Employment Effects of selected scenarios from the Energy roadmap 2050

Final report for the European Commission (DG Energy)

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Legal notice

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Contents

List of Abbreviations

BAU: Business As Usual

CCS: Carbon Capture and Storage

CGE: Computable General Equilibrium

CPI: Current Policy Initiatives

ETS: Emissions Trading System

GDP: Gross Domestic Product

GHG: Greenhouse Gases

GVA: Gross Value Added

FTE: Full-Time Equivalent

ICT: Information and Communication Technology

LFS: Labour Force Survey

RES: Renewable Energy System

NAICS: North American Industry Classification System

NACE: Statistical Classification of Economic Activities in the European Community

SBS: Structural Business Statistics (Eurostat database)

Solar PV: Solar, photovoltaic

STEM: Science, Technology, Engineering, and Math (skills)

Units:

toe: tonne of oil-equivalent

MWh: megawatt-hour

MW: megawatts

GW: gigawatts

tCO2: tonnes of CO2

mtCO2: million tonnes of CO2

Executive Summary

This report provides an assessment of the employment and labour market impacts of the scenarios in the Energy Roadmap 2050 (European Commission, 2011b, henceforth referred to as the Energy Roadmap). It also provides estimates of the current level of employment in energy supply sectors in the EU, breaking down the more aggregated data published by Eurostat.

Estimates of employment in energy supply sectors

The following table shows estimates of employment in the EU28 in the energy supply sectors in 2009 and 2010.

Table 0.1: Estimates of direct employment in energy supply sectors, EU28, 000s

	2009	**2010**
B05: Mining of coal and lignite	**329.5**	**335.1**
510: Mining of hard coal	217.2	232.2
520: Mining of lignite	112.3	102.9
No country distribution available	0.0	0.0
B06: Extraction of crude petroleum and natural gas	**99.2**	**96.7**
610: Extraction of crude petroleum	64.8	62.4
620: Extraction of natural gas	24.0	34.3
No country distribution available	10.4	0.0
B07: Mining of metal ores	**34.7**	**39.9**
721: Mining of uranium and thorium ores	30.4	34.1
No country distribution available	0.0	0.0
Sectors out of the scope of the study	4.3	5.8
B08: Other mining and quarrying	**256.1**	**237.8**
892: Extraction of peat	10.3	10.8
No country distribution available	7.1	0.0
Sectors out of the scope of the study	238.7	227.0
B09: Mining support service activities	**96.4**	**105.1**
910: Support activities for petroleum and natural gas extraction	89.1	97.8
No country distribution available	0.0	0.0
Sectors out of the scope of the study	7.3	7.3
C19: Manufacture of coke and refined petroleum products	**207.9**	**217.8**
1910: Manufacture of coke oven products	13.3	12.3
1920: Manufacture of refined petroleum products	194.6	205.5
No country distribution available	0.0	0.0
D35: Electricity, gas, steam and air conditioning supply	**1 656.6**	**1 671.5**
3511: Production of electricity	586.4	591.9
3512: Transmission of electricity	75.2	67.5
3513: Distribution of electricity	474.6	425.9
3514: Trade of electricity	70.6	68.9
3521: Manufacture of gas	22.3	90.5

3522: Distribution of gaseous fuels through mains	138.2	142.6
3523: Trade of gas through mains	42.2	57.0
3530: Steam and air conditioning supply	245.6	218.4
No country distribution available	1.7	8.9
Total No country distribution	19.2	8.9
Total Sectors out of the scope of the study	250.3	240.1
Total NACE of interest	2 410.9	2 455.0

Note: "No country distribution available " represents employees in the NACE Rev.2 2-digit grouping that could not be apportioned into the relevant subsectors of interest due to the lack of data sources at NACE Rev.2 4-digit level.

"Sectors out of the scope of the study" represents employees in the NACE Rev.2 2-digit grouping who are not included in the NACE Rev.2 4-digits sectors shown in the table because they are employed in sectors that are not of interest to the energy system.

Lessons from the literature

A literature review was carried out to summarise the main findings from research that is relevant to the assessment of employment impacts of energy policies.

Methods used to estimate employment impacts of energy policy

The most common approach used in the literature is a 'partial' one that looks at the possible employment impacts of development and deployment of a single technology. This typically makes use of engineering or firm-level data to provide an estimate of the number of jobs required to produce and operate specific equipment. The measure of employment given is usually gross.

In a few cases macroeconomic models that provide a representation of the whole economy have been used. These calculate indirect effects and estimate net employment impacts for the whole economy, but do not have the same level of detail about the specific technologies involved.

Sectors that stand to gain or lose

The scenarios in the energy roadmap all require European firms and households to spend more on investment goods and less on energy; the sectors that produce the investment goods will be the ones that stand to gain the most (when new equipment is being deployed). The sectors that will lose out are those that supply fossil fuels (unless CCS is a large part of the portfolio) and possibly some intensive users of energy. Some energy-intensive industries also feature in the supply chains of sectors that will benefit.

However, the main impacts will be felt within, rather than between, sectors. This means that it is not enough to determine which sectors win and which lose out as the impacts are more subtle. Previous findings suggest that the most important developments will be changes to existing jobs rather than a large number of jobs being created or lost, although there may be quite substantial movements between companies.

Types of worker that face the largest impacts of energy policy

The reviewed studies confirm that the shift in demand for the products of different sectors will be reflected in the availability of jobs. Those in construction and engineering seem likely to benefit. Highly-skilled workers will be more able to adapt to changes in policy. Since the changes would be implemented over the decades to 2050, a key to successful adaptation will be the equipping of new entrants by the education and training system.

Mobility between sectors, and competition for skilled labour

Low rates of labour mobility in Europe, both between sectors and geographical areas, could lead to dislocation (unemployment and unfilled vacancies), particularly in the short term. This could have a negative impact on both the economy and achieving the decarbonisation targets. An improvement in basic skills (and hence mobility between jobs) could be an important part of smoothing the transition to a low-carbon economy.

Potential labour market impacts of the structural change anticipated in the Energy Roadmap

There is no clear consensus about whether the overall net impact on employment (defined as number of jobs) will be positive or negative, but in almost all cases the impacts are small at macroeconomic level.

There are some general trends that are quite clear, however. These include the findings for sectoral employment (as discussed above) and the impacts across various skills groups. The overall impact on the quality of jobs is not clear; some of the skills expected to be in greater demand are quite high level (engineers, software), while others are medium-skill (construction). It is difficult to assess the impacts of decarbonisation on the other factors that are often used to assess job quality.

Modelling the Energy Roadmap 2050 scenarios

The main analysis presents the quantitative results of representing the scenarios in two macro-sectoral models: E3ME and GEM-E3. Both models have an extensive track record of being applied for policy analysis and impact assessment at the European level, particularly with regards to energy and climate policy. Although the scope and coverage of the two models are broadly similar, they embody rather different views about how the economy functions. We therefore obtain results from the two perspectives so as to identify cases where the conclusions from the models agree regardless of their different theoretical underpinnings and cases where the conclusions are very sensitive to those underpinnings.

The baseline for this exercise is the Current Policy Initiatives (CPI) case from the Energy Roadmap. Both models have been calibrated to be consistent with this.

The carbon reduction targets are met in 2050 in all the scenarios except the baseline. This is achieved through a variety of measures, including substantial changes in the fuel mix used for electricity generation, CCS, carbon pricing, investment in energy efficiency and efficiency standards for vehicles. The scenarios show different ways of meeting the targets. All the scenarios (but not the baseline) assume that the rest of the world also takes action to decarbonise. This results in a lower global oil price.

The scenarios raise revenues from carbon taxes, which may be spent on public sector investment. Any changes in net revenues are balanced by adjusting employers' social security payments, which affect directly the cost of labour. Alternative approaches to revenue recycling were also tested (see below).

The scenarios

The following table provides a summary description of the Energy Roadmap 2050 scenarios that were modelled.

Name	EU policy	Global policy	Fossil fuel prices	Description
BA	Current policies	Current policies	Baseline	Baseline.
S1	Higher energy efficiency	Decarbonisation	Reduced	Energy efficiency standards apply to household appliances, new buildings and electricity generation.
S2	Diversified	Decarbonisation	Reduced	No specific support measures for energy

	supply technologies			efficiency and RES. Nuclear and CCS are not constrained.
S3	High RES	Decarbonisation	Reduced	Achievement of high overall RES share and high RES penetration in power generation.
S4	Delayed CCS	Decarbonisation	Reduced	This scenario follows a similar approach to the Diversified supply technologies scenario but assumes a constraint on CCS while having the same assumptions for nuclear as scenarios 1 and 2.
S5	Low nuclear	Decarbonisation	Reduced	This scenario follows a similar approach to the Diversified supply technologies scenario but imposes constraints on power generation from nuclear. It has the same assumptions for CCS as scenarios 1 and 2.

Results: GDP

The models predict that the scenarios will have a modest impact on EU GDP. The E3ME model predicts a slight increase in GDP (2-3%) by 2050 compared to the baseline (boosted by the lower oil prices), while the GEM-E3 model suggests a GDP reduction of 1-2%. This is compared to an 85% increase in GDP in the baseline over 2013-50. In most cases there is not much difference in the GDP outcome between the different scenarios. In summary, the effects of all the scenarios on GDP are minor in nature.

Results: employment

Both models predict an increase in employment levels in the scenarios, compared to the baseline. The range of outputs is 0 to 1.5% depending on the scenario, with the results from the E3ME model roughly 1 percentage point higher than those from the GEM-E3 model.

The increases in employment will be largest in the construction sector and the sectors that produce energy-efficient equipment. There may also be an increase in agricultural employment due to higher demand for biofuels, depending on the extent to which this displaces other agricultural production. In the power generation sector the analysis suggests that total employment could either increase or decrease slightly, depending on the choice of scenario and the future maintenance requirements for renewables.

In other sectors the employment effects are more ambiguous as they are affected both by the revenue recycling methods used in the scenarios and any response in wage demands. It is important to note that these scenarios assume that there is available labour to fill vacant positions, i.e. there is not full employment in the baseline.

Results: skills

The nature of jobs in the power sector is likely to change as there is a shift from conventional power sources to renewables. In the wider economy, however, the model results suggest that there will not be major shifts in the balance of high and low-skilled labour.

This does not mean that there may not be important changes in skills requirements within existing jobs. Previous analysis has shown that the main impacts are likely to be shifts within sectors rather than movements between sectors. The analysis shows that many existing jobs will change in focus without necessarily being replaced with new jobs.

Sensitivity analysis

The sensitivity analysis carried out with the models suggests that these results are fairly robust. Assumptions about the labour intensity of new technologies (measured as jobs per GW capacity) in the electricity sector and baseline rates of GDP growth do not have much impact on the results. The impact of the changing oil price on the results was also separated in the sensitivity testing.

One issue that may be important is the way in which national governments use the revenues that are collected from carbon taxes. The results from the E3ME model suggest that this could have quite a large impact on overall employment results. Efficient use of the revenues is therefore worth exploring further, although this is not necessarily related directly to EU energy policy.

1 Introduction

1.1 Overview of this report

This report provides an assessment of the employment and labour market impacts of the scenarios in the Energy Roadmap 2050 (European Commission, 2011b, henceforth referred to as the Energy Roadmap). It also provides estimates of the current level of employment in energy supply sectors in the EU28, breaking down the more aggregated data published by Eurostat.

The Energy Roadmap

The 2050 target of an 80-95% reduction in greenhouse gas emissions from 1990 levels is much more ambitious than the 20% reduction incorporated in the current 20-20-20 target for 2020. If the 2050 target is to be achieved, large-scale changes in the energy system will be required in the short to medium term so that investment in new infrastructure does not produce a 'lock-in' to fossil fuel-based technologies. It is often stressed that early action is required to avoid higher future costs and to reduce frictions as energy production shifts towards renewable sources (e.g. OECD, 2008).

While the Energy Roadmap 2050 provides plausible routes by which the target can be achieved, the assessments that have been made so far of the advantages or disadvantages of each route have not yet given detailed consideration to the impact on the labour market. This report aims to fill that gap.

Sectoral employment effects

The Energy Roadmap highlights ten key transformations of the energy system, which are likely to have important impacts (both positive and negative) on employment in many different economic sectors. Some examples considered in this report are:

- construction and engineering, which could benefit from a large-scale investment programme, such as in RES equipment
- transport and energy-intensive manufacturing, which could lose out due to higher energy costs
- sectors producing fossil fuels (e.g. coal mining) or the equipment for fossil fuel-based technologies, which could reduce in size due to lower demand

The resulting changes in wage rates and net incomes will affect indirectly all sectors of the economy, including service sectors.

It is therefore necessary to consider not just the macro-level impacts (whether the net effect is to boost or reduce employment) but also impacts at the level of particular sectors and skills to gain a complete understanding of labour market developments in each of the Energy Roadmap scenarios. It is also important to note that the decarbonising scenarios propose that global action is taken and a failure of the EU's labour market to anticipate labour, skill and qualification shortages could make Europe less competitive.

Aims of the project

This study examines the labour market implications of a selection of the scenarios in the Energy Roadmap. The analysis considers the composition, quantity and quality of employment, including both the short-term transitional impacts that arise from investment in new technologies and increases in the price of energy, and the longer-term labour market trends.

The main analysis presents the quantitative results of representing the scenarios in two macro-sectoral models. Both models have an extensive track record of being applied for policy analysis and impact assessment at the European level, particularly with regards to energy and climate policy. Although the scope and coverage of the two models are broadly similar, they embody rather different views about how the economy functions. The intention, therefore, is to obtain results from the two perspectives so as to identify cases where the conclusions from the models agree, regardless of their different theoretical underpinnings, and cases where the conclusions are very sensitive to those underpinnings.

- E3ME, which is developed and operated by Cambridge Econometrics, is an econometric model with macroeconomic properties in the Keynesian tradition. There is no assumption that the labour market clears, even in the long run, or that prices adjust to achieve market clearing. E3ME is currently a model of the European economies; activity and prices in the rest of the world are given by assumption.
- GEM-E3, which is developed and maintained by the National Technical University of Athens, is a Computable General Equilibrium model with macroeconomic properties in the neoclassical tradition. The user can select from alternative options for closure and price adjustment/market clearing. The world version of GEM-E3 represents the entire global economy.

A fuller description of the models and the key differences between them is given in the appendices.

Some of the issues of interest in this study go beyond the detail and scope of the two models, and so this report presents the results of an exercise to construct detailed employment estimates for the energy sectors together with some additional data analysis and qualitative assessment.

1.2 Structure of this report

Main report The databases for the two macro-sectoral models are maintained by their modelling teams, but an additional data collection exercise was carried out specifically for this study. This task paid particular attention to the detailed sectors involved in the production of energy, since these are expected to be particularly affected in the Energy Roadmap scenarios. The approach that is followed combines sectoral and micro-level data sets to build up a picture of current employment levels in these sectors. The results are presented in Chapter 2.

Chapter 3 summarises the findings of previous analysis in the area, including work on ‘green jobs’. It builds on previous literature reviews and highlights features that are specific to the Energy Roadmap.

Chapter 4 describes the scenarios that were assessed, and Chapters 5 and 6 present the results of the exercises to represent the scenarios in the two models.

Chapter 7 addresses some of the important issues that cannot be addressed by the macroeconomic modelling. This includes a more detailed analysis of occupational and skills requirements that builds on the previous model results and also examines some of the more subtle labour market aspects of the transition to a low-carbon economy.

Chapter 8 presents the conclusions of the study.

Appendices The appendices to this report are provided separately. They provide further details on the data and literature that were used, and also discuss sensitivities in the modelling results and provide key ratios that can be used in further analysis. The appendices include descriptions of the E3ME and GEM-E3 macroeconomic models.

2 Data Collection

2.1 Introduction

Context and objective

The estimate of employment effects of decarbonisation of the energy system requires granular, detailed statistical figures at sector and country level. Official employment statistics produced at European level and published by Eurostat are presented at an aggregate level which does not allow such a detailed analysis.

The available Eurostat data allow us to classify employment activity by sector according to the Statistical Classification of Economic Activities in the European Community (NACE.Rev.2), which can reach maximum four digits[1] of disaggregation. Eurostat Labour Force Survey (LFS) employment data are published at two digits of aggregation. For the sector 'production of electricity', the NACE.Rev.2 classification does not allow the kind of further breakdown into the main components that is available in the North American Industry Classification System (NC-NAICS 2012).

The main objective of this task is to construct a dataset for employment in the energy sector with particular reference to a group of specific sub-sectors of interest relating to the energy system. The aim is to obtain a four digit breakdown for all the sectors in the energy system, while maintaining consistency with Eurostat published figures. In the case of production of electricity we attempt to reach the same level of granularity of the NC-NAICS 2012.

Specific data requirements

The complete list of sectors of interest is:

B. Extractive Sector (NACE Section B: Mining and Quarrying)

- 05.10 Mining of hard coal
- 05.20 Mining of lignite
- 08.92 Extraction of peat
- 07.21 Mining of uranium and thorium ores
- 06.10 Extraction of crude petroleum
- 06.20 Extraction of natural gas
- 09.10 Support activities for petroleum and natural gas extraction

C. Manufacturing Sector (NACE Section C: Manufacturing)

- 19.10 Manufacture of coke oven products
- 19.20 Manufacture of refined petroleum products

D. Utilities Sector (NACE Section D: Electricity, Gas Steam and Air Conditioning Supply)

- 35.11 Production of electricity
  - NC 221112 Power generation, fossil fuel (e.g., coal, gas, oil), electric
  - NC 221111 Power generation, hydroelectric
  - NC 221113 Power generation, nuclear electric
  - NC 221114 Electric power generation, solar
  - NC 221115 Electric power generation, wind
  - NC 221116 Electric power generation, geothermal
  - NC 221117 Biomass electric power generation

[1] The European industry standard classification system consists of a six digit code, but only the first four digits are the same in all European countries and hence exploitable for the purpose of this analysis.

NC 221118 Electric power generation, tidal

35.12 Transmission of electricity
35.13 Distribution of electricity
35.14 Trade of electricity
35.21 Manufacture of gas
35.22 Distribution of gaseous fuels through mains
35.23 Trade of gas through mains
35.30 Steam and air conditioning supply

Basic approach To produce the statistics at this level of detail we collect information from various data sources to compute shares that are then used to break down the more aggregated Eurostat LFS published statistics. We use Eurostat Structural Business Statistics (SBS) on employment where available to apportion LFS data. To cover the remaining gaps we use firm-level data sourced from the dataset Amadeus by the Bureau Van Dijk. For the production of electricity we base our figures on data from EurObserv'ER, combined with other information sourced from published literature. We present figures for the EU28 for 2009 and 2010. The figures are consistent with official statistics published in the Eurostat LFS database.

Remaining sections in this chapter In the next section we provide an overview of the data sources, followed by a discussion of the methodology used in Section 2.3. We present results, aggregated for the EU28, for all the subsectors of interest in Sections 2.4 and 2.5.

2.2 Data sources

Overview In this section we provide an overview of all the data sources that are used to obtain the employment figures at the desired level of disaggregation, highlighting the aspects of interest for this study and the pitfalls in the data. The sources used are:

- Eurostat LFS data as the main source for headline figures of employment
- Eurostat SBS at Nace.Rev.2 four digit level to apportion Eurostat LFS figures
- Eurostat data for electricity production capacity in the 28 countries of interest
- Amadeus micro-data for constructing shares at four digit NACE.Rev.2 disaggregation level, when SBS data are not available
- EurObserv'ER for information on employment in renewable energies
- other sources used to compensate ad-hoc gaps in the data

It should be noted that figures from the different sources reported in this section are not directly comparable with the figures contained in Section 2.4. Figures reported in this section are not harmonised with Eurostat figures and are directly based on the sources presented, whereas figures in Section 2.4 are consistent with aggregates published by Eurostat. To make the difference clearer, we have adopted a grey colour background for all the tables with data contained in this section.

The Eurostat LFS interactive database provides statistics for all the 28 countries of interest and for the period 2009-11. We used years 2009 and 2010 that should be subject to less revisions in the years to come. Consistently with this we have also used data for the years 2009 and 2010 for Eurostat SBS and Amadeus. As regards information on renewables we had to rely on all available information provided by EurObserv'Er for different years – 2008, 2009, 2010, 2011 and 2012. Relevant to this report is the availability of the following information:

- employment by country

- a two digit NACE.Rev.2 identifier

Data can be extracted with quarterly or annual frequency.

Eurostat LFS data

We have used employment data at the lowest level of disaggregation allowed by the Eurostat LFS database, i.e. NACE.Rev.2 at two digit level.

Table 2.1 provides further details of the data that are publicly available through the LFS for all the countries and sectors in the scope of this project.

The coverage of the energy sectors is often very poor. For example, in DK, LT, LU and MT data are not published for any sector apart from D35. Even for larger countries, such as DE and FR, the data exhibit some gaps. Data look more complete for countries such as the CZ, PL, RO, ES and the UK.

Table 2.1: Availability of data for the energy economic sector, 2009 and 2010

	Economic sectors of interest[2]						
	B05	B06	B07	B08	B09	C17	D35
AT	X	O	X	✓	X	✓	✓
BE	X	X	X	✓	X	✓	✓
BG	✓	X	✓	✓	X	✓	✓
CY	X	X	X	O	X	X	✓
CZ	✓	✓	✓	✓	✓	✓	✓
DK	X	X	X	X	X	X	✓
EE	X	✓	X	✓	X	✓	✓
FI	X	X	O	✓	X	✓	✓
FR	X	X	X	✓	X	✓	✓
DE	✓	✓	X	✓	O	✓	✓
EL	✓	X	X	✓	X	✓	✓
HU	✓	X	X	✓	X	✓	✓
IE	X	X	✓	✓	X	X	✓
IT	X	✓	X	✓	✓	✓	✓
LV	X	X	X	✓	X	X	✓
LT	X	X	X	X	X	X	✓
LU	X	X	X	X	X	X	✓
MT	X	X	X	X	X	X	✓
NL	X	✓	X	✓	✓	✓	✓
PL	✓	✓	✓	✓	✓	✓	✓
PT	X	X	X	✓	X	O	✓
RO	✓	✓	X	✓	✓	✓	✓
SK	✓	X	X	✓	X	✓	✓
SI	✓	X	X	✓	X	X	✓
ES	✓	✓	✓	✓	✓	✓	✓
SE	X	X	✓	✓	X	✓	✓
UK	✓	✓	X	✓	✓	✓	✓
HR	X	✓	X	✓	✓	✓	✓

Notes: "X": no data published (small sample); "✓": Data available over the whole period considered, O: Data available in a discontinuous fashion over the period considered.

Sources: Eurostat, database lfs_egan22d[3]

[2] The classification used is NACE Rev.2.

[3] For more information, see http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

Restricted micro-data

The Eurostat LFS micro-data are restricted to public access but constitute the basis of an available dataset on labour statistics covering the EU27 and, for more recent years, also HR. The LFS guide reports all variables available in the micro-data and, with regards to the industry coding, it is stated that, depending on the country, the greatest level of disaggregation following the NACE.Rev.2 classification is either at two or at three digits. Given that the industry breakdown for energy-related sectors required here is at four digits, the Eurostat micro-data would still not provide the desired level of granularity. We therefore decided to explore alternative micro-data sources, starting with Amadeus.

It is also worth noting that the data gaps identified in Table 2.1 for the sectors and countries of interest may reflect a general lack of underlying micro-data. If this is the case then even having access to the Eurostat micro-data might not solve the problem as it stands.

Eurostat SBS data

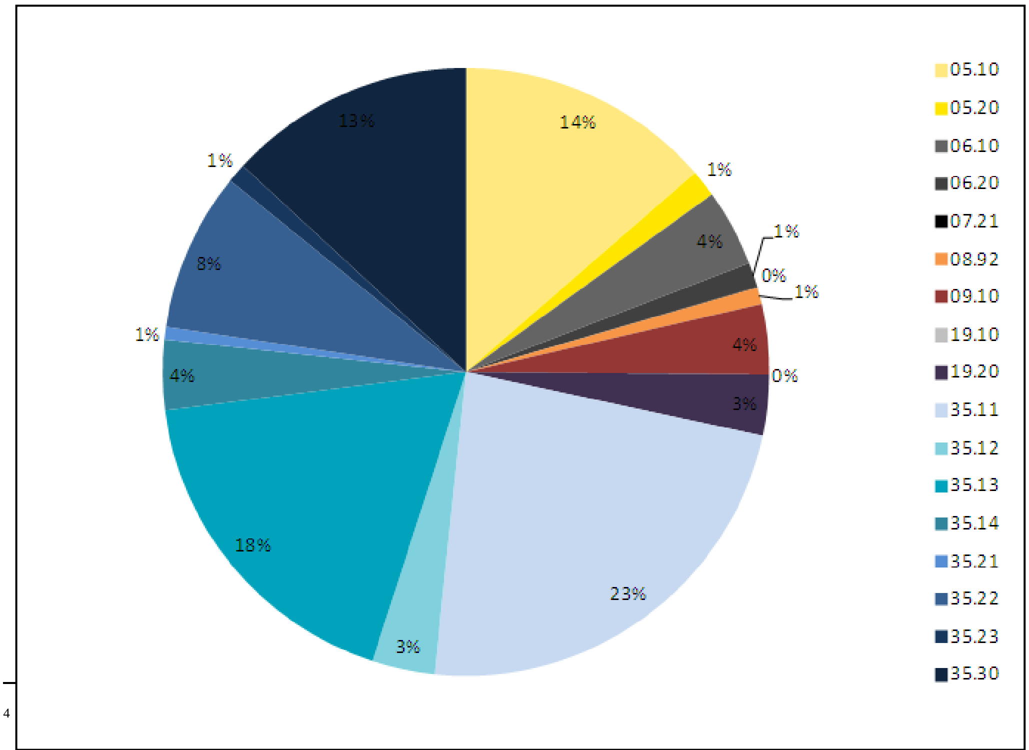
Structural business statistics (SBS) provide data on industry, construction, trade and services. The data are presented according to the NACE activity classification and are in principle available for the EU28.

The statistics can be broken down to the NACE.Rev.2 four digit level. The number of people employed was the indicator used for this study.

Breakdown of the sectors of interest

Figure 2.1 reports the share of employees among the sectors of interest. The sector with the highest share is 35.11 – Production of electricity with 23% of employment of the overall energy sector. The sector 35.13 – Distribution of electricity is also an important sector with a share of 18%[4].

Figure 2.1: Distribution of sectors of interest, NACE Rev.2 – 4digits, SBS, 2010



4 summing up LFS NACE Rev.2 data at two digits level. This implies that the percentages reported in Figure 2.1 cannot be directly obtained by summing up numbers contained in other tables of this report (e.g. Table 0.1), which result from the sum of LFS data that have been used as a numeraire.

Eurostat data on electricity production capacity

Energy statistics are an integral part of the European system of statistics. Eurostat data cover the production, transformation, consumption, exports and imports of electricity by sector and fuel type. Relevant for this study are data on electricity generation capacity, which are used to infer the number of direct employees in the sectors connected to the production of electricity. As an example, Table 2.2 presents figures on capacity in the sector D35.11 across the 28 countries for both producers and autoproducers of electricity.

Table 2.2: Eurostat data on average annual power generation capacity in MW, 2010

Country	NC 221111	NC 221112	NC 221113	NC 221114	NC 221115	NC 221116	NC 221117*	NC 221118
AT	12 929	3 593	0	154	981	1	3 485	0
BE	1 425	7 987	5 927	904	912	0	1 130	0
BG	3 048	4 570	1 892	25	488	0	4	0
HR	2 141	1 892	0	0	79	0	9	0
CY	0	1 463	0	7	82	5	8	0
CZ	2 196	11 360	3 900	1 727	213	0	432	0
DK	9	8 369	0	7	3 802	0	1 248	0
EE	6	2 570	0	0	108	0	67	0
FI	3 155	8 724	2 700	7	197	0	1 910	0
FR	25 332	27 407	63 130	1 030	5 994	0	1 417	240
DE	11 028	70 418	20 467	17 320	27 209	8	6 664	0
EL	3 018	10 513	0	202	1 298	0	41	0
HU	53	6 108	2 000	2	293	0	535	0
IE	530	6 371	0	0	1 389	0	36	0
IT	21 520	72 459	0	3 470	5 794	728	2 183	0
LV	1 576	935	0	0	30	0	16	0
LT	876	2 507	0	0	133	0	29	0
LU	1 134	488	0	29	44	0	28	0
MT	0	571	0	0	0	0	0	0
NL	37	22 254	510	88	2 237	0	1 489	0
PL	2 342	29 773	0	0	1 108	0	134	0
PR	5 093	9 275	0	134	3 796	25	584	0
RO	6 474	11 618	1 411	0	388	0	20	0
SK	2 516	3 311	1 820	20	3	0	183	0
SI	1 254	1 212	666	12	0	0	47	0
ES	18 535	49 497	7 450	4 653	20 693	0	960	0
SE	16 732	4 797	8 977	11	2 019	0	3 818	0
UK	4 385	70 826	10 865	77	5 378	0	2 193	1

Sources: Eurostat, database nrg_113a; *: Net maximum capacity.

Subsector NC 221117 includes biomass and municipal wastes (RES and non RES). The biomass element covers organic, non-fossil material of biological origin, which may be used for heat production or electricity generation, including wood and wood waste, biogas, and biofuels. The municipal waste element combines a biodegradable (RES) and non RES wastes. Industrial RES and non RES is not included.

Amadeus micro-data

Amadeus contains comprehensive information on around 19m companies across European countries[5]. The information collected is mainly based on firms' financial accounts. Relevant for this study are the following variables included in Amadeus:

- the number of employees per firm
- country
- sector specified according to NACE Revision at four digit level

Data coverage

We have extracted data for the 28 countries of interest imposing as the only criterion that information on the number of employees and NACE Rev.2 sector was not missing.

Table 2.3: Number of firms per relevant sector contained in Amadeus – 2009, 2010

	Economic sectors of interest[6]													
	2009							2010						
	B05	B06	B07	B08	B09	C19	D35	B05	B06	B07	B08	B09	C19	D35
AT		5	3	116	1	6	172		7	3	127	2	6	197
BE				84	8	18	78				83	8	18	82
BG	15	2	14	83	2	8	142	15	2	13	78	2	7	147
HR		2		64	4	7	65		2		64	4	7	66
CY				3		1					3		1	
CZ	8	1	1	82	13	9	295	8	3	1	101	11	11	348
DK		5	1	25	9	2	99		5	1	23	10	3	99
EE		2		32		1	54		2		30	1	3	52
FI			4	59	3	5	201			5	71	3	5	211
FR		16	7	411	6	32	140	3	19	7	481	6	38	182
DE		2	1	137	4	55	1 088		3	2	148	5	66	1 130
EL	2	1	2	62		26	82	2	1	2	63		28	115
HU	4	6	3	60	19	9	171	5	6	3	57	15	10	164
IE	3	2	4	22	5	4	36	3	2	5	15	5	3	37
IT	2	13	4	588	10	160	745	2	18	4	608	13	176	825
LV				53			121				53			124
LT		3		34		4	102		3		34		4	105
LU				2			6				2			6
MT		1			3				1			3		
NL		51		59	65	27	106		45		57	72	29	97
PL	19	18	3	281	39	58	627	9	5	1	99	16	21	312
PT			3	227	5	1	133			4	211	5	2	149
RO	13	10	12	166	43	26	226	14	11	13	174	50	27	267
SK	2			23	1	2	30	2			29	2	2	49
SI	2	1	2	37	2	5	155	3	1	2	39		5	154
ES	31	32	37	778	15	26	797	28	32	32	754	15	25	822
SE			7	94	16	14	288			7	97	16	14	299
UK	28	208	49	191	180	33	238	26	228	53	200	208	36	319
Total EU 28	129	381	157	3 773	453	539	6 197	120	396	158	3 701	472	547	6 358

Notes: The classification used is NACE Rev.2.
Sources: Amadeus.

[5] For more information please refer to:
http://www.bvdinfo.com/Products/Company-Information/International/AMADEUS.aspx

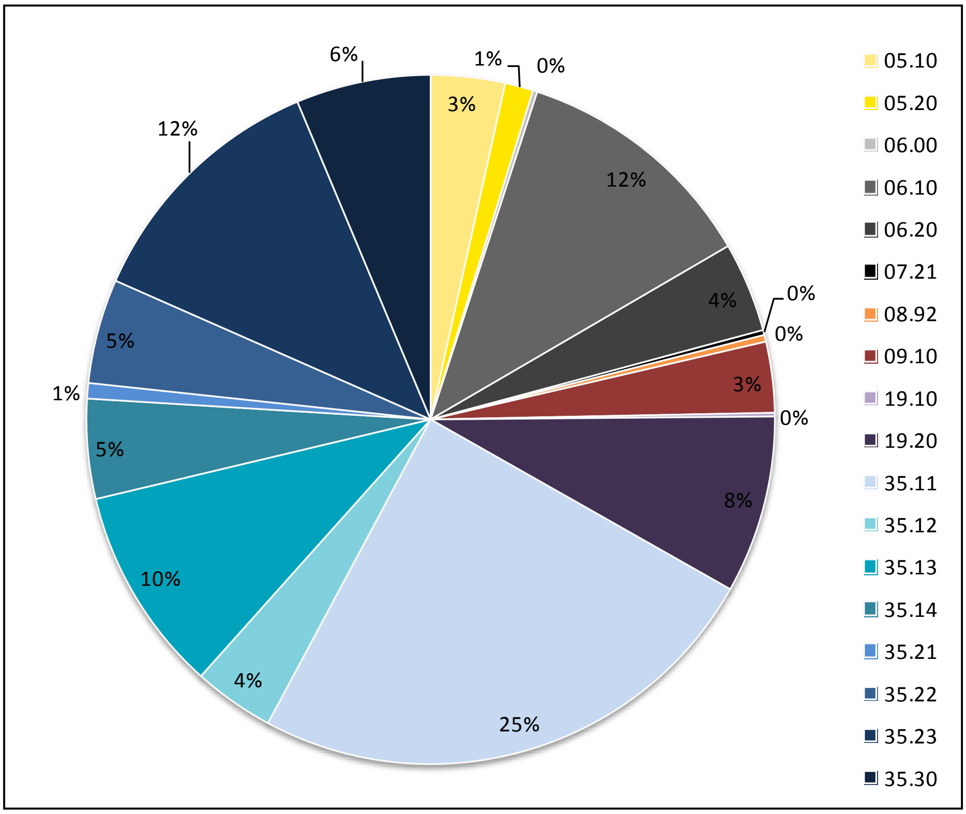
[6] The classification used is NACE Rev.2.

Table 2.3 provides details on the number of firms that we were able to look at. Data are aggregated at two digits and hence also include firms whose employment is not directly related to the four digit sectors of interest. For instance, for the mining of hard coal and lignite (B05) we have identified only 129 and 120 firms for 2009 and 2010, respectively. For the overall two digit sector B07 (mining of metal ores), Amadeus contains information for 157 firms in 2009 and 158 in 2010. The largest number of firms concentrates in the sector of electricity, gas, steam and air conditioning supply D35: 6,197 firms in 2009 and 6,358 in 2010.

Breakdown of the sectors of interest

In Figure 2.2 we report the share of each economic activity at the NACE Rev.2 four digit level of disaggregation for all the employees in the EU28. We consider only the employment in the relevant sectors[7], for which we sum up the number of employees reported by each individual company. Based on the total number of employees per relevant sector we calculate the shares reported in the figure. The sector with the highest share is 35.11 – Production of electricity with 25% of employment of the overall energy sector.

Figure 2.2: Distribution of sectors of interest, NACE Rev.2 – 4 digit level



Sources: Amadeus.

EurObserv'ER

The EurObserv'ER barometer measures the progress made by renewable energies in each sector and in each Member State of the European Union. We considered data published in 2008, 2009, 2010, 2011 and 2012. EurObserv'ER produces a series of indicators covering energy, technological and economic dimensions.

[7] As opposed to Table 2.3, where we reported the number of firms for the overall NACE Rev.2 aggregated at 2 digits, hence including also NACE Rev.2 at four digits not necessarily relating to energy production.

Figures on direct and indirect employment in renewable energy sectors presented in the following tables are directly sourced from EurObserv'ER and are therefore not directly comparable with figures reported in Section 2.4, whose figures are all produced apportioning Eurostat published data.

Most relevant here is that EurObserv'ER provides data on employment for the renewable energy sectors contained in the production of electricity. Employment data are available for five sectors connected to renewable energy: wind, solar, hydroelectric, geothermal and biomass (see Table 2.4).

As regards tidal energy production, EurObserv'ER does not provide the number of employees but it provides a list of installed units among the European Union[8]. Meanwhile, Eurostat only provides data on installed capacity for France and the UK.

It should be stressed that the data provided by EurObserv'ER include both direct and indirect employment. For the purpose of the data collection we are interested in isolating direct employment, which will serve as an input to the modelling scenarios described in Chapter 4. Indirect employment will be calculated as an output of the macroeconomic models. Direct jobs include renewable manufacturing, equipment and component supply, onsite installation or operation and maintenance. Indirect jobs are those that result from activity in sectors that supply the materials or components used, but not exclusively so, by the renewable sectors (such as jobs in copper smelting plants, whose production may be used for manufacturing solar thermal equipment, but may also be destined for appliances in totally unconnected fields. Another example could be employment temporarily generated in sectors related to construction. Employment in such sectors could experience relatively high peaks during the setting up phase of new plants of renewable energy production).

The table below presents employment figures broken down between direct and indirect employment. Ratios were applied to EurObserv'ER data to estimate direct and indirect jobs. More details on the sources used to calculate the ratios are presented in Sections 2.2 and 2.3. At this stage it is worth noting that these figures are not directly comparable to those reported in the results at the end of this section. The main reason for this to be the case is that the figures in Table 2.4 are directly based on EurObserv'ER data used as a numeraire, whereas in other tables contained in the results section we apportion Eurostat LFS figures to have consistency with published official statistics on employment across different sectors.

Employment in the biomass production of electricity appears to be relatively high with around 30% of total employment in renewables. The share of biomass employment has been calculated directly based on EurObserv'ER figures in the sectors that Eurostat indicates to be directly related to the biomass energy production: municipal wastes, wood/wood wastes/other solid wastes, landfill gas, sewage sludge gas, other biogas, liquid biofuels[9].

