: Residue yield for wine/Vineyards (low, medium, high)

Country	RCRa	Crop yield (t/ha)	Residue yield (t/ha)	Residue yield (per state) (mt)
Lowest (Bulgaria)	5	3.3	9.78	1.38
Medium (Greece)	6	8.7	31.28	3.2
Highest (Luxembourg)	7	14.5	60.83	0.12

[a] Residue to crop ratio

8 Annex C – Calculations for realistic potential of agricultural crop residues

Table 78: Legend - Calculations for realistic potential of agricultural crop residues

Term	Definition	Formula (if applicable)	Chapter in the report
High yielding	A group of countries with highest level of per hectare yield for a specific crop		2,2
Medium yielding	A group of countries with medium level of per hectare yield for a specific crop		2,2
Low yielding	A group of countries with lowest per hectare yield for a specific crop		2,2
Technical potential (TP)	Derived from the theoretical potential, takes into account technical limitations for yield increase	$TP = \sum (ARY+IRYBPS) \times RR$ ARY=actual residue yield IRYBPS=Increase in residue yield under best practice strategies RR=Recovery rate	2,16
Actual residue yield		ARY=CRR*TCP (t/region) CRR=Crop to residue ratio TCP=Total crop production	2,16
Recovery rate	Refers to mainly harvesting procedures and technologies, implications on transport, handling, storage		2,15
Technical sustainable potential (TSP)	The harvestable biomass limited by technical and ecological constraints, derived from TP	TSP= (TP*SRR) TP=Technical potential SRR=Sustainable removal rate	2,16
Sustainable removal rate (SRR)	Mainly refers to soil humus balance, soil erosion		2,15
Realistic potential	The realistic potential is derived from the technical-sustainable potential		2,18
Regional barrier	Caused by regional aspects, e.g. policies, social acceptance, regional economic resource		2,17

Table 79: Calculations for realistic potential for EU-27 of agricultural crop residues

	Current residue yield for each category				*Increase through optimization of strategies through crop specific strategies*					*Technical potential (TP)*					*Technical sustainable potential (TSP)*				
Crop	High yielding	Medium yielding	Low yielding	**Total (Mt)**	High yielding	Medium yielding	Low yielding	Total increase (Mt)	**Total residue yield (Mt)**	Recovery rate	High yielding	Medium yielding	Low yielding	**Total (Mt)**	Sustainable removal rate (SRR)	High yielding	Medium yielding	Low yielding	**Total TSP**
Wheat	20,4	27,1	76,1	123,6	0,41	1,35	6,1	7,8	131,4	0,7	14,6	19,9	57,5	92,0	0,5	7,285556301	9,955054929	28,76243773	**46,00305**
Grassland	28,4	18,7	91,3	138,4	0,57	0,93	7,3	8,8	147,2	0,9	26,1	17,6	88,8	132,5	1	26,10792	17,62425	88,76304	**132,4952**
Barley	9,3	18,2	18,8	46,2	0,46	1,45	1,9	3,8	50,0	0,7	6,8	13,7	14,5	35,0	0,5	3,401021674	6,868685329	7,237981	**17,50769**
Maize	12,1	19,2	28,1	59,4	0,24	0,96	2,3	3,5	62,8	0,6	7,4	12,1	18,2	37,7	0,6	4,42759528	7,251112462	10,93797389	**22,61668**
Rye	0,5	3,4	3,6	7,4	0,03	0,27	0,4	0,7	8,1	0,7	0,4	2,5	2,8	5,7	0,5	0,185940984	1,271365591	1,377722823	**2,835029**
Oats	1,5	2,2	2,0	5,6	0,08	0,17	0,2	0,4	6,1	0,7	1,1	1,6	1,5	4,3	0,5	0,55476524	0,820266792	0,751373058	**2,126405**
Sunflower	0,4	2,6	2,7	5,7	0,01	0,13	0,2	0,4	6,1	0,5	0,2	1,4	1,5	3,0	0,6	0,119611736	0,822134089	0,880639024	**1,822385**
Rape	2,0	6,9	19,4	28,3	0,04	0,34	1,6	1,9	30,2	0,5	1,0	3,6	10,5	15,1	0,6	0,623374825	2,167485358	6,278727205	**9,069587**
Sugar beet	0,4	2,6	2,7	5,7	0,01	0,13	0,2	0,4	6,1	0,3	0,1	0,8	0,9	1,8	0,4	0,047844694	0,328853636	0,35225561	**0,728954**
Vineyard	0,1	1,4	1,2	2,6	0,001	0,04	0,05	0,1	2,7	0,8	0,1	1,1	1,0	2,2	0,6	0,031749881	0,671504172	0,590271288	**1,293525**
																16,67746061	**30,15646236**	**57,16938163**	**104,0033**