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[8] Based on EurObserv'ER barometer 2012, France, Finland, Portugal, Spain and the United Kingdom produce tidal energy; Denmark, Ireland, Netherlands and Sweden are testing tidal projects.

[9] Eurostat provides the following definition of biomass: "Biomass is organic, non-fossil material of biological origin that can be used for heat production or electricity generation. It includes: wood and wood waste; biogas; municipal solid waste; biofuels." (sourced from: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-CD-12-001/EN/KS-CD-12-001-EN.PDF). Remark :direct jobs in biomass generation may go beyond jobs on manufacturing plants and systems burning biomass, its installation and maintenance. The EurObserve'ER definition may also include agricultural, municipal wastes and biomass supply transport jobs.

The EurObserv'ER barometer also publishes percentages on the split of employment into manufacturing, distribution, installation and operation and maintenance. These shares are not available for all countries. For the small hydropower and biomass sectors, we used the shares published in the edition 2009 (for a more complete overview of EurObserv'ER data and the evolution over time the reader could refer to Appendix A). Based on these shares, we have apportioned the figures contained in Table 2.4. The underlying assumption to obtain these figures is that the shares of direct and indirect employment remain constant across the categories of manufacturing, distribution, installation, operation and maintenance. Table 2.5 contains data for direct employment whereas Table 2.6 provides figures for indirect employment. It should be noted that EurObserv'ER data do not often allow a precise breakdown into the categories by employment type. To avoid inconsistencies with the data displayed in Table 2.4 we have added the category "Other" where we report the data that we are not able to apportion.

Table 2.4: Data on employment in renewable energy sectors as sourced from EurObserv'ER for the year 2010

Country	Small hydropower		Solar-photovoltaic		Wind		Geothermal		Solid biomass	
	directs	indirects	directs	indirects	directs	indirects	directs	indirects	directs	indirects
AT	772	278	1 108	3 292	1 314	1 986	973	127	10 693	6 707
BE	74	26	3 739	3 921	1 194	1 806	470	180	1 500	1 400
BG	221	79	586	614	1 194	1 806	217	83	1 397	1 303
CY	0	0	78	82	159	241	0	0	26	24
CZ	221	79	3 905	4 095	139	211	615	235	3 259	3 041
DK	<50	<50	195	205	9 952	15 048	<100	<100	2 587	2 413
EE	<50	<50	<50	<50	139	211	723	277	1 449	1 351
FI	294	106	<50	<50	2 548	3 852	2 098	802	11 951	11 149
FR	1 838	662	28 700	40 550	10 120	10 480	2 280	1 520	6 780	41 620
DE	5 589	2 011	52 626	55 174	38 256	57 844	9 120	4 180	38 725	22 175
EL	331	119	4 113	4 312	597	903	<100	<100	1 164	1 086
HU	294	106	2 236	2 344	199	301	832	318	2 380	2 220
IE	74	26	<50	<50	796	1 204	<100	<100	310	290
IT	2 022	728	21 968	23 032	11 385	17 215	4 449	1 701	5 174	4 826
LV	257	93	<50	<50	<50	<50	<50	<50	2 690	2 510
LT	110	40	<50	<50	100	150	<100	<100	1 552	1 448
LU	<50	<50	<50	<50	20	30	<50	<50	26	24
MT	0	0	<50	<50	0	0	0	0	0	0
NL	147	53	1 745	555	430	2 170	1 302	498	1 681	1 569
PL	603	217	<50	<50	654	846	543	207	11 253	10 497
PT	1 287	463	1 709	1 791	1 791	2 709	145	55	3 984	3 716
RO	294	106	<50	<50	597	903	<100	<100	6 053	5 647
SK	221	79	732	768	0	0	<100	<100	1 138	1 062
SI	331	119	244	256	0	0	<100	<100	854	796
ES	1 177	423	13 840	14 510	12 241	18 509	434	166	6 398	7 202
SE	1 103	397	361	379	1 990	3 010	8 826	3 374	15 521	14 479
UK	735	265	2 441	2 559	5 971	9 029	1 085	415	2 070	1 930

Notes: * Figures for small and large hydropower.
Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008, 2009 and 2012"Baromètre 2012 des énergies renouvelables électriques en France " .

Table 2.5: Data on direct employment in renewable energy sectors split into manufacturing (MFG), distribution, installation, and operation and maintenance (O&M)

Employment in manufacturing installation and O&M – Eurobserv'ER																
	Small hydropower				Solar - photovoltaic				Wind				Solid - Biomass		
	MFG	Instal.	O&M	Others	MFG	Instal. And Distrib.	O&M	Others	MFG	Instal.	O&M	Others	MFG Distrib. Instal.	O&M	Others
AT	309	77	386		499	609			1 182		131				10 693
BE				74	112	3 627						1 194			1 500
BG				221	117		469					1 194			1 397
CY				0				78				159			26
CZ				221		976	2 929					139			3 259
DK				<50	156	20		20	8 459		1 493				2 587
EE				<50				<50				139			1 449
FI	194		100					<50	2 293	255					11 951
FR	184		1 655		3 731		24 969		5 060	4 048	1 012		5 424	1 356	
DE	4 191	559	838		26 313	21 050	5 263		32 518		5 738		17 426	5 809	15 490
EL				331				4 113				597			1 164
HU				294				2 236				199			2 380
IE				74				<50				796			310
IT	1 213	506	303		6 590	12 082	3 295		2 277	5 693	3 416				5 174
LV				257				<50				<50			2 690
LT				110				<50				100			1 552
LU			<50					<50				20			26
MT				0				<50				0			0
NL				147	873	873						430			1 681
PL	543	30	30					<50	490	65	98				11 253
PT				1 287				1 709				1 791			3 984
RO				294				<50				597			6 053
SK				221				732				0			1 138
SI				331	98	146						0			854
ES				1 177	2 768	11 072			3 672	4 896	3 672				6 398
SE	165	717	165	55	343	18						1 990			15 521
UK	662	37	37					2 441	1 672		1 612	2 687			2 070

Notes: "Others" include employees that we were not able to apportion given the lack of information on the breakdown into the desired categories.

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008, 2009, 2011and 2012
"Baromètre 2012 des énergies renouvelables électriques en FR".

Table 2.6: Data on indirect employment in renewable energy sectors split into manufacturing (MFG), distribution, installation, and operation and maintenance (O&M)

Employment in manufacturing installation and O&M – Eurobserv'ER																
	Small hydropower				Solar - photovoltaic				Wind				Solid - Biomass		
	MFG	Instal.	O&M	Others	MFG	Instal. And Distrib.	O&M	Others	MFG	Instal.	O&M	Others	MFG Distrib. Instal.	O&M	Others
AT	111	28	139		1 481	1 811			1 788		199				6 707
BE				26	118	3 803						1 806			1 400
BG				79	123		491					1 806			1 303
CY				0				82				241			24
CZ				79		1 024	3 071					211			3 041
DK				<50	164	20		20	12 791		2 257				2 413
EE				<50				<50				211			1 351
FI	70		36					<50	3 467	385					11 149
FR	66		596		5 272		35 279		5 240	4 192	1 048		33 296	8 324	
DE	1 509	201	302		27 587	22 070	5 517		49 167		8 677		9 979	3 326	8 870
EL				119				4 312				903			1 086
HU				106				2 344				301			2 220
IE				26				<50				1 204			290
IT	437	182	109		6 910	12 668	3 455		3 443	8 607	5 164				4 826
LV				93				<50				<50			2 510
LT				40				<50				150			1 448
LU			<50					<50				30			24
MT				0				<50				0			0
NL				53	277	277						2 170			1 569
PL	195	11	11					<50	635	85	127				10 497
PT				463				1 791				2 709			3 716
RO				106				<50				903			5 647
SK				79				768				0			1 062
SI				119	102	154						0			796
ES				423	2 902	11 608			5 553	7 404	5 553				7 202
SE	60	258	60	20	360	19						3 010			14 479
UK	238	13	13					2 559	2 528		2 438	4 063			1 930

Notes: "Others" include employees that we were not able to apportion given the lack of information on the breakdown into the desired categories.

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008, 2009, 2011 and 2012 "Baromètre 2012 des énergies renouvelables électriques en FR".

Other sources

In order to break down the sector 35.11 – Production of electricity, we used some complementary sources. "Le Baromètre 2012 des énergies renouvables électriques[10]" and "the state of renewable energies in Europe" (editions 2008, 2009 and 2012) have been used to apportion employment between its direct and indirect components in the case of renewable energy. To estimate employment in the nuclear sector we refer to

[10] This report has been published by EurObserv'ER in collaboration with the French agency for environment and enerrgy (L'Agence de l'environnement et de la maîtrise de l'énergie – ADEME).

one sector study for FR[11], where it is estimated that there are around 125,000 direct employees in the electronuclear sector.

Table 2.7: Sources used to estimate employment in the sector of the production of electricity.

	Eurobserv'ER	Eurostat	Additional sources
Fossil Fuel		Electrical capacity	IEG –workers (operations) in FR
Nuclear power		Electrical capacity	Sector study for FR: direct employment
Hydropower	"The State of renewable energies in Europe", edition 2012 Direct + indirect employment for Small hydropower = central < 10 megawatts	Electrical capacity "Hydropower (main activity producers and autoproducers – hydro)"	UFE, employment direct+indirect in total in FR in 2010 Eurobserv'ER gives the total of employment for small hydropower)
Solar photovoltaic	"The State of renewable energies in Europe", edition 2008, 2009 and 2012 Direct + indirect employment	Electrical Capacity	"Baromètre 2012 des énergies renouvelables électriques en FR " Direct employment (Equipment, installation and operations)
Solar thermal	"The State of renewable energies in Europe", edition 2008, 2009 and 2012 Direct + indirect employment	Electrical Energy	The ratio of direct employment for solar photovoltaic was used
Wind power	"The State of renewable energies in Europe", edition 2008, 2009 and 2012 Direct + indirect employment	Electrical Capacity	"Baromètre 2012 des énergies renouvelables électriques en FR" Direct employment (Equipment, installation and operations)
Biomass - biofuels	Direct + indirect employment	Electrical Energy	The ratio of direct employment was taken as the average of the other biomass ratio
Biomass – biogas, solid biomass, municipal wastes	"The State of renewable energies in Europe", edition 2008, 2009 and 2012 Direct + indirect employment	Electrical Capacity	"Baromètre 2012 des énergies renouvelables électriques en FR " Direct employment (Equipment, installation and operations)
Tidal		Electrical Capacity	Website of "La Rance" for FR and "Working for a Green Britain" considering Operations and Maintenance jobs in the UK

[11] We refer to a study published by PWC: "Le poids socio-économique de l'électronucléaire en FR" published in May 2011.

2.3 Methodology

In this section we illustrate the methodological aspects of combining information from different data sources to reach the required degree of detail, while maintaining comparability with Eurostat LFS data. Eurostat SBS data and Amadeus have been used to construct the NACE.Rev.2 data at the four digit level of disaggregation; EurObserv'ER and Eurostat data on electricity production capacity have been used to break down the production of electricity in the categories of the NC – NAICS 2012 at the six digit level. In some cases we refer to other sources to refine or validate our estimates.

Using Eurostat SBS data

The Eurostat SBS are presented according to NACE.Rev.2 activity classification at four digits of disaggregation. SBS cover all the countries required but not all the sectors of interest by country. When Eurostat SBS data are available we use it to apportion Eurostat LFS data.

Aggregating Amadeus firm level micro-data at NACE.Rev.2 four digits

Amadeus contains firm-level data for the EU28. Our method in this case consists of summing up the number of employees by country and by relevant NACE.Rev.2 four digit sector to then apportion the Eurostat LFS figures that are at two digit level. Amadeus data are used only when Eurostat SBS data are not available.

Apportioning the production of electricity with EurObserv'ER and Eurostat data

As regards the production of electricity we follow a similar procedure but this time in two steps. In the first step we isolate employment in the sector "production of electricity" (NACE.Rev.2 - 35.11) based on Eurostat SBS and Amadeus data. In the second step we apportion the data according to shares based on EurObserv'ER data. In particular the EurObserv'ER reports employment data for five out of the eight NAICS into which the North American System breaks down the production of electricity. These are:

- NC 221111 Power generation, hydroelectric
- NC 221114 Electric power generation, solar
- NC 221115 Electric power generation, wind
- NC 221116 Electric power generation, geothermal
- NC 221117 Biomass electric power generation

Using ratios between the employment and installed capacity

As regards the remaining three sectors included in production of electricity, we identified the level of generation in some European countries, such as FR and the UK, and then calculated a ratio between the number of employees in the sector and the electricity capacity (in MW) as provided by Eurostat. Ratios are applied to other countries based on the assumption that technologies are homogeneous across countries.

For hydroelectric power generation EurObserv'ER provides data only on small-scale production. Also in this case we rely on the ratio between the number of employees and the megawatt electricity capacity in FR to infer employment in other countries.

Based on the Eurostat data on electrical capacity we identified only two countries where tidal energy is produced – FR and the UK. For these two countries we have used ad hoc studies to provide estimates of employment in the sector.

Table 2.8 summarizes all the methods and assumptions made for estimating employment in sectors related to the production of electricity.

Table 2.8: Methods and assumptions for estimating employment in sectors related to the production of electricity

Sector	Method used	Sector
NC 221111 Power generation, hydroelectric	EurObserv'ER reports figures including both direct and indirect employment. Direct employment is separated using figures reported for FR. EurObserv'ER does not contain data for HR, for which estimates can be obtained by the average ratio of number of employees per unit of production capacity in the EU27 based on Eurostat data. EurObserv'ER only provides data on small hydropower plants. To complete this information we used French data, which provides employment on small and large hydropower. This data can be used in combination with Eurostat data on production capacity of electricity to compute ratios for FR and apportion then to all remaining countries.	NC 221111 Power generation, hydroelectric
NC 221112 Power generation, fossil fuel (e.g., coal, gas, oil), electric	Based on the ratio of employee per unit of electricity production capacity installed in FR (Secretariat des groupements d'employeurs des industries electriques et gazieres), we can compute the number of employees in other European countries.	NC 221112 Power generation, fossil fuel (e.g., coal, gas, oil), electric
NC 221113 Power generation, nuclear electric	Data on employment in the nuclear sector are available in a study by PWC for FR. These data can be used in combination with information on the capacity of production per country in megawatts provided by Eurostat to estimate nuclear power generation in the remaining countries.	NC 221113 Power generation, nuclear electric
NC 221114 Electric power generation, solar NC 221115 Electric power generation, wind NC 221116 Electric power generation, geothermal NC 221117 Biomass electric power generation	Eurobseerv'ER reports figures including both direct and indirect employment in the last editions. Direct employment is separated using figures reported for FR in the study (Le baromètre des energies renouvelables en FR, 2012) and for other countries in the editions 2008 of "The State of renewable energies in Europe". Ratios were calculated based on data for the following countries: Solar photovoltaic: FR, AT, PL and the NL Solar thermal: DE, ES, FR and the NL Wind: FR, PL and the NL Geothermal: FR and AT Biogas: FR and PL Biomass: DE, ES, FR and AT When no ratio for a specific country could be calculated, the average ratio was used. EurObserv'ER does not contain data on HR, for which estimates can be obtained using the average ratio of number of employees per unit of production capacity in the EU27 based on Eurostat data.	NC 221114 Electric power generation, solar NC 221115 Electric power generation, wind NC 221116 Electric power generation, geothermal NC 221117 Biomass electric power generation
NC 221118 Electric power generation, tidal	Eurostat data on capacity allow us to identify only two countries where tidal energy is produced – FR and the UK. For these two countries we referred to ad-hoc sources reporting employees in operation and maintenance.	NC 221118 Electric power generation, tidal

2.4 Aggregated results for the EU28

In this section we present headline figures for the EU28 in all the sectors of interest in the years 2009 and 2010 (see Table 2.9).

Table 2.9: Estimates for direct employment in the NACE Rev.2 codes of interest

Employment (1,000)	**2009**	**2010**
B05: Mining of coal and lignite	**329.5**	**335.1**
510: Mining of hard coal	217.2	232.2
520: Mining of lignite	112.3	102.9
No country distribution available	0.0	0.0
B06: Extraction of crude petroleum and natural gas	**99.2**	**96.7**
610: Extraction of crude petroleum	64.8	62.4
620: Extraction of natural gas	24.0	34.3
No country distribution available	10.4	0.0
B07: Mining of metal ores	**34.7**	**39.9**
721: Mining of uranium and thorium ores	30.4	34.1
No country distribution available	0.0	0.0
Sectors out of the scope of the study	4.3	5.8
B08: Other mining and quarrying	**256.1**	**237.8**
892: Extraction of peat	10.3	10.8
No country distribution available	7.1	0.0
Sectors out of the scope of the study	238.7	227.0
B09: Mining support service activities	**96.4**	**105.1**
910: Support activities for petroleum and natural gas extraction	89.1	97.8
No country distribution available	0.0	0.0
Sectors out of the scope of the study	7.3	7.3
C19: Manufacture of coke and refined petroleum products	**207.9**	**217.8**
1910: Manufacture of coke oven products	13.3	12.3
1920: Manufacture of refined petroleum products	194.6	205.5
No country distribution available	0.0	0.0
D35: Electricity, gas, steam and air conditioning supply	**1 656.6**	**1 671.5**
3511: Production of electricity	586.4	591.9
3512: Transmission of electricity	75.2	67.5
3513: Distribution of electricity	474.6	425.9
3514: Trade of electricity	70.6	68.9
3521: Manufacture of gas	22.3	90.5
3522: Distribution of gaseous fuels through mains	138.2	142.6
3523: Trade of gas through mains	42.2	57.0
3530: Steam and air conditioning supply	245.6	218.4
No country distribution available	1.7	8.9
Total No country distribution	19.2	8.9
Total Sectors out of the scope of the study	250.3	240.1
Total NACE of interest	2 410.9	2 455.0

Notes: "No country distribution available " represents employees that could not be apportioned into the relevant subsectors of interest due to the lack of data sources at NACE Rev.2 4 digits level. "Sectors out of the scope of the study" include NACE Rev.2 four digits sectors not pertaining to the group of specific sub-sectors of interest relating to the energy system.

Sources : Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus.

The totals for each sector in Table 2.9 at two-digit level correspond to LFS figures. The disaggregated figures at four digit level are apportioned using SBS or Amadeus figures. Table 2.10 displays a further breakdown of the electricity sector into the NAICS of interest.

Table 2.10: Direct employment for the breakdown of the production of electricity, NACE D35.11[12]

	NC221111	NC221112	NC221113	NC221114	NC221115	NC221116	NC221117	NC221118
2010	32.8	160.4	141.7	88.2	54.2	8.0	106.5	0.1
2009	32.5	158.9	140.4	87.4	53.7	7.9	105.5	0.1

Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus and EurObserv'ER.

In the Eurostat database, the figures aggregated at EU28 level are often different from the sum of the disaggregated figures reported at country level. This might happen because at country level the sample might be too small to comply with confidentiality standards. This could also occur for aggregations where Eurostat sometimes reports missing values for more disaggregated figures. For internal consistency in this document we have forced the country figures to sum up to the aggregated sector figures at EU28 level. Our figures remain comparable to the Eurostat LFS figures by country and sector NACE Rev.2 at two digit level.

[12] It should be noted that figures in this table are not directly comparable to the ones contained Table 2.4 because in Table 2.4 we apportioned directly EurObserv'ER data, whereas in The totals for each sector in Table 2.9 at two-digit level correspond to LFS figures. The disaggregated figures at four digit level are apportioned using SBS or Amadeus figures. Table 2.10 displays a further breakdown of the electricity sector into the NAICS of interest.

Table 2.10 we considered LFS as a numeraire.

2.5 Results for the EU28 at country level

B0510 - Mining of hard coal
B0520 - Mining of lignite

Mining of hard coal is still an important sector in some Central and Eastern European countries. In 2010 the country exhibiting the highest number of employees was PL with 165289, followed by RO with 20170, and the CZ with 16718. In the UK employment in the sector nearly halved (from 9600 to 4600) over the period 2009-2010. This result fully reflects trends in Eurostat LFS data. Mining of lignite also appears to be more important in Central and Eastern Europe with RO (18830 in 2010), the CZ (16682 in 2010) and BG (16450 in 2010) displaying the highest number of employees (Table 2.11).

Table 2.11: Estimates for direct employment in the sectors B0510 and B0520

	2009			2010		
Country	**B0510**	**B0520**	**No country distribution available**	**B0510**	**B0520**	**No country distribution available**
AT	*0*	*0*	0	*0*	*0*	0
BE	*0*	*0*	0	*:*	*:*	:
BG	**277**	**15 823**	0	**250**	**16 450**	0
HR	:	:	:	:	:	:
CY	*0*	*0*	0	*0*	*0*	0
CZ	**18 187**	**18 413**	0	**16 718**	**16 682**	0
DK	*0*	*0*	0	*0*	*0*	0
EE	*0*	*0*	0	*0*	*0*	0
FI	*0*	*0*	0	*0*	*0*	0
FR	*:*	*:*	:	*:*	*:*	:
DE*	25 659	21 241	0	21 259	19 941	0
EL	*0*	*6 900*	0	**0**	**6 600**	0
HU	*149*	*2 751*	0	*300*	*3 000*	0
IE	*0*	*0*	0	**:**	**:**	:
IT	*:*	*:*	:	**:**	**:**	:
LV	*:*	*:*	:	*0*	*0*	0
LT	*0*	*0*	0	*0*	*0*	0
LU	*0*	*0*	0	*0*	*0*	0
MT	:	:	:	:	:	:
NL	:	:	:	*0*	*0*	0
PL	*139 379*	*18 521*	0	*165 289*	*7 611*	0
PT	*0*	*0*	0	*0*	*0*	0
RO	*20 286*	*17 114*	0	*20 170*	*18 830*	0
SK	*0*	*6 500*	0	*0*	*8 300*	0
SI	*0*	*2 800*	0	*0*	*2 900*	0
ES	**3 632**	**2 268**	0	**3 656**	**2 544**	0
SE	:	:	:	:	:	:
UK	*9 600*	*0*	0	*4 600*	*0*	0

Notes: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.
*For Germany additional data on hard coal and brown coal extraction from national public sources enabled to estimate the breakdown of the number of employees from the NACE Rev.2 B05 two digits sector into B0510 and B0520.

Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus.

B0610 - Extraction of crude petroleum B0620 - Extraction of natural gas

Extraction of petroleum is most important in terms of jobs in RO (24008 employees) and in the UK (19380 employees) in 2010. For extraction of natural gas, the country with the highest number of employees is IT with a positive trend from 6500 in 2009 to 8291 in 2010. DE has also a significant number of employees in the gas sector (8000 in 2010, data are missing for 2009). It is interesting to note that the number of employees does not seem to be directly proportional to the quantity of gas or petroleum extracted per country. For example the Netherlands, does not have one of the highest number of employees in these sectors. It is worth mentioning that the distribution of employees across European states and the time trend exhibited over the two years considered depend almost entirely on Eurostat LFS data and not on our apportionment methodology. For example the greatest fall in employment in these two sectors observed in Poland is directly observable in the trend of Eurostat LFS figures NACE Rev.2 aggregated at two digits levels – 13600 in 2009 and 9300 in 2010.

Table 2.12: Estimates for direct employment in the sectors B0610 and B0620

Country	2009			2010		
	B0610	**B0620**	**No country distribution available**	**B0610**	**B0620**	**No country distribution available**
AT	:	:	3 300	:	:	:
BE	:	:	0	:	:	0
BG	**:**	**:**	:	**0**	**0**	0
HR	**0**	**3 400**	0	**0**	**5 700**	0
CY	:	:	0	:	:	0
CZ	**0**	**800**	0	**46**	**954**	0
DK	*:*	:	:	*:*	*:*	:
EE	**4 200**	**0**	0	**4 900**	**0**	0
FI	:	:	0	:	:	0
FR	**:**	**:**	:	**:**	**:**	:
DE	:	:	7 100	*0*	*8 000*	0
EL	**:**	**:**	:	**:**	**:**	:
HU	*:*	*:*	:	*:*	*:*	:
IE	**:**	**:**	:	**:**	**:**	:
IT	**0**	**6 500**	0	**9**	**8 291**	0
LV	:	:	0	*:*	*:*	:
LT	*:*	*:*	:	*:*	*:*	:
LU	:	:	0	:	:	0
MT	**:**	**:**	:	**:**	**:**	:
NL	*999*	*5 401*	0	*766*	*3 934*	0
PL	**11 901**	**1 699**	0	**8 506**	**794**	0
PT	:	:	0	:	:	0
RO	*26 811*	*5 589*	0	*24 008*	*5 792*	0
SK	**:**	**:**	:	**0**	**0**	0
SI	:	:	:	:	:	:
ES	**3 800**	**100**	0	**4 830**	**170**	0
SE	:	:	:	:	:	:
UK	**17 078**	**522**	0	*19 380*	*620*	0

Notes: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.
Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus.

B0721 - Mining of uranium and thorium ores

Mining of uranium and thorium ores is present in six European countries. In 2010 PL had the highest number of employees (16400) followed by BG (9400) and ES (3637). The remaining two countries where this sector has employees are FI (2300) and SE (2335).

Table 2.13: Estimates for direct employment in the sector B0721

	2009			2010		
Country	**B0721**	**Sectors out of the scope of the study**	**No country distribution available**	**B0721**	**Sectors out of the scope of the study**	**No country distribution available**
AT	*:*	:	:	*:*	:	:
BE	:	:	:	:	:	:
BG	*10 100*	0	0	**9 400**	0	0
HR	:	:	:	:	:	:
CY	:	:	0	:	:	0
CZ	**0**	2 200	0	**0**	3 600	0
DK	**0**	0	0	**0**	0	0
EE	:	:	0	:	:	0
FI	*:*	:	:	*2 300*	0	0
FR	*:*	:	:	*:*	:	:
DE	**0**	0	0	**0**	0	0
EL	**:**	:	:	**:**	:	:
HU	*:*	:	:	**:**	:	:
IE	**:**	:	:	**:**	:	:
IT	**:**	:	:	**:**	:	:
LV	:	:	0	:	:	0
LT	:	:	0	:	:	0
LU	:	:	0	:	:	0
MT	:	:	:	:	:	:
NL	:	:	:	:	:	0
PL	**16 600**	0	0	**16 400**	0	0
PT	**:**	:	:	**:**	:	:
RO	*:*	:	:	*:*	:	:
SK	**:**	:	:	**:**	:	:
SI	:	:	0	:	:	0
ES	*1 179*	121	0	*3 637*	263	0
SE	**2 496**	2 004	0	**2 335**	1 965	0
UK	**0**	0	0	*:*	:	:

Notes: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.

Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus.

B0892 - Extraction of peat

In 2010 extraction of peat was present in 15 European countries but it only exceeded 1,000 employees in four countries: EE with 1089, FI with 1919, DE with 2463 and LV with 3195 (See Table 2.14).

Table 2.14: Estimates for direct employment in the sector B0892

Country	2009			2010		
	B0892	**Sectors out of the scope of the study**	**No country distribution available**	**B0892**	**Sectors out of the scope of the study**	**No country distribution available**
AT	**13**	6 287	0	**0**	6 400	0
BE	*0*	4 300	0	*0*	3 700	0
BG	:	:	7 100	*60*	5 740	0
HR	**0**	3 000	0	*0*	3 100	0
CY	*0*	600	0	*0*	0	0
CZ	**176**	9 524	0	**173**	8 827	0
DK	**:**	:	:	**:**	:	:
EE	**1 274**	926	0	**1 089**	911	0
FI	*1 908*	2 392	0	*1 919*	2 381	0
FR	*183*	20 417	0	*199*	19 801	0
DE	2 857	39 743	0	*2 463*	36 337	0
EL	**0**	5 800	0	**0**	5 000	0
HU	**94**	4 806	0	*139*	3 661	0
IE	**0**	5 900	0	**0**	5 400	0
IT	*0*	20 000	0	*0*	21 700	0
LV	*2 343*	957	0	*3 195*	1 105	0
LT	*:*	:	:	*:*	:	:
LU	*:*	:	:	*:*	:	:
MT	:	:	:	:	:	0
NL	**164**	2 436	0	*26*	2 174	0
PL	**703**	22 897	0	**602**	20 398	0
PT	**0**	14 900	0	*0*	18 400	0
RO	*26*	8 374	0	*19*	8 081	0
SK	**214**	2 686	0	**283**	3 217	0
SI	**0**	900	0	**0**	900	0
ES	*63*	32 337	0	*57*	27 643	0
SE	*276*	3 324	0	*215*	2 885	0
UK	**10**	26 190	0	*396*	19 204	0

Notes: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.

Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus

B0910 - Support of activities for petroleum and natural gas extraction

The support for activities connected to the sector of petroleum and natural gas in 2010 was very high in the UK with 57743 employees followed by RO with 16644 employees. The countries with the next highest number of employees in this sector are DE and PL with 5500 and 5440 employees respectively. IT follows with 4700 employees (Table 2.15).

Table 2.15: Estimates for direct employment in the sector B0910

	2009			2010		
Country	**B0910**	**Sectors out of the scope of the study**	**No country distribution available**	**B0910**	**Sectors out of the scope of the study**	**No country distribution available**
AT	**:**	:	:	*0*	0	0
BE	**:**	:	:	**:**	:	:
BG	*:*	:	:	**:**	:	:
HR	**2 500**	0	0	**3 400**	0	0
CY	:	:	0	:	:	0
CZ	**1 359**	1 541	0	**32**	868	0
DK	*:*	:	:	**:**	:	:
EE	:	:	:	**:**	:	:
FI	*:*	:	:	*:*	:	:
FR	*:*	:	:	*:*	:	:
DE	**:**	:	:	**5 500**	0	0
EL	:	:	:	:	:	:
HU	*:*	:	:	*:*	:	:
IE	**:**	:	:	**:**	:	:
IT	**5 500**	0	0	**4 700**	0	0
LV	*:*	:	:	*:*	:	:
LT	:	:	0	:	:	0
LU	:	:	0	:	:	0
MT	**:**	:	:	**700**	0	0
NL	*2 000*	0	0	*2 199*	1	0
PL	*5 142*	4 158	0	*5 440*	4 960	0
PT	**:**	:	:	**0**	0	0
RO	*17 837*	463	0	*16 644*	556	0
SK	**:**	:	:	**:**	:	:
SI	**:**	:	:	**:**	:	:
ES	**1 760**	740	0	**1 451**	549	0
SE	**:**	:	:	**:**	:	:
UK	*53 028*	372	0	*57 743*	357	0

Notes: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.
Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus.

C1910 - Manufacture of coke oven products C1920 - Manufacture of refined petroleum products

The manufacture of coke oven products is quite narrow in most of European countries. In 2010 only three countries reported more than 1000 employees: the CZ with 1914, PL with 6315 and the UK with 1903. Employment in the manufacture of refined petroleum products is much more widespread in Europe. The countries with the higher number of employees are DE, IT and the UK with 25377, 30401 and 31597 employees respectively for the year 2010 (See Table 2.16).

Table 2.16: Estimates for direct employment in the sectors C1910 and C1920

Country	2009			2010		
	C1910	C1920	No country distribution available	C1910	C1920	No country distribution available
AT	**0**	**3 900**	0	**0**	**4 300**	0
BE	**0**	**7 500**	0	*0*	*9 900*	0
BG	**0**	**9 600**	0	**0**	**6 600**	0
HR	**0**	**2 800**	0	**0**	**3 100**	0
CY	**:**	**:**	:	**:**	**:**	:
CZ	**744**	**1 256**	0	**1 914**	**2 486**	0
DK	**:**	**:**	:	**:**	**:**	:
EE	*0*	*1 500*	0	*0*	*1 500*	0
FI	**0**	**2 700**	0	**0**	**2 700**	0
FR	**0**	**14 800**	0	**0**	**10 000**	0
DE	**303**	**25 697**	0	**223**	**25 377**	0
EL	*38*	*7 262*	0	**17**	**6 783**	0
HU	*830*	*6 170*	0	*807*	*5 993*	0
IE	**:**	**:**	:	**:**	**:**	:
IT	*569*	*27 631*	0	**899**	**30 401**	0
LV	*:*	*:*	:	*:*	*:*	:
LT	**:**	**:**	:	**:**	**:**	:
LU	:	:	0	:	:	0
MT	:	:	:	:	:	:
NL	*0*	*9 000*	0	*0*	*10 100*	0
PL	*9 218*	*12 682*	0	*6 315*	*13 485*	0
PT	**:**	**:**	:	*0*	*4 700*	0
RO	*132*	*13 968*	0	*148*	*12 552*	0
SK	**0**	**3 700**	0	**0**	**3 200**	0
SI	**:**	**:**	:	**:**	**:**	:
ES	**135**	**18 365**	0	**103**	**17 897**	0
SE	**0**	**2 600**	0	**0**	**2 800**	0
UK	**1 333**	**23 467**	0	**1 903**	**31 597**	0

Notes: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.

Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus.

35.11 - Production of electricity 35.12 - Transmission of electricity 35.13 - Distribution of electricity 35.14 - Trade of electricity

Data for the production, transmission, distribution and trade of electricity are the most complete. With the exception of MT, data are available for all the countries considered in this study. The sectors with the larger shares of employees are the production and distribution of electricity. DE is the country with the highest number of employees in these two sectors; 127194 and 98660 in 2010. The only country with a comparable number of employees in production of electricity is FR with 90916 (Table 2.17).

Table 2.17: Estimates for direct employment in sectors 35.11 to 35.14

	2009				2010			
Country	**D35.11**	**D35.12**	**D35.13**	**D35.14**	**D35.11**	**D35.12**	**D35.13**	**D35.14**
AT	*7 942*	*2 570*	*7 880*	*1 567*	*8 755*	*2 640*	*8 351*	*2 049*
BE	11 829	1 619	9 241	5 147	*12 392*	*1 696*	**9 681**	**5 392**
BG	*16 366*	**4 684**	*8 511*	**3 770**	*17 960*	**5 050**	*9 240*	**3 885**
HR	**2 224**	**1 162**	**9 367**	**1**	**2 627**	**1 365**	**10 888**	**2**
CY	*3 200*	*0*	*0*	*0*	*1 500*	*0*	*0*	*0*
CZ	**20 116**	**790**	**4 782**	**531**	**19 960**	**777**	**3 350**	**690**
DK	*5 575*	*890*	*5 597*	*906*	*5 647*	*1 011*	*5 281*	*992*
EE	*3 064*	**0**	**1 256**	**529**	*3 469*	**0**	**1 487**	**637**
FI	*8 091*	**2 907**	**1 719**	*2 611*	*7 633*	**2 754**	**1 552**	*2 434*
FR	**83 570**	**15 926**	**44 760**	*4 620*	**90 916**	**17 326**	**51 295**	*3 052*
DE	**143 276**	**3 234**	**122 919**	**7 936**	**127 194**	**3 520**	**98 660**	**6 280**
EL	**26 282**	**0**	**0**	**297**	**24 017**	**0**	**0**	**331**
HU	*12 979*	**1 056**	**6 626**	*2 261*	*11 770*	**:**	**:**	*2 240*
IE	**10 932**	**0**	**0**	**1 337**	**10 514**	*0*	**0**	**1 160**
IT	*32 622*	*5 028*	*35 013*	*8 851*	*31 271*	*4 835*	*33 319*	*9 050*
LV	*2 207*	*672*	*3 506*	*54*	*2 481*	*658*	*3 549*	*89*
LT	*3 913*	*1 124*	*4 590*	*133*	*2 720*	*738*	*3 964*	*137*
LU	**682**	*0*	**198**	**0**	**102**	*0*	**306**	**0**
MT	:	:	:	:	:	:	:	:
NL*	9 347	6 819	3 396	6 728	8 673	6 769	1 935	6 100
PL	*36 220*	*3 412*	*65 539*	*3 634*	*46 315*	**581**	*58 328*	*5 106*
PT	*9 020*	**939**	**9 010**	*242*	*6 925*	*625*	*6 458*	*253*
RO	*46 072*	2 902	*25 236*	*4 569*	*47 000*	*2 988*	*24 585*	*4 656*
SK	*9 233*	**687**	**381**	*4 545*	*8 255*	**657**	**366**	*4 133*
SI	*2 660*	*601*	*3 671*	*215*	*2 511*	*533*	*3 266*	*210*
ES	*30 759*	*3 389*	*28 658*	*7 546*	*32 655*	*3 433*	*27 046*	*6 986*
SE	*9 352*	**321**	**5 238**	*1 998*	*9 070*	**316**	**5 078**	*2 005*
UK	**38 853**	**14 420**	*67 470*	**524**	*49 601*	*9 198*	*57 878*	*1 030*

Note: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.
*For the Netherlands, we performed an additional desk review on balancesheets of major firms to complement primary data.collected from Amadeus on NACE Rev 2 D35 sector.

Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus

35.21 - Manufacture of gas
35.22 - Distribution of gaseous fuels through mains
35.23 - Trade of gas through mains
35.30 - Steam and air conditioning supply

In 2010 DE was the country with the highest number of employees in the sector manufacture of gas with 73550, followed by the UK with 8269 employees and the NL with 6775. The UK reports the highest number of employees in the distribution of gaseous fuel (in 2010, 48432) followed by IT (in 2010, 21947). In 2010 FR had the highest number of employees for the trade of gas through mains with 18730 employees, followed by PL with 15401.

As regards steam and air conditioning supply FR, DE and PL have the highest number of employees; 31215, 31887 and 43642 respectively for the year 2010 (Table 2.18).

Table 2.18: Estimates for direct employment in the sectors 35.21 to 35.23, and 35.30

	2009					2010				
Country	**D35.21**	**D35.22**	**D35.23**	**D35.30**	**No country distribution available**	**D35.21**	**D35.22**	**D35.23**	**D35.30**	**No country distribution available**
AT	*5*	*2 278*	*430*	*2 128*	5	*7*	*2 500*	*468*	*2 430*	0
BE	8	1 474	12	71	8	**8**	**1 545**	**12**	**75**	0
BG	*0*	*2 121*	*414*	*5 335*	0	*0*	*927*	*449*	*5 189*	0
HR	**0**	*1 289*	**441**	**916**	0	**0**	*1 947*	**538**	*1 233*	0
CY	*0*	*0*	*0*	*0*	0	*0*	*0*	*0*	*0*	0
CZ	**0**	**7 719**	**2 412**	**21 350**	0	**0**	**7 226**	**1 633**	**23 164**	0
DK	*110*	*669*	*92*	*1 961*	110	*119*	*631*	*102*	*2 017*	0
EE	*0*	**207**	**111**	*2 533*	0	*0*	**243**	**0**	*2 864*	0
FI	*1*	**5**	0	**566**	1	*10*	**5**	*0*	**511**	0
FR	*576*	**3 185**	**17 345**	29 918	576	**0**	**3 566**	**18 730**	*31 215*	0
DE	**8 100**	**8 005**	**4 243**	**37 687**	8 100	**73 550**	**5 043**	**3 965**	**31 887**	0
EL	**0**	**541**	**1 465**	**15**	0	**0**	**492**	**1 330**	**30**	0
HU	*13*	*3 834*	*2 442*	*8 590*	13	*18*	*3 502*	*2 454*	*8 661*	7 356
IE	**0**	**0**	**31**	*0*	0	*0*	**0**	**26**	*0*	0
IT	*514*	*22 557*	*7 488*	*5 128*	514	*384*	*21 947*	*7 542*	*5 252*	0
LV	*0*	*1 565*	*45*	*5 250*	0	*0*	*1 620*	*49*	*5 654*	0
LT	*0*	*1 939*	*35*	*6 766*	0	*0*	*1 688*	*37*	*5 916*	0
LU	**0**	**220**	*0*	**0**	0	**0**	**492**	**0**	**0**	0
MT	:	:	:	:	:	:	:	:	:	1 500
NL*	7 045	3 966	0	0	7 045	6 775	4 049	0	0	0
PL	**88**	*14 071*	**13**	**67 124**	88	**17**	*12 710*	**15 401**	*43 642*	0
PT	*63*	*1 778*	*258*	*190*	63	*50*	*1 159*	*93*	*139*	0
RO	*326*	*16 048*	*2 786*	*30 861*	326	*429*	*13 571*	*2 431*	*30 141*	0
SK	**0**	**5 370**	**185**	*10 299*	0	**0**	**4 509**	**155**	*8 925*	0
SI	:	*147*	:	*874*	:	*0*	**130**	**0**	*750*	0
ES	**579**	*4 991*	**1 234**	*1 344*	579	**822**	*4 503*	**1 142**	*1 713*	0
SE	*51*	*138*	**0**	*6 401*	51	*80*	*135*	**0**	*6 617*	0
UK	**4 773**	**34 091**	**696**	*274*	4 773	*8 269*	*48 432*	*426*	*366*	0

Notes: Data reported in italic have been apportioned based on SBS, while data reported in bold have been apportioned based on Amadeus.
*For the Netherlands, we performed an additional desk review on balancesheets of major firms to complement primary data.collected from Amadeus on Nace rev 2 D35 sector.

Sources: Authors' calculations based on LFS (lfs_egan22d), SBS (sbs_na_ind_r2), Amadeus.

Power generation NC 221112 - fossil fuel (e.g., coal, gas, oil), NC 221111 - hydroelectric NC 221113 - nuclear electric NC 221114 - solar

Employment in the sector of power generation through fossil fuel is developed across all countries (data are missing for MT). DE, PL, RO and the UK each have more than 15000 employees in this sector. FR has the highest number of employees in nuclear power generation with 53727 employees. DE has the highest number of employees in solar power generation with 27864 employees, followed by FR with 13698 employees (See Table 2.19).

Table 2.19: Estimates for direct employment in the sectors NC 221111, NC 221112, NC 221113 and NC 221114[13]

	2009				2010			
Country	**NC221111**	**NC221112**	**NC221113**	**NC221114**	**NC221111**	**NC221112**	**NC221113**	**NC221114**
AT	1 714	715	0	1 108	1 889	789	0	1 222
BE	288	2 474	5 553	1 897	302	2 592	5 818	1 987
BG	1 899	4 328	5 420	926	2 084	4 750	5 948	1 016
HR	784	1 167	0	106	926	1 378	0	126
CY	0	2 054	0	746	0	963	0	350
CZ	854	6 128	6 364	3 485	847	6 081	6 315	3 458
DK	6	1 595	0	128	6	1 616	0	129
EE	12	1 566	0	0	13	1 774	0	0
FI	477	1 833	1 716	14	450	1 729	1 619	13
FR	4 358	7 088	49 386	12 591	4 741	7 711	53 727	13 698
DE	3 081	25 413	22 344	31 387	2 735	22 560	19 836	27 864
EL	2 364	11 178	0	9 529	2 161	10 214	0	8 707
HU	67	4 681	4 637	144	61	4 245	4 205	130
IE	489	7 681	0	298	470	7 388	0	287
IT	2 922	14 576	0	7 564	2 801	13 973	0	7 251
LV	450	317	0	0	505	356	0	0
LT	454	1 675	0	0	316	1 164	0	0
LU	343	233	0	34	51	35	0	5
MT	:	:	:	:	:	:	:	:
NL*	6	6 152	426	1 050	6	5 708	396	975
PL	638	20 635	0	191	816	26 386	0	245
PT	1 545	2 980	0	1 342	1 186	2 287	0	1 030
RO	6 227	17 396	6 391	0	6 352	17 746	6 520	0
SK	1 185	2 168	3 606	814	1 059	1 939	3 224	727
SI	515	506	841	190	486	478	794	180
ES	2 474	10 397	4 734	6 159	2 627	11 038	5 026	6 539
SE	249	709	4 015	128	242	688	3 894	124
UK	1 110	21 151	9 816	1 347	1 418	27 003	12 531	1 720

Sources: Authors' calculations based on:
EurObserv'ER, "The State of renewable energies in Europe", 2008, 2009 and 2012
"Baromètre 2012 des énergies renouvelables électriques en FR ",EurObserv'ER
"Le poids socio-économique de l'électronucléaire en FR", PWC.

[13] It should be noted that figures in this table are not directly comparable to the ones contained Table 2.4, Table 2.5 and Table 2.6. This is due to the fact that in Table 2.4, Table 2.5 and Table 2.6 we apportioned directly EurObserv'ER data, whereas in Table 2.19 we considered LFS as a numeraire.

Power generation NC 221115 - wind NC 221116 - geothermal NC 221117 - Biomass NC 221118 - tidal

DE reports the highest number of employees in these four sectors with the exception of tidal. The fact that tidal energy production is present only in two countries is a direct consequence of the fact that Eurostat reports tidal electric power generation only present in two countries: FR and the UK (Table 2.20).

Table 2.20: Estimates for direct employment in the sectors NC 221115, NC 221116, NC 221117 and NC 221118[14]

	2009				2010			
Country	**NC221115**	**NC221116**	**NC221117**	**NC221118**	**NC221115**	**NC221116**	**NC221117**	**NC221118**
AT	400	296	3 709	0	441	326	4 089	0
BE	565	0	1 051	0	592	0	1 101	0
BG	1 728	0	2 066	0	1 896	0	2 267	0
HR	123	0	44	0	145	0	52	0
CY	342	0	58	0	160	0	27	0
CZ	115	0	3 169	0	114	0	3 145	0
DK	2 898	0	949	0	2 935	0	961	0
EE	130	0	1 356	0	147	0	1 535	0
FI	103	0	3 947	0	97	0	3 724	0
FR	3 998	0	6 125	24	4 350	0	6 664	26
DE	21 092	5 028	34 931	0	18 725	4 464	31 010	0
EL	970	0	2 241	0	886	0	2 048	0
HU	233	0	3 217	0	211	0	2 918	0
IE	1 467	0	998	0	1 410	0	959	0
IT	3 499	1 367	2 693	0	3 354	1 311	2 582	0
LV	10	0	1 431	0	11	0	1 608	0
LT	102	0	1 683	0	71	0	1 170	0
LU	15	0	57	0	2	0	9	0
MT	:	:	:	:	:	:	:	:
NL*	182	0	1 530	0	169	0	1 420	0
PL	692	0	14 062	0	885	0	17 982	0
PT	879	71	2 204	0	675	55	1 692	0
RO	1 366	0	14 692	0	1 393	0	14 988	0
SK	0	0	1 460	0	0	0	1 306	0
SI	0	0	607	0	0	0	574	0
ES	3 928	0	3 066	0	4 170	0	3 255	0
SE	450	0	3 802	0	436	0	3 687	0
UK	2 724	0	2 671	33	3 478	0	3 409	42

Sources: Authors' calculations based on:
EurObserv'ER, "The State of renewable energies in Europe", 2008, 2009 and 2012
"Baromètre 2012 des énergies renouvelables électriques en FR ",EurObserv'ER
"Le poids socio-économique de l'électronucléaire en FR", PWC.

[14] It should be noted that figures in this table are not directly comparable to the ones contained Table 2.4, Table 2.5 and Table 2.6. This is due to the fact that in Table 2.4, Table 2.5 and Table 2.6 we apportioned directly EurObserv'ER data, whereas in Table 2.20 we considered LFS as a numeraire.

3 Review of Previous Literature

3.1 Introduction

This chapter presents our review of previous analysis looking at the employment effects of developments in the energy system. The literature review is designed to be complementary to the modelling. It has helped to inform the scenarios, and it provides insight into aspects of the scenarios that the modelling cannot cover, for example because an issue is beyond the scope of the models or because there are limitations in the level of detail at which data are available to support modelling.

The review covers both assessment *methods* used and the *outputs* of previous analysis. It focuses on the same issues that the present study is addressing; i.e. the impacts of energy policy on the quantity and quality of jobs in Europe. While our focus is on labour market impacts, we also consider wider economic developments since these provide the essential context for understanding the impacts on the labour market. Although the aim of the review is to inform understanding of impacts in Europe, we include studies conducted for other countries where these provide helpful insights.

Key questions to cover

The key questions we address are:

- what are the methods used in the literature to estimate the employment impacts of energy policies?
- what types of workers are most/least sensitive to different energy policies?
- which sectors benefit most/least from different types of energy policies (e.g. energy-efficiency policies, introduction of low-carbon technologies)?
- what is the potential for workers from declining sectors to move into new growing sectors? to what extent will new sectors be competing for skilled labour?
- what are the potential labour market impacts of the structural change anticipated in the Energy Roadmap?

Structure of this review

We begin with a brief review of different methodological approaches that have been followed (Section 3.2). We then (Section 3.3) summarise a recent study that was carried out for the European Commission (DG Employment and Social Affairs) looking at ‘green jobs’. This study focused on the current EU environmental targets and so covers the period up to 2020. Consequently, it does not cover the emergence of new technologies post-2020 and it does not give much weight to new entrants to the labour market.

Section 3.4 gives an overview of the Energy Roadmap 2050 as well as a summary of some analyses related to it. Section 0 considers the period up to 2050, with a focus on some of the key technologies that are identified in the Roadmap. Section 3.6 assesses interaction between the sectors and competition for skills.

Section 3.7 approaches the issue from a different angle, by comparing the scenarios in the Energy Roadmap to the experience of previous periods of rapid technological development. This picks up on one of the key messages from the DG Employment study, that decarbonisation is only one of many examples of technological development taking place within the wider economy.

The final section concludes with the key messages from the review. A complete list of studies that were included is provided in Appendix B.

3.2 Methodological approaches that have been followed

Scope and approach

The research has generally followed either "top-down" approaches using input-output models of the economy or "bottom-up" approaches which are rather simple analytical accounting methods (for a review of the advantages and limitations of these approaches see Kammen et al, 2004). The approaches found in the literature can be broadly categorised into categories depending on the focus:

- incremental employment created by a specific project in the energy sector (for instance see Pfeifenberger et al, 2010 and ECF, 2010b)
- evaluation of total employment in an energy sub-sector
- macro-economy wide assessment of employment effects of different forms of a stimulus program in which the energy sector is one possible recipient of government spending (see Pollin et al, 2009)
- comparison of employment creation of alternative energy technologies (see for instance Grover, 2007)

Defining and categorising the jobs created

Employment effects are quantified in terms of number of jobs or in terms of job-years. One job-year (alternatively referred to as a person-year or a full-time equivalent job) is defined as the full time employment of one person for a duration of one year. Often the terms ‘‘jobs’’ and ‘‘job-years’’ are used interchangeably in the literature, but a growing stance in the literature suggests that the approach of referring to ‘‘jobs’’ created without duration may be misleading[15]. In the case of energy efficiency, employment effects are measured as the number of jobs generated per unit of investment in energy efficiency programmes (for a comprehensive review see Janssen and Staniazszek, 2012). A further categorisation of the employment effects estimated in the existing studies regards the distinction between people employed in construction, installation and manufacturing (CIM) and those employed in operation and maintenance (O&M) of the energy-related project.

Employment effects are also categorised in terms of direct, indirect and induced jobs.

Direct employment

Direct employment effects quantify the number of people employed by the project, energy sector or sub-sector. Estimations of the direct employment effects use information on the expenditure involved in a project, the technology and scale of the project and the typical employment per unit of money spent. These data are usually taken from industry, project design specifications, information on typical installations, etc. and are collected by business or research institutions.

In the process of estimating the direct employment effects of a specific policy or project it remains important to specify the degree to which manufacturing will be carried out domestically and the duration of the CIM and the O&M jobs.

Indirect employment

Indirect employment effects estimate the number of people employed in sectors supplying the inputs to the project, the energy sector or sub-sector. Often input-output methods are used for this purpose.

Induced employment

Induced employment effects estimate the number of people employed to provide goods and services to meet the consumption demands of the additional directly and indirectly employed workers including employment effects of changes in other sectors and activities indirectly due to the financing of the energy-related projects.

[15] See Wei et al (2010) for a detailed discussion. Recent research addresses this criticism and report job effects in terms of job/years.

Macroeconomic studies sometimes refer to induced employment as the impacts of the macroeconomic equilibrium and closure.

The literature contains fewer examples in which indirect and induced employment effects are calculated. This usually requires the availability at least of an input-output table which can link the output of the project sector to all the supply sectors, both immediate and indirect; the estimation of induced employment effects goes beyond this and requires full scale whole-economy modelling. In cases where input-output tables are available, Leontief multipliers of direct, indirect, and induced effects are typically calculated and used. Evidence on the indirect and induced employment effects in the literature to date comes in large from the bulk of developed countries (particularly the US and the EU).

Potential weaknesses of different approaches

The different methodologies have their advantages and disadvantages (for a detailed critical review see Bacon and Kojima, 2011). Estimates based on “top-down” approaches and static input-output tables may suffer from lack of sectoral detail, in which case the estimated effects might not be fully representative. Moreover such approaches may not represent effects of scale or substitution caused by changes in prices and wages brought about by large sector investments. An additional point to consider regards the timing of employment impacts which depends in large on the nature of the projects. For a given amount of CIM expenditure, those projects having long lead times will likely result in a smaller number of jobs at any point in time than alternatives that have shorter gestation periods. However, addressing these drawbacks at a macroeconomic level can be difficult because of lack of information.

Analysis of the employment effects should also take into consideration the impacts of crowding out effects on demand that may arise from the financing of the projects and the second order effects that can affect interest rates and wage rates. For instance studies that have considered the implications of equivalent taxes on employment have found that the net employment created by a subsidy or fiscal injection can be modest if account is taken of the jobs lost as a result of an equivalent increase in taxes to maintain long-run budget neutrality, and this can be the case for programmes that promote renewable energy.

Studies have also paid little attention to the impact on household budget of consumers increasing spending on energy programmes. This is particularly important for the estimation of the effects of energy efficiency projects. Even after households have paid for the costs of the improvement, energy efficiency programs may save households money, which could result in additional expenditure and employment or conversely they may induce lower demand by households if energy efficiency costs have a multi-year payback time (ECF, 2010).

In general, projects that increase the cost of energy to the user (such as obligations for generation from renewables) will result in reduced expenditure on other goods and services, possibly inducing reduction in employment at national level (Hillebrand et al, 2006; Frodel et al, 2009). Another point to consider is the financial context in which the energy project is evaluated. When investors are confident (for example prior to 2008), the risk premium that they demand is likely to be lower than in periods of uncertainty, which has an important impact on the cost of capital-intensive projects.

3.3 The DG Employment 'Green Jobs' study

Introduction

This Green Jobs study was completed by a consortium comprising Cambridge Econometrics, the Institute for Employment Research at Warwick University and GHK Consulting (now ICF-GHK) in 2011. It is available on the DG Employment web site[16] and is referred to as Cambridge Econometrics et al (2011) in this report.

The underlying aim of the study was to provide an assessment of the employment impacts of the '20-20-20' environmental targets in the EU:

- to reduce GHG emissions by 20% by 2020 compared to 1990 levels
- to have a 20% share of energy being generated by renewables in 2020

The study also considered the objective of a 20% reduction in energy consumption, due to efficiency measures.

A subsequent study by Eurofound (2012) built on the results of this project to consider aspects of job quality. We also discuss the findings of that study towards the end of this section.

Macroeconomic and detailed sectoral analysis

The E3ME macro-sectoral model was used to assess a set of scenarios that considered each element of the targets individually. It found that the policies required to meet the 2020 targets could lead to a small net increase in employment, mainly due to the large levels of investment required in renewables and energy-efficient equipment. The results showed that the jobs that were created were mainly in the construction and engineering sectors (and their supply chains), while there could be reductions in employment in fossil fuel sectors.

The modelling was only able to consider changes in employment at approximately the NACE 2-digit sectoral level[17], as this was the greatest level of detail supported by the available data. It is clear that there could also be movements in employment *within* these sectors, which the modelling was not revealing. The analysis therefore also included a set of case studies of sub-sectors where there could be either large reductions or increases in employment, or changes in the nature of the jobs involved.

In general the study found that in most cases it would be possible for displaced workers to find jobs in newer and growing sub-sectors, although additional training may be required in some cases (which may or may not be provided by the companies involved). There could also be some quite negative localised impacts when a town is dependent on a single factory or mine that faces closure.

Churn and technological change more generally

The study also considered the possible gross employment effects and the impacts of the policies on jobs created and lost. It concluded that although the policies would lead to increased churn in the labour market, this would not represent a substantial increase on the rates of job creation and destruction that typically occur in the economy.

This led into a discussion of technological development and the changing nature of jobs in a dynamic economy, including the current trend towards increased services employment. The scenarios of the 20-20-20 targets presented a view of accelerated technological change, which was induced by policy, but resembled other periods of rapid technological development, such as the ICT revolution. In that case, new

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[16] See www.ec.europa.eu/social/BlobServlet?docId=7436&langId=en

[17] That is, the 42 sectors in the version of the E3ME model used for the study.

products changed the nature of many different industries and the jobs within these industries. This theme is picked up in Section 3.7 below.

Building on this analysis

While the Green Jobs study included much that is relevant to the present study (and indeed it included its own literature review), its scope was in some respects more limited.

Time coverage

The Green Jobs study largely focused on the period up to 2020, as this was the target year for the policies that were assessed. In this review we consider the period up to 2050. This has two important implications.

- The DG Employment study covered a period when Europe's economies were expected to be operating largely below capacity, due to the financial crisis and recession. The sectors that produce investment goods (and which were the principal beneficiaries in the scenarios) were particularly affected by the recession, and so it was envisaged that there would be a large available stock of labour that could be drawn on to produce new equipment.
- The period up to 2020 is largely concerned with changes to the existing labour force. Looking in the longer term up to 2050, many of today's workers will have retired and new workers will have entered the labour market.

Energy technologies

The Green Jobs study did not consider all of the technologies that are explicitly noted in the Energy Roadmap scenarios. For example, there was a relatively limited discussion of nuclear power in the study, whereas it is the basis of one of the scenarios in the Roadmap.

We therefore pay particular attention to these technologies, and how they might develop in future, in the sections below.

The Eurofound study

The Eurofound study, Gaušas et al. (2013), was carried out by the Public Policy Management Institute in Lithuania. It reinforced and built on the results of the Green Jobs report. The study reiterated the previous conclusions that there are movements in jobs between sectors but that the most important development will be a general greening of existing jobs.

The study looked in detail at ten specific sectors, with the aim of identifying possible future changes in job quality, but was unable to determine clear trends. Nevertheless the results suggested that the impacts were likely to be quite small. The policy recommendations included improving the dialogue between policy makers and industry to allow businesses to anticipate changes in future skills requirements.

Conclusions

The Green Jobs study concluded that at macroeconomic level the impacts of environmental policy were typically small; while green policies were not going to lead to large net job losses, there were not going to be substantial numbers of net new 'green' jobs either. Instead it was suggested that there might be some movement between sectors and a general 'greening' of existing jobs.

However, it seemed likely that in a few specific cases there could be adverse impacts from energy/climate policy as a result of low labour mobility (both between sectors and geographically) and workers becoming displaced and unable to find new jobs. It was suggested that older workers might be particularly affected. In addition, there could be skills shortages in some specific positions, notably related to research and engineering.

It was therefore recommended that there could be an active role for policy in helping to manage the short-term transition from older to newer technology types, but that this should be seen in the context of the wider labour market, which is in a constant transition due to technological progress and other economic factors.

These conclusions are all relevant to the present study but the focus here is more on long-term outcomes up to 2050, rather than short-term transition periods.

3.4 Energy Roadmap 2050

This section provides an overview of literature examining the Energy Roadmap 2050 and the potential costs and economic implications of implementing policies designed to meet the Roadmap objectives.

The Roadmap

The Energy Roadmap 2050 explores the challenges set in delivering a reduction of GHG emissions by at least 80% compared to 1990 levels by 2050, while maintaining or improving on the current reliability of electricity supply, energy security and economic growth in the EU.

The importance and ambitious nature of the Roadmap objective is made evident by the large amount of literature focusing on the potential impact of the different scenarios outlined in the Roadmap and other possible alternatives. Because the target set in the Energy Roadmap 2050 cannot be achieved without almost complete decarbonisation of the power sector, most studies concentrate on possible technology mixes that can be used to achieve such an objective and their implications for emissions reduction, future investment and energy prices. Some, but relatively few, studies focus on the economic and labour market impact of these scenarios.

The Impact Assessment accompanying the Energy Roadmap 2050 (European Commission 2011) included a stakeholder consultation in which a selection of decarbonisation studies published up to 2010 were reviewed in order to compare different views on how the EU can decarbonise its economy. Three main studies (and six main scenarios[18]) were analysed by the European Commission for the development of the Energy Roadmap, which we have also reviewed. The scenarios are listed in Table 3.1, from which it can be seen that renewables and nuclear are among the key technologies required to achieve the 2050 objective. CCS is considered in the ECF and Eurelectric scenarios but, because the technology is not yet ready for widespread deployment, it is not considered in the others.

The five decarbonisation policy scenarios included in the Energy Roadmap 2050, which draw on the stakeholder scenarios and findings, are:

- energy efficiency
- diversified supply technologies
- high renewables use
- delayed CCS
- low nuclear

[18] Strictly speaking, seven policy scenarios are included. Scenario 1 is a BAU Reference scenario which takes account of policies implemented by 2010. Scenario 1b is is an updated Reference scenario which takes account of initiatives that had been adopted or proposed by the EC since March 2010. The remaining five scenarios represent alternative decarbonisation pathways.

Table 3.1: Roadmap 2050 stakeholder scenarios

Scenario	CO_2 reduction compared to 1990	Fossil fuel price assumptions, 2050	Sources of electricity production in 2050
Baseline	-20%		
Greenpeace Advanced Energy Revolution Scenario	-97%		Based 91% on RES (including imports). Nuclear phase-out. No CCS. Rest is supplied by gas.
Greenpeace Energy Revolution Scenario	-90%	Oil – 124 €2005/barrel Natural gas – 22 €2005/GJ Coal – 143 €2005/T	Based 98% on RES (including imports). Nuclear phase-out. No CCS. Rest is supplied by gas.
ECF Roadmap 2050: 40% RES, 60% RES and 80% RES Scenarios	-96%	Oil – 73 €2005/barrel Natural gas – 9 €2005/GJ Coal – 69 €2005/T	For the 40% case nuclear accounts for 27% and CCS for 30%.
Eurelectric Power Choices Scenario	-90%		Nuclear accounts for 30%. Significant contribution of CCS coal and gas power plants (around 30%).

The results of the various impact assessment studies are summarised in the following paragraphs.

Investment requirement

Whatever mix of technology is used to achieve the emission targets, all the studies agreed that the switch to low-carbon technologies will require significant investment. At present, all low-carbon technologies carry a relatively high capital cost. The European Climate Foundation (ECF) study (2010) estimated that the proposed decarbonised scenarios require an increase in capital expenditure for the power sector of 50% to 110% compared to baseline[19]. Another study (SEFEP, 2012), which looks at the Energy Roadmap scenarios, estimated the required additional annual investment at around €270bn over the next 40 years. This is equivalent to additional investment of 1.5% of EU GDP per annum (the present annual level of investment across the whole economy is 19% of GDP).

The cost of the required investment is also affected by the increased transmission capacity and generation backup requirements needed by low-carbon technologies. Generally, generation backup requirements tend to increase as the share of renewables in the electricity generation mix increases (see e.g. ECF, 2010).

Impact on energy prices

The reviewed papers accept that the switch to low-carbon technologies leads to increases in energy prices. In the short term the cost of electricity in the decarbonised pathways is higher than the baseline, and more so in the pathways with higher renewable shares (ECF, 2010 and Eurelectric, 2009). This result is widely supported.

[19] The baseline is defined as the following electricity generation split: 17% nuclear, 49% coal/gas, 34% renewable sources.

For example a study on the impact of feed-in tariffs in Germany (Traber, and Kemfert, 2007) found that the support for renewables in Germany had led to an increase in both consumer and industry electricity prices, but more so for industry. However, more recent evidence (particularly in Germany) suggests that a large share of renewables could lead to a breakdown of marginal cost pricing in electricity, so there is considerable uncertainty about future changes in electricity prices.

Steinbuks et al (2009) argue that if the increase in prices persists in the medium term it can lead to changes in industry structure: as the price of energy services raises the price of intermediate and final goods throughout the economy, a series of price and quantity adjustments ensue, with energy-efficient goods and sectors likely to gain at the expense of energy-intensive ones. In the long term, energy prices in the decarbonised scenarios could be lower compared to baseline, if widespread energy efficiency measures are implemented (ECF, 2012).

But it should be noted that it is difficult to gauge the full impact on energy prices, as the switch to a decarbonised energy sector could lead to a decrease in fossil fuel prices.

Overview of GDP and employment impacts

GDP and employment impacts vary across the scenarios, with ECF (2010) estimating a relatively small impact on GDP and employment. The net impact on overall employment is generally expected to be small, but with larger differences in particular sectors. Sectors linked to investment in low-carbon technologies and energy efficiency (e.g. construction, mechanical engineering, electrical engineering) are likely to see an increase in employment, while energy-intensive industries may suffer (e.g. iron and steel, metal products, coal, petroleum and gas) (see Cambridge Econometrics et al, 2011).

These impacts are highly dependent on global policy, as a study by Hübler and Löschel (2012) points out. Using a CGE modelling approach, they show how various global and national climate action policies can have significant welfare impacts (see Table 3.2). In their results, the estimated welfare cost to the EU induced by the decarbonisation envisaged in the Roadmap could stay below 0.3% until 2020 and below 2% until 2035 in terms of consumption losses, with no action from the rest of the world. The cost might increase to 3% afterwards and possibly much more in the absence of technological breakthroughs (this is the case of the fragmented action scenarios listed in Table 3.2).

Conclusions

Some studies have already attempted to estimate the economic costs and benefits of the Roadmap. There are many more which look at the economic and social impacts of higher energy costs more generally, with only a small selection covered here. However, the focus of the present study is less to look at the overall macro-level picture, but more to concentrate on the *employment* effects, in aggregate and in specific sectors. This depends critically on the choices of technologies adopted and the speed of transition. In the next section we consider in more detail some of the key sectors and technologies that are likely to be involved.

Table 3.2: Scenarios on global climate change action

	Emissions target[1]	Policy characteristics in the EU27	Policy characteristics abroad	EU27 welfare impact[2] 2050
1 Reference	(-21) -40	Currently implemented and agreed policies	Copenhagen pledges for 2020 & kept constant afterwards	
2 Fragmented action	(-25) -80	EU Decarbonisation Roadmap	As above	-6.0%
3 Fragmented Action Free	(-25) -80	EU Decarbonisation Roadmap with extended allocation of free allowances	As above	-6.5%
4 Fragmented Action CDM	(-25) -80	EU Decarbonisation Roadmap with extended & optimistic CDM use	As above	-0.2%
5 Global Action	(-25) -80	EU Decarbonisation Roadmap	Copenhagen pledges intensified for all regions & up to 80% by 2050 in Annex 1	-5.8%
6 Global Action National	(-25) -80	EU Decarbonisation Roadmap & equalisation of ETS and non-ETS prices	Copenhagen pledges intensified as above	-3.4%
7 Global Action International	(-25) -80	EU Decarbonisation Roadmap & full international emissions trading	Copenhagen pledges intensified as above	-2.7%

Notes: 1) Emissions targets are for (2020) and 2050, compared to 1990 levels.
2) Welfare change is measured as the Hicks Equivalent Variation referring to the change in expenditures (in value form) of the representative EU consumer. Figures are % difference from baseline.

Sources: Hübler and Löschel, 2012.

3.5 Focus on specific technologies to 2050

This section provides information on the potential impact on sectoral employment and the skills mix of the key low-carbon technologies. We discuss a selection of the most important technologies in turn. At the end of the section we present tables that summarise employment estimates associated with specific technologies.

An increasing number of studies have focused on estimating the employment associated with alternative energy technologies (like EWEA, 2009b), as well as the employment effects of energy-related policies and projects. Research ranges from studies at project level (indicative is the CH2MHILL, 2009 study on photovoltaic reserve and the ECF, 2010b study on building energy retrofit) and subsector level (see for instance PWC, 2011 study on the oil and gas sector) to macroeconomic studies focusing on the impact on macro employment effects of energy sector projects (see Pollin et al, 2009) and on total employment effects of scenarios, for example on penetration of different types of renewable energy (see for instance UNEP, 2008 and REN21, 2010).

Studies estimating the employment associated with alternative energy technologies come mainly from organisations associated with the specific technologies (see for instance various reports on employment effects of wind energy produced by the European Wind Energy Association-EWEA , or the reports on US solar employment needs produced by the Solar Electric Power Association).

Although there is quite a wide range of literature regarding these technologies, many studies come from an engineering perspective and therefore do not contain as much information about employment or skills requirements (or economic impacts more generally). We are therefore sometimes required to infer the possible employment impacts, whether these arise directly (i.e. in technology development, or installation or operation) or indirectly (e.g. through changes in electricity or carbon prices).

Key Technology: Renewables

The EU is one of the world's biggest promoters of renewable energy. In 2007 EU leaders agreed that 20% of the region's final energy consumption should be produced from renewable energy sources and in 2010 the EU's Member States implemented the Renewable Energy Directive (Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources), making the 2020 renewable target legally binding.

In 2010, close to 20% of electricity generated in the EU27 came from renewable sources, with Austria, Sweden and Portugal all having over 50% of generated electricity from renewable sources. Germany, France and the UK were all below the EU average, with only 17%, 14.5% and 6.7% respectively of generated electricity coming from renewable sources[20].

Renewables are expected to play a key role in achieving the objectives of the Energy Roadmap 2050 and they feature predominantly in the stakeholder scenarios which contributed to it. Although some renewable technologies are not yet fully commercially viable, there is significant policy support for their implementation. Expansion of renewable technologies is likely to lead to new types of jobs and skill requirements.

[20] Eurostat data for 2010. Last updated on 21/06/2012.

Employment and skills

Renewable energy technologies have been found to be more labour-intensive than conventional energy technologies in delivering the same amount of energy output (see Table 3.3). As such, increased implementation of renewable technologies is likely to lead to increased employment, at least in the sectors directly connected to the manufacture and operation of such technologies.

In Europe, current job gains (at least in gross terms) are expected to be greatest in biomass technologies, both in the biomass energy industry and in fuel supply, but all renewable technologies show long-term net job creation (ECOTEC, 2008, OECD, 2012, Fankhauser et al, 2008). A study by ECOTEC (2008) on the expansion of renewables in the EU expects job gains to be the greatest in the agriculture and manufacturing sectors, while the conventional energy supply industry is predicted to lose less than 2% of its workforce by 2020. The jobs displaced as a result of subsidies to support renewable energy deployment are estimated to be considerably fewer than corresponding job gains (both direct and indirect impacts) elsewhere in the economy. UNEP (2008) also points out that bioenergy has the highest potential to create jobs in many OECD countries. However, the expansion of this sector will likely lead to increased competition with the agricultural food sector and put pressure on land and other resources; it is not clear whether this involves displacement of workers from agriculture.

While agriculture employs only around 5% of the total workers in the EU, this figure varies from country to country. In Romania the agricultural sector employs almost 30% of the total number of workers, while in Greece and Portugal the figure is around 11%[21]. As such, a future expansion in bioenergy will lead to disproportionate impacts across EU Member States, whether positive or negative.

Table 3.3: Average employment over the life of a facility (jobs/MW)

	Construction, manufacturing, installation	Operation & maintenance and fuel processing	Total employment
Solar PV	5.76–6.21	1.20–4.80	7.41–10.56
Wind	0.43–2.51	0.27	0.71–2.79
Biomass	0.40	0.38-2.44	0.78-2.84
Coal	0.27	1.01	0.74
Gas	0.25	0.70	0.95

Sources: Kammen et al. (2006) cited in Fankhauser, 2008.
Notes: Ranges refer to the results of different studies. Employment is shown relative to the average installed capacity, correcting for differences in capacity factor, because renewable installations operate only 20% of the time, compared with 80% for fossil fuel plants.

Fraunhofer ISI et al (2009) used the NEMESIS and ASTRA models to look at the impact of renewable energy policy in the EU up to 2030. The study explored the following scenarios:

- No policy - reference case for the subsequent assessment, the case of no further RES support until 2030.

[21] Eurostat data from 2010, national accounts, last updated on 31/01/2013.

- BAU with moderate export share - all existing RES policies will be continued until 2030 in the EU and worldwide. Exports in absolute numbers increase, but the EU's export share declines over time.
- BAU with optimistic export share - all existing RES policies will be continued until 2030 in the EU and worldwide, leading to innovations within the EU and a slightly decreasing export share of the EU.
- Accelerated deployment policies (ADP) with moderate export share - acceleration of RES deployment policies. A moderately declining export share is assumed for the EU.
- ADP with optimistic export share - acceleration of RES deployment policies. A slightly decreasing export share is assumed for the EU.

The scenario results are given in Table 3.4. The results from the NEMESIS model show that the ADP scenarios have the greatest gain in employment. Under these scenarios, the most important technologies contributing to the additional employment are wind energy, solar energy and liquid biofuels for transport. More optimistic assumptions on future world market shares for renewable technologies have an important impact on the employment in the renewables sector and could increase the net number of employees by more than 120,000 compared to the moderate export assumptions baseline. The study finds that, in gross terms, EU future employment in the renewable energy sources sector could grow to 2.8m employees in 2020 and 3.4m employees by 2030.

Table 3.4: Model results 2030, % from 'No policy' baseline (Fraunhofer ISI et al., 2009)

Scenario	NEMESIS (EU27 + Norway excluding Cyprus and Bulgaria)		Astra (EU27 + Norway and Switzerland)	
	GDP	**Employment**	**GDP**	**Employment**
BAU with moderate export share	0.14	0.08	0.30	0.14
BAU with optimistic export share	0.20	0.12	0.30	0.15
ADP with moderate export share	0.36	0.24	0.40	0.03

Sources: Fraunhofer ISI et al., 2009.

The employment results from the ASTRA modelling exercise are considerably smaller than the NEMESIS results, particularly for the ADP scenarios. The reasons for the difference in results between the models reflect the different treatment of investment between the two. The renewables investment is added as a whole into the output equation of NEMESIS, while in ASTRA it is split into the investment component and the export component, which both also enter the final demand and output equations, but differ in how they affect transport demand and productivity growth in the national economies. Furthermore, the treatment of the renewable investment that is not traded also differs across models. NEMESIS treats it as final demand (generating trade indirectly after), while ASTRA uses its trade model directly to assign the supply of the intermediate goods to EU countries. In addition, energy costs have slightly different treatments between models, with a cost increase affecting the trade model and competitiveness in NEMESIS, while in ASTRA it has more effect on consumption patterns and the input-output relations from the energy sector to the other sectors.

Thus in the ADP scenario, the stronger impact of the energy cost increase after 2026 modelled by ASTRA significantly dampens the growth in employment.

Another study looking at the sectoral implication of the expansion of renewables in Germany (Blazejczak et al., 2011) found that changes in the structure of final demand have an impact on sectoral employment, even without considering future changes in the inter-linkages between sectors. The manufacturing industry benefits the most, but there are also large positive employment effects in business-related service sectors. In contrast, employment in public and private services decreases. Over time, the differences decrease due to second-round effects.

A study conducted by Sastresa et al. (2010) in Aragon, Spain looks at the quality[22] of jobs created by the renewable sector. The author found that the wind energy sector had a positive impact on the quality of jobs, while solar thermal and photovoltaic technologies resulted in lower quality jobs. However, Del Rio and Burguillo (2008, quoted in Lambert and Silva, 2012) argue that, in the case of renewable energy placed in a rural location, jobs with low skill requirement are likely to provide more employment benefits to the local community, due to the likely low skill level of rural workers.

Employment in solar

Among renewable technologies, photovoltaics have one of the highest growth rates and have now begun to achieve grid parity (the point at which alternative means of generating electricity is equal in cost, or cheaper than grid power) in some regions. Although unlikely in our opinion, a study estimates that by 2050 electricity from photovoltaics could cover up to 90% of total global energy demand, given a global capital investment in photovoltaic manufacturing capacity of $500bn (2010 prices) by around 2030 and $1,500bn by 2050. Global employment in photovoltaic manufacturing is predicted to rise to 6m by 2050 (Grossmann et al., 2012).

Employment in wind

The European Wind Energy Association (EWEA, 2009) estimates that wind energy employment in the EU will more than double by 2020, from 154,000 in 2007 to almost 330,000. According to the report, on-shore wind energy will continue to provide more jobs to 2020. By 2025, off-shore wind energy employment will exceed on-shore employment and by 2030, more than 375,000 people will be employed in the European wind energy sector (160,000 on-shore and 215,000 off-shore). Currently 75% of direct employment in the wind energy sectors is in Germany, Denmark and Spain. In the UK, a report (Esteban et al., 2011) on the British North Sea energy sector claims that, if adequate policies are put in place to support the sector, the off-shore renewable industry could absorb each year the job losses arising from the depletion of North Sea oil. According to the report, by 2020 the oil and gas industry would employ between around 14,000 and 18,000 people (depending on the scenario) and the renewables sector would have between 1,400 and 1,800 employees maintaining structures and 14,000 and 18,000 involved in the installation of new devices. By 2050 the oil and gas industry would only have between 1,600 and 4,000 employees left, but the off-shore renewable sector would be employing 10,000 to 12,000 people in maintenance and 19,000 to 20,000 people in the installation of new devices.