	Allocation for other uses (29%)			*TSP after allocation for other uses*			
Crop	High yielding	Medium yielding	Low yielding	High yielding	Medium yielding	Low yielding	Total TSP after allocation
Wheat	2,112811327	2,886965929	8,341106942	5,172744973	7,068088999	20,42133079	32,66216476
Grassland	19,58094	13,2181875	66,57228	6,52698	4,4060625	22,19076	33,1238025
Barley	0,986296285	1,991918746	2,09901449	2,414725388	4,876766584	5,13896651	12,43045848
Maize	1,284002631	2,102822614	3,172012428	3,143592649	5,148289848	7,765961461	16,05784396
Rye	0,053922885	0,368696021	0,399539619	0,132018099	0,90266957	0,978183205	2,012870873
Oats	0,16088192	0,23787737	0,217898187	0,39388332	0,582389422	0,533474871	1,509747614
Sunflower	0,119611736	0,822134089	0,880639024	0,119611736	0,822134089	0,880639024	1,822384849
Rape	0,623374825	2,167485358	6,278727205	0,623374825	2,167485358	6,278727205	9,069587388
Sugar beet	0,047844694	0,328853636	0,35225561	0,047844694	0,328853636	0,35225561	0,72895394
Vineyard	0,031749881	0,671504172	0,590271288	0,031749881	0,671504172	0,590271288	1,293525341

	Decrease through regional barriers			*Realistic Potential (RP) for EU-27*			
Crop	High yielding (1.5%)	Medium yielding (2.5%)	Low yielding (5.5%)	High yielding	Medium yielding	Low yielding	**Realistic potential (Mt/yr)**
Wheat	0,077591175	0,176702225	1,123173193	5,095153799	6,891386774	19,2981576	**31,2846982**
Grassland	0,0979047	0,110151563	1,2204918	6,4290753	4,295910938	20,9702682	**31,6952544**
Barley	0,036220881	0,121919165	0,282643158	2,378504508	4,754847419	4,856323352	**11,9896753**
Maize	0,04715389	0,128707246	0,42712788	3,096438759	5,019582602	7,33883358	**15,4548549**
Rye	0,001980271	0,022566739	0,053800076	0,130037827	0,88010283	0,924383128	**1,93452379**
Oats	0,00590825	0,014559736	0,029341118	0,38797507	0,567829687	0,504133753	**1,45993851**
Sunflower	0,001794176	0,020553352	0,048435146	0,11781756	0,801580737	0,832203878	**1,75160217**
Rape	0,009350622	0,054187134	0,345329996	0,614024203	2,113298224	5,933397209	**8,66071964**
Sugar beet	0,00071767	0,008221341	0,019374059	0,047127024	0,320632295	0,332881551	**0,70064087**
Vineyard	0,000476248	0,016787604	0,032464921	0,031273632	0,654716568	0,557806367	**1,24379657**
			Only for agric crops	**11,89835238**	**22,00397714**	**40,57812042**	**74,4804499**
			Including grassland	**18,32742768**	**26,29988807**	**61,54838862**	**106,175704**

Table 80: Calculations for realistic potential for Belarus, Russia, and Ukraine of agricultural crop residues

Current residue yield for each category					***Increase through optimization of strategies through crop specific strategies***					***Technical potential (TP)***					***Technical sustainable potential (TSP)***				
Crop	Belarus	Russia	Ukraine	**Total (Mt)**	Belarus	Russia	Ukraine	Total increase (Mt)	**Total residue yield (Mt)**	Recovery rate	Belarus	Russia	Ukraine	**Total (Mt)**	Sustainable removal rate (SRR)	Belarus	Russia	Ukraine	**Total TSP**
Wheat	1,553438	44,7895497	16,851668	63,19465507	0,03	2,24	1,3	3,6	66,8	0,7	1,1	32,9	12,7	46,8	0,5	0,554577	16,46016	6,36993	**23,38467**
Grassland	28,44	18,65	91,32	138,41	0,57	0,93	7,3	8,8	147,2	0,9	26,1	17,6	88,8	132,5	1	26,10792	17,62425	88,76304	**132,4952**
Barley	1,567288	12,9095579	7,5122418	21,98908766	0,08	1,03	0,8	1,9	23,9	0,7	1,2	9,8	5,8	16,7	0,5	0,575978	4,879813	2,892213	**8,348004**
Maize	0,519002	5,27037692	13,114357	18,90373591	0,01	0,26	1,0	1,3	20,2	0,6	0,3	3,3	8,5	12,1	0,6	0,190578	1,992202	5,098862	**7,281642**
Rye	0,978992	2,86886527	0,7302072	4,578064369	0,05	0,23	0,1	0,4	4,9	0,7	0,7	2,2	0,6	3,5	0,5	0,35978	1,084431	0,28113	**1,72534**
Oats	0,431506	3,87276509	0,5406353	4,844906745	0,02	0,31	0,1	0,4	5,2	0,7	0,3	2,9	0,4	3,7	0,5	0,158579	1,463905	0,208145	**1,830628**
Sunflower	0,036556	18,772531	17,50664	36,31572748	0,00	0,94	1,4	2,3	38,7	0,5	0,0	9,9	9,5	19,3	0,6	0,011186	5,913347	5,672151	**11,59668**
Rape	0,551699	1,1065712	1,8846908	3,542961096	0,01	0,06	0,2	0,2	3,8	0,5	0,3	0,6	1,0	1,9	0,6	0,16882	0,34857	0,61064	**1,12803**
Sugar beet	0,899883	7,06416866	3,7469771	11,71102884	0,02	0,35	0,3	0,7	12,4	0,3	0,3	2,2	1,2	3,7	0,4	0,110146	0,890085	0,485608	**1,485839**
Vineyard	0,065491	1,35822041	1,1824345	2,606145562	0,001	0,04	0,05	0,1	2,7	0,8	0,1	1,1	1,0	2,2	0,6	0,03175	0,671504	0,590271	**1,293525**
																2,161393	**33,70402**	**22,20895**	**58,07436**

	Allocation for other uses (14.5%)			***TSP after allocation for other uses***			
Crop	Belarus	Russia	Ukraine	Belarus	Russia	Ukraine	Total TSP after allocation
Wheat	0,08041371	2,386723128	0,923639899	0,474163599	14,07343638	5,446290438	19,9938904
Grassland	19,58094	13,2181875	66,57228	6,52698	4,4060625	22,19076	33,1238025
Barley	0,083516862	0,707572866	0,419370896	0,492461498	4,172240002	2,472842179	7,13754368
Maize	0,02763374	0,288869359	0,739334992	0,162943777	1,703333116	4,359527025	6,22580392
Rye	0,05216803	0,157242505	0,040763818	0,30761149	0,927188566	0,240365959	1,47516601
Oats	0,022993897	0,212266255	0,030180964	0,1355847	1,25163895	0,177963614	1,56518726
Sunflower	0,001622003	0,857435352	0,822461957	0,009564224	5,055911902	4,849689474	9,9151656
Rape	0,024478888	0,05054264	0,088542775	0,144341029	0,298027289	0,522097051	0,96446537
Sugar beet	0,015971125	0,129062361	0,070413194	0,094174564	0,761022889	0,415195039	1,27039249
Vineyard	0,004603733	0,097368105	0,085589337	0,027146148	0,574136067	0,504681951	1,10596417

	Decrease through regional barriers			Realistic Potential (RP) for Belarus, Russia, Ukraine			
Crop	Belarus (5.5%)	Russia (4.4%)	Ukraine (4.4%)	Belarus	Russia	Ukraine	**Realistic potential (Mt/yr)**
Wheat	0,026078998	0,619231201	0,239636779	0,448084601	13,45420518	5,206653659	**19,10894344**
Grassland	0,3589839	0,19386675	0,97639344	6,1679961	4,21219575	21,21436656	**31,59455841**
Barley	0,027085382	0,18357856	0,108805056	0,465376116	3,988661442	2,364037123	**6,818074681**
Maize	0,008961908	0,074946657	0,191819189	0,15398187	1,628386459	4,167707835	**5,950076164**
Rye	0,016918632	0,040796297	0,010576102	0,290692858	0,886392269	0,229789857	**1,406874983**
Oats	0,007457159	0,055072114	0,007830399	0,128127542	1,196566836	0,170133215	**1,494827593**
Sunflower	0,000526032	0,222460124	0,213386337	0,009038192	4,833451778	4,636303137	**9,478793107**
Rape	0,007938757	0,013113201	0,02297227	0,136402272	0,284914088	0,499124781	**0,920441141**
Sugar beet	0,005179601	0,033485007	0,018268582	0,088994963	0,727537882	0,396926457	**1,213459302**
Vineyard	0,001493038	0,025261987	0,022206006	0,02565311	0,54887408	0,482475945	**1,057003135**
			Only for agric. crops	**1,746351523**	**27,54899001**	**18,15315201**	**47,44849354**
			Including grassland	**7,914347623**	**31,76118576**	**39,36751857**	**79,04305195**

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