[22] To determine quality the authors constructed a Quality Factor (QF) for each technology ranging between 1 and -1, with 1 indicating a very specialised, stable and local job. The QF was calculated using adjustment factors for territoriality, temporal nature of job and specialisation of job but the exact adjustment factors are not described in detail by the authors.

Another study on the expansion of wind and marine energy in the UK found that a near tenfold increase in wind would result in an increase in direct full-time employment from 10,600 in 2010 to 55,600 in 2021. A further 32,700 indirect roles will also be supported through broader supply of goods and services to the industry. The majority of these positions are likely to be skilled jobs requiring either full-time vocational and higher education courses or specialist on-the-job training (RenewableUK, 2011).

The wind energy sector is already suffering from skill shortages. Blanco and Rodrigues (2009) conducted a survey of companies working in the wind energy sector across the EU and found that the number of engineers that graduate every year is insufficient for the needs of the economy. Interviewed companies claim that the most difficult positions to fill are related to operation and maintenance, project management and aerodynamics, computational and fluid dynamics engineering. Furthermore, most reviewed sources pointed out that graduates often need additional specialisation to work in the sector, placing an additional cost on to the firms involved.

Key Technology: Energy Efficiency

The EU Ecodesign Directive (Directive 2009/125/EC) was implemented in 2005 and sets mandatory ecological requirements for energy-using and energy-related products sold in all the Member States. Its scope currently covers more than 40 product groups (such as boilers, light bulbs, TVs and fridges) and in 2009 a revision of the Directive extended its scope to energy-related products such as windows, insulation materials and certain water-using products.

In 2012 the EU adopted the Directive 2012/27/EU on energy efficiency which promotes energy efficiency within the EU in order to ensure the achievement of the Union's 2020 20% headline objective on energy efficiency and to pave the way for further energy efficiency improvements beyond that date. This Directive establishes a common framework of measures for the promotion of energy efficiency within the Union in order to ensure the achievement of the 2020 targets. The Intelligent Energy – Europe II Programme (IEE II, see European Commission 2010), launched in 2010 and building on the experience of its predecessor IEE I which ran from 2003, provides financial support for projects that promote energy efficiency (as well as greater uptake of new and renewable resources in energy use).

Another important piece of legislation on energy efficiency is the Energy Performance of Buildings Directive (EPBD) (Directive 2002/91/EC,EPBD), first published in 2002, which required all EU countries to strengthen their building regulations and to introduce energy certification schemes for buildings. All countries were also required to have inspections of boilers and air-conditioners. In 2010 a recast of the EPBD was adopted by the European Parliament in order to strengthen the energy performance requirements and to clarify and streamline some of the provisions.

Economic impact

Ecofys (2012) estimated that a full implementation of the Ecodesign Directive could result in net savings for European consumers and businesses of around €90bn per year in 2020. This means net savings of €280 per household per year, and reinvesting these savings in other sectors of the economy could result in the creation of 1m jobs.

The Impact Assessment of the Energy Efficiency Directive looks at various policy options to assess the potential economic, social and environmental impact of implementing the directive. The impact analysis is split by various levels of policy options. The first level relates to whether there should be legally binding energy efficiency targets on Member States. A second level of analysis relates to the nature and impact of legal measures; most of the options are based on the current instruments of the Directive as well as new policy measures (the energy savings obligation and tools to enhance generation efficiency and grid efficiency). Potential alternatives are also reviewed. The overall GDP impact of the proposed package of measure is estimated to be positive in 2020, with most sectors benefitting but the notable exception of the sectors that are related to fuel. The increased efficiency is expected to lead to lower input fuel needs for the other sectors resulting in increased employment and wages. Results from the E3ME model suggest that total EU employment is estimated to increase by 0.18% compared to baseline in 2020 (European Commission, 2011).

Employment and skills

All the studies reviewed here agree that the construction sector will be the main direct beneficiary of increasing energy efficiency standards, mainly because retrofitting and improvement of buildings is a labour-intensive process. A modelling exercise carried out by BPIE (2011), which looks at the impact of implementing energy efficiency in buildings by 2050 across Europe, highlights the potential employment gains. The study considered five scenarios, focusing on various speeds (slow, medium and fast) and depths of renovation (minor, moderate, deep and nearly zero energy). Individual scenarios combine different speeds and depths, and are compared to a business-as-usual scenario, which assesses what would happen if there were no changes from the approach taken today.

The number of net jobs created appears to be highest in the scenarios with the highest level of energy efficiency implementation (deep and two-stage, see Table 3.5).

Table 3.5: Main scenario results over 2050, EU

Scenario Building renovation type		**Baseline**	**1A Slow & Shallow**	**1B Fast & Shallow**	**2 Medium**	**3 Deep**	**4 Two-stage**
Saving as % of today	%	9	34	32	48	68	71
Investment costs (present value)	€bn	164	343	451	551	937	584
Savings (present value)	€bn	187	530	611	851	1 318	1 058
Average annual net jobs generated	m	0.2	0.5	0.5	0.7	1.1	0.8

Sources: BPIE, 2011.

These findings are further supported by an analysis (3CSEP, 2012) which looks at the employment impacts of deep building energy retrofits in Poland. The report estimates that a programme costing between €2.2bn and €7bn in 2010 prices (depending on the speed of the retrofit – S3 would be the most expensive) and saving between €0.6bn and €1.3bn in 2010 prices would have a direct labour impact in the construction sector of between 15,000 and 87,000 full-time equivalent jobs in 2020 compared to baseline. Most of the new jobs will require skilled labour (see Table 3.6).

Table 3.6: Direct labour impacts on the construction sector, divided by skill level, Poland

Employment, thousands FTE	Baseline	S1- slow retrofit	S2- medium retrofit	S3 - fast retrofit	S4 - suboptimal medium retrofit
Professional	1	7	11	16	3
Skilled	12	34	57	90	26
Unskilled	6	5	8	11	5
Direct labour involved: total	19	46	76	106	34

Sources: 3CSEP, 2012

The 3CSEP (2012) report further looks at the net employment effect, distinguishing between three types of induced effects: those generated by the additional jobs created by the investment in construction, those destroyed by job losses in the energy sector, and the induced impacts fuelled by the energy cost savings at a sectoral level. The results are presented in Table 3.7.

Much of the employment gain is an indirect and induced result of renovation activities (i.e. in the sectors supplying materials and other inputs to the construction sector, plus in all other sectors of the Polish economy positively impacted by the programmes). In 2020, 75% to 80% (depending on the scenario) of the gross employment created corresponds to these categories, whereas only 20% to 25% of those jobs are created in the construction sector. The largest indirect and induced employment gains can be seen in the following industries: community and social services (a very labour-intensive sector), manufacturing (a sector making an important contribution to the programme through the supply of materials for the renovations) and the construction sector.

Table 3.7: Indirect and induced impacts for the renovation scenarios in 2020, Poland

Employment, thousands FTE	Baseline	S1	S2	S3	S4
Agriculture, hunting, forestry and fishing	1.3	4.0	6.6	9.3	2.7
Mining and quarrying	-1.2	-0.7	-1.0	-1.5	-1.5
Manufacturing	6.6	30.1	33.5	46.9	12.6
Electricity, gas and water supply	-3.7	-4.0	-6.5	-9.1	-5.2
Construction	11.6	32.2	53.7	75.2	22.9
Wholesale, retail, trade, restaurants and hotels	1.5	4.5	7.6	10.6	3.0
Transport, storage and communications	0.8	2.8	4.7	6.5	1.8
Finance, insurance, real estate and business services	1.3	4.3	7.2	10.1	12.7
Community, social and personal services	7.3	23.5	39.3	55.0	15.5

Sources: 3CSEP, 2012.

Looking outside the EU, Bezdek (2007) estimates that increased energy efficiency initiatives in the US could result in between 17,800 and 32,000 thousand jobs (direct and indirect) (see Table 3.8).

Table 3.8: Jobs created by 2030 compared to baseline, 2006, USA, thousands

Scenario	Renewable Energy	Energy Efficiency
Baseline	1 305	14 953
Moderate renewables and energy efficiency initiatives	3 138	17 825
Advanced renewables and energy efficiency initiatives	7 198	32 185

Sources: Bezdek, 2007.

A literature review (Pearce and Stilwell, 2008) on the employment effects of climate change policies in Australia finds that, in the medium term, the implementation of efficiency measures would result in more jobs than would otherwise be the case, because of the labour-intensive nature of making improvements.

Key Technology: CCS

While a small number of pilot projects are being implemented, large-scale CCS deployment remains unproven and it could take time before such technology becomes commercially viable. There is also considerable uncertainty about possible employment effects. However, CCS shows potential and an IEA (2012) analysis suggests that without CCS, overall costs to reduce global emissions to 2005 levels by 2050 could increase by 70%.

One of the main issues with CCS technology is the high energy penalty. The technology is expected to use between 10% and 40% of the energy produced by a power station (Rochon, 2008), which means that wide-scale CCS adoption could result in the loss of all efficiency gains in coal power plants of the last 50 years, and increase resource consumption by a third. Another issue regarding CCS deployment is the safe and permanent storage of CO_2 and potential storage leakage rates that could undermine any climate change mitigation effect. Furthermore, with today's technology, CCS would increase the cost of generating electricity by 50% to 100% (IIASA, 2012). Even with the high fuel penalty, overall levels of CO_2 abatement would remain high (around 80% to 90%) compared to a plant without CCS (IPCC, 2005) and it is possible for CCS, when combined with biomass, to result in net negative emissions.

At present, there are four CCS projects running in the EU. These are listed in Table 3.9.

Table 3.9: Current CCS projects in the EU

Project title	Location	Type	Facility	Storage area
Demonstration Project Jänschwalde	Germany	Integrated CCS project	Power generation	Saline aquifer Birkholz/Beeskow, saline aquifer Neutrebbin, depleted natural gas field Altmark
Bełchatów CCS Project	Poland	Integrated CCS project	Power generation	Three potential storage sites have been identified. The detailed appraisal of sites is ongoing.
ROAD-Project (Rotterdam)	The Netherlands	Integrated CCS project	Other, Power generation	P18-A - offshore depleted gas reservoir
Compostilla Oxy CFB 300	Spain	Integrated CCS project	Power generation	Duero basin

Sources: http://www.zeroemissionsplatform.eu/projects/eu-projects.html

Cost of CCS implementation and potential impact

Because CCS is such a new technology, there are a limited number of studies that focus on its potential impact on emissions and electricity generation, and even fewer that focus on the potential economic and employment effects.

From the technology point of view, some believe industrial CCS applications (or zero emissions plants) can be commercialised by 2020, with first-of-a-kind plants coming into operation in the EU by 2015. However, the investment required to bring CCS to market is substantial. Early demonstration of CCS in industrial-scale power plants will require a considerable increase in spending, as up-front investment for CCS-equipped plants is approximately 30% to 70% higher than for standard plants. Operating costs are currently 25% to 75% more than in non-CCS coal-fired plants, mostly due to efficiency losses and costs of capture and transportation of CO_2[23]. Furthermore, more R&D expenditure would be required to improve the process.

As noted by Eurelectric (2009) and others, there is an important interaction between CCS and the carbon price. IEA (2012) provides estimates of the carbon prices at which CCS (in both the power sector and for industry) becomes competitive. At these points, there could be quite large and non-linear impacts on the EUA price, which would affect all sectors covered by the ETS.

Employment and skills

It is difficult to estimate the employment effects of widescale implementation of CCS since there are so few applications. In terms of skill mix, it is safe to assume that implementation of this technology would require the updating of existing skills (e.g. plant workers, construction of plants) and introduction of new skills (e.g. specialised

[23] European Commission, DG Research and Innovation, http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-ccs [Accessed 07/02/2013]

to CCS implementation and R&D). Obviously, sectors related to CCS technologies would benefit directly.

AEA (2008) looks at the possible value to UK business of coal-related carbon abatement technologies to 2030 under different scenarios and estimates an increase in CCS-related employment of just over 25,000 jobs by 2030 (gross measure), based on 5GW of new coal plant capacity with CCS.

In a study on the impact of low-carbon energy alternatives on employment in the US (Wei et al., 2009) the authors find that aggressive energy efficiency measures combined with a 30% renewables target in 2030 can generate over 4m full-time equivalent job-years through 2009-30, while increasing nuclear power to 25% and CCS to 10% of overall generation in 2030 can yield an additional 500,000 job-years. For CCS, three technology options[24] are considered in the paper and the resultant job numbers for these options are estimated at 0.17, 0.22 and 0.16 job-years per GWh respectively.

However, another study focusing on potential job creation of low-carbon technologies in the US (Engel and Kammen, 2009) found that CCS does not yet appear to have strong influence in generating net employment. The study results suggest that CCS has a lower job multiplier compared to the average multiplier for renewable technologies.

Key Technology: Nuclear

According to the International Atomic Energy Agency (IAEA), there were 67 civil nuclear power reactors under construction in 15 countries[25] in 2012. In the US the licences of well over a third of the country's reactors have been extended to 60 years[26]. However, Japan's 2011 Fukushima Daiichi nuclear disaster prompted a rethink of nuclear energy policy across the world. China, India and Japan have announced a thorough review of their plans on nuclear energy. Germany decided to close all its reactors by 2022 and Italy has effectively banned nuclear power; Spain and Switzerland have banned the construction of new nuclear reactors. Belgium is considering shutting down three of its seven reactors by 2015. On the other hand, France has continued to express confidence in its own nuclear plans (as has the US), while Poland and Lithuania have announced plans to start a nuclear power industry.

At present 14 of the EU Member States use nuclear energy for power generation, with just over 130 nuclear reactors in operation. Over 40% of these reactors are located in France, while four more are under construction in Finland, France and Slovakia and another eight are planned[27].

Economic and emissions impacts

Analysis of the Roadmap decarbonisation pathways shows the role that nuclear energy can play in reducing emissions. SEFEP (2012) explores the scale of the higher emissions that would follow if nuclear is excluded from the future energy generation mix. For example, the removal of nuclear from the Greenpeace Advanced Revolution Scenario[28] would result in an increase in CO_2 emissions of 45%. The analysis by Eurelectric (2009) shows that the inclusion of nuclear in the decarbonisation scenarios

[24] Post combustion carbon storage for pulverised coal, post combustion retrofit for natural gas and pre-combustion capture design for IGCC.

[25] http://www.iaea.org/pris/

[26] http://www.world-nuclear.org/info/inf41.html#licence

[27] http://www.reuters.com/article/2013/06/13/us-eu-nuclear-safety-idUSBRE95C0GQ20130613

[28] Greenpeace, 2010. The scenario consists of 98% electricity generation from renewables (including imports), nuclear phase-out and no CCS. The rest is supplied by gas.

leads to lower average electricity prices. Bauer et al (2011) estimates that early retirement of nuclear power plants could lead to a discounted cumulative global GDP loss of 0.07% by 2020 and double that if, in addition, new nuclear investments are excluded. In terms of achieving emissions reduction targets, the authors find that nuclear power is only of moderate importance. In the presence of a carbon budget, nuclear power plants can contribute to reducing the short-fall from decommissioning old plants (mainly coal), but they can be substituted by a mix of natural gas with CCS, hydropower and wind.

A separate modelling exercise (Bretschger et al., 2012) looking at a potential phase-out of nuclear energy in Switzerland by 2035 finds that this can be achieved at relatively low costs, even when the expansion capacities of other technologies are limited. Consumer welfare is expected to decrease by at most 0.4% compared to business as usual.

Employment

A report for DG Energy (2012) analyses the employment effects of nuclear if it contributes 20% of electricity in 2050[29]. The detailed breakdown of potential (gross) jobs created in the EU is given in Table 3.10.

Up to 2020, the DG Energy report expects most activities in the nuclear energy sector to be in safety upgrades (post-Fukushima outcomes) and the launch of the studies and first implementations of the long-term operation (LTO) programmes. The estimated impact on jobs and value creation is limited: 10,000 jobs and €1bn per year (see Table 3.10). It is expected that most LTO programmes would be implemented between 2015 and 2035 leading to an additional employment of 50,000, while new-build projects are expected to generate an additional 250,000 jobs between 2025 and 2045. In addition to these numbers, there is the employment generated by decommissioning plants and waste management activities (see Table 3.10).

Looking outside the EU, Engel and Kammen (2009) examined the job creation potential of low-carbon technologies in the US and found that nuclear has quite a low job multiplier compared to renewable technologies, but slightly higher than conventional energy technologies (see Table 3.11).

[29] The the share nuclear in the 2050 electricity mix was set to match the Energy Roadmap 2050 Delayed CCS Scenario share of 20%.

Table 3.10: Breakdown of potential jobs from nuclear energy

Time frame	Activity	Jobs created over the period, absolute values	Value created
2012-2050	Regular operation	900 000	€70bn/year
2012-2020	Stress test	10 000	€1bn/year
2012-2030	LTO[1] (including stress test)	50 000	€4.5bn/year
	Decommissioning	7 000	€1bn/year
	Waste management	10 000	€3bn/year
2030-2050	New build	250 000	€25bn/year
	Decommissioning	20 000	€2.5bn/year
	Waste management	10 000	€2.5bn/year

Notes: 1) LTO = long-term operation.
Sources: DG Energy, 2012.

Table 3.11: Average employment for different energy technologies

Technology	Total job-years per GWh
Nuclear	0.15
Biomass	0.22
Solar PV	0.91
Wind	0.17
Coal	0.11
Natural gas	0.11

Sources: Engel and Kammen, 2009.

Skills requirements

Jobs in the nuclear sector typically have high-skill requirements, covering a range of specific disciplines (e.g. nuclear physics), needed not only on the sites of the nuclear plants but also in the supply industry. As pointed out by Cambridge Econometrics et al (2011), many European countries have an aging workforce with respect to these skills. Opposition in several EU Member States calls into question the extent to which the required skills will be available in the future should it be decided to invest again in nuclear.

For example, in 2010 the number of nuclear experts employed across the EU was estimated around 77,000 (the highest share employed in France followed by the UK), with the biggest share of experts falling in the 45-55 age group (see EHRO-N, 2012). In 2009 the total number of nuclear engineering students and students following nuclear energy related subjects that graduated (on BSc, MSc, or PhD) was just over 2,800. Given current trends, by 2020, the total need for nuclear experts by the nuclear organisations active in the EU27 in 2010 is estimated at around 38,900.

Key Technology: Electric Vehicles

In 2009 the European Parliament agreed to a move to mandatory targets for the CO_2 emission performance of light-duty vehicles registered in the EU, following insufficient progress under the voluntary agreement. This Regulation (EC No 443/2009) sets an average CO_2 target for new cars sold to 130 gCO_2/km by 2015 (gradually phased in from 2012). For 2020, Regulation 443/2009 sets a target of 95 gCO_2/km. The regulation was reviewed by the European Commission and approved with amendments to Annex II (monitoring and reporting of emissions) in January 2013.

As a consequence, the car industry is likely to focus on producing vehicles with a far smaller carbon footprint (i.e. greater fuel efficiency and new propulsion systems including electrification of transport as a key policy), while the transport sector will be looking at a better-balanced mix of transport modes, re-prioritizing rail and public transport (WWF, 2009). Furthermore, a decarbonised electricity supply, as highlighted in the Energy Roadmap 2050 scenarios, offers substantial opportunities to reduce emissions in end-use sectors through electrification, like switching from internal combustion engine vehicles to electric vehicles (EVs) and plug-in hybrids (PHEVs) (IEA, 2010).

Employment and skills

The motor vehicles industry and the transport sector will be the most affected by the increased support for electric vehicles and hybrids. The medium-skilled workforce in motor vehicles manufacture, such as technicians, welders or machine-operators, is likely to be the least affected by the change in production techniques brought about the by the introduction of EVs and PHEVs. However, change in business models coupled with the increased sophistication of cars, are likely to lead to increased demand in medium and high skill level jobs, such as software engineers, electrical engineers and managers. The improvement of current electric and hybrid technologies, as well as the development of new technologies, will influence the demand for researchers in the manufacturing sector. Development of new battery technologies stands out as a key area in this respect.

In the transport sector, the introduction of EVs and PHEVs would generate demand for specialised technician and maintenance specialists familiar with such technologies. However, the required skill level of these jobs is low to medium. Another part of the transport sector that is likely to change significantly is logistics. The re-organisation and re-engineering of the transport system could lead to substantial retraining processes for some occupations, as well as new professional development opportunities. The required skill level for this sector is medium to high (e.g. logistic analysts, managers, engineers). Workers in the rail transport sector would only need to top-up existing skills.

Cambridge Econometrics and Ricardo-AEA (2013) look at the macroeconomic impact of the transition to low-carbon light duty vehicles in road transport, and estimates the potential net employment gain across the EU of supporting low-carbon (including electric and hydrogen fuel-cell) vehicles at over 2 million jobs by 2050. The report estimates that around a quarter of the new jobs are in the car manufacture value chain (e.g. engineering, metal products). The rest are distributed across a wide variety of sectors benefitting from increased consumer expenditure released by reduced fuel use. The report includes a specific analysis of skill requirements.

CET (2009) estimates the rate of market adoption of electric vehicles in the US to 2030 and analyses the potential economic and employment impacts. The net employment gain is estimated between 130,000 and 350,000 jobs by 2030. New jobs are created in the battery manufacturing industry and in the construction, operation, and maintenance of a domestic charging infrastructure network. The job gains outweigh modelled job losses among gas station attendants, mechanics, and parts industry manufacturers.

Summary employment effects by key technology

We draw together here a range of employment estimates by key technology.

Table 3.12 presents estimates that are reported in terms of jobs per MW of installed capacity. The estimates vary widely, and some studies provide limited evidence to support the estimates. For instance the findings about PV effects on job creation vary from 7.4/MW to as many as 51/MW. Job creation by wind projects vary from 0.7/MW to 16.7/MW. Job impacts of natural gas using power generation vary between 1.0/MW and 10.4/MW. Estimates of jobs generated by coal-based power generation range between 1.0/MW and 18.2/MW. The estimation of jobs associated with biomass range between 0.8/MW and 4/MW.

Table 3.12: Employment effects of alternative energy technologies, total jobs per MW[30]

Energy technology	Country / region	Total jobs per MW	Source
Biomass	Spain	4	Moreno and Lopez (2008)
	US	0.8	REPP (2001)
	US	0.78	Kammen et al (2006)
	US	0.78-2.84	Fankhauser et al (2008)
Clean coal with CCS	US	2.5	UNEP SEF Alliance (2009)
Coal	US	2.2	UNEP SEF Alliance (2009)
	US	18.2	UNEP SEF Alliance (2009)
	US	6	UNEP SEF Alliance (2009)
	US	1	REPP (2001)
	US	1.01	Fankhauser et al (2008)
	US	1.01	Kammen et al (2006)
Gas	US	0.6	UNEP SEF Alliance (2009)
	US	10.4	UNEP SEF Alliance (2009)
	US	1	UNEP SEF Alliance (2009)
	US	3.5	UNEP SEF Alliance (2009)
	US	0.95	Fankhauser et al (2008)
	US	0.95	Kammen et al (2006)
Hydro	US	3	UNEP SEF Alliance (2009)
Nuclear	US	5	UNEP SEF Alliance (2009)
	US	14	UNEP SEF Alliance (2009)
Oil	US	4	UNEP SEF Alliance (2009)
Solar-PV	Spain	34.6	Moreno and Lopez (2008)
	US	6.5	UNEP SEF Alliance (2009)
	US	45	UNEP SEF Alliance (2009)
	US	1.1	UNEP SEF Alliance (2009)

[30] UNEP SEF Alliance (2009) summarises the results of a number of earlier studies. Estimation differentials are associated with source and methodology differentials. For a detailed review of the sources and methodologies see UNEP SEF Alliance (2009), Table III-12, page 81.

Energy technology	Country / region	Total jobs per MW	Source
	US	7.4	REPP (2001)
	World	51	EPIA and Greenpeace (2008)
	World	10.6	UNEP SEF Alliance (2009)
	US	7.41-10.56	Fankhauser et al (2008)
Solar-Thermal	US	40	UNEP SEF Alliance (2009)
	US	35.5	REPP (2001)
	Spain	2.22	Caldés et al (2009)
	US	7.41	Kammen et al (2006)
Wind	EU	15.4	UNEP SEF Alliance (2009)
	US	3.6	UNEP SEF Alliance (2009)
	US	0.9	UNEP SEF Alliance (2009)
	US	5.1	UNEP SEF Alliance (2009)
	US	16.7	UNEP SEF Alliance (2009)
	US	6.6	UNEP SEF Alliance (2009)
	US	4	UNEP SEF Alliance (2009)
	US	0.7	REPP (2001)
	World	2.8	EPIA and Greenpeace (2008)
	Spain	0.86	Blanco and Rodrigues (2009)
	Belgium	6.97	Blanco and Rodrigues (2009)
	Denmark	5.44	Blanco and Rodrigues (2009)
	Austria	0.76	Blanco and Rodrigues (2009)
	Czech Republic	0.86	Blanco and Rodrigues (2009)
	Spain	1.35	Blanco and Rodrigues (2009)
	Germany	1.71	Blanco and Rodrigues (2009)
	France	2.44	Blanco and Rodrigues (2009)
	UK	0.48	Esteban et al (2011)
	US	0.71	Kammen et al (2006)
	US	0.71-2.79	Fankhauser et al (2008)

Table 3.13 presents results in which the employment effects are distinguished by CIM and O&M stages. Again, a wide range is reported. Estimates show that the effects differ considerably between the two stages. For instance hydro is found to have a high impact during CIM stage but a relatively low impact during O&M. Only in the case of biomass is the scale of job impact similar between the CIM and O&M stages. Table 3.14 presents estimates of employment effects that are related to the energy produced.

Table 3.13: Employment effects of alternative energy technologies, in total jobs per MW in CIM and O&M

Energy technology	Country / region	Total jobs per MW		Source
		CIM	O&M	
Biomass	US	0.4	0.38-2.44	Fankhauser et al (2008)
Coal	US	0.27	0.74	Fankhauser et al (2008)
Gas	US	0.25	0.7	Fankhauser et al (2008)
Geothermal	US	4	1.7	Moreno and Lopez (2008)
	US	17.5	1.7	Moreno and Lopez (2008)
Hydro	Spain	18.6	1.4	Moreno and Lopez (2008)
Solar-PV	US	7.14	0.12	ECRP (2003)
	US	5.76-6.21	1.2-4.8	Fankhauser et al (2008)
	US	7.1	0.1	Moreno and Lopez (2008)
Solar-Thermal	World	33	10	EPIA and Greenpeace (2008)
	US	5.7	0.2	Moreno and Lopez (2008)
Wind	UK	28.8	0.42	Esteban et al (2011)
	US	0.43-2.51	0.27	Fankhauser et al (2008)
	US	2.6	0.2	REPP (2001)
	Germany	14	-	Greenpeace (1997)

Table 3.14: Employment effects of alternative energy technologies, in total jobs in CIM and O&M per MWp (installed) and MWa (average effective) and in total job-years per GWh[31]

Energy tech.	Total jobs/MWp		Total jobs/MWa		Total job-years/GWh		Source
	CIM	O&M	CIM	O&M	CIM	O&M	
Biomass	0.11	1.53	0.13	1.8	0.01	0.21	EPRI (2001)
	0.21	1.21	0.25	1.42	0.03	0.16	REPP (2001)
Coal	0.21	0.59	0.27	0.74	0.03	0.08	REPP (2001)
Geotherm.	0.16	1.79	0.18	1.98	0.02	0.23	WGA (2006)
	0.44	1.7	0.49	1.89	0.06	0.22	Heavner and Churchill (2002)
	0.1	1.67	0.11	1.86	0.01	0.21	EPRI (2001)
Natural Gas	0.03	0.77	0.03	0.91	0	0.1	Heavner and Churchill (2002)
Nuclear	0.38	0.7	0.42	0.78	0.05	0.09	INEEL (2004)
Small Hydro	0.14	1.14	0.26	2.07	0.03	0.24	EPRI (2001)
Solar PV	1.48	1	7.4	5	0.84	0.57	EPIA and Greenpeace (2008)
	1.29	0.37	6.47	1.85	0.74	0.21	REPP (2006)
	0.29	0.12	1.43	0.6	0.16	0.07	EPRI (2001)
Solar Thermal	0.41	1	1.03	2.5	0.12	0.29	Skyfuels/NREL (2009)
	0.18	0.38	0.45	0.95	0.05	0.11	NREL (2006)
	0.23	0.22	0.57	0.55	0.07	0.06	EPRI (2001)
Wind	0.4	0.4	1.15	1.14	0.13	0.13	EWEA (2009)
	0.15	0.14	0.43	0.41	0.05	0.05	REPP (2006)
	0.44	0.18	1.25	0.5	0.14	0.06	McKinsey (2006)

As with estimates of the employment effects of alternative technologies, studies of the employment effects of energy efficiency also yield varied results and provide only rather limited evidence (Table 3.15).

[31] MWp= Peak MW, MWa=average MW. All estimates based to USA case study. For a detailed discussion see Wei et al (2010). For details on sources and methodologies see Wei et al (2010).

Table 3.15: Employment effects from energy efficiency actions (jobs per million euro)

Jobs per €m	Region	Source	Action
21.2	EU	CECODHAS (2009)	Building retrofits
7.5	EU	Janssen and Staniazszek (2012)	Energy Performance of Buildings Directive (EPBD) option B1: Quality and compliance requirements for certificates
9.4	EU	Janssen and Staniazszek (2012)	Energy Performance of Buildings Directive (EPBD) option A3: Abolishing the 1000 m² threshold (all buildings)
10	EU	Janssen and Staniazszek (2012)	Energy Performance of Buildings Directive (EPBD) option A1: Lowering the renovation threshold to 500 m² (all medium sized buildings)
10.5	EU	Janssen and Staniazszek (2012)	Energy Performance of Buildings Directive (EPBD) option A2: Lowering the threshold to 200 m² (all buildings apart from small ones (mainly single family houses)
13.7	EU	Janssen and Staniazszek (2012)	Energy Performance of Buildings Directive (EPBD) option D1: Specifying EU-wide energy performance requirements
20	EU	Janssen and Staniazszek (2012)	Energy Performance of Buildings Directive (EPBD) option B2: Requiring that the recommended cost-effective measures of the certificate are realized
27.3	EU	Janssen and Staniazszek (2012)	Energy Performance of Buildings Directive (EPBD) option D2: Introducing a benchmarking mechanism
26.6	EU	Wade et al (2000)	Assessment of employment effects of the EU SAVE programme implemented in the mid-1990s in various EU Member States
37	Hungary	ECF (2010b)	Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme in Hungary
23.2	UK	SAVE: UK Case Studies (1996)	Energy saving
9.7	USA	Sundquist (2009)	Energy-efficient retrofits (Estimation of the direct jobs involved in, by examining a small amount of case studies)
15.3	USA	National Association of Home Builders (2009)	Building retrofits
17.4	USA	Hendricks et al (2009)	Energy-efficient retrofits
16.6	USA	Pollin et al (2009)	Adoption of the clean-energy components of the American Recovery and Reinvestment Act (ARRA) programs and the entire American Clean Energy and Security Act (ACESA)

3.6 Interaction between the sectors

This section considers the interaction of the key technologies discussed in Section 0, and discusses the possible implications that the widescale introduction of such technologies could have on the structure of employment and skill requirements in the EU. The majority of technologies are specific to the power generation sector, because all the Roadmap scenarios lead to the complete decarbonisation of this sector. As outlined in Section 0, the other two areas of interest are energy efficiency and electric vehicles.

There are few examples of this kind of overall assessment in the reviewed literature. The reason for this is noted in Cambridge Econometrics et al (2011): a macroeconomic approach is required to understand the interactions and possible supply constraints, but the level of detail required to address the issues usually goes far beyond that which is available in the data at macroeconomic level.

Summary of employment impacts

The reviewed literature comes to the general conclusion that low-carbon electricity tends to offer more jobs per unit of investment and megawatt of capacity than fossil fuel equivalents. The power sector will see quite profound changes in skills and qualification requirements, but this sector only accounts for a small share of total employment.

More important, in terms of absolute levels of employment, is the labour required within the engineering and construction sectors to meet the investment demand for new equipment. Smaller in absolute terms, but a potentially important bottleneck, is the requirement for skilled labour to carry out research and development activities for new products and industrial processes.

These services will be required for all the technologies discussed in Section 0 (and others) and, if the following two conditions are not met, there is the possibility that these technologies (and other sectors) will end up competing for the relevant skilled labour:

- there are enough available workers
- the available workers have the necessary skills

At the same time declining industries will cut employment in response to lower product demand. This includes the extraction and fuel supply sectors, but also some energy-intensive sectors. The declining sectors may therefore release labour that could meet the needs of the new and growing sectors, but there is no guarantee that the skills of these workers will match what is required in the new jobs.

Finally, it is also necessary to consider movements of workers *within* sectors and the changing skills requirements. Again, if there is a shortage of workers with the required skills this would likely mean competition between companies for a limited pool of talent.

This section therefore focuses on areas where there could be skills shortages and what the impacts of these shortages might be.

Skills demand and shortages

In general, green jobs, both new specialties and existing occupations that have been modified to be greener, have diverse skill requirements. Their requirements overlap to a large extent with those used in similar non-green occupations. This implies that special training associated with green jobs can often take the form of top-up training to adapt workers who are already qualified in an occupation to using greener technologies or ways of working (e.g. energy efficient buildings).

Some emerging green occupations have new educational requirements, although this should not be challenging as most are sub-specialties within long-standing disciplines, such as engineering positions in the renewable energies sector or systems analysts who develop ICT support for smart power grids (OECD, 2012).

Green jobs are very heterogeneous in terms of job skill requirement, pay levels and working conditions. It is therefore not obvious that the transition towards low-carbon growth will have a marked impact either for better or worse on job quality or inequality, and these will still need to be addressed by other policy instruments (Gaušas et al., 2013; OECD, 2012). Table 3.16 contains an overview of green jobs, their skills requirements and potential policy issues in Europe.

Table 3.16: Skills profile of potential green jobs

Occupation	Growth profile	Skill profile	Policy issues
Renewable energy sector			
Professional/associate professional engineers and technicians and skilled trades	Growing demand expected in the medium term. Competition with other sectors.	Medium and high	Shortage of engineers reported by companies working in the sector. New entrants require additional training.
Professional and technician level skills in mechanical, electrical, and chemical engineering, waste collection and management	Increased demand for biofuels	Low to high	Skill needs of the biomass sector are not yet clear. Pressure on food production.
Nuclear energy sector			
Professional/associate professional engineers, skilled plant worker, sector-specific high-level specialisations (e.g. nuclear physicists)	Nuclear policy in the EU	Low to high	Need for high level specific-specialisation. Current policy may affect future supply of this type of skills.
Construction			
Skilled trades, semi-skilled trades	Increasing renewable capacity. Energy-efficient buildings	Low and medium	Initial vocational education and training (IVET) sets standards for energy-efficient buildings.
Manufacture of motor vehicles			
Engineering technicians, welders, transportation equipment painters, metal fabricators, computer-controlled machine operators, engine assemblers, and production helpers	Greening production techniques for vehicles components	Low to medium general skills with medium job-specific skills	Close integration of industry and education. In the UK North East's Low Carbon Economic Area (LCEA): creation of the National Training Centre for Sustainable Manufacturing
Computer software engineers, electrical engineers and operations managers	Changes in production methods and business models	Medium and high	Low Carbon Future Leaders Graduate Placement Scheme placing recent university graduates in the UK
Applied researchers, fundamental researchers	Development of future technologies	High	National Low Carbon Vehicle Research and Development

Occupation	Growth profile	Skill profile	Policy issues
			Centre in the UK
Transport			
Specialized technicians of fuel cell batteries, automotive maintenance technicians	Introduction of renewable and cleaner fuels for transportation	Low to medium level for installation and maintenance	Uncertainty about which fuels for transportation will eventually be used
Railroad conductors, locomotive engineers, truck and bus drivers	Greening existing occupations	Top-up existing skills	
Automotive engineers, freight forwarders, fuel cell engineers, logistics analysts, logistics engineers, logistics managers, supply chain managers, transportation engineers and transportation planners	Reorganisation and the re-engineering of the transportation systems	Medium and high level skills, combined with sector-specific, pre-existing medium and high-level competencies	Best candidates could be incumbent employees with retraining to get needed skill mix, but with a substantial retraining process for some occupations and a role for new professional development tracks in tertiary education
ICT			
‘Smart’ grids specialists, ‘smart’ buildings specialists, database administrators	Rapid growth projected for ‘smart’ ICT applications to raise energy efficiency (e.g. ‘smart’ grids, transport systems, buildings)	Medium and high	Cross-sectoral demand, with using sectors subcontracting to ICT service providers
Precision agriculture and biomass farming technicians	Increasing application of geographic information systems to agriculture and forestry production, and the management and construction of buildings	Medium and high, mixed with skills for gathering and interpreting physical topography data	
Mining sector			
Operators of heat coproduction, geospatial information technologists	Upgrading core technologies	Medium	Eesti Energia developed training programmes for current and new employees
Geospatial information scientists and technologists, managers for heat coproduction, energy auditing, and technology developers and managers	Supply chain re-organization, and upgrading management practices	High level for development of new technologies and production re-organization	Estonia revised and coordinated higher-education programmes in mining
Recycling & Waste management			
Waste sorting and reception	Long-established occupation	Low qualification, minimal on-the-job training	Low job quality and health risks are main concerns. No skill deficits
Recycling and waste technician; waste-recycling operator	Long-established subsector	Vocational qualification. In France general certificate of vocational qualification; in Germany dual apprenticeship	The number of take-ups falls short of satisfying demand

Occupation	Growth profile	Skill profile	Policy issues
		training	
Hazardous waste management specialist	Growing demand expected in medium and long run due to tighter regulations	Medium and high level	Potential shortage of qualified workers in the medium term
Sustainable design manager, recycling and reclamation engineer, coordinator of recycling activities, regulatory programme compliance officer	Rising longer-term demand from other sectors (e.g. manufacturing) and tighter regulations	High-level skills to address organizational sustainability issues, to embed recycling, reuse and remanufacturing in products' design	Role for new professional development tracks in tertiary education

Sources: Based on OECD (2012), expanded for other sectors by authors.

Where the interactions might be

While it is not possible to come up with a comprehensive list of occupations that will be in high demand, Table 3.16 suggests that there are two important areas of skills where demand is likely grow:

- Design of new products – this includes highly-skilled researchers, engineers and technicians. Examples include chemical engineers in the development of new battery technologies and physicists in several power sector technologies. Software engineering stands out as a particular skill that is required by many of the sectors, including smart grids and technologies.
- Implementation of new technologies – this includes a more medium-skilled set of jobs, including a large part of the construction sector. Many of these jobs may be similar to existing positions and the current workforce could be adapted to cope with the demand through additional training schemes.

The first of these groups appears the most likely to be the sources of shortages or 'bottlenecks' in skills capacity (see below), at least in the short term. However, it should also be noted that these skills are typically in demand at *any* time of technological advancement when the rapid development and deployment of new products becomes a high priority; this is discussed in the next section.

Table 3.16 also suggests some other groups (e.g. managers) that are in high demand but these are more likely to be transferrable skills from other sectors, including ones where employment is projected to decline in the scenarios.

It is important to bear in mind that, as well as potentially competing with each other for skills, these sectors must also compete with all the other sectors in the economy, for example biofuels competing with other types of agriculture. In some cases these are rapidly-growing sectors (e.g. ICT) that have demands for high-skilled workers and are able to offer high wage rates.

Potential bottlenecks

Skills shortages or bottlenecks occur when there is not enough of one type of worker to fill particular positions. Theoretically they should only occur in the short term as labour markets should be able to adjust in time to fill gaps (e.g. as new graduates see opportunities in the market). In practice, this may not always be the case.

Bottlenecks could occur for several reasons, including:

- the workforce does not have the correct skill types
- there is a geographic mismatch between skills supply and demand
- other (e.g. demographic factors, such as ageing populations)

Given the scale of the changes in total employment predicted by all the reviewed studies, the key issue is *labour mobility*, either between occupations or geographical areas. This is the main theme in the policy recommendations (see below).

Possible impacts of skills shortages

Before considering remedial policy, however, we must ask the question of whether this is an important issue, and what the result might be if there is a shortage of workers within a particular sector[32]. Theoretically, the following outcomes (or a combination of them) are possible:

- It is not possible to meet production levels and environmental targets are missed (worse environmental outcome).
- Competition for workers drives up wage rates for highly skilled labour. This leads to an increase in product prices and demand falls, meaning targets are missed (worse environmental outcome).
- Competition for workers drives up wage rates for highly skilled labour. This leads to an increase in product prices but demand is either maintained, or is met by imports (worse economic outcome).

This is not an issue that has been widely considered at the macroeconomic level, but Cambridge Econometrics et al (2011) looked at a scenario in which wage rates are forced upwards by (an arbitrary) 0.5% due to mismatches between skills supply and demand. The scenario was assessed using the E3ME model and the conclusion was that the mismatch could lead to a 0.1% fall in GDP compared to baseline, with a range of 0 to -0.4% across most Member States. Although this difference is not large, its scale is comparable to the small changes in GDP in the main scenarios; suggesting that the issue is worth considering further.

Policy responses

It is not always clear that a policy response is required (or helpful) to address this issue. In some cases the market may correct itself (although possibly with a long lead time) as displaced workers take the initiative to train in new skills. In other cases, the companies involved will be best-placed to offer the relevant training. This seems to be most likely in cases where new positions are quite similar to existing jobs.

Chapter 6 of Cambridge Econometrics et al (2011) provides an assessment of the policy options available. The main theme is that policies that improve flexibility in the labour market more generally will provide assistance in managing the transition of structural change that is required in the Energy Roadmap scenarios.

When considering the skills aspect, it is generally found that priority should be given to improving science, technology, engineering and maths (STEM) skills at all levels (see also OECD, 2011), as well as the broad range of technical, managerial and leadership skills. Currently there is a perceived shortage of graduates with STEM skills across the EU, with demand expected to increase in the short and medium term. However, the supply of STEM skills remains insufficient because of level of achievement in school (OECD PISA survey[33] found that nearly 1 in 5 pupils surveyed

[32] In this case we assume that any domestic shortfall in workforce skills is not met by higher immigration levels although this is a possibility.

[33] OECD, 2009.

had low level science skills across the EU25), negative perception about STEM-related jobs (such as lower pay) and a declining number of graduates in the area (EU Skills Panorama, 2012). Furthermore, a high outflow from the labour market is expected due to large-scale retirements (European Commission, 2009). For example, in the UK, up to 70% of current high-skilled employees in the nuclear industry will retire by 2025 (Business Europe, 2012). To avoid exacerbating the skill shortages in this area, greater advances are need in improving attainment of STEM skills in schools, as well as enhancing the wrap-around skills needed for the effective application of STEM skills in a multi-disciplinary environment.

Conclusions

The number of studies that explore the whole-economy skills implications of energy policy is quite limited. However, drawing on the lessons from sectoral studies, it appears that some of the technologies in the Roadmap scenarios require labour inputs from the same groups of workers, in particular highly skilled engineers. Particularly in the short term, this may lead to skills shortages that could have adverse impacts on either environmental or economic outcomes (or both). In the longer term the impact is likely to put further demands on the supply of workers with STEM skills which are already an area of concern in Europe.

Due to the very specific nature of these shortages it is difficult to design policy that could avert these outcomes. The reviewed studies therefore suggest that the focus of policy is on improving labour mobility, particularly between sectors, by improving teaching of basic skills that can later be adapted for specialised use.

3.7 ‘Churn’ and previous cases of rapid technological change

In the period up to 2050 there are likely to be quite profound changes in Europe’s economies. These could be due to demographic changes, increased globalisation or many other factors, but in particular due to technological advancement. The changes affect all parts of society, including the labour market, and, for the most part, cannot be predicted in advance.

In the modelling exercise, most of these issues are factored into the baseline (that is, they are not affected by the scenarios) and so are not considered explicitly in the analysis. However, they can be quite important when considering the gross impacts from the scenarios.

Labour market churn

For this analysis it is necessary to consider the concept of labour market ‘churn’, which is the number of people starting or leaving jobs, as distinct from the number of workers in jobs. Churn can reflect economic factors (jobs lost or created) or demographic developments in the form of retirements and new labour market entrants. Rates of churn in the labour market are affected by many different factors. The financial crisis provided a large shock to Europe’s labour markets, leading to increased churn. However, it has been reported that the recession following the crisis led to lower rates of churn as workers were less willing to switch jobs.

Technological progress can also be a key driver of labour market churn. New technologies are often associated with new companies, so that when new technologies displace older technologies this leads to movements of workers between companies (and possibly sectors). The Energy Roadmap scenarios present the prospect of the adoption of an array of new technologies (renewables, nuclear, CCS, efficiency measures, electric vehicles, etc.) in place of existing technologies.

For this reason, Cambridge Econometrics et al (2011) provided an assessment of the EU's 2020 environmental targets in the context of overall labour market churn. The study found that rates of churn vary substantially between different sectors, but the impacts of the scenarios that were modelled would be quite small, compared to developments that were already factored into the baseline.

Previous cases of rapid technological change

If we view the Energy Roadmap scenarios as a specific case of technological change then we can gain further insight from other cases where new technologies have led to substantial economic restructuring. The most notable case in recent times is the Information and Communication Technology (ICT) revolution that began in the 1970s (again, see Cambridge Econometrics et al, 2011).

Although the ICT revolution has led to the creation of many new types of job, they are often quite niche. Far more important in macroeconomic terms has been the impact that ICT has had on existing jobs, and the skills required to carry them out effectively. This has more recently extended into households, as internet connections and personal devices have proliferated.

We suggest that the impacts from structural change in the energy system could be somewhat similar, with a fairly wide dispersal of changes as many jobs adapt in some way or another to a low-carbon future. In some cases this may require further training, which may be given internally or through external courses, as we see currently for e.g. use of computer software. Educational courses will also adapt to offer relevant material for the new regime.

In terms of skills impacts there may also be similarities. It is widely held that ICT has benefited more highly skilled workers, who have been able to use it to improve their productivity, while automation has replaced some low and medium-skilled jobs. At present this is also evident in the technologies discussed in Section 0, as it is more highly skilled researchers and product designers who are most in demand.

Possible differences

The most obvious difference between the ICT revolution and predictions in advances in low-carbon technologies is the economic context in which it will be carried out. While the ICT revolution was a strong driver of economic growth, the reviewed literature suggests that environmental policy will at best only have a very small positive impact on aggregate GDP levels and may cause a reduction overall. This may make the transition more difficult, as there will be less opportunity to provide support to groups in society who lose out from the changes.

3.8 Conclusions

The aim of this review was to provide an overview of the potential employment effects of long-term developments in the energy system. It is intended to be complementary to the modelling exercise and to provide insight to aspects of the scenarios that the modelling cannot cover, for example due to limitations in scope or the level of detail at which data are available.

At the start of this chapter we asked the following key questions:

- What are the methods used in literature to estimate the employment impacts of energy policies?
- What type of workers are most/least sensitive to different energy policies?
- Which sectors benefit most/least from different types of energy policies (e.g. energy-efficiency policies, introduction of low-carbon technologies)?

- What is the potential for workers from declining sectors to move into new growing sectors? To what extent will these new sectors be competing for skilled labour?
- What are the potential labour market impacts of the structural change anticipated in the Energy Roadmap?

The findings from the review are summarised below.

What are the methods used in literature to estimate the employment impact of energy policies?

The most common approach used is a ‘partial’ one that looks at the possible employment impacts of development and deployment of a single technology. This typically makes use of engineering or firm-level data to provide an estimate of the number of jobs required to produce and operate specific equipment. The measure of employment given is usually gross. However, there is a considerable level of uncertainty regarding these estimates, with values of jobs per MW varying between sources, more so for newer technologies (see Table 3.12). In addition, it is not clear how the coefficients will change over time. This makes it somewhat difficult to estimate the employment impact of implementing specific technologies.

In a few cases macroeconomic models that provide a representation of the whole economy have been used. Although there are certain benefits from this kind of approach, notably the possibility of estimating net employment impacts for the whole economy, these models typically do not have the same level of detail about the specific technologies involved.

What type of workers are most/least sensitive to different energy policies?

The reviewed studies suggest that the most important factors are:

- sector of employment
- skill level

The sector of employment will determine whether the worker is likely to be impacted by changes in policy. For example, workers in the energy supply sector will see reduced job security, as will some in certain energy-intensive sectors. Those in construction and engineering seem likely to benefit (see below).

The skill level determines how well-equipped the worker is to deal with this type of change. Although the low/medium/high classification is a considerable simplification of the many and varied skill types that are relevant here, the evidence reviewed suggests that highly-skilled workers will be more able to adapt to changes in policy.

It should also be noted that this question refers mainly to existing workers; in the period up to 2050 a large proportion of the existing labour force will retire. The question then arises as to whether the education and skills system will adapt so that new entrants to the workforce are equipped to meet future requirements.

Which sectors benefit most/least from different types of energy policies (e.g. energy-efficiency policies, introduction of low-carbon technologies)?

The reviewed literature is fairly consistent in addressing this question. In general, the Energy Roadmap scenarios involve a large shift from energy to capital and the sectors that produce this capital will be the ones that stand to gain the most. This will be most pronounced in the period where new equipment is being deployed.

The sectors that will lose out are those that supply fossil fuels (unless CCS is a large part of the portfolio) and possibly some intensive users of energy. It should be stressed though that some energy-intensive industries also feature in the supply chains of sectors that will benefit.

However, the main impacts will be felt within, rather than between, sectors. This means that it is not enough to determine which sectors win and which lose out as the impacts are more subtle. Previous findings suggest that the most important developments will be changes to existing jobs rather than a large number of jobs being created or lost, although there may be quite substantial movements between companies.

What is the potential for workers from declining sectors to move into new growing sectors? To what extent will these new sectors be competing for skilled labour?

Low rates of labour mobility in Europe, both between sectors and geographical areas, could lead to dislocation (unemployment and unfilled vacancies). This is an important issue in the short term, as it is only covered in the macroeconomic modelling to a limited extent.

The result could be that displaced workers are unable to find jobs in growing sectors, leading to both higher rates of unemployment and a shortage of available skilled labour. This could have a negative impact on both the economy and achieving the environmental targets.

Labour mobility is therefore an important area where public policy could play a role. The reviewed literature suggests that an improvement in basic skills could be an important part of smoothing the transition to a low-carbon economy.

What are the potential labour market impacts of the structural change anticipated in the Energy Roadmap?

We can infer some likely outcomes from the reviewed literature.

There is no clear consensus about whether the overall net impact on employment (defined as number of jobs) will be positive or negative, but in almost all cases the impacts are small at macroeconomic level.

There are some general trends that are quite clear, however. These include the findings for sectoral employment (as discussed above) and the impacts across various skills groups are quite consistent as well.

The overall impact on the quality of jobs is not clear; some of the skills expected to be in greater demand are quite high level (engineers, software), while others are medium-skill (construction). It is difficult to assess the impacts of decarbonisation on the other factors that are often used to assess job quality.

4 The Scenarios

4.1 The Energy Roadmap scenarios

The scenarios that are considered in this report are consistent with those in the Energy Roadmap. They are summarised in Table 4.4 and described in more detail in the Roadmap itself (see European Commission, 2011b and 2011c). The scenarios were represented in both the macroeconomic models that were used for the analysis (see Chapters 5 and 6), making the model inputs as consistent as possible.

4.2 The baseline

The Current Policy Initiatives (CPI) baseline scenario for the EU includes policies and measures adopted until March 2010. The 2020 target for RES and GHG emissions are expected to be achieved in the baseline and energy savings are realised through the imposition of energy efficiency standards and regulation measures for households, transport (car regulation) and the service sector. Households decrease their energy intensity by using more energy efficient equipment and by undertaking investment improving thermal integrity of buildings. In transport more efficient cars (including hybrid cars) are increasingly used to comply with the CO_2 performance standards set by the CO_2 from cars regulation.

Beyond 2020 it is assumed that there are no GHG emission reduction targets for EU countries and any improvements in GHG intensity are due to policies adopted, including the Emission Trading System (with ETS allowances decreasing by 1.74% per year until 2050), the deployment of RES, the implementation of energy efficiency measures and the penetration of more efficient vehicles in the transport sector and generally more efficient technologies in all sectors.

Non-European countries are assumed to meet the targets they have set themselves for GHG emission reduction up to 2020, using a price-based mechanism. After 2020 it is assumed that adopted measures and market forces will bring an average annual improvement of GHG intensity by 1% until the end of the projection period (2050), without imposing any emission reduction target post 2020.

Rates of economic growth

The rate of EU GDP growth in the baseline slows over the projection period due to demographic factors, to around 1.5% per annum after 2030 (see Table 4.1). This is consistent with the figures published in the DG ECFIN Ageing report (European Commission DG ECFIN 2009).

Rates of GDP growth outside Europe are set to fall gradually over time, to around 2.5% pa by 2050.

Table 4.1: PRIMES Baseline Macroeconomic Inputs, EU27[34]

	2010	2030	2050
Population, m	499	520	515
GDP, €2005bn	11 386	16 825	22 560
Consumer expenditure, €2005bn	6496	9423	12 743
GVA, €2005bn	10 136	15 051	20 168

Energy prices Baseline energy price assumptions are shown in Table 4.2. Fossil fuel prices are projected to increase significantly in the short term relative to 2010 levels. In the longer term, coal prices increase moderately above 2020 levels and by considerably less than oil and gas prices.

Table 4.2: Baseline Energy Prices (euro/boe, 2008 prices)

	2010	2020	2030	2050
Oil	59.1	72.9	90.8	117.6
Natural gas	37.4	51.2	65.7	91.3
Coal	15.8	23.7	28.0	31.1

The transport sector The EU transport sector is assumed to use increasing amounts of biofuels, according to the biofuel obligations set by the Energy and Climate policy package for 2020. For the longer term, the CPI scenario assumes some degree of electrification of road transportation which is much below the indicative projections included in the White Paper on Transport (European Commission, 2011d). The RES share indicator in transport increases from 10% in 2020 to 20% by 2050 because of the biofuels and the increased use of electricity, part of which is produced using RES.

Throughout the period the EU transport system remains dependent on the use of fossil fuels. Fossil fuels account for 95% and 83% of final transport sector energy demand in 2010 and 2050 respectively. Electrification in the transport sector emerges in the period after 2020. This is driven by market forces facilitated by national policies including subsidies to electric and plug-in hybrid cars in the early stages and development of recharging infrastructure in dense urban areas. Conventional vehicles account for almost 100% of the fleet in 2020. The shares of rechargeable vehicles increase to 2.2% in 2030 and 15.4% in 2050.

4.3 The policy scenarios

The policy scenarios are summarised in Table 4.4. In each scenario there is a reduction in CO_2 emissions of 85% from 1990 levels. This is consistent with the 80% reduction of total GHG emissions and is driven by a combination of carbon pricing, investment in efficiency and developments in the electricity sector.

[34] In the Energy Roadmap the modelling covered the 27 EU Member States. Projections for Croatia started to be covered in 2012-2013

The additional revenues from carbon pricing compared to the baseline (both in auctioned ETS allowances and from taxes applied to non-ETS sectors) are used to reduce employers' labour taxes.

Decarbonisation in the rest of the world

For the non–EU countries it is assumed that they will adopt ambitious GHG mitigation policies, beyond pledges included in the CPI, so that globally emissions in 2050 are 50% below 1990 levels and global emissions decrease continually after 2020. This emission reduction trajectory at global level is roughly consistent with CO_2 emission concentration levels at 450 ppm, the level proposed to limit the likelihood of exceeding the two degrees temperature rise.

Crucially for these scenarios this results in a lower global oil price. When comparing the scenario results to baseline, they therefore include the effects of both the policies in the Roadmap scenarios *and the reduction in oil prices*; the results should therefore be used for comparison between scenarios, rather than comparison against the baseline. The prices used in the scenario are given in Table 4.3.

The sensitivity analysis includes a case where oil prices are the same in the baseline and scenarios. This is discussed further in the appendices.

Table 4.3: Scenario Energy Prices (% difference from baseline)

	2020	2030	2050
Oil	-5	-25	-45
Natural gas	0	-20	-50
Coal	-15	-19	-37

Implementation in the macroeconomic models

The aim was to ensure that the scenarios are implemented consistently between the two macroeconomic models. However, due to differences in specification, there are inevitably some differences. The approaches followed are discussed further in Chapters 5 and 0.

Table 4.4: Outline of Scenarios

Name	EU policy	Global policy	Fossil fuel prices	Description
BA	Current policies	Current policies	Baseline	Baseline.
S1	Higher energy efficiency	Decarbonisation	Reduced	Energy efficiency standards apply to household appliances, new buildings and electricity generation.
S2	Diversified supply technologies	Decarbonisation	Reduced	No specific support measures for energy efficiency and RES. Nuclear and CCS are not constrained.
S3	High RES	Decarbonisation	Reduced	Achievement of high overall RES share and high RES penetration in power generation.

S4	Delayed CCS	Decarbonisation	Reduced	This scenario follows a similar approach to the Diversified supply technologies scenario but assumes a constraint on CCS while having the same assumptions for nuclear as Scenarios 1 and 2.
S5	Low nuclear	Decarbonisation	Reduced	This scenario follows a similar approach to the Diversified supply technologies scenario but imposes constraints on power generation from nuclear. There are the same assumptions for CCS as in Scenarios 1 and 2.

4.4 Sensitivities

In addition to the main policy scenarios, a set of sensitivities was tested. These scenarios were designed to test the robustness of the modelling results. The results of the sensitivities are discussed briefly in Chapters 5 and 0, with full results provided in Appendix C. Because the macroeconomic models have different specifications, not all the sensitivities were tested in both of them. The main options that were tested were:

- Policy in the rest of the world – The aim of this scenario is to separate the effects of EU policy from policy measures that are taken in the rest of the world. This explores possible competitiveness effects.
- Baseline energy prices – This sensitivity allows the model results to separate the impacts of policy action in the EU from the changes in the oil price resulting from policy measures in non-EU countries.
- Baseline GDP growth – If there is faster economic growth then the emission targets are likely to be more difficult to meet. This sensitivity compares the scenarios if the level of action required changes.
- Employment ratios – As new technologies develop, it is not clear how labour intensive they will become. This sensitivity tests the macroeconomic effects of varying the number of jobs that are created in the new sectors.
- Responsiveness of labour market – This sensitivity tests assumptions about how the wider labour market might respond in the scenarios.
- Net investment levels – E3ME in general assumes that there is available finance for the large amounts of investment required in the scenarios. This scenario shows the impacts if the finance is not available and instead displaces other investment.
- Revenue recycling method – The main scenarios assume that left-over revenues from the carbon tax and auctioned ETS allowances are used to reduce employers' social contributions. These sensitivities test alternative options.

Table 4.5 summarises the sensitivity testing.

Table 4.5: Sensitivity Testing

Sensitivity	Reason for Testing
Sensitivities tested in E3ME	
Revised oil price	To isolate the effect of European policy
Baseline GDP growth	To test robustness of results
Net investment levels	The assumption that finance is available
Employment ratios	To test different labour intensities
Revenue recycling method	To test key assumption
Sensitivities tested in GEM-E3	
Revenue recycling method	To test key assumption
Revised oil price	To isolate the effect of European policy
Policy in the rest of the world	To isolate the effect of European policy
Responsiveness of labour market	To test robustness of results
Fixed/flexible EU current account	To test key assumption

5 Results from the E3ME Model

5.1 Introduction

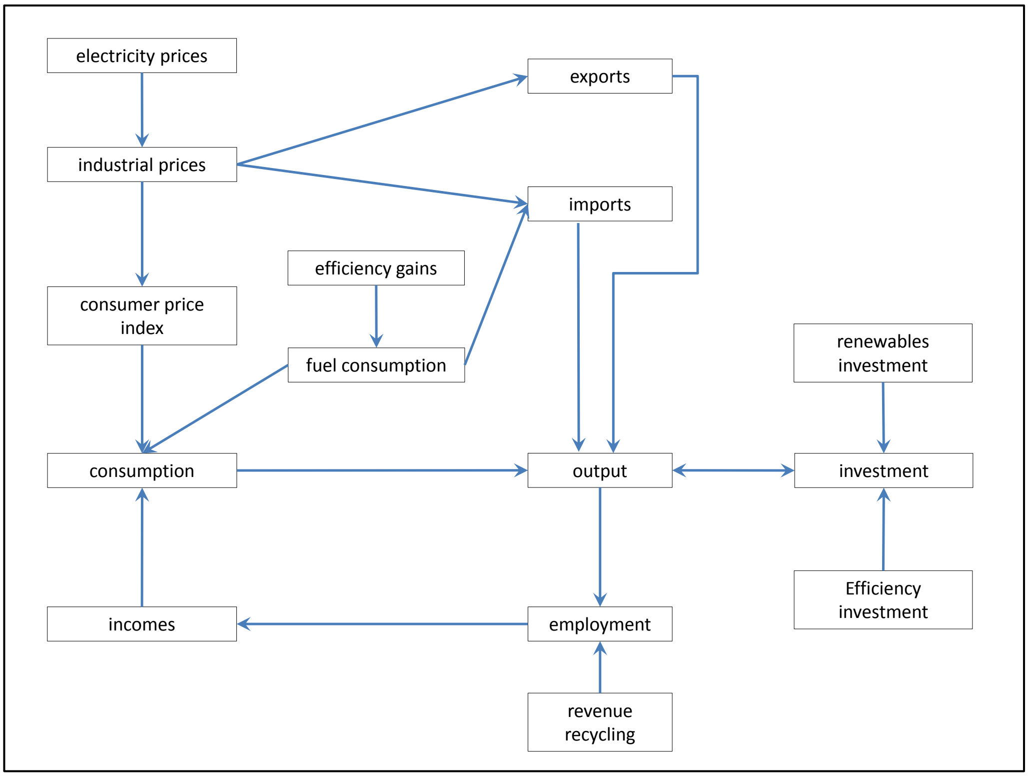
The main purpose of this chapter is to present the results of the modelling exercise using E3ME.

We begin with two sections that describe the preparatory work for the modelling. In Section 5.2 we give a brief description of how E3ME was adapted to incorporate the detailed employment data for energy supply sectors that was developed under the task reported in Chapter 2. In Section 5.3 we describe how the scenarios were represented in the model inputs.

The subsequent presentation of results begins with the reductions in emissions and energy consumption that are achieved in the scenarios, and the carbon prices and investment required to achieve these reductions. We then present the macroeconomic results, which provide the context for the labour market outcomes, and finally present the results for employment and other labour market variables which are the outcomes of ultimate interest in this study.

There is a short description of the E3ME model in Appendix E and the full manual is available on the model website (www.e3me.com). Figure 5.1 summarises the main linkages in the model that are relevant to the scenarios developed here.

Figure 5.1: Main Model Linkages in E3ME



5.2 Model development: Incorporating the new data

One of the features of this study was to link the new detailed estimates of employment (see Chapter 2) with the macroeconomic models. The E3ME model was therefore expanded to include more detailed estimates of employment in the power sector, based on installed capacity.

The approach was to use the estimates of coefficients (see Appendix D) for number of jobs per GW of capacity in 2010. These ratios were assumed to remain unchanged in the main scenarios for existing technologies. For tidal and geothermal power it was assumed that the ratios would stabilise at a level similar to those for other renewables. This assumption is, however, tested in the sensitivity analysis.

These job estimates only relate to the *operation* of plants (i.e. jobs classified within the NACE sector 35.11), as the investment jobs are allocated mainly to the construction and engineering sectors for which the model's existing employment relationships are used. The number of other jobs in the electricity sector (e.g. related to sales and distribution) is assumed to remain unchanged.

Results for employment by generation type are presented together with the other results in Section 5.4.

5.3 Scenario specification

This section describes how the scenarios described in Chapter 4 were implemented in the E3ME model.

Baseline The baseline in E3ME has been calibrated to match the PRIMES model outputs in the Energy Roadmap CPI as closely as possible. Many of the outputs from the PRIMES simulations are incorporated into the E3ME solution. These include the sectoral economic projections, energy and ETS prices, projections of energy demand by sector and by fuel, and sectoral CO_2 emissions. E3ME's Energy Technology sub-model of electricity capacity and generation also makes use of some of the more detailed PRIMES outputs.

Further processing However, in order to meet E3ME's data requirements, it was necessary to carry out some additional expansion and processing:

- Classifications were converted. For the most part, because E3ME and GEM-E3/PRIMES use similar data sources, the classifications[35] also tend to be quite similar. There are, however, some differences. For example, E3ME has a more detailed disaggregation of service sectors, and so the PRIMES outputs have to be mapped to E3ME's classification.
- Point estimates for occasional years were converted to the annual time series on which E3ME operates; a simple interpolation method is used.
- Additional social and economic variables were estimated. Only a small set of economic variables (GDP and the ones that are direct drivers of energy demand)

[35] By 'classification' here we mean the categories adopted when the model has a disaggregated treatment of a variable. For example, by the classification of industry sectors we mean the number and definition of the industry sectors represented in the model (which are defined in terms of the NACE classification). Variables that are measured by industry sector, such as employment and gross value added are calculated in the model for each element of the classification.

are presented in the PRIMES outputs. E3ME requires a complete specification of the national accounts variables, and so estimates for the other variables must be constructed (in a way that is consistent with the variables presented in the PRIMES outputs). The procedure followed to achieve this is described below (under 'proxies for other economic indicators').

These additional steps were carried out using software algorithms based in the Ox programming language (Doornik, 2007). The result of this exercise is a set of baseline projections that is both consistent with the published figures and the integrated economy-energy-environment structure of E3ME (including additional detail not available in the published figures).

Energy demand and prices

The PRIMES figures include a comprehensive set of projections for Europe's energy systems and the resulting emissions. Prices for energy-related industries in E3ME were set to be consistent with the PRIMES energy price assumptions. In addition, it is assumed that there is convergence in electricity prices between Member States in the period up to 2050, due to greater integration of national grids and the effective operation of the internal energy market.

Proxies for other economic indicators

The PRIMES figures provide projections for economic activity as a driver of energy demand, but the figures tend to be provided only for a small number of (sometimes quite aggregated) indicators (e.g. GDP, household spending or value added for some energy-intensive sectors). As the complete structure of the national accounts is represented in the E3ME model, this means that associated projections for other economic variables must be estimated (that is, the outturns for those variables that could occur, consistent with the PRIMES figures).

This process was carried out using a methodology that is as consistent as possible between the economic variables, for example ensuring that the components of GDP sum to the correct total, and that similar indicators, such as gross and net output, follow the same patterns of growth. A set of software algorithms was used to carry out this exercise, written in the Ox programming language.

The PRIMES datasets provide economic projections for GDP, gross value added (GVA) and household incomes in constant prices. E3ME's projections of growth in GDP and GVA by sector are set to match the rates in the published PRIMES figures[36]. Economic output by sector (which is gross, defined as intermediate demand plus GVA and the product taxes) was set to grow at the same rate as each sector's GVA.

Table 5.1: E3ME Baseline Macroeconomic Values, €2005bn, EU28

	2010	2030	2050
GDP	11 586	17 149	22 985
Consumer expenditure	6 599	9 606	12 967
Investment	2 701	4 017	5 357
Exports	1 804	3 056	4 432
Imports	1 822	2 972	4 258

Sources : Cambridge Econometrics.

[36] There are small differences in the *levels* between E3ME and PRIMES because the two model use different vintages of historical data.

Table 5.2: E3ME Baseline Output by Sector, €2005bn, EU28

	2010	2030	2050
Agriculture	411	488	491
Extraction Industries	121	145	171
Basic manufacturing	2 850	4 007	5 113
Engineering and transport equipment	2 419	3 606	4 820
Utilities	691	861	979
Construction	1 452	2 147	2 661
Distribution and retail	2 235	3 600	5 135
Transport	714	1 149	1 608
Communications	2 194	3 537	4 998
Business services	4 917	7 802	11 108
Public services	3 654	5 079	6 417
Total	21 658	32 421	43 501

Sources: Cambridge Econometrics.

E3ME's (total) consumer spending was set to grow at the same rate as the household income figures, following the standard economic assumption that, in the long run, all income is spent. Detailed consumer spending by spending categories was set to grow using historical trends and then constrained to the total.

Other components of output (at sectoral level), mainly investment and trade, were also set to grow at rates based on historical rolling averages and then constrained to the total output that was based on the GVA projections.

Prices for industries other than the energy-related ones reported in the PRIMES figures were projected using historical trends.

The E3ME baseline employment numbers are shown in Table 5.3.

Table 5.3: E3ME Baseline Employment by Sector, m, EU28

	2010	2030	2050
Agriculture	11.6	9.4	6.7
Extraction Industries	0.8	0.5	0.6
Basic manufacturing	16.8	14.9	11.4
Engineering and transport equipment	16.6	15.3	13.2
Utilities	2.6	2.3	2.6
Construction	16.1	16.5	12.9
Distribution and retail	32.5	35.2	27.9
Transport	7.0	6.9	6.1
Communications	21.3	22.9	23.9
Business services	35.3	41.0	49.9
Public services	65.8	66.8	63.3
Total	226.4	231.7	218.5

Sources: Cambridge Econometrics.

The policy scenarios

In each policy scenario, the emission reduction targets for 2050 are met. However, the means to achieve the targets vary between scenarios. The main modelling inputs are:

- developments in the power generation sector, in terms of:
  - capacity, generation, fuel consumption
  - investment
  - electricity prices
- investment in energy efficiency
- carbon pricing
- fuel switching in the transport sector
- increased vehicle efficiency
- revenue recycling

In general the scale of the inputs matches that which is given in the Energy Roadmap. In two cases, the model outturns did not achieve the emission reduction targets when the Energy Roadmap inputs were used, and so a greater level of effort (a stronger policy) was implemented in the model. These cases were: (1) the scale of investment in energy efficiency, and (2) the carbon price. These differences are discussed in the relevant sections below.

Each of the inputs is described here.

Power generation

Although E3ME includes its own bottom-up model of the electricity sector, it is not as detailed as the PRIMES model and so we take the results from PRIMES as exogenous. This means that the E3ME results match those from PRIMES for the generation mix up to 2050.We also match the scale of generation using CCS to the PRIMES results.

We have imposed by assumption the amount of investment required to construct new generation capacity; again this is consistent with the figures published in the Energy Roadmap.

The electricity price is a key input to the scenarios. The standard approach in E3ME is to link electricity prices to 'levelised costs'. Under this methodology, unit generation costs are estimated based on capital and operating costs for each plant type (with the capital costs spread over the lifetime of the plant). Electricity prices are based on the unit generation costs plus a mark-up.

We estimated electricity prices for each scenario (based on our own data) and then compared the results to the figures presented in the Energy Roadmap. As our results were similar to those that were published, we fixed electricity prices to match those in the Energy Roadmap. The comparison exercise provides some reassurance that imposing the Energy Roadmap electricity prices does not introduce a major inconsistency into E3ME.

Investment in energy efficiency

A large part of the reduction in CO_2 emissions is achieved through increases in energy efficiency. Some of these increases can be brought about through behavioural change, but it is also necessary to invest in new equipment and buildings.

The starting point for defining the investment was the figures (in monetary terms) that are quoted in the Energy Roadmap. This is then converted into units of energy savings using a coefficient derived from the IEA's World Energy Outlook (IEA, 2012). This investment was then shared between energy carriers, sectors and countries in proportion to energy consumption. Finally, the energy saving per unit of investment was calibrated so that the outcome for energy use in the scenarios broadly matched the outcomes shown in the Energy Roadmap.

It is assumed that the investment is funded directly by government subsidy and this is included in the policy scenarios as exogenous. Investment that takes place therefore affects the public balance and revenues available for recycling (see below). If we had assumed the lower level of investment in energy efficiency published in the Roadmap, additional revenues would have been available for recycling: there would have been a smaller boost to sectors dependent on investment spending (construction and engineering) and a larger boost to sectors benefiting from the recycled revenues.

Carbon pricing

Carbon pricing is another key component of the scenarios. It is assumed that current policy arrangements remain in place up to 2020, but ETS prices are allowed to increase up to 2025 and then an economy-wide carbon price is implemented over the rest of the forecast period. It is assumed that there is full auctioning of ETS allowances from the power sector post-2020 and revenues are also generated by the carbon tax imposed on the non-ETS sectors.

The carbon prices required (according to E3ME's energy consumption equations) to meet the emission reduction targets are similar to those in the Energy Roadmap but slightly higher. They are discussed in Chapter 4.

Fuel switching in vehicles

The transport sector is an important contributor to overall emissions levels up to 2050 and so some additional factors were included in the scenarios.

E3ME does not currently model fuel switching in vehicles as there are no historical data on which to estimate model parameters. The shares of electricity and biofuels in final energy consumption by road transport are therefore set by assumption to match the estimates in the Energy Roadmap.

Increased vehicle efficiency

An additional efficiency factor was added to the road transport sector to take into account regulation on fuel efficiency and emissions standards. This had a modest impact on total emissions levels by 2050.

Revenue recycling

All of the scenarios are revenue neutral in design, meaning that any direct changes in tax revenues or spending rates are balanced. In the scenarios presented in this report, the policies that affect directly the public balance are the carbon pricing (both auctioned ETS allowances and carbon tax revenues) and the funding for investment in energy efficiency.

The net effect on government revenues arising from these two measures is balanced by changes in employers' labour taxes (or social security contributions). The revenue recycling therefore directly affects the cost of labour, with any reductions in tax rates likely to lead to increases in employment levels. In countries where employers' social contributions are already close to zero, it is possible that the revenues will be used to subsidise labour. We test the effect of alternative ways of recycling the revenues in the sensitivity analysis.

It should be noted that the final results can be quite dependent on the revenue recycling. The different methods of accumulating and spending revenues (e.g. carbon taxation, investment, labour taxes) have different employment effects. The final net employment results include all these effects but weighted differently in the scenarios. This is discussed further below (see Table 5.8).

5.4 Model results

Overview This section presents the model results. We start with the inputs that were derived to obtain the targets, then consider the energy and emissions impacts, the macroeconomic outcomes and the impacts on employment. The final part of this section considers some of the other labour market indicators from the modelling.

The inputs required Due to differences in model design, specification and parameters, our inputs are not able to match exactly those from the Energy Roadmap while still meeting the emission reduction targets. As described in the previous section, we therefore scaled up the carbon prices and efficiency investments so that the targets were met. In addition, the revenues available for recycling were calculated and used to adjust tax rates on labour.

Table 5.4 summarises the revised scenario inputs that were used. The 2050 carbon prices in the scenarios range from just over €300/tCO_2 in S1 to almost €400/tCO_2 in S5; the pattern of the differences between scenarios is similar to that in the Energy Roadmap. The amount of additional (public-funded) investment in energy efficiency amounts to more than €5 trillion over the period up to 2050 in most of the scenarios; in the energy efficiency scenario (S1) our analysis shows that the amount of investment required almost doubles (this is consistent with the finding in the Energy Roadmap). It is assumed that this investment is additional to investment in the baseline and does not cause ‘crowding-out’ effects. This assumption is significant and is discussed further in Section 5.5.

Table 5.4: Inputs to the Scenarios

	Carbon Price (2050), €/tCO_2 (2008 prices)	Investment*, cumulated to 2050, €bn (2008)	Average Employers' Social Security Rate (2050)
Baseline	51.7	0	18.1
S1	304.6	10 053	17.6
S2	341.9	5 452	15.5
S3	366.1	5 589	15.3
S4	352.8	5 486	15.5
S5	396.4	5 486	15.1

Notes: * Investment shown is additional to that which is in the baseline.
Sources: E3ME, Cambridge Econometrics.

Employers’ social security tax rates are set so as to balance government revenues so that the scenarios are directly revenue neutral compared with the baseline. The rates are set at national level; the table shows a European average for 2050.

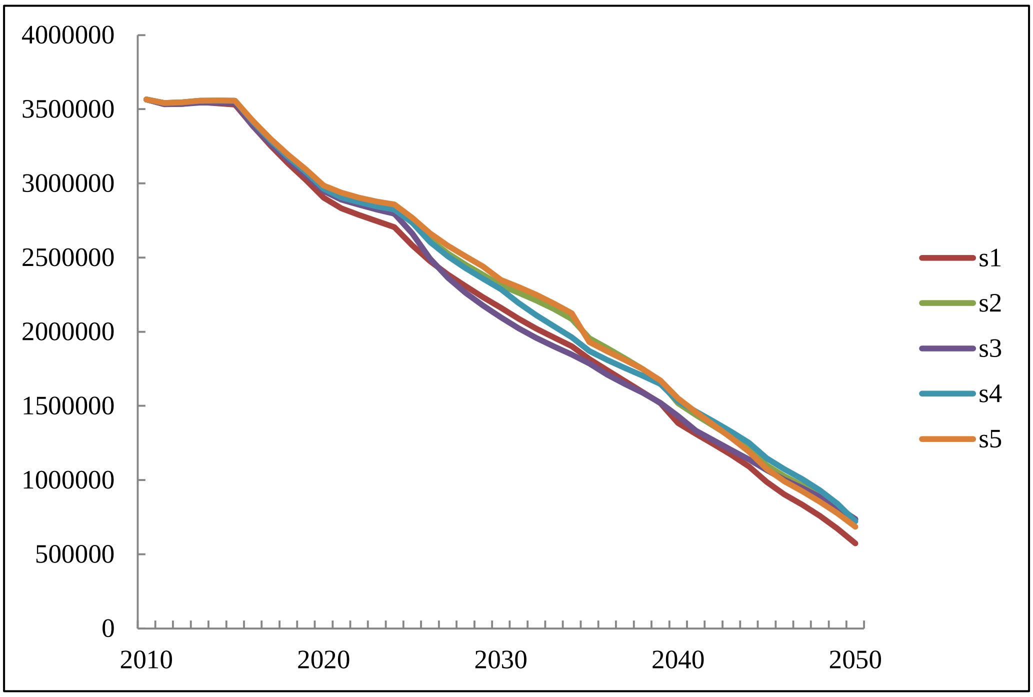
Electricity prices Table 5.5 shows the different retail electricity prices that were used in the scenarios. It is immediately obvious that electricity prices are much higher in the High RES scenario (S3), reflecting the higher cost of generation from renewables. In the high energy efficiency scenario, there is not much difference from the baseline electricity prices.

Table 5.5: EU Average Electricity Prices (€/toe, 2008 prices)

	2010	2020	2030	2040	2050
Baseline	1 400.7	1 411	1 420	1 426	1 436
S1		1 412	1 442	1 437	1 389
S2		1 405	1 430	1 430	1 385
S3		1 495	1 665	1 785	1 853
S4		1 416	1 455	1 467	1 439
S5		1 411	1 420	1 426	1 436

Notes: 1 toe = 11630kWh.
Sources: Cambridge Econometrics, Energy Roadmap.

Figure 5.2: EU27 CO_2 Emissions from Energy Use, th tCO_2



Energy and environment

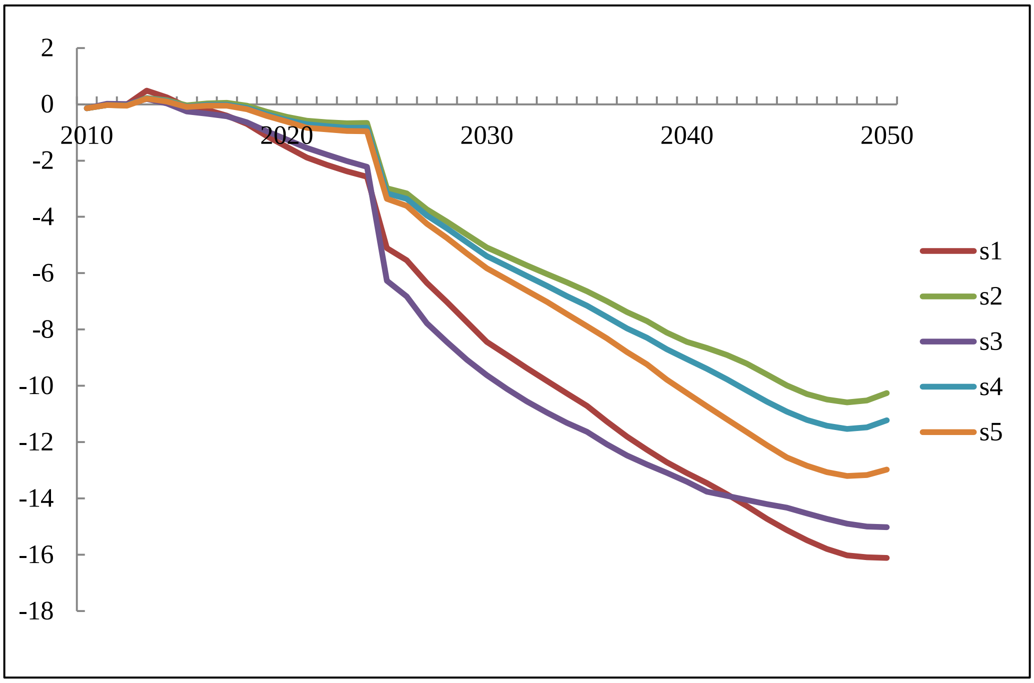
Figure 5.2 shows the overall profile of the reduction in emissions. The end point in 2050 is given by the reduction target. Within this aggregate reduction, emissions from power generation fall to almost zero (including the contribution from CCS) and most other sectors see a reduction in emissions of around 60% compared to the baseline. The transition path is broadly linear.

The reduction in final energy consumption is much smaller. This reflects the large share of the emissions reduction that is due to:

- switching between fossil fuels
- switching to renewable electricity
- switching to nuclear electricity
- take-up of CCS

The reduction in final energy consumption varies across the scenarios, but not necessarily in the way we might have expected (see Figure 5.3) before taking account of price changes. While the reduction in energy consumption is slightly larger in the high energy efficiency scenario (S1), as expected, a similar reduction is found in the high RES scenario. The reason for this is that electricity prices are much higher in this scenario (see Table 5.5) and, as electricity makes up a large share of total consumption, this pushes down overall energy demand.

Figure 5.3: EU Final Energy Demand Reduction, % from baseline



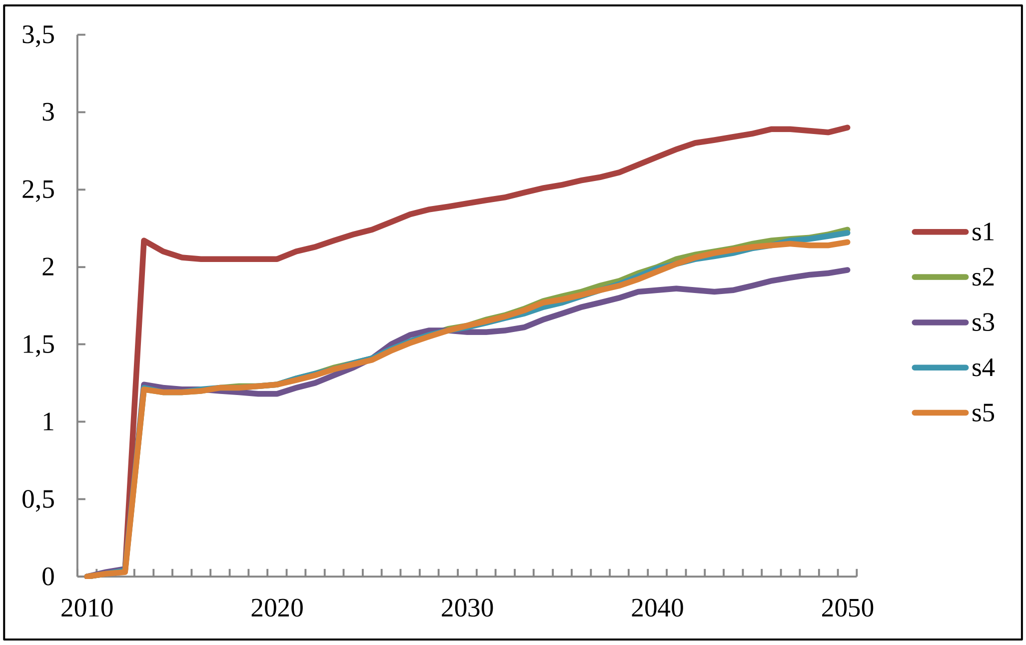
Macroeconomic impacts

For most sectors, employment levels in E3ME are modelled as a function of economic output and relative labour costs. To understand and interpret the employment impacts it is therefore necessary first to consider the context given by the macroeconomic impacts of the scenarios. Figure 5.4 presents the overall impact on GDP over time, compared to the baseline. There is a positive net effect in all the scenarios, but it is important to remember that some of this is due to the assumption that global oil prices will be lower (see Section 5.5). The largest increase in economic output is in the high energy efficiency scenario (S1), reflecting the strong boost to investment (which does not crowd out investment by other sectors in E3ME, see Section 5.5)[37], while the high renewables scenario (S3) has a slightly lower outcome than the others.

The profile of the GDP impacts to some extent reflects the scenario assumptions. We have assumed that the additional investment is spread evenly over the period 2013-50, meaning that there is a large increase in the first year that is then maintained throughout the projection period. Further increases in GDP (compared to the baseline) are due largely to the oil price used in the scenarios, which falls (relative to the baseline) gradually over time.

[37] The investment is paid for by higher rates of employers' social security tax rates. While this may lead to higher prices and some loss of competitiveness, it is not enough to offset the positive contribution to GDP from higher investment.

Figure 5.4: EU28 GDP, % difference from baseline



Results by economic indicator

Table 5.6 shows the results by main economic indicator for 2050. This confirms that the reason S1 comes out higher is the much larger scale of investment required to meet the emission reduction targets. Despite having higher GDP, household expenditure in this scenario is actually lower than in most of the other scenarios, in part due to lower employment rates (discussed below).

In the diversified, delayed CCS and low nuclear cases (S2, S4 and S5) there is little noticeable difference between the macroeconomic results. The impact on GDP is slightly lower compared to that of S1 due to the smaller scale of investment required to meet the target. The positive impact on household consumption is higher under most of these scenarios than S1 due to the correspondingly larger employment impacts (see discussion of employment impacts below).

GDP impacts are lowest (but still positive) under the High RES Scenario (S3). This is due to the effect of an increased share of renewables in power generation on electricity prices, and the pass-through of these costs to households. As a result, there is an increase in the consumer price level which offsets some of the positive impact of the employment effects on household income and consumption.

Table 5.6: EU28 Summary of Results, % difference from baseline, 2050

	S1	S2	S3	S4	S5
GDP	2.9	2.3	2.0	2.2	2.2
Consumption	1.3	1.5	1.1	1.4	1.3
Investment	7.4	4.0	3.4	4.0	3.8
Exports (extra-EU)	0.4	0.4	0.2	0.3	0.2
Imports (extra-EU)	0.5	0.0	-0.6	-0.1	-0.2
Prices	-0.3	-0.5	0.2	-0.3	-0.1

Sources: E3ME, Cambridge Econometrics.

Table 5.7: EU28 Output by sector, % difference from baseline, 2050

	S1	S2	S3	S4	S5
Agriculture	3.1	2.8	2.5	2.8	2.7
Extraction Industries	0.5	0.0	-0.1	0.1	-0.3
Basic manufacturing	5.2	3.7	3.4	3.7	3.6
Engineering and transport equipment	5.1	2.9	2.3	2.9	2.8
Utilities	10.2	-3.3	-7.1	-3.3	-3.1
Construction	10.0	5.7	5.2	5.7	5.6
Distribution and retail	2.3	1.8	1.6	1.8	1.7
Transport	1.8	1.8	1.2	1.7	1.5
Communications	4.0	3.2	2.9	3.1	3.1
Business services	3.1	2.3	2.0	2.3	2.2
Public services	1.2	1.1	1.1	1.1	1.1

Sources: E3ME, Cambridge Econometrics.

In terms of competitiveness effects, there is a very small increase in exports to the rest of the world under all five scenarios, although this is a result mainly of the reduced oil prices in the policy scenarios. Imports of fossil fuels are reduced in the scenarios, but imports of some other goods increase.

Sectoral results

Table 5.7 shows the main impacts at broad sectoral level. As might be expected, the sectors that benefit the most in all the scenarios are the ones that produce investment goods, such as construction and engineering; this is particularly the case in S1.

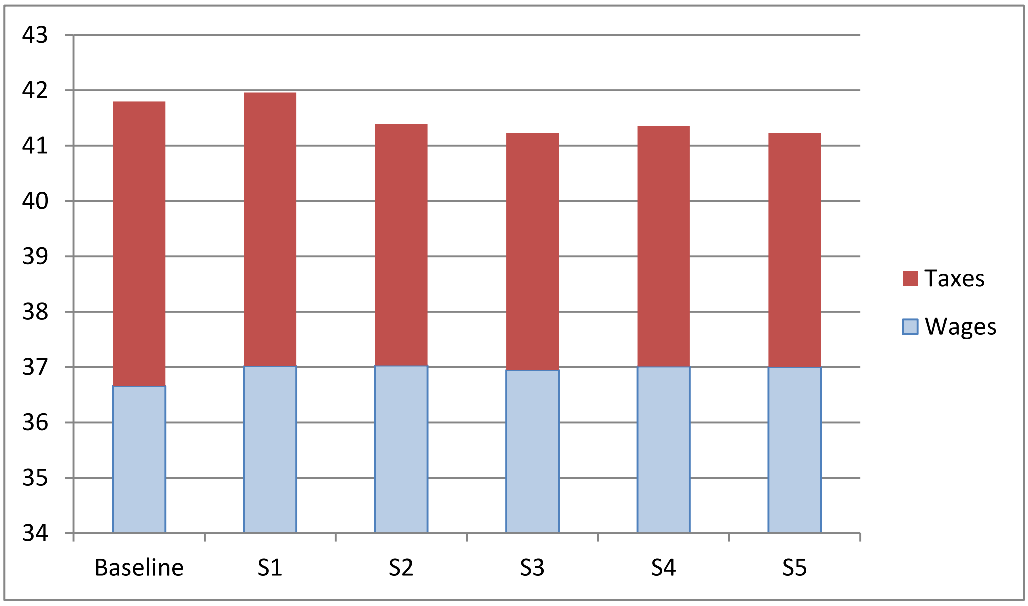
The effects on other sectors are somewhat more complicated to interpret. Some of the energy-intensive sectors (basic metals and mineral products) are an important part of the supply chains that produce the investment goods, but the impact of the carbon prices makes their products more expensive. For scenarios S2, S4 and S5, in which the carbon price does much more of the work in achieving the target compared to the energy efficiency investments undertaken in S1, there is a relatively large reduction in output in the electricity and gas supply sectors. This has a knock-on effect up the supply chain on the extraction industries. The largest reduction in the output of the utility supply sectors occurs under S3, due to the increased cost of power generation when renewables penetration is high. Most services sectors see small increases in overall output, but the increase is less than the average increase in GDP.

Wage rates and labour costs

Figure 5.5 presents the change in average labour costs in each scenario, split into wages and tax (social security) payments. Wage rates are determined endogenously in E3ME at the sectoral level and are influenced by productivity, inflation rates, unemployment rates and wages in other sectors/countries. The full equation specification is provided in the model manual.

In these scenarios, the tax element is determined by the scale of revenue recycling. In the baseline it is assumed that employers' social security contribution rates remain fixed over time. In the policy scenarios the rates change in response to the level of carbon tax and ETS revenues and the amount of publicly funded investment required.

Figure 5.5: EU28 Average Annual Labour Costs (adjusted axis, €000s, 2008 prices)

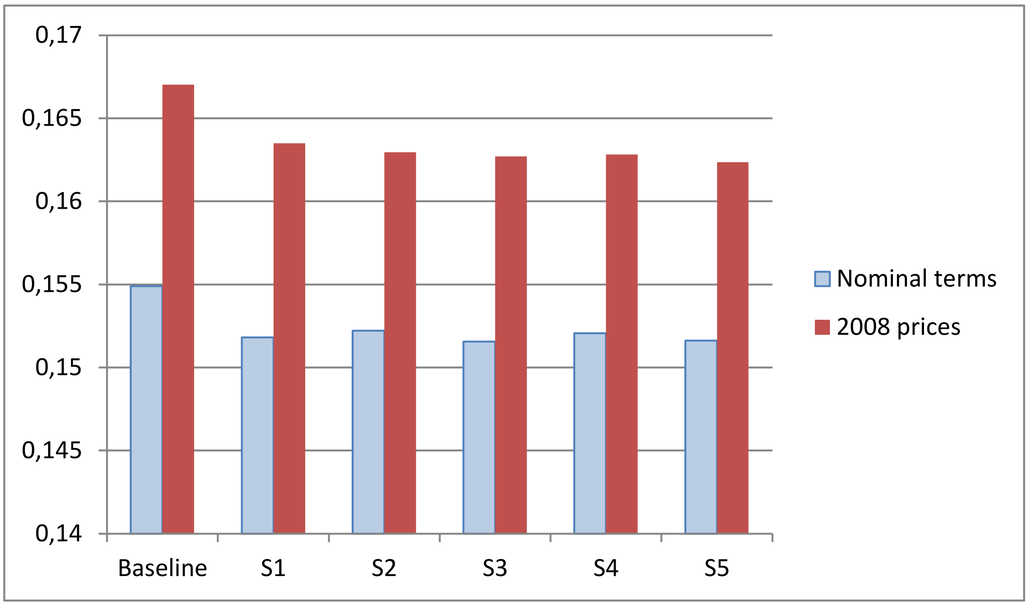


The figure shows that there is little change in average wage rates across the scenarios, but the tax element is higher in the energy efficiency scenario (S1). The higher investment costs in this scenario mean that the net revenues available for recycling to reduce labour taxes are lower. Higher labour costs results in lower employment levels.

It is important to note that, while total wages are higher in the scenarios compared to baseline (by around 2%), the reduction in labour taxes and increase in economic activity from the additional investment in energy efficiency result in a higher level of employment, such that average wages rates remain relatively constant across scenarios.

Figure 5.6 presents EU28 unit labour costs (defined as total wages plus taxes paid per unit of output) in each scenario. The slight decrease in unit labour costs across the scenarios (both in nominal and real terms) is the result of lower labour taxes (because of revenue recycling) as well as an increase in output, caused by the additional investment in energy efficiency. In the case of the energy efficiency scenario (S1), because of the higher tax element, the reduction in unit labour cost is mostly a result of increased output.

Figure 5.6: EU28 Unit Labour Costs, 2050, wages and taxes per unit of output



Employment Figure 5.7 presents the employment impacts of the scenarios compared to the baseline. Again it should be remembered that the results show the combined impact of both the policies and the reductions in international energy prices.

Up until 2025 there is little change in overall European employment levels in the scenarios compared with the baseline. However, once the carbon tax is applied to the non-ETS sectors, there is an increase in employment that is maintained throughout the rest of the projection period.

This illustrates the trade-offs that are involved in these scenarios. The primary driver of higher employment rates is the revenue recycling that directly reduces labour costs (see below). This is balanced against the large amounts of investment required, which also create more jobs but not as many as the equivalent reduction in labour taxes. For this reason S1, which has the highest amount of investment, results in the least positive outcome for employment, despite having the best outcome for GDP. By 2050 in S1 there is an additional 2.9m jobs compared to baseline, while the other scenarios have increases of 3.0-3.2m jobs.

Figure 5.7: EU28 Employment, % difference from baseline

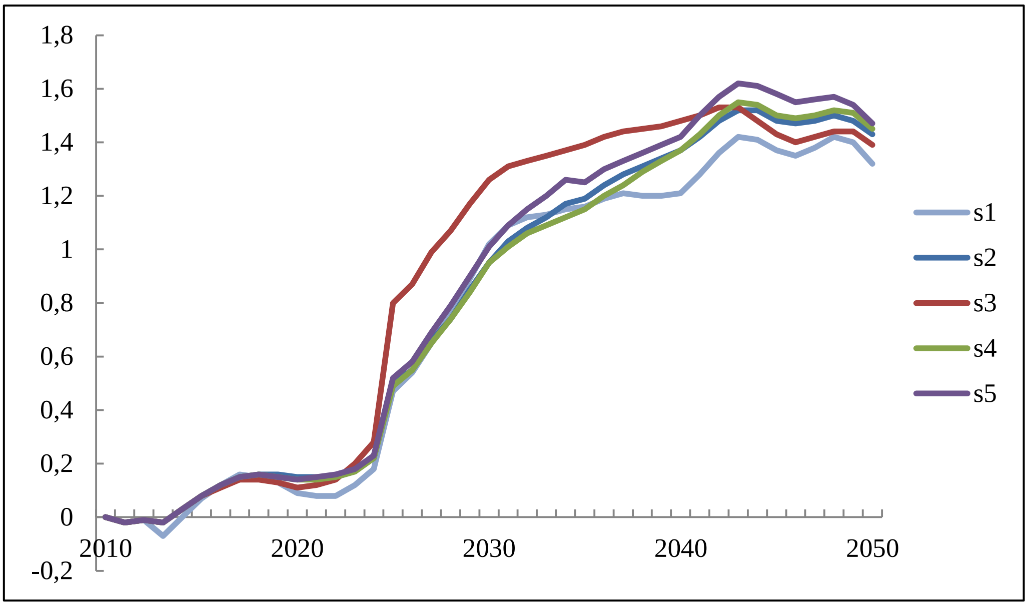


Table 5.8 summarises this relationship by showing the changes in employment that E3ME predicts would arise from €100bn of annual spending in different ways, compared with the reduction in jobs associated with €100bn raised through carbon taxes. The net impact is positive: more jobs are gained from the ways in which the revenues are recycled than are lost by raising the revenue.

The key relationship is the one between employers' social security contributions and investment. As €100bn spending on employers' social contributions creates more jobs than €100bn of investment, the scenarios that have the highest investment levels (and therefore the lowest reductions in employers' contributions) come out with less positive results for employment. This explains why employment results for S1 are lower than for the other scenarios.

However, it should be stressed that the ranking of the scenarios is dependent on the assumption about how revenues are used. If instead the revenues from carbon taxes were used to reduce VAT or income tax rates, the scenarios with more investment could create more jobs. **The method of revenue recycling is therefore important in determining the ranking of the scenarios in terms of employment.** This is considered further in the next section.

The methodology used to derive the figures in the table is provided in Appendix D.

Table 5.8: Employment changes associated with revenue raising and recycling

Expenditure	Additional Jobs for €100bn spend
Carbon tax*	-182 406
Employers' social contributions	815 443
Public investment	708 441
Income taxes	221 484
VAT	291 730

Notes: Table shows additional jobs created in 2020 for €100bn (2008 prices), stepped up gradually over time. * The carbon tax is applied to the non-power sector and raises, rather than spends, revenue. See Appendix D for details.
Sources: E3ME, Cambridge Econometrics.

Sectoral employment

The outcomes for sectoral employment broadly follow those for sectoral output described above, with construction, engineering and their supply chains benefiting the most. Table 5.9 shows that, as noted above, employment effects in S1 are lower than in the other scenarios, as the revenues available for recycling are much lower for all sectors (and by 2050 employers' rates increase for many countries).

In general, there are quite large increases in employment in all sectors, with the exception of the extraction sectors (which are small and treated as exogenous in the modelling) and utilities.

Table 5.9: EU28 Employment by sector 2050, % difference from baseline

	S1	S2	S3	S4	S5
Agriculture	1.4	1.7	1.7	1.7	1.9
Extraction Industries	0.0	0.0	0.0	0.0	0.0
Basic manufacturing	2.6	2.2	2.2	2.2	2.3
Engineering and transport equipment	1.8	1.8	1.7	1.7	1.8
Utilities	0.0	0.0	0.0	0.0	0.0
Construction	2.7	2.6	2.4	2.7	2.7
Distribution and retail	1.5	1.4	1.2	1.4	1.4
Transport	1.2	1.5	1.5	1.6	1.7
Communications	2.8	2.5	2.4	2.5	2.6
Business services	1.0	1.1	1.1	1.1	1.1
Public services	0.4	0.9	0.9	0.9	0.9

Sources: E3ME, Cambridge Econometrics.

Power sector employment

Using coefficients estimated from the data presented in Chapter 2, more detailed results are available for the power sector. These are presented in Table 5.10.

It should be noted that the projections are based on assumptions about fixed number of jobs per GW of installed capacity, and that these assumptions do not change over time; this could affect the results for solar in particular which are likely to be over-estimates. This is tested in the next section. The coefficients are given in Appendix D.

Table 5.10: Power sector employment, thousand persons, EU28, 2050

	BASE	S1	S2	S3	S4	S5
Conventional	250.5	74.7	110.4	45.5	72.1	146.4
Hydro	31.6	31.9	31.9	32.1	31.9	32.0
Nuclear	136.2	84.2	110.7	25.1	130.9	16.6
Solar	1 185.0	1 671.7	1 774.7	2 866.0	1 764.4	1 900.6
Wind	355.4	445.9	484.6	749.5	497.3	532.0
Geothermal	2.9	4.3	5.3	8.9	6.3	6.4
Biomass	35.1	41.5	40.7	46.6	43.2	42.8
Tidal	32.3	40.1	40.6	71.9	40.2	49.2

Sources: E3ME, Cambridge Econometrics.

Employment by Member State

Table 5.11 shows the employment impacts at Member State level. With only a few exceptions, employment increases by between 0 and 2% compared to the baseline. As outlined above, the increases in employment are due to a combination of oil price effects, investment and reductions in employers' labour taxes. The results at Member State level reflect the relative magnitude of the impacts of each of these, as well as linkages between the Member States. The countries where the impacts are largest are often those that are smaller and relatively more dependent on more volatile trade flows; these are usually located in Central and Eastern Europe. These countries are also often more energy intensive and have lower existing energy prices, making them more sensitive to the policies in the scenarios.

In almost all cases the results for S1 are less positive than the results for the other scenarios, and the only examples of employment decreases are in this scenario. Sweden is the main exception to this, in part because of the nature of its domestic industry that produces investment goods. For similar reasons, Denmark is one of the few countries that has more positive results for the high RES scenario (S3).

Croatia is another exception. The model outputs suggest a very high level of investment would be required in Croatia to meet the emission reduction targets; while this could lead to a large expansion of the construction sector it is also very likely that there would be capacity constraints preventing this from happening.

Table 5.11: Employment in the scenarios by Member State, % difference from baseline

	S1	S2	S3	S4	S5
Belgium	0.3	0.6	0.7	1.0	0.7
Denmark	1.7	1.5	2.2	1.6	1.5
Germany	1.2	1.2	1.2	1.2	1.2
Greece	1.7	1.4	1.2	1.4	1.5
Spain	1.9	1.6	1.5	1.7	1.6
France	1.2	1.2	1.1	1.2	1.2
Ireland	0.8	1.0	1.0	1.0	1.1
Italy	1.3	1.6	1.3	1.6	1.6
Luxembourg	1.9	1.7	1.7	1.7	1.9
Netherlands	1.4	1.6	1.4	1.6	1.6

Austria	1.1	1.3	1.2	1.3	1.4
Portugal	1.9	1.7	1.6	1.7	1.8
Finland	1.6	1.7	1.2	1.7	1.7
Sweden	1.4	0.8	0.8	0.8	0.9
UK	0.6	1.1	1.2	1.2	1.2
Czech Republic	1.7	1.8	2.0	1.9	1.8
Estonia	2.5	2.3	2.0	2.2	2.3
Cyprus	2.9	2.9	1.8	2.9	2.4
Latvia	2.2	2.9	3.2	2.9	3.0
Lithuania	2.3	2.7	2.7	2.7	3.5
Hungary	1.5	2.1	2.0	2.0	2.1
Malta	2.2	2.3	2.1	2.3	2.4
Poland	1.3	1.6	1.8	1.5	1.7
Slovenia	2.6	3.2	2.5	2.9	3.4
Slovakia	2.0	2.4	2.1	2.3	2.5
Bulgaria	3.7	3.7	3.9	3.6	3.3
Romania	2.1	1.9	1.9	1.9	1.9
Croatia	2.7	3.0	3.0	2.9	3.5

Sources: E3ME, Cambridge Econometrics.

Other labour market indicators

Although population is treated as exogenous in E3ME, rates of labour market participation are modelled. Labour participation rates are higher when:

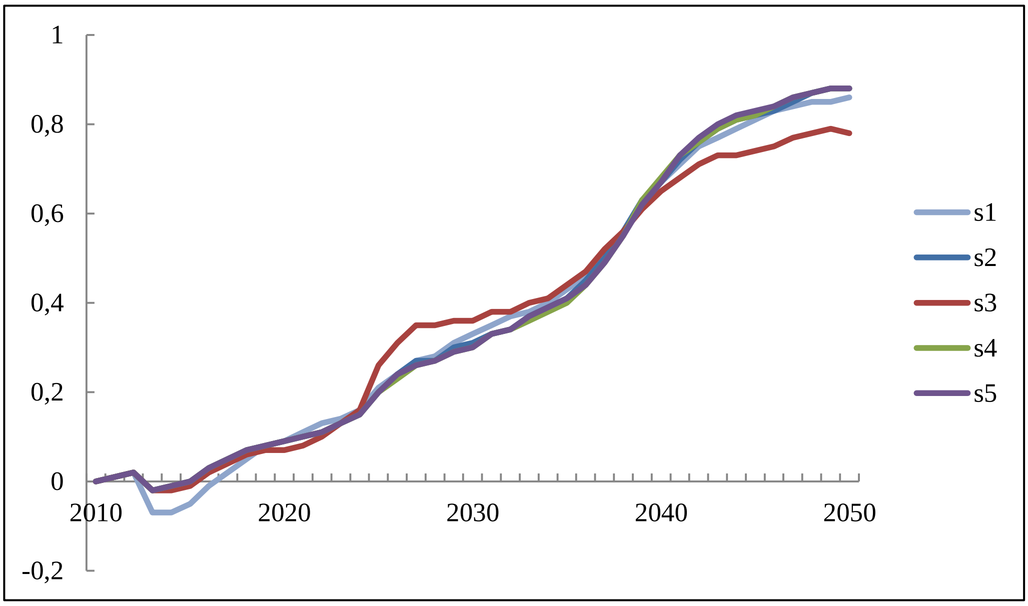
- economic output is higher
- real wages are higher
- skills levels are higher
- unemployment is lower

Each relationship is empirically estimated and the full equation specification is provided in the model manual. Labour market productivity affects participation rates indirectly through the higher wages that more productive workers can demand.

Figure 5.8 shows how the scenarios impact on labour supply. Overall there is a gradual increase in impact on labour supply over time (although again this is partly due to oil price assumptions). It is noticeable that the increase in labour supply only begins after 2025, when employment growth is higher (mainly due to the carbon tax and increased revenue recycling). The increase in labour force is mainly driven by older workers postponing retirement decisions. These impacts occur in the context of a *declining* labour force due to an aging population in the baseline.

The increase in labour supply is slightly higher in the diversified, delayed CCS and low nuclear scenarios (S2, S4 and S5). This is because these three scenarios have higher employment rates than the energy efficiency case (S1) and higher rates of real incomes and output than the high RES case (S3).

Figure 5.8: EU28 Labour Force, % difference from baseline



Unemployment

Unemployment in E3ME is determined as the difference between labour supply and labour demand. The charts presented in this section have shown that in the scenarios there are increases in both indicators. However, as E3ME does not assume market-clearing wages in the labour market (or market-clearing prices in other markets), wages do not adjust to balance the increases in supply and demand, even in the long run.

Table 5.12 presents the changes in unemployment in the scenarios. It should be stressed that some of the reduction is due to the lower oil prices in the scenarios. The net effect is to reduce unemployment in Europe by around 650,000 to one million persons. The reduction is smaller in the energy efficiency case due to the lower employment increases.

Table 5.12: Change in Unemployment, EU, 2050

Scenario	Change in Unemployment, 000s
Energy Efficiency (S1)	-655.6
Diversified Supply (S2)	-808.9
High Renewables (S3)	-945.8
Delayed CCS (S4)	-859.5
Low Nuclear (S5)	-893.3

Sources: E3ME, Cambridge Econometrics.

Average working hours

The employment results presented in this section are measured on a headcount basis. Another way that labour demand can increase is through increases in average working hours. E3ME includes a set of equations that determines average working hours based on economic demand and available capacity. However, the results from the model show that there is very little impact on working hours in the long run, with a maximum impact in some Member States of +0.1% by 2050.

5.5 Sensitivity analysis

This section only summarises the results from the sensitivity analysis, a more detailed set of results is provided in Appendix C.

Sensitivity testing was carried out for:

- the oil price effect
- baseline rates of GDP growth
- investment crowding out effects
- employment ratios
- different types of revenue recycling

These are discussed in turn below.

Factoring out the oil price effects

The policy scenarios include an ambitious programme of decarbonisation in the rest of the world that leads to an oil price that is lower than in the baseline. The modelling results therefore include both the impact of European policy and that of lower oil prices (which benefit European consumers at the expense of non-European producers). For this reason, and in order to isolate the effects of EU policy, Table 5.13 presents scenario results produced relative to a baseline where the oil price is the same as in the main scenarios. The table includes results for the EU28 as a whole, including all sectors.

As expected, when oil price effects are factored out, the employment impacts are lower than those presented in the previous section. The difference is around 600,000 jobs.

Table 5.13 Employment Impacts without the Oil Price Effect in 2050 (EU28, ‘000s)

Scenario	Change in Employment, excluding oil price effect	Change in Employment, main scenarios
Energy Efficiency (S1)	2 288	2 870
Diversified Supply (S2)	2 540	3 123
High Renewables (S3)	2 437	3 019
Delayed CCS (S4)	2 580	3 162
Low Nuclear (S5)	2 627	3 209

Notes: The first column shows results compared to a baseline where the oil price is the same as in the policy scenarios. The right hand column shows the results compared to the main baseline (which has the higher oil price).
Sources: E3ME, Cambridge Econometrics.

Changes to baseline economic growth rates

Table 5.14 shows the impacts in a case where the underlying GDP growth in Europe is higher. An exogenous increase in exports was added to the baseline and all the scenarios, so that GDP in 2050 is around 15% higher than in the main baseline. As would be expected, baseline employment levels in this sensitivity are also higher.

The table shows that the impacts of the scenarios are very similar, regardless of baseline GDP growth rates. When baseline GDP is higher, there is an increase in additional employment. This is because the higher level of economic activity generates a higher level of carbon tax revenues in the scenarios, which are used to lower the rate of employers' social security contributions, thereby encouraging a somewhat larger increase in employment.

Table 5.14: Employment Impacts with Higher Baseline GDP Growth in 2050 (EU28, '000)

Scenario	Change in Employment, higher baseline GDP	Change in Employment, main scenarios
Energy Efficiency (S1)	3 256	2 870
Diversified Supply (S2)	3 466	3 123
High Renewables (S3)	3 382	3 019
Delayed CCS (S4)	3 484	3 162
Low Nuclear (S5)	3 589	3 209

Notes: The first column shows net change in employment when the same policy scenarios are run but with higher rates of GDP growth in the baseline and the scenarios. The right hand column shows the results from the main scenarios compared to the main baseline.
Sources: E3ME, Cambridge Econometrics.

Possible 'crowding out' effects

It is an implicit assumption in these results that there is available finance for investment. This finance could come from outside Europe or be diverted from financial assets. This sensitivity considers the case in which the financing is instead diverted from other real investments in the EU. Effectively it shows the main results minus the positive effects of the additional investment.

Table 5.15 shows the impacts of the scenarios under these revised assumptions. The employment benefits are much smaller, around 1.3m less than in the baseline (2m in S1 due to the higher investment). However, they are still positive in all scenarios, due to a combination of the oil price effects and the revenue recycling.

Table 5.15: Employment Impacts with 'Crowding out Effect' in 2050 (EU28, '000)

Scenario	Change in Employment, 'crowding out effect'	Change in Employment, main scenarios
Energy Efficiency (S1)	926	2 870
Diversified Supply (S2)	1 839	3 123
High Renewables (S3)	1 708	3 019
Delayed CCS (S4)	1 872	3 162
Low Nuclear (S5)	1 952	3 209

Notes: The first column shows net change in employment when the same policy scenarios are run but with no additional investment due to crowding out. The right hand column shows the results with no crowding out.
Sources: E3ME, Cambridge Econometrics.

Testing different employment ratios

The employment ratios are the number of jobs in each type of power generation per unit of installed capacity. In the main scenarios, the employment ratios are derived from the figures presented in Chapter 2. This may produce an over-estimate of the projected number of jobs, as there may be economies of scale in the future as installed capacity increases. For example, if more solar panels are installed, people employed in maintaining them would spend less time travelling between sites.

We tested two sensitivities to assess the overall impact of this assumption. In the first of these we assume that the employment ratios in new renewable technologies (i.e. excluding wind and hydro) fall to a rate that is similar to fossil fuel plants; in the second we assume that the ratios fall to a rate that is similar to wind.

Table 5.16 presents the results under the revised assumptions. It shows that the effects are very limited at macroeconomic level (although there are some quite substantial differences within the electricity supply sector).

Table 5.16: Employment impacts with different power sector assumptions (EU28, '000)

Scenario	Coefficients similar to Fossil Fuels	Coefficients similar to Wind	Change in Employment, main scenarios
Energy Efficiency (S1)	2 872	2 872	2 870
Diversified Supply (S2)	3 122	3 123	3 123
High Renewables (S3)	3 021	3 021	3 019
Delayed CCS (S4)	3 163	3 163	3 162
Low Nuclear (S5)	3 208	3 207	3 209

Notes: The first two columns show net change in employment for the same policy scenarios but with different assumptions about the future labour intensity of the power sector. The final column shows the results from the main scenarios.
Sources: E3ME, Cambridge Econometrics.

Testing alternative revenue recycling methods

As shown in Table 5.8, the different revenue recycling methods can have quite a considerable impact on employment. To some extent the short-term differences shown in that table are maintained throughout the period to 2050, although it should be noted that the employment effects of higher investment tend to decline over time due to rising productivity.

With this in mind, we tested two alternative options for recycling revenues: reducing income tax rates and reducing VAT rates. The reductions in these tax rates were of the same magnitude as the reductions in employers' social contributions so that the scenarios were still revenue neutral. The results are shown in Table 5.17.

Table 5.17: Employment impacts with alternative revenue recycling (EU28, '000)

Scenario	Change in Employment, Income Tax Reductions	Change in Employment, VAT Reductions	Change in Employment, main scenarios
Energy Efficiency (S1)	2 735	2 855	2 874
Diversified Supply (S2)	2 989	2 669	3 130
High Renewables (S3)	2 855	2 490	3 026
Delayed CCS (S4)	3 015	2 717	3 166
Low Nuclear (S5)	3 085	2 712	3 220

Notes: The first two columns show net change in employment when the same policy scenarios are run but with alternative forms of revenue recycling. The last column shows the results from the main scenarios.
Sources: E3ME, Cambridge Econometrics.

As expected, both options lead to lower employment increases in the scenarios because the tax reduction is no longer focused on employment taxes. There is not much change in S1 (as the amount of revenues available for recycling are very low anyway) but in the other scenarios there is a modest difference of around 100,000 jobs. This has the effect of reducing the difference between the scenarios.

5.6 Summary

Headline results

The results from E3ME suggest that in the Energy Roadmap scenarios there could be an increase in net EU employment of up to 3m jobs (1.2%). This can be broken down as follows:

- 0.6m are due to a lower international oil price as a result of the global adoption of policies that cut demand for fossil fuels
- 1.3m are due to the additional investment that is required to meet the targets
- the remainder is due to the recycling of revenues from carbon taxes and auctioned ETS allowances

There are also some negative factors in the scenarios:

- a higher carbon price will lead to a loss of jobs in the energy supply sectors and some energy-intensive sectors
- higher electricity prices will lead to some job losses across the economy

By 2050, net employment in the power sector could increase by 0.4 to 0.7m jobs. In the case of high RES the increase could be up to 1.8m jobs. However, it should be noted that there is considerable uncertainty about the power sector results.

Comparing scenarios and revenue recycling

The scenarios are designed to be compared with each other. The key results are as follows:

- The high energy efficiency scenario will have higher investment expenditure. The cost of this investment may be higher than the revenues available from carbon taxation and auctioned ETS allowances, at least in some years. This reduces the scope for using available revenues to boost employment (see below).

- The scenario with a high renewables share has a higher electricity price, which will reduce the net positive impact on jobs.

The results for the other three scenarios are quite similar to each other. One important issue to consider is the revenue recycling method applied. The main scenarios use additional revenues to cut taxes on labour, reducing the overall cost to employers; this has the direct effect of increasing jobs. The alternative revenue recycling measures that were tested also produced increases in employment, but these are not as large.

The choice of revenue recycling method is also important when comparing the different scenarios; the scenarios that have large amounts of surplus revenue appear better when the method of revenue recycling that is adopted is targeted at labour taxes.

Sectoral impacts

The macroeconomic modelling can only assess impacts at the 2-digit sectoral level. In this chapter we have aggregated results to show the main impacts across a set of broad sectors. The qualitative character of the results is as expected: the sectors that produce investment goods (notably construction) are the primary beneficiaries and other engineering firms and their supply chains also increase employment. In addition, the model results suggest that there would be employment increases across almost all the sectors defined in the model.

However, it is important to note that this does not rule out the possibility that particular sub-sectors could see significant job losses, and nor do the net positive effects mean that the structural changes will be smooth, particularly in face of low labour mobility or weak adaptability. Some workers may not be able to move from declining to growing sectors and there may be some localised impacts as well. These issues are discussed in Chapter 7.

6 Results from the GEM-E3 Model

6.1 Introduction

This chapter presents the modelling results from the GEM-E3 model for the scenarios described in Chapter 4. Section 6.2 discusses the modelling methodology and Section 6.3 presents the results. The remaining sections look at the sensitivity analysis and draw conclusions from the analysis.

We compare the results of the two models in Chapter 8.

6.2 Modelling methodology

This section provides the methodology on how the different decarbonisation scenarios were implemented in GEM-E3. In the paragraphs below we present the different mechanisms of GEM-E3 and describe how these are calibrated to replicate the structural changes projected by PRIMES for each decarbonisation scenario.

Like E3ME, GEM-E3 includes a representation of the energy system but lacks the details and engineering information that are present in the PRIMES model. Therefore, as with E3ME, the GEM-E3 power sector projections are calibrated to those obtained from the PRIMES model. This task involves matching the energy system results for the decarbonisation scenarios with the corresponding modules of the economic models. Further details about the power sector are provided below.

GHG emission reduction targets

At the EU level, an 85% reduction in energy related CO2 emissions by 2050 is assumed (which is consistent with the 80% reduction in total GHG emissions). The PRIMES projections include an emissions reduction trajectory in 5-year steps for the period up to 2050. This trajectory is also simulated using GEM-E3 (see Table 6.1).

It is assumed that the non–EU countries adopt ambitious GHG mitigation policies, beyond pledges included in the CPI, so that globally emissions in 2050 are 50% below 1990 levels and global emissions continuously decrease after 2020. This emissions reduction trajectory at the global level is broadly consistent with CO2 emission concentration levels stabilising at 450 ppm, a condition which maintains the chances not to exceed the two degrees temperature rise.

Emissions reductions are implemented in the GEM-E3 model by distinguishing two different groups, namely the EU and the non-EU group. Each group is assumed to set a different carbon price, the level of which is endogenously estimated by the model so as to meet the targeted emissions reduction separately by group. The emissions reduction path for the non-EU group is unchanged in all the decarbonisation scenarios. The emissions reduction in the EU may vary by scenario but the projections make sure that all decarbonisation scenarios emit the same amount in terms of cumulative emissions (carbon budget).

Carbon prices are the main driver of emissions reductions in GEM-E3 in both regional groups; they apply to both ETS and non-ETS sectors (the model endogenously calculates the level of the carbon price so as to meet the given emission reduction constraint). Carbon price revenues by the state are endogenously recycled in the economy (of each group separately) to reduce labour costs by decreasing employers' social security contributions. In previous research using GEM-E3 we have demonstrated that among the various recycling options, reduction of labour costs is the most effective in terms of mitigating the GDP and employment impacts of decarbonisation (a finding also confirmed by the E3ME model).

Table 6.1: GHG emissions reductions

% change from 2005	2020	2030	2050
EU27	20	36	79

Energy efficiency

Energy consumption is endogenous in GEM-E3. Energy consumed by production sectors is derived from profit maximisation (or cost minimisation in case of perfect competition market regimes) under technology possibilities represented by the KLEM production functions which involve a substitution possibility frontier among all production factors depending on relative factor prices. Energy consumed by households is derived from utility maximisation under a revenue constraint. Utility is derived from consumption by purpose (food, clothing, mobility, entertainment, etc.) which is further split into consumption by product. Substitutions are possible depending on relative prices. Consumption by purpose is derived either from consumable goods and services or from the operation of durable goods. For durable goods, stock accumulation depends on new purchases and scrapping. Durable goods include houses, heating and cooking appliances and private cars, which consume (non-durable) goods and services, including energy products. The latter are endogenously determined depending on the stock of durable goods and on relative energy prices.

Energy efficiency in GEM-E3 is realised in three ways:

i) as a result of changes in the prices of energy relative to prices of other commodities and production factors (substitution effect)

ii) through improvement in technical progress embodied in the energy inputs of the KLEM production functions and the functions which determine non-durable goods consumption of durables (the technical progress coefficients being projected exogenously in the version of GEM-E3 used for the present study)

iii) by investing money to improve the energy intensity of production or consumption, along cost-potential energy saving curves which are estimated by sector and are connected with the production and consumption functions in the model.

The cost-potential energy saving curves are calibrated to bottom-up information from various sources and constitute a reduced-form representation of energy saving possibilities, aggregating a large variety of techniques and interventions aimed at improving energy efficiency. The cost-potential curves exhibit decreasing returns to scale (increasing slopes) assuming that the energy saving potential is intertemporally limited by sector.

Spending for energy savings is treated as an investment which has no repercussions on productive capacity but acts on the demand side as it requires goods and services for implementation. The financing of investment for energy saving is modelled in a complex way: a) it can act to the detriment of other factors or goods spending and productive investment if investment is self-financed, for example when an efficiency regulation or standard is imposed on a sector’s activity; b) it can be subsidised by the state together with a mechanism of recovering subsidised costs through (optionally) taxation increase, c) it can be triggered by a virtual incentive which represents the shadow value of a system-wide energy efficiency target with varying incentive values until the overall target is met. Model-based scenarios can combine the above three mechanisms.

Energy efficiency progress through the above mentioned cost-potential energy curves implies that firms and households invest to improve the efficiency of energy use. This further implies that the economy substitutes energy for materials (equipment, insulation, etc.) and services (e.g. provided by technicians for installation). It is assumed that the investment expenditure produces results one period after it takes place and continuously for a period of at least 20 years. The purpose of the investment concerns only the reduction of the unit consumption of energy in the sector or energy use of households, in which the investment takes place.

Economic agents use part of their income (unless they are subsidised) to acquire goods and services that are used to improve their energy efficiency. These goods and services accumulate to an energy saving capital stock that provides permanent energy efficiency improvements.

To enforce the energy saving scheme (implied by the decarbonisation scenarios) to firms and households the following methodology is adopted. The government is assumed to raise a virtual energy tax (proportional to the energy consumption of each economic agent) and imposes a certain rate of taxation to all consumers (firms and households) of energy. The tax rate is endogenously determined so as to collect exactly the amount required to subsidise the energy consumers for undertaking energy saving investment as required to meet the targeted energy efficiency improvement. As tax revenues are used by the government to finance exactly the energy saving expenditures, public budget neutrality is ensured. The GEM-E3 model includes energy efficiency cost curves that relate expenditures with improvements in energy efficiency. Using this relationship it is possible to calculate for each sector the exact amount required to be spent in order to attain certain energy efficiency levels. In modelling terms it is always ensured that the (virtual) tax revenues suffice to finance the required energy saving expenditures. Essentially the government is used in the model to reallocate firms' and households' funds from their "optimum" placement to the required energy saving expenditures; this is why we use the term virtual energy tax. The energy efficiency targets by sector are calibrated to the PRIMES model projections by scenario.

The energy saving technology has a specific structure in terms of commodities and services that are necessary for construction and implementation. The model formulates this additional demand using fixed technical coefficients that split the energy saving expenditure into different commodities and services (i.e. construction, equipment goods, electrical goods etc.). Thus energy savings have indirect effects on employment through implementation of the energy saving investments.

The decarbonisation scenarios imply different amounts of expenditure for energy savings depending on the degree of reliance on energy efficiency progress by scenario. The additional expenditures relative to the CPI scenario are used as an input to GEM-E3 in order to calibrate the required energy efficiency investments.

Power supply

GEM-E3 includes a bottom-up representation of power generation where electricity producing technologies are treated as separate production activities. The electricity producing technologies are characterised by different cost structures and conversion efficiencies. The projections of capital, labour and fuel costs by power generation technology influence the determination of the technology mix in power generation. Generation costs include annual payments for capital investment, operation-maintenance costs, and fuel costs which depend on fuel prices. The costing data are calibrated to the assumptions of the PRIMES model by scenario.

Investment in new capital for each power technology requires products and services, for example construction, metals, machines, and insurance services. The capital requirements differ by type of power generation technology.

An important modelling choice is the formulation of a driver in the model that induces higher RES deployment than under baseline conditions. The usual formulation is to assume that the state applies a special support scheme (a feed-in-tariff) on RES use, which alters the relative costs of production factors in supply sectors and of end-products in final consumption, and hence induces substitution of conventional energy in favor of RES. Alternatively the exact deployment of RES per country can be imposed on to GEM-E3 by adjusting the value shares of the power generation production function.

Shift parameters in the power generation production functions are calibrated dynamically to allow GEM-E3 to replicate the projections from PRIMES in each scenario regarding the mix of technologies in power generation.

Renewable energy forms in other sectors

The renewable energy forms (excluding those used in power generation) are represented in GEM-E3 as: i) solar for heat used in households, ii) biomass used for combustion in various sectors and iii) biofuels blended with oil products to produce transportation fuels.

Solar for heat use is combined with use of non-durable goods (energy inputs) in durables, such as houses. Thus solar reduces other energy inputs to durables within the households' consumption function and is accompanied with increasing expenditure in equipment (e.g. solar heaters).

The consumption matrix is extended to include biomass inputs for combustion purposes in houses in cases where such information was not included in the original input-output data. Similarly, agricultural products used as production factors (inputs) in production sectors are sub-divided to represent separately biomass for combustion purposes. Biomass is supplied by the agricultural sector. The biofuels are assumed to be more expensive per unit of energy service than the conventional energy products. The blending of biofuels and conventional fuels is assumed to take place in the oil refining and oil distribution sector. The blending function is controlled by exogenous parameters to calibrate to PRIMES projections and includes upper bounds for biofuels.

Waste used for energy purposes is assumed to be a by-product of several sectors (water and sewage, agriculture, other industries, etc.) produced at zero cost. The use of waste, however, involves costs (for example for pre-treatment, packaging and transportation) which are borne by the sectors consuming waste for energy combustion purposes. The potential of waste feedstock is assumed to be limited and is calibrated to PRIMES projections.

Transport

GEM-E3 represents passenger and freight transportation split into three sectors which refer to the transportation mode: land, air and water. Each transport sub-sector sells services to other production sectors and to households. Transportation using private cars and motorcycles is part of final consumption by households and more specifically it is provided by the durable goods (cars and motorcycles) which are purchased by households.

As mentioned above, households purchase goods and services for various purposes from which they get utility. Some of these goods and services are consumed directly, whereas others are consumed through the use of durable goods, such as houses, appliances and cars. GEM-E3 follows a complex specification to represent this structure of final consumption by distinguishing between durables and non-durables and by linking the consumption of goods and services to the use of durable goods. The stock of durable goods changes dynamically as a result of endogenous investment by households in new durable goods. The unit operation cost of new durables influences the purchasing decisions of households.

Households can choose the mix between public transportation and the use of private cars and motorcycles depending on utility, income and relative unit costs. Using private cars entails a cost to the consumer which includes annualised expenditure for acquiring the vehicle and annual expenditures for operation, maintenance and fuelling. Three types of vehicle are represented in the model: conventional, electrical and plug-in hybrid. Each vehicle type has different structures in terms of acquisition and operation costs. Cars are purchased from the transport equipment sector.

By calibrating the scale and share parameters of the production and consumption functions deriving inputs to the various transport means, it is possible to replicate the fuel and electricity mix in public and personal transport as projected by PRIMES by scenario. Similarly, the durable choice functions in the households modelling are calibrated to replicate the PRIMES projections of the future fleet structure.

International fuel prices

The GEM-E3 projection of fossil fuel prices is calibrated to replicate the projection of world fossil fuel prices, as assumed for the decarbonisation scenarios up to 2050 (see Table 4.3).

External closure

GEM-E3 is a global model and, as it follows general equilibrium theory, it applies the Walras law at a global scale. Current accounts by region may vary by scenario. Restrictions can be optionally imposed on current accounts by region and in this case relative interest rates by region are determined by the model as shadow values of these restrictions.

GEM-E3 is an open economy model for the EU region, since its current account can change by scenario. This weakens comparability of macroeconomic implications on the EU of the various scenarios and so matters for the net results on employment estimated using GEM-E3 in the context of the various decarbonisation scenarios. To improve comparability of scenarios, we use an option of GEM-E3 which imposes that either the EU's or each Member States' current account as a percentage of GDP must remain unchanged in decarbonisation scenarios relative to the CPI projections. This restriction implies that the average EU interest rates or the individual, relative to the average global interest rates, re-adjust endogenously in the model results by scenario, so as to keep the current account as a percentage of GDP unchanged.

For example, if the decarbonisation scenarios lead the EU economy to require additional (relative to the CPI scenario) external financing to support increased spending for decarbonisation purposes, relative EU interest rates are re-adjusted upwards so as to increase the cost of capital and crowd out other investment, thereby keeping the current account balance at the targeted level. The decarbonisation scenario results therefore have, by design, the same implied external financing as the CPI.

6.3 GEM-E3 Results on activity and employment

Introduction Calculating the employment effects from RES deployment, the implementation of energy efficiency programmes, biofuels production and transport electrification is a complex task since it requires taking into account not only the direct effects of increased demand on the sectors supplying the respective products and services, but also the indirect effects from changes in competitiveness and income reallocation. The input-output (IO) multipliers approach, which is widely used as a methodological tool to assess the employment impacts of energy efficiency investments and RES deployment, cannot capture the effects on employment induced by factor substitution and changes in sectoral and national competitiveness. The literature survey presented in Chapter 3 notes that several studies examine the direct employment effects but that only very few examine the entire sequence of direct and indirect effects on the economy.

In this chapter both approaches are adopted: a static IO model and the GEM-E3 model (a global CGE model that represents all EU Member States individually) are used to assess the EU employment effects of five decarbonisation scenarios included in the Energy Roadmap 2050. The results of the static IO model provide a first approximation to the employment impacts whereas the general equilibrium economic results capture the series of structural changes taking place in the EU energy system and provide the net effect on economic activity and employment.

The decomposition of the net equilibrium effect on activity and employment of each scenario to its components requires an identification of the sequence of changes occurring in the EU energy and economic system and of the main sectors involved. In comparison with the CPI scenario, the deployment of RES, the implementation of energy efficiency programmes, the production of biofuels and the electrification of transport together involve more investment in power generation, higher demand for agricultural products because of biofuels, higher demand for equipment goods that correspond to solar heaters and geothermal heat units and higher demand for goods and services that are used to build energy saving capital. Higher demand for the goods and services mentioned above implies lower use of oil, gas and solids, a large part of which are imported.

Therefore by considering the flow of goods and services across the economy, directly and indirectly, the transition to a decarbonized economy induces more domestic economic activity for producing goods and services than under the reference case which involves more use of conventional (mostly imported) energy sources.

The sectors that are expected to incur the largest impacts on activity and hence employment, fall under the following categories:

- Agriculture: This sector provides the feedstock for the biofuels and the biomass and it is a low skilled labour intensive sector.
- Fossil fuel extraction, process and distribution sectors: These sectors are expected to present negative employment effects since they can be substituted with low or carbon free energy products.
- Power producing sectors: A restructuring in power generation occurs in all the scenarios examined. The mix of power generation technologies differs from one

scenario to another but the share of carbon intensive technologies is always small. The restructuring always takes place in favour of low fuel intensive and high capital intensive power technologies.
- Manufacturing and Service sectors: These sectors are responsible for the production of the RES equipment, the production and operation of electric and plug-in hybrid cars, the energy saving equipment and the equipment required to perform end-of-pipe abatement GHG emission reductions.
- Construction: This sector installs energy efficiency improvements and is an important component of the capital requirements of most of the power generation technologies.

The investments required to decarbonize the energy system create demand in the sectors producing the investment goods. The GEM-E3 model includes an explicit accounting framework (investment matrix) that decomposes total sectoral investment to specific demand for investment goods. The structure of the investment matrix is based on a reconciliation of data from various sources.

For the power generation technologies the sources used include the European Wind Energy Association (EWEA, 2009) for PV, biomass and wind and the National Renewable Energy Laboratory (NREL) of the US Department of Energy Jobs and Economic Development programme (JEDI) for coal and conventional power generation technologies. Table 6.2 presents the average EU investment matrix, in percentage shares for all power generation technologies identified in the model.

Table 6.2: Investment matrix for power generation technologies (EU average)

% shares	Coal fired	Oil fired	Gas fired	Biomass	Hydro	Wind	PV
Agriculture	0.0	0.2	0.0	13.8	0.2	0.0	0.0
Ferrous & non-Ferrous	0.0	0.9	0.0	0.0	1.2	11.0	0.0
Chemical Products	0.0	0.0	0.0	1.3	0.0	6.3	0.0
Electric Goods	13.5	5.5	18.7	0.0	4.7	6.5	6.8
Transport equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Equipment	31.1	17.7	19.9	0.0	13.1	39.9	19.9
Construction	40.7	60.6	45.9	68.0	64.5	28.6	50.4
Market Services	14.5	14.8	15.4	17.0	16.1	7.7	22.9
Total	100	100	100	100	100	100	100

Sources: E3M-lab calculations based on EWEA (2009) and JEDI.

Transport related expenditures generate demand for the transport equipment sector (expenditures are associated with demand for electric and hybrid plug-in cars). Energy efficiency expenditures create demand for electric goods industries (appliances conforming to energy saving standards, energy saving bulbs etc.), construction (building retrofits, energy saving improvements in buildings etc.) and market services (administrative, financing services etc.). Table 6.3 presents the structure of energy efficiency investments.

Table 6.3: Sectors delivering the energy saving capital (% shares)

Construction	Electric Goods	Market Services	Total
70	20	10	100

Sources: E3M lab calculations based on Peltier (2010).

Sectoral employment multipliers and effects: Static IO

In order to calculate the employment multipliers in a static Leontief methodology we use the input-output tables from the GEM-E3 database. The input-output tables are based on historical data for the year 2010. The tables have been extended so as to include separately ten power generation technologies. Appropriate assumptions and data on inputs to power generation sectors have been employed in this process. The GEM-E3 input-output employment multipliers provide a first approximation to the overall employment effects, most importantly they provide an indication of the labour intensiveness of the economy wide production value chain implied by the renewable penetration or the energy efficiency. Of course the input-output Leontief methodology ignores price driven substitution, ignores dynamics and has no macroeconomic closure which implies that it neglects crowding out effects. The results of this simple methodology generally over-estimate the overall employment and activity effects of demand-pushing changes (as in the case of investment for energy efficiency and low carbon). The input-output tables provide a static snapshot of the EU economies which depicts the inputs used by each sector, the outputs produced by each sector, and the relationship between sectoral output and final demand among the different agents. In order to calculate the employment multipliers one needs to calculate the direct requirements table (an algebraic manipulation of the make and use table showing the amount of a commodity required by a sector to produce one currency unit of output) and the Leontief inverse matrix.

In order to assess the employment effects, rather than simply output effects, the Leontief inverse matrix has to be converted into an employment requirements table. This table is used to estimate the number of jobs throughout the economy that are needed, both directly and indirectly, to deliver one euro of final demand for a specific commodity. The employment/output ratios for each sector must be calculated and combined with the Leontief inverse matrix to create the employment requirements table.

In addition to the direct and indirect employment effects, induced employment effects were estimated following a similar methodology. In this case the household sector is treated as an additional industry by adding an extra row and column into the direct requirements table accounting for the compensation of employees and the household expenditure coefficients respectively. Thus it was possible to estimate the total employment effects which account for the direct, indirect and induced effects as a result of changes in demand for one or more sectors in the economy.

Labour intensive sectors have relatively higher direct employment effects (see Table 6.4). Indirect and consumption induced employment effects vary depending on the extent of inter-sectoral linkages that each sector has with the rest of the sectors as well as due to the shares of the domestic content of inputs to their production.

Sectors expected to be affected from investments in RES, energy efficiency and transport (like construction, equipment goods industries and services) present relatively high total employment effects. This is associated with the labour intensity of the sectors, the share of the domestically produced inputs to the latter and labour compensation. In general, relatively labour intensive sectors with relatively lower average labour compensation (like the agriculture sector) or sectors with high shares of inputs of domestic origin (services, construction) record relatively higher employment effects. The more labour intensive a sector is, the higher the employment/output ratio will be. Hence labour-intensive sectors will employ more employees for the same level of output. Sectors that use relatively more of domestically produced inputs to their production have a higher employment effect. A higher domestic content implies that a production increase of the specific sector will be associated with more employment being generated in the EU rather than in other economies from where inputs are imported. Finally, if other things remain equal, a sector of production will register a higher employment effect if average labour compensation is lower.

Table 6.4: Employment effects per €1m (EU27 IO table), in FTE jobs

	Direct FTE jobs	Indirect FTE jobs	Induced FTE jobs	Total FTE jobs
Agriculture	17.5	4.1	5.7	27.3
Coal	10.6	3.1	4.7	18.3
Crude Oil	0.3	0.3	0.3	1.0
Oil	0.2	0.5	0.3	1.0
Gas	1.6	0.8	1.2	3.7
Electricity supply	2.1	4.8	3.8	10.6
Ferrous & N. ferrous metals	3.7	3.9	4.8	12.4
Chemical Products	1.8	2.9	3.2	7.9
Other energy intensive	3.4	4.2	4.9	12.5
Electric Goods	3.8	2.8	2.4	9.0
Transport equipment	1.6	3.3	3.6	8.5
Other Equipment Goods	2.3	3.4	4.5	10.2
Consumer Goods Industries	3.2	5.4	4.0	12.5
Construction	6.3	5.2	6.1	17.6
Transport (Air)	1.1	3.0	3.0	7.1
Transport (Land)	3.8	4.3	4.5	12.6
Transport (Water)	2.2	4.0	3.2	9.5
Market Services	6.9	4.2	5.1	16.1
Non Market Services	12.8	3.5	9.6	25.9

Sources: E3M-Lab calculations.

Given the structure/composition of investment undertaken in power generation technologies, energy efficiency and transport, the investment impact is different in each case depending on the employment effects of the sectors which provide inputs to these investments.

Table 6.5 summarises the employment effects of investments in alternative power generation technologies. RES technologies record a greater impact on employment. This is associated with the demand generated from such investments for sectors with relatively higher total employment effects (mainly construction).

Table 6.5: Total employment effects from investment in alternative power generation technologies, number of FTE equivalent jobs per GWh

Coal fired	Oil fired	Gas fired	Nuclear	Biomass	Hydro	Wind	PV
0.72	1.69	0.94	0.64	1.82	1.09	1.07	5.05

Sources: E3M Lab calculations.

Table 6.6 presents the total employment effects of investments in energy efficiency and transport. They are found to generate 15.73 and 8.48 FTE jobs respectively per million euro spend. Energy efficiency investments generate demand for construction, electric goods and market services. These sectors have relatively higher total employment effects, thus the impact is found to be larger in magnitude than the effects of investments in transport, which create demand for the transport equipment sector that records a relatively lower employment effect.

Table 6.6: Employment effects of investments in energy efficiency and transport

	Total FTE jobs per € million demand
Energy efficiency	15.73
Transport	8.48

Sources: E3M Lab calculations.

Employment in the baseline (BA) scenario (CPI)

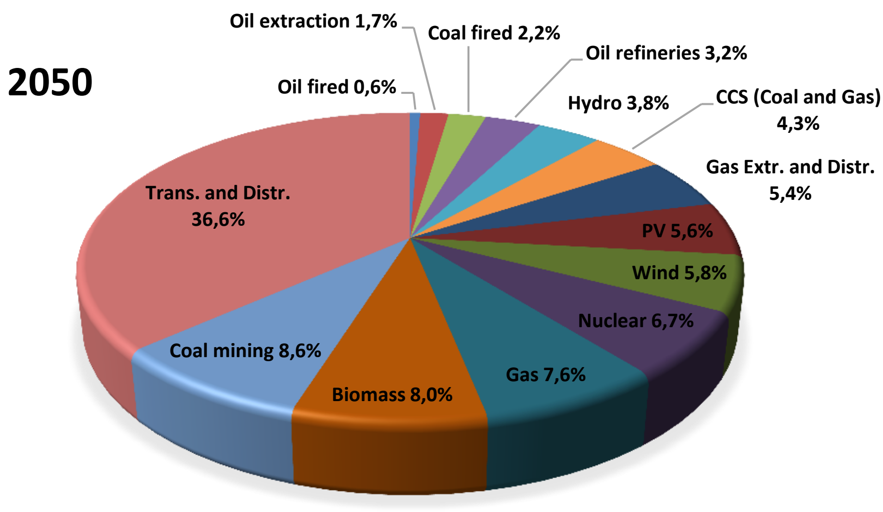
In 2010, 1.2% of total EU employees were working in energy sectors (see Table 6.7). In the baseline this share is projected to increase marginally over the next 40 years to reach 1.6% in 2050. This increase is attributed to increasing energy production from countries with energy sectors that are more labour intensive than the EU average. Figure 6.1 presents how employment is allocated over the different energy sectors in 2050.

Table 6.7: GEM-E3 Baseline Employment by Sector, millions, EU28

	2010	2030	2050
Agriculture	12.8	11.5	11.1
Fossil extraction and manufacturing	0.8	0.6	0.6
Electricity supply	0.86	1.15	1.33
Industry	37.4	32.2	28.7
Construction	19.8	19.7	20.0
Transport	8.4	6.7	5.8
Market services	79.8	69.3	61.4
Non market services	59.8	81.9	93.7
Power technologies	1.0	1.3	1.7
Total	220.7	224.3	224.3

The transmission and distribution sector accounts for 36.6% of total employment in the energy sectors in 2050. The increase from a 31% share in 2010 (see Figure 6.1) is attributed to two factors: i) the increase of power generation in countries with relatively high labour intensities in the transmission and distribution sectors and ii) the substitution of conventional fossil fuel technologies with RES technologies that are more capital intensive. Coal mining and gas extraction and distribution account for 14%. In 2050 the deployment of RES and the gradual transition towards CCS power generation increase employment in these sectors (from 11% in 2010 to 23% in 2050).

Figure 6.1: Composition of employment in energy sectors (CPI)



Sources: GEM-E3.

Cost in terms of GDP and welfare for each Roadmap scenario

The carbon prices drive substitutions between production factors and between goods and services in final demand. The assumed structural changes in power generation towards clean energy technologies (renewables, CCS, etc.), in energy savings (higher investment and less demand for energy products) and in the transport sector (in favour of biofuels and electricity) intensify production factor substitutions driven by carbon prices. All substitutions imply higher demand for materials and equipment and lower demand for fossil fuels in the delivery of energy services to end-consumers of energy (in intermediate and final consumption of energy). As the substitutions are not found profitable[38] under the reference scenario assumptions (which do not include ambitious emission reduction), the additional substitutions simulated under the strict emission reduction assumptions entail net costs for consumers of energy, in the sense that additional capital costs are higher than the present value of reduced costs for purchasing energy products implied by substitutions towards clean and more efficient energy (either in final demand or in power sector). Consequently, the unit cost of energy services (useful energy) delivered to consumers is higher in the decarbonisation scenario relative to the baseline because the induced progress in clean

[38] The substitutions are not profitable in the reference case where there is no need for stringent emission reductions. This is not the case in the decarbonisation scenario.

energy technology is not sufficient to offset cost increases and substitutions cannot be perfect.

The PRIMES model results provide numerical estimations of the additional energy system costs, which correspond to the additional payments that the final energy consumers have to make in order to get the cleaner energy services; these cost estimations by PRIMES are cumulatively below 1% of cumulative EU GDP. Partly the additional costs are offset by the reduction of the imported fuel bill due to global decarbonisation, therefore the final PRIMES cost estimation is below 0.3% of cumulative EU GDP. The GEM-E3 model has calibrated the decarbonisation scenario to PRIMES model projections and thus the initial additional cost estimation is similar to the PRIMES model results. However, the final GDP impacts as calculated by GEM-E3 differ as the model simulates second order and equilibrium effects of the additional energy system costs. Table 6.8 presents the increases from baseline in unit cost of electricity for all scenarios. As expected the highest increase is presented in the high renewable case. There is also a larger increase when cheaper nuclear power is excluded from the mix.

Table 6.8: Impact on average retail price of electricity in period 2015 - 2050

	% change from BA
S1 (High energy efficiency)	1.10
S2 (Diversified supply technologies)	1.44
S3 (High RES)	6.70
S4 (Delayed CCS)	1.31
S5 (Low nuclear)	5.72

Sources: GEM-E3.

As the unit production costs increase, the purchasing power of income due to labour and capital earnings decreases, hence domestic demand tends also to decrease. This implies a depressive effect on GDP. On the other hand, as decarbonisation is more intensive in materials and equipment, hence in capital and labour than the substituted fossil fuels, which in the case of the EU are mostly imported, domestic demand tends to increase. The net effect on domestic demand is generally uncertain. The general equilibrium model results obtained using GEM-E3 (but also confirmed in the literature by numerous other general equilibrium models, see for instance Rivers et al (2013), Bohringer et al (2006), Allana et al. (2008), Fridolfosn (2013), Rahimaisa et al. (2006), Kancs (2007), Kuster (2007), Wissema et al (2003)), indicate that the cost effect on domestic demand is higher than the demand push effect due to additional requirements for material and equipment, hence the net effect on domestic demand is found negative (cumulative EU GDP over the 2015-2050 is reduced by 0.59% compared to the reference case in the diversified scenario). The restructuring in the context of decarbonisation is capital intensive hence the primary factor market for capital is strained implying upward pressures on unit capital costs (average EU cost of capital increases by 3.2% as compared to the reference). A similar effect is observed for the labour market as the restructuring is more labour intensive than fossil fuel supply.

The effects on wage rates tend to be upward but the magnitude of the effect depends on labour market flexibility. As in Europe involuntary unemployment prevails, any additional demand for labour can be met through the pool of unemployed and hence the pressure on wages is mitigated (i.e. wages do not increase when labour demand increases).

Under the influence of both unit costs and primary factor costs, the prices of domestic goods tend to increase, which from a single country perspective undermines competitiveness and induces higher imports and lower exports. The loss of competitiveness drives an increase in imports, while lower domestic demand, driven by higher unit costs, tends to decrease imports. Exports tend to decrease because of higher domestic prices.

Since GEM-E3 is a global model the overall effect on EU GDP depends on changes in the economic activity of the rest of the world. Global activity is reduced when all regions simultaneously decarbonise their energy system (because of the depressive effects on demand of additional costs for energy incurred for decarbonisation purposes) and the crowding out effects of the additional decarbonisation spending. Cumulatively (2015-2050) world GDP is reduced by 1% compared to the reference case[39]. This implies that demand for EU exported goods and services diminishes in the decarbonisation context.

The impact of decarbonisation in non-EU countries is negative but not uniform as it depends on the production structure of each economy. Economies that rely heavily upon exports of fossil fuels are negatively affected by lower world demand and the consequent fall in international fuel prices. Low cost producing countries, such as China are characterised by high energy intensity because of directly or indirectly (lack of environmental controls) subsidised fossil fuels and so these countries have to bear significant costs in order to restructure their energy system away from fossil fuels, compared to developed countries. Hence the depressive effects on domestic demand are exacerbated in these countries compared to developed ones. Cumulative exports over 2015-2050 of China for example are reduced by 2.1% and its imports increase by 2.2% compared to the reference case. These findings confirm diminishing effects on EU exports, which obviously adversely affects EU activity in the decarbonisation context.

The negative economic effects at a global level come primarily from the increase of unit production costs, as the decarbonised energy services are more expensive and production factor substitutions are imperfect. Because of the high labour and capital intensity of decarbonisation, global revenues tend to shift from consumption to investment and primary production factor markets are stressed. Due to the capital resource constraints, which reflect the savings and investment balance in general equilibrium models, the additional - compared to reference - investments needed to decarbonise the energy system imply lower capital availability for agents not involved

[39] All scenarios examined produce virtually the same GDP results at the world level: The GHG abatement decisions for non-EU countries are identical across scenarios whereas changes in EU GDP can influence only marginally world GDP. The GDP reductions at the world level mean that the average annual growth rate over 2015-2050 changes from 2.40% to 2.37%.

in the decarbonisation process. This is a crowding out effect. In other words, the relative unit costs of capital tend to increase as a result of the substitutions in favour of domestic activity which comes from higher capital intensiveness implied in the decarbonisation context relative to the reference case.

The reduction of fossil fuel prices due to global climate action decreases the overall prices and costs, allowing consumers to maintain demand and compensate for the additional investment costs needed for energy restructuring purposes. Thus fossil fuel prices mitigate and can even offset the depressive demand effect due to decarbonisation costs. This is mainly found to hold in developed countries which have high fossil fuel prices (totally reflecting costs and including high taxation) but less in developing countries where fossil fuel prices are subsidised and taxation is low. In these latter countries the decarbonisation costs dominate over cost gains due to lower fossil fuel prices and so the depressive effects on demand persist in the decarbonisation context.

The main depressive effect on EU trade is not due to increased production costs, i.e. due to lower foreign competitiveness, but due to the reduction of global activity and hence the reduced demand for products exported by the EU. In addition, the increased production costs in non-EU countries implies that European consumers face higher prices for imported products and services. This acts negatively on consumption and increases EU production costs.

In the model, the current account as a percentage of GDP in each region, including the EU, is constrained to remain unchanged[40] from reference levels; thus interest rates need to readjust upwards. Assuming perfect competition in global capital markets, the rise of interest rates will be needed in case of a trend towards deficit which attracts capital flows from the rest of the world, which are modelled via an increase in the terms of trade. Thus the average price of exports of the decarbonising country increases and the average price of imports decreases. As a result the investment-savings constraint of the decarbonising economy is relaxed and unit capital costs decrease, implying a moderation of upward capital cost effects. On the other hand, the increased interest rate induces more savings by households and less private consumption, which have a depressive effect on domestic demand counteracting the positive effects of the adjusted interest rate.

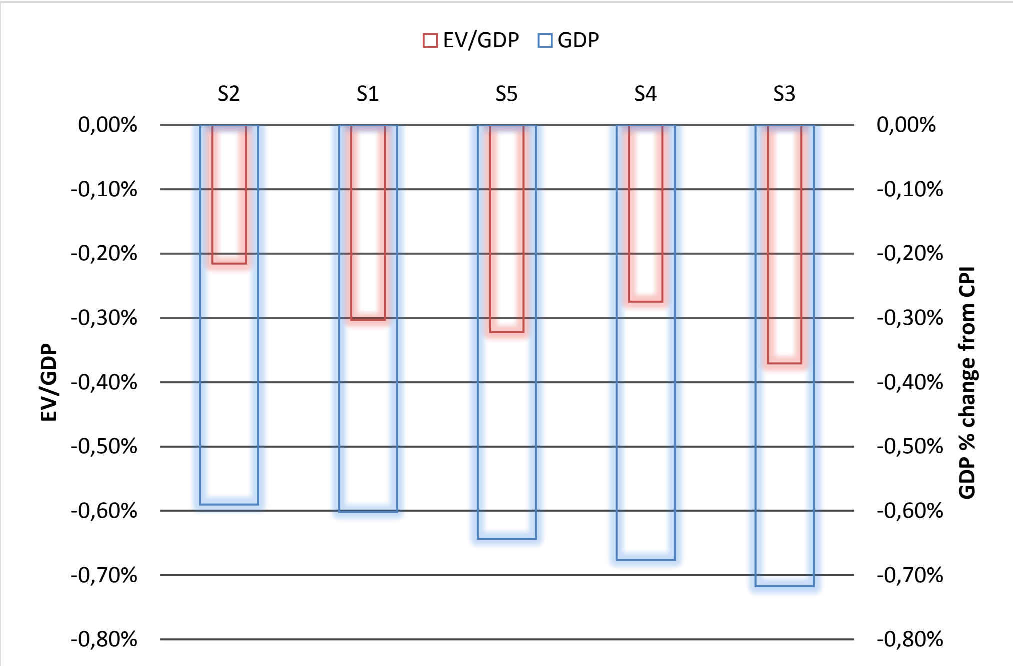
As mentioned above the transition to the decarbonised economy implies an increased demand for domestic resources in the form of goods and services, and labour, for investment and operation and a lower demand for imports of fossil fuels. Therefore by considering only the flow of goods and services across the economy, directly and indirectly, and ignoring crowding out effects and other implications as simulated by general equilibrium models, the decarbonised energy system induces more domestic

[40] The GEM-E3 model for the EU is an open economy model (for the EU as a whole which is assumed to use the euro as a single currency) since the current account of the EU as a whole can change from one scenario to another without necessarily considering effects on monetary variables. But when policy scenarios are quantified with the model, it is necessary to impose a certain overall monetary condition so that a policy scenario is comparable with the Baseline scenario. For example, if the policy scenario, such as the decarbonisation scenario, leads the EU economy to get additional (from Baseline) external financing intended to finance part of the activity related to the energy savings, then the EU economy will enjoy a clear benefit, since it will improve energy efficiency without having to equally reduce financing of other economic activities. This would imply higher deficit in its current account with the rest of the world. Then the results of this policy scenario would not be comparable with those of the Baseline because part of the impacts would be explained by the additional resources from abroad. To make the scenario comparable it is necessary to impose a global EU monetary constraint which determines a certain variable (e.g. a basic interest rate) which otherwise would be left exogenous and unchanged from the Baseline. In the present exercise, the euro basic interest rate adjusts so as to render current account of the EU as percentage GDP unchanged from the Baseline.

economic activity for producing goods and services relative to the baseline. This result is reproduced by studies that follow a microeconomic accounting or a simple Input-Output Leontief multiplier methodology[41]. Such studies ignore the cost and price effects and the crowding out effects which are described above. In contrast the GEM-E3 model accounts for these effects.

Cumulative (2015-2050) EU GDP is reduced in all scenarios examined compared to the baseline case. The reductions range from 0.59% in the diversified technologies scenario (S2) to 0.72% in the high RES scenario (S3) (Figure 6.2). In terms of GDP annual growth rates over the 2015-2050 period, the EU rate of growth has changed from 1.64% in the baseline to 1.63% in the (S2) scenario.

Figure 6.2: Impact on cumulative GDP and Equivalent Variation (EV)



Sources: GEM-E3.

Welfare is measured through Hicksian Equivalent Variation[42]. The welfare implications of all scenarios are small in magnitude since they take into account the changes in the labour market (employment increases in all scenarios examined). The share of the money metric of welfare (Equivalent Variation) to GDP is -0.21% in the diversified scenario (S2) and falls to -0.37% in the high RES scenario (S3).

The scenario that presents the highest adjustment cost in terms of GDP and welfare is the high RES scenario (S3). This result is attributed to the effect of RES deployment on: i) electricity prices, ii) production costs and iii) import requirements for biofuels. In this scenario production costs increase much more than any other scenario simulated (the GDP deflator increases by 3.2% in 2050 compared to the baseline

[41] See for instance Kammen et al (2006) and Wei et al (2010).

[42] Hicksian Equivalent Variation is defined as the income that should be given or taken away (at baseline prices) to the consumer so as to bring him/her to the new utility level. For welfare improving the equivalent variation must be positive.

scenario). This has a direct effect on the competitiveness of the EU and hence on its trade. The increased need for biofuels leads in this scenario to an increase of feedstock/final product imports mainly from Brazil and raw materials (mainly metals) and equipment from low cost producers such as China and India.

The energy efficiency scenario (S1) together with the delayed CCS (S4) scenario present the lowest adjustment costs. S4 essentially implies a diversified energy portfolio based on a least cost approach.

Overview of aggregate employment effects

All the scenarios examined present a positive net effect on employment. Employment is found to be affected by the following key factors.

The response of wages to changes in labour demand

The increased demand for domestically produced goods and services is translated into increased demand for capital and labour. It was found that the response of the labour market to the increased demand for workers plays an important role in determining the net employment effect. When the increased demand for labour can be satisfied from the pool of unemployed without increasing wages then the net effect on employment is positive. In alternative formulations where labour supply can only partially respond to an increased demand for labour (and wages increase) the net effect on employment is negative but small.

Changes in the structure of production

Each scenario implies a different mix of activities/sectors contributing to the decarbonised economy, depending on the power generation mix and energy efficiency investments assumed. Some sectors are both labour intensive and increase employment throughout the economy via their input requirements. Based on the employment multipliers calculated with the input-output tables of the GEM-E3 model, the sectoral mix used in the High efficiency scenario displays high employment multipliers.

The carbon tax recycling choice

Tax revenues are recycled back into the economy by reducing labour taxes. This option benefits employment since it reduces labour costs and it provides incentives to employers to increase hiring rates[43].

The employment effects as quantified by the GEM-E3 model are presented in Table 6.9.

The next sections present the results on activity and employment for all scenarios quantified with the GEM-E3 model. The analysis focuses on the two extreme scenarios (in terms of performance in activity and employment): the high energy efficiency case (S1) and the high RES case (S3).

For the remaining scenarios detailed results are presented in Appendix C. Scenario S2 (Diversified supply technologies) achieves the same carbon budget as all other scenarios examined but in the least cost way since there is no specific support measures for energy efficiency and RES while nuclear and CCS are not constrained. In this scenario GDP is reduced cumulatively in 2015-50 by 0.59% compared to the reference scenario. This represents the smallest reduction among the different scenarios examined. Employment increases by 0.11% cumulatively over the same

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[43] In order to test the importance of the choice of recycling rule on employment a sensitivity run has been performed where revenues from carbon tax are recycled back to the economy by direct lump-sum transfers to the households. The sensitivity run with lump sum transfers to households' income produced positive employment effects but at a lower level from the case where labour taxes were reduced. See Section 6.4 for further details.

period. In scenario S4 (Delayed CCS) GDP is reduced cumulatively over 2015-2050 by 0.67% compared to the reference scenario. Employment effects are similar to scenario S2. Scenario S5 (Low nuclear) can be seen as a policy scenario that implies tight constraints on what is essentially a cost effective electricity generation option. As the key alternatives are relatively expensive (RES and CCS) the scenario leads to an increase in generation costs. GDP is reduced by 0.65% compared to reference case cumulatively over 2015-2050 while employment increases marginally (0.02% cumulatively over 2015-2050) compared to the reference scenario.

Table 6.9: EU Aggregate employment effects over the different scenarios (carbon tax recycling: reduction of labour costs)

	Reference (BA)	High Energy Efficiency (S1)	Diversified (S2)	High RES (S3)	Low CCS (S4)	Low Nuclear (S5)
2050						
Total Economy*	224 280	225 476	225 438	224 746	225 518	225 340
Absolute difference from BA	-	1 196	1 157	466	1 238	1 059
% change from BA		0.5	0.5	0.2	0.6	0.5
2015-2050						
Total Economy**	13 340	13 361	13 356	13 342	13 355	13 343
% change from BA	-	0.16	0.12	0.01	0.11	0.02

* 1000s persons
** Cumulative employee hours (in bn)
Sources: GEM-E3.

S1: High energy efficiency

Compared to CPI, energy saving expenditures imply a demand side push effect and an efficiency effect on the economy. The efficiency effect leads to an improvement of energy productivity whereas the demand push effect leads to an increased demand for goods and services required to produce the energy saving equipment. The efficiency effects are considered to be permanent in the economy whereas the demand push effects occur only during the implementation period. The magnitude of the demand effect depends both on the amount and the specific structure of the energy saving investment.

Changes in energy consumption patterns and technology, reflecting the energy efficiency improvement, lead to an overall substitution of imported commodities (coal, oil, gas) with domestically produced goods.

The net equilibrium effect on overall activity is negative (cumulative GDP is reduced by 0.60% as compared to baseline).

Table 6.10: Macro aggregates (EU) in the high energy efficiency scenario (S1)

High energy efficiency	2020	2050	Cumulative

(% changes from Reference)			**2015-2050**
Gross Domestic Product	-0.02	-0.63	-0.60
Investment	-0.04	1.78	0.40
Public Consumption	0.00	-0.30	-0.18
Private Consumption	-0.02	-0.09	-0.24
Exports	-0.26	-3.10	-2.37
Imports	-0.23	2.17	0.95
Terms of Trade[44]	-0.03	1.97	-

Sources: GEM-E3.

The restructuring of power generation requires additional investments. Household consumption is less affected since employment increases hence sustaining households' disposable income. Households' savings from energy bills are used to increase consumption in non-energy products. To the extent that these products are not imported, domestic activity is stimulated.

At a sectoral level the effects on production are mixed. The energy and energy intensive sectors register output reductions as compared to the baseline whereas the sectors that build the energy saving equipment are affected less or even increase their output. The construction and electric goods sectors increase their production as compared to the baseline over the period 2015-2050.

Table 6.11: Sectoral production (EU) in the high energy efficiency scenario

High energy efficiency Cumulative 2015-2050	**Production % changes from Reference**
Agriculture	4.08
Ferrous and non-ferrous metals	-0.92
Chemical Products	-0.89
Other energy intensive	-0.23
Electric Goods	1.94
Transport equipment	-1.38
Other Equipment Goods	0.58
Consumer Goods Industries	-0.68
Construction	2.30
Transport Services	-1.30
Market & Non-Market Services	-0.34

Sources: GEM-E3.

Total employment (economy-wide) is found to be positively affected. It increases by 0.16% over 2015-2050 compared to the reference case. The demand for both skilled and unskilled workers increases.

[44] Terms of trade: the ratio of price of exports over the price of imports. The balance of trade deteriorates however the terms of trade improve (prices of exported commodities increase more than the price of imported commodities hence fewer exports can "buy" more imports).

Table 6.12: Employment (EU) in the high energy efficiency scenario

High energy efficiency % changes from Reference	Cumulative 2015-2050
Employment (employee hours)	0.16
Skilled	0.12
Unskilled	0.19

Sources: GEM-E3.

The sectoral effects on employment largely follow the results on sectoral production. Hence it is the agriculture, electric goods and construction sectors that register positive employment effects. In absolute terms the sectors that show the largest increases in employment are construction, agriculture and electric goods.

The restructuring in power generation and in the rest of the energy sectors leads to a net negative employment effect on all energy sectors. As expected, the fossil fuels sectors register employment decreases whereas employment increases mainly in the biomass, wind and PV sectors.

The high efficiency scenario presents the highest increase in employment among all the scenarios examined. This is attributed to the mix of the sectors that are active in the decarbonisation process. The sectors delivering the energy efficiency improvements are not only labour intensive themselves but they also create employment in other sectors (this is confirmed by the employment multipliers presented in the section above).

Table 6.13: Sectoral employment (EU) in the high energy efficiency scenario

High energy efficiency Cumulative change 2015-2050	in %	in billion hours
Agriculture	2.44	16.8
Ferrous and non-ferrous metals	-0.86	-2.2
Chemical Products	0.09	0.2
Other energy intensive	-0.31	-0.9
Electric Goods	1.82	3.0
Transport equipment	-0.55	-1.0
Other Equipment Goods	0.09	0.3
Consumer Goods Industries	-0.27	-1.3
Construction	2.10	24.7
Transport Services	-0.02	-0.1
Market & Non-Market Services	-0.17	-14.9

Sources: GEM-E3.

Table 6.14: Employment in the power generation sectors (EU)

High energy efficiency Cumulative change 2015-2050	in %	in billion hours
Coal fired	-29.06	-2.5

Oil fired	-55.78	-0.5
Gas fired	-23.00	-3.7
Nuclear	-8.37	-1.1
Biomass	15.45	2.4
Hydro electric	4.70	0.4
Wind	21.23	2.0
PV	32.86	2.5

Sources: GEM-E3.

S3: High RES

In this scenario it is assumed that a high overall RES share and high RES penetration in power generation will be achieved by 2050. RES deployment has two direct effects on activity:

A positive effect from the stimulus to domestic production (substitution effect)

Deploying the RES is equivalent to substituting part of energy purchases from abroad by goods and services produced domestically since the increased energy supply from RES reduces the use of fossil fuels and so energy imports become lower than under baseline conditions. This implies that domestic production of goods and services required for the deployment of RES increases as a result of such a substitution.

A negative effect from increasing production costs (price effect)

RES deployment above a market equilibrium level entails higher costs per unit of energy service. Electricity in the RES scenario costs more per unit of output than in any other scenario examined. The additional biofuels substitute for oil products in road transportation but at a higher cost per unit of delivered energy. The increasing use of biomass (for biofuels and also for direct combustion in all sectors) implies an increase in the demand for agricultural products and exerts upwards pressure on agricultural prices. This implies higher costs incurred in sectors using agricultural products as inputs (for example the food industry).

The additional costs and price increases induced by RES penetration are reflected onto prices of all domestic commodities and impact negatively on the competitiveness of the EU economy.

Substituting imported commodities (oil, gas, coal) by domestically produced commodities (and biomass to some extent) and by domestically produced RES equipment (at least, partly), imply higher use of capital and labour resources per unit of GDP. The additional RES deployment and also the induced increase in domestic production of goods and services imply higher investment in many sectors, compared to the baseline.

The final, general equilibrium implications of the RES deployment scenario in terms of GDP and its components are presented in Table 6.15.

Table 6.15: Macro aggregates (EU) in the High RES scenario

High RES % changes from Reference	2020	2050	Cumulative 2015-2050
Gross Domestic Product	-0.01	-0.82	-0.72
Investment	-0.03	2.87	0.62
Public consumption	0.00	-0.30	-0.18

Private Consumption	0.00	-0.60	-0.48
Exports	-0.24	-4.04	-2.73
Imports	-0.22	1.74	0.73

Sources: GEM-E3.

This scenario is characterised by higher adjustment costs in terms of GDP than any other scenario examined. The price effect counterbalances the positive substitution effects and hence trade deteriorates (exports fall more than in any other scenario).

Table 6.16: Sectoral production (EU) in the High RES scenario

High RES Cumulative 2015-2050	Production % changes from Reference
Agriculture	4.02
Ferrous and non-ferrous metals	-1.77
Chemical Products	-1.58
Other energy intensive	-0.87
Electric Goods	1.06
Transport equipment	-1.86
Other Equipment Goods	0.54
Consumer Goods Industries	-0.92
Construction	1.69
Transport Services	-2.16
Market & Non-Market Services	-0.49

Sources: GEM-E3.

The deployment of RES implies an increased demand for equipment and electrical goods and a growing agricultural production, the latter driven by the increasing share of biofuels in final energy demand.

Through bilateral trade adjustments, the countries change their export and import patterns according to their relative competitiveness and production specialisation by sector. Agricultural production is positively affected in most countries, but agricultural imports also increase. EU imports are mainly increased by importing electrical goods equipment, and raw materials to build power generation equipment (mainly metals) from low cost producing countries. The sectors related to RES deployment increase their production but are not higher than the other scenarios examined since overall activity decreases (i.e. S3 presents the highest GDP reductions in all the scenarios quantified by the GEM-E3 model).

Table 6.17: Employment (EU) in the High RES scenario

% changes from BA	Cumulative 2015-2050
Employment (employee hours)	0.01
Skilled	0.02
Unskilled	0.00

Sources: GEM-E3.

Table 6.18: Sectoral employment (EU) in the High RES scenario

High RES Cumulative change 2015-2050	in %	in billion hours
Agriculture	2.45	16.8
Ferrous and non ferrous metals	-1.67	-4.2
Chemical Products	-1.02	-2.1
Other energy intensive	-0.93	-2.7
Electric Goods	1.46	2.4
Transport equipment	-0.86	-1.5
Other Equipment Goods	0.58	1.9
Consumer Goods Industries	-0.29	-1.4
Construction	1.35	15.9
Transport Services	-0.27	-1.1
Market & Non-Market Services	-0.22	-19.8

Sources: GEM-E3.

Table 6.19: Employment in the power generation sectors (EU) in the High RES scenario

High RES Cumulative change 2015-2050	in %	in billion hours
Coal fired	-29.79	-2.5
Oil fired	-50.05	-0.4
Gas fired	-25.25	-4.0
Nuclear	-26.53	-3.5
Biomass	10.77	1.7
Hydro electric	0.92	0.1
Wind	54.12	5.0
PV	110.96	8.5

Sources: GEM-E3.

6.4 Sensitivity analysis

Overview

In order to test the results of the GEM-E3 model regarding the employment effects of the different roadmap scenario five additional sets of simulations were performed. Within the general equilibrium context each option has a different impact on the allocation of income, activity and employment. The sensitivity runs performed with the GEM-E3 model are:

i) Alternative recycling options of carbon tax revenues

ii) Fixed or flexible EU current account

iii) Weak response of international fossil fuel prices to global decarbonisation

iv) Responsiveness of labour market

v) Higher GHG mitigation policies from non-EU countries

Alternative revenue recycling schemes

Carbon taxes can be used to reduce distortions generated by other taxes (Shackleton et al (1993)). Many studies (Capros et al (2009), Bosquet (2000)) confirm that using carbon tax revenues to reduce labour taxes results in more efficient price signal in terms of activity and employment than lump sum recycling or reduction of indirect taxes. However other tax recycling options can be considered in order to achieve different objectives:

i) Lump sum transfers to household: a measure to support household income

ii) Reduction of general rates of indirect taxes

iii) Subsidization of RES power generation

iv) Increased R&D expenditures for carbon free power generation technologies

Testing all the alternatives is beyond the scope of this study. However we want to test whether the positive net employment effects presented above are the result of the transition to a more labour intensive economy or the result of labour tax reduction. Towards this end the option (i), lump sum transfer, was considered.

Table 6.20: Impact of alternative tax recycling option on GDP and employment (lump sum transfer to households)

% change from BA (2015-2050)	S1 (lump sum transfer to HH)	S1 (reduction of labour tax)
Gross Domestic Product	-0.69	-0.60
Investment	0.13	0.40
Private Consumption	-0.31	-0.24
Exports	-2.50	-2.37
Imports	0.82	0.97
Employment (employee hours)	0.06	0.16

Sources: GEM-E3.

Increased household income (via the lump sum transfer) can be either used to increase consumption or to increase savings. In the quantification with the GEM-E3 model consumption decreases and savings increase. This is the result from fixing the EU current account as a % of GDP to the reference level so interest rates need to readjust upwards.

Interest rates increase because the transition to a more capital intensive economy requires additional financing. In the model it was assumed that the EU would self-finance these investments (via an increase in its terms of trade) rather than creating a trade deficit. As a result of higher interest rates the investment-savings constraint in the model is met.

Households take advantage of the higher (than the reference) interest rates and prefer to postpone consumption (i.e. they save). In addition increases in non-wage income remove incentives to enter the labour market. This recycling option is not efficient either in terms of GDP or employment. Both are lower as compared to the default recycling option.

Current account closure

The decarbonisation restructuring is more capital/equipment and material intensive and less fuel intensive than the baseline. The implied additional demand induces higher investment as it tends to increase domestic activity. This further implies stressing the capital market and, as the model-based simulation follows a general equilibrium approach, it implies higher requirements of total savings, both for domestic savings and external capital flows. At the same time, exports/imports flows change: the economy requires less imports of fuels but higher imports of non-energy commodities driven by higher demand trends; also part of commodities that are exported in the baseline are redirected to the domestic market driven by higher demand trends; but in addition, in case foreign competitiveness is undermined due to higher energy services costs incurred in the EU during system transition, exports of the EU decrease and imports increase. The net effects on exports/imports are uncertain but most likely the changes are towards a deterioration of the trade balance. The combined effect of the capital and trade balances is likely to show a trend towards a deficit in the current account under decarbonisation conditions compared to the baseline. If such a deficit is possible then the EU would benefit from higher resource inflows coming from the rest of the world which would of course ease decarbonisation by avoiding the adjustments in current account which will have restrictive effects on the EU economy and the capital balance. However, this situation would imply some incomparability of macroeconomic results under the decarbonisation conditions compared to the baseline. In reality also, even if such easiness through the current account balance is observed during a certain period of time, it is unlikely to last over a long period of time. Feedback reactions and adjustments would take place sooner or later.

As the model follows a general equilibrium logic, current account imbalances cannot be tolerated in a counterfactual scenario, such as the decarbonisation, and the model needs to simulate adjustments to obtain a comparable resource basis between the decarbonisation and baseline. For this purpose the model adjusts real interest rates (basic lending rate) by region so as to obtain in all scenarios the same current account as a percentage of GDP as in the baseline.

The decarbonisation conditions would imply a trend towards a negative imbalance of the current account in the EU, therefore higher interest rates would be required, compared to the baseline in order to rebalance the current account. An increase in the real interest rate implies higher savings, lower private consumption and lower investment under capital mobility conditions. These changes obviously tend to re-equilibrate both the capital and trade balances.

Flexibility in the EU current account

In order to test the impact from fixing the EU current account all roadmap scenarios were quantified with a flexible EU current account. These simulations were performed with both the default recycling option and the lump-sum income transfer to household option.

Letting free the EU current account leaves interest rates unchanged from the baseline scenario and hence lower from the default S1 scenario. The financing of the decarbonised economy is done via the rest of the world and hence the EU's balance of trade deteriorates (imports increase as compared to the reference case and exports decrease). Low interest rates promote investment and increase consumption both acting positively on GDP. The adjustment cost in the case where the EU decarbonises its economy with a free current account was found to be lower than the default case because part of the financing was realised from non-EU countries.

The results for the S1 scenario are presented in Table 6.21 whereas the results for the rest of the scenarios can be found in the Appendix.

Table 6.21: Impact of alternative tax recycling option on GDP and employment

% change from BA (2015-2050)	S1 (reduction of labour tax, Fixed EU current account)	S1 (reduction of labour tax, Flexible EU current account)	S1 (lump sum transfer to HH, Flexible EU current account)
Gross Domestic Product	-0.60	-0.57	-0.72
Investment	0.40	1.13	0.52
Private Consumption	-0.24	0.70	0.25
Exports	-2.37	-4.36	-3.81
Imports	0.97	3.48	2.45
Employment	0.16	0.19	0.08

Sources: GEM-E3.

When the EU current account is relaxed the balance of trade deteriorates and employment increases.

Labour market flexibility

The GEM-E3 model includes a wage curve[45] in order to represent involuntary unemployment. Following the findings of Bargain et al (2012) and Sorensen (1999) the labour supply elasticity of GEM-E3 was calibrated to -0.1.

The responsiveness of wages to higher demand for labour is important in determining the overall activity effect since it affects the country's competitiveness. If higher demand for labour cannot be met easily from the pool of unemployed then wages increase and unit production costs increase.

The GEM-E3 model was recalibrated to higher (double of the default) and lower (half of the default) labour supply elasticities. The results are presented in Table 6.22.

Table 6.22: Energy efficiency scenario with different labour supply elasticities

% change from BA (2015-2050)	S1 (Default elasticity)	S1 (Half elasticity)	S1 (Double elasticity)
Gross Domestic Product	-0.60	-0.57	-0.63
Investment	0.40	0.45	0.36
Private Consumption	-0.24	-0.20	-0.28
Exports	-2.37	-2.36	-2.38
Imports	0.97	0.98	0.95
Employment	0.16	0.22	0.10

[45] A curve that negatively relates wages and unemployment.

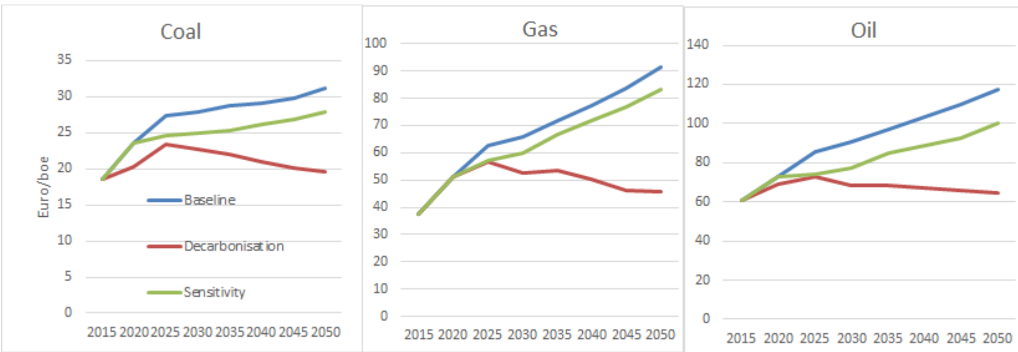
Sources: GEM-E3.

In countries with high unemployment rates it is reasonable to assume that increased demand will not lead to higher wages. This would occur only in countries where unemployment is near to the natural rate or there is specific demand for skills with limited supply. It is found that the labour supply elasticity is an important determinant of the employment effects.

International fuel prices

Decarbonising the world economy leads to a substitution of fuels with other production factors (mainly capital). As a result demand for fossil fuels is expected to fall globally and fuel prices are expected to decrease. In the default scenarios quantified with the GEM-E3 model fuel prices are assumed to decrease compared to the baseline. Cheaper fuel prices have a positive effect in particular on economies that are characterised by high energy intensities. In order to evaluate the impact from lowering fuel prices an alternative scenario was simulated where fossil prices do not fall as much as assumed in the roadmap scenarios. The trajectories of the default and sensitivity scenario fossil fuel prices are presented in Figure 6.3.

Figure 6.3: Assumptions on international fossil fuel prices



With higher fossil fuels prices it is found that the adjustment cost increases (GDP is reduced by 0.7% compared to the baseline over the 2015-2050 period). This has also a negative effect on employment, that now marginally decreases over the 2015-2050 period. The results for the S1 scenario are presented in Table 6.23.

Table 6.23: High energy efficiency scenario with high fossil fuel prices

% change from BA (2015-2050)	**S1 (default fossil fuel prices)**	**S1 (high fossil fuel prices)**
Gross Domestic Product	-0.59	-0.70
Investment	0.42	0.23
Private Consumption	-0.24	-0.18
Exports	-2.34	-2.88
Imports	0.99	0.47
Employment	0.16	-0.06

Sources: GEM-E3.

Non-EU countries' GHG mitigation policy

The impact of the stringency of the GHG mitigation policy adopted from non-EU countries on EU employment and activity was tested by quantifying a scenario where non-EU countries intensify even more their GHG emission reduction targets.

In this scenario EU GDP is found to be 0.44% lower than the baseline over 2015-2050 in the scenario. The EU reduces its imports as the production costs in non EU countries increase. Exports are reduced due to slackened world demand (higher production costs globally reduce activity at a world level and income which leads to even lower demand for EU exports).

The higher abatement effort from non-EU countries requires additional financing. The EU, in order to retain its current account neutrality (and not to finance part of the investments realised abroad), needs to decrease its basic interest rate. This leads to higher investment and a substitution of labour with capital (thus lower demand for employment than the default scenario).

Table 6.24: High energy efficiency scenario with intensified GHG mitigation policy from non EU countries

% change from BA (2015-2050)	S1 (default global decarbonisation)	S1 (RoW intensify targets)
Gross Domestic Product	-0.59%	-0.44%
Investment	0.40%	0.50%
Private Consumption	-0.24%	-0.09%
Exports	-2.30%	-4.10%
Imports	1.00%	-1.00%
Employment	0.16%	0.05%

Sources: GEM-E3.

6.5 Conclusions

The employment effects examined are the result of a multitude of adjustments taking place in the EU economy in response to the different decarbonisation scenario assumptions. The net effect on employment depends on a number of factors, including the labour intensity of the sectors that contribute to the decarbonised energy system, the extent to which decarbonisation is supported by domestically produced or imported goods and services and on the response of the labour market.

The main conclusions that can be derived are as follows:

- The impact on employment is different by sector. Sectors related to fossil fuel extraction, process and distribution are negatively affected. Sectors related to the construction of energy saving and RES equipment are positively affected. The net general equilibrium effect on employment is positive but small.
- Sensitivity runs showed that the overall employment effects are not significantly dependent on the choice of carbon revenue recycling. The options considered are

the reduction of labour taxes and lump sum transfers to household income. The option of reducing labour costs always results in higher net employment effects than the lump sum case.

- The scenario that assumes high primary energy savings by 2050 and stringent implementation of the EU Energy Efficiency plan (S1) provides the best employment prospects as it stimulates activity in labour intensive sectors and at the same time it does not deteriorate EU competitiveness through increases in production costs.
- The response of the labour market is crucial in determining the net employment effect. When the increase of labour demand is met through the pool of unemployed workers, wages do not increase and the net effect on employment is positive. Workers' or skills' scarcity exert an upward pressure on wages which deteriorates competitiveness and hence has a negative impact on activity.
- Variation in international fossil fuel prices is important in determining net employment effects.
- In the high RES scenario employment effects are not driven by the direct employment multipliers but by competitiveness effects. Increasing RES has two main effects on the EU economy: a demand push effect created by the goods and services required to build the RES equipment and a price effect created by the increase in production costs due to higher electricity prices and more expensive primary production factors (mainly capital). The additional costs and price increases induced by RES penetration are reflected onto the prices of all domestic commodities and induce loss of competitiveness of the EU economy, hence imports increase and exports decrease. The "price effect" which acts negatively on domestic activity and employment cancels out the positive effects from increased demand for domestic resources. Hence the net effect is a reduction of GDP which is the main reason for reducing employment in this scenario.

7 Detailed Labour Market Impacts

7.1 Introduction

Previous research has sought to estimate the impact of climate change policies on the future demand for skills, typically using occupation and qualification as a proxy measure of skill. The most comprehensive analysis to date was that conducted for the *Green Jobs: Trade and Labour* study undertaken for DG Employment (Cambridge Econometrics et al, 2011). In general, the study concluded, through a series of scenarios, that climate change policy, however it might be configured, has a relatively modest impact on the overall demand for skills relative to a baseline scenario which assumes business as usual. In comparison to other factors which are likely to drive the demand for skills over the period to 2020, changes to climate change policy were projected to have only a limited impact on the pattern of skill demand overall. But this general finding may disguise changes which are taking place at a local or regional level, or changes which are taking place within an occupation such that the content of a job is changed substantially as a result of green policy.

Skills demands

The skill demand projections in Cambridge Econometrics et al (2011) were produced at a relatively high level of aggregation (i.e. 2-digit ISCO in relation to occupations) and had a ten-year time horizon. Bearing in mind that the shifts in occupational skill demand in the projections are driven in large measure by changes in the demand for labour by the industrial sector, the impact of climate change or energy policy may be expected to be felt more over the longer, than the shorter, term. Industries which have a large carbon footprint may adapt to changes, or expected changes, in climate change policy through, for instance, the introduction of new production systems that lower carbon emissions (and which potentially create a demand for new skills). Alternatively the industry may decline more rapidly than previously expected (thereby bringing about skill obsolescence). Of course, there will be an increase in demand for some skills associated with climate change mitigation measures. The skills in question are likely to extend beyond environmental services to include the production of new technologies which, for instance, facilitate carbon capture, reduce energy consumption, and so on. The key point is that these changes may take longer than ten years to reveal their impact upon the occupational structure of employment.

Changes within sectors

The other key factor to consider is the impact of climate change or energy policy on the content of jobs. Changes in content are always readily identifiable in changes in the occupational structure of employment because they affect the skills required within an occupation. Studies commissioned by Cedefop indicate the way in which tasks within jobs are affected by green policy (see Cedefop, 2010, for a synthesis). In general the studies reveal that many jobs will be affected in some way simply as a consequence of people needing to be more aware of the environmental impacts of the way they go about their jobs. There is not an increase in demand for green jobs or skills per se, but rather the greening of many existing jobs. This is also revealed in Cambridge Econometrics (2011), and in a study conducted in the USA (Dierdorff et al., 2009; 2011). Related to the impact on skill demand within occupations has been an interest in the wider impact on occupational job quality and whether changes to energy policy adversely affect the demand for relatively high paid, high quality jobs. If skilled jobs are being lost in, say, energy-intensive workplaces belonging to large companies in the manufacturing sector, there is no guarantee that the skilled jobs being created by, for instance, SMEs in the environmental services sector, offer the same terms and conditions of employment or provide job opportunities to the same groups of workers.

Geographical elements

A further issue to consider is that the impact of policy might be felt locally rather than regionally or nationally; and the impact at the local level on skill demand may well be substantial, especially if it affects the dominant industry or employer in a local area. For example, the closure of the aluminium smelter in Lynmouth, Northumberland, UK in 2012, which was blamed on rising energy costs, resulted in the loss of 500 jobs in a semi-rural area.

So, when looking at projections of skill demand derived from differing scenarios there is a need to consider, that there may be a great deal of change taking place which is not immediately apparent from first glance at the occupational projections. Therefore it is necessary to bear in mind when considering the implications of the occupational projections for skill demand, that much may be happening under the surface.

7.2 Results by skill group

The projections provided in this section are to 2025, because the model used to provide the projections has this as a cut-off point[46]. It is expected that the effects of policy change on the occupational structure of employment will have their main impact during this period and that any differential impact between the scenarios is likely to have petered out by the end of the period.

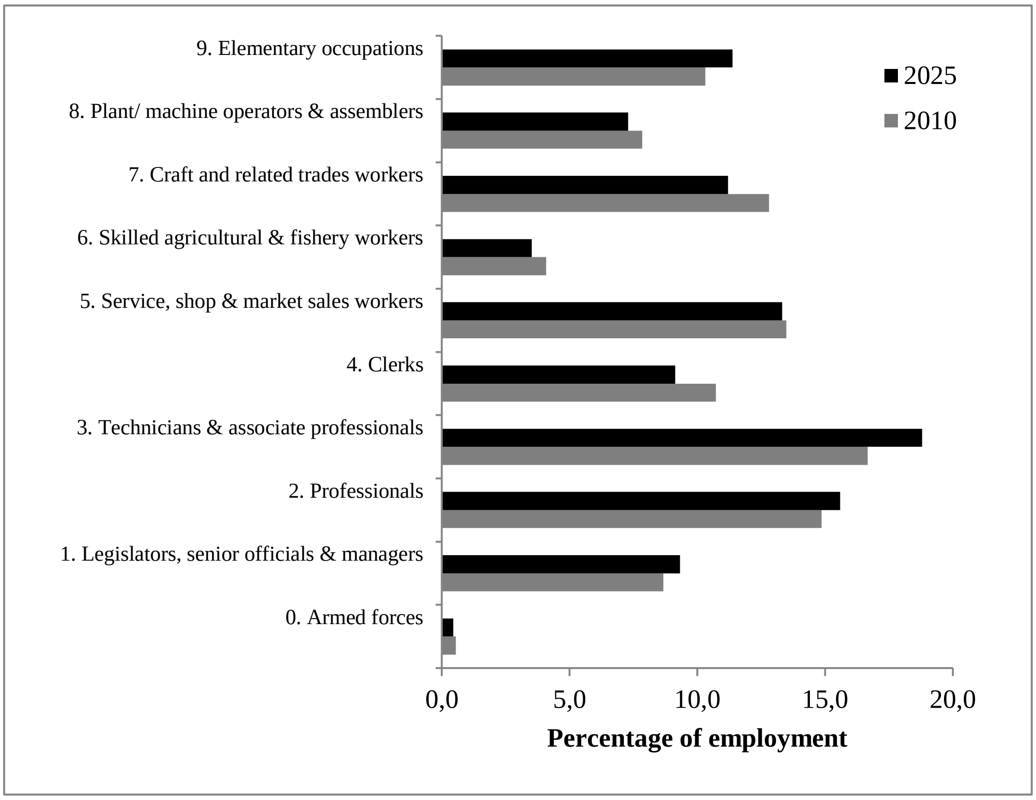
The results presented in this chapter build on the outputs from the E3ME model, as presented in Chapter 5.

Baseline trends

Figure 7.1 and Table 7.1 show how the occupational structure in the EU28 is expected to change over the period 2010 to 2025 under the baseline. The results reveal a well documented pattern with relatively strong employment growth in higher-level occupations (managers, professionals, and associate professionals) and some growth in relatively less skilled occupations (i.e. elementary occupations). This reflects the pattern of hollowing out in the skills structure resulting from the bias of technological change in favour of skills (Autor et al., 2003). Analysis of task-based technological change suggests routine tasks are liable to be replaced by automation and these tasks are typically found in jobs in the middle of the occupational structure (e.g. in clerks and craft and skilled trades) occupations. In contrast, higher-level skilled jobs, which require their incumbents to utilise cognitive skills, cannot be easily automated. Nor is it easy to automate some relatively low skilled jobs, such as those which are commonly found in the service sector where the incumbents need to interact with other individuals – for example in the hospitality sector. The same pattern of occupational change is also likely to result from trends in globalisation, notably the relocation of, for instance, manufacturing jobs – often plant and machine / craft and skilled trades occupations – to countries with lower labour costs (Goos, et al., 2011).

[46] The occupational projections are produced using the same method as that used to produce occupational projections for Cedefop by the Institute for Employment Research at the University of Warwick – see http://www.cedefop.europa.eu/en/about-cedefop/projects/forecasting-skill-demand-and-supply/skills-forecasts.aspx

Figure 7.1: Occupational change 2010 to 2025, EU28



The percentage of employment accounted for by senior officials and management, professionals, and associate professionals will have increased from 40% in 2010 to 44% in 2025. All other occupations, except elementary occupations, are expected to show a decline.

While several occupations are projected to show a decline in the number of people employed over the period 2010 to 2025, it needs to be borne in mind that over the same period people will leave occupations for a variety of reasons, such as retirement. When replacement demands are factored in, to give the total number of people who will be needed to fill jobs, then it is apparent that there is a positive net requirement in all occupational groups. Overall, it is estimated that, over the period 2010 to 2020 there will be an overall increase in employment of around 7m in the EU28, but there will be around 80m job openings to be filled over the period. These job openings will be in several types of occupations, including those where the overall number of people employed is expected to decline.

Table 7.1: Changes in the occupational structure of employment, 2010 to 2025

	Employment Levels				Change		Occupational Shares (%)	
EU28	**2010**	**2015**	**2020**	**2025**	**Change 2010 - 2025**	**% change 2010 - 2025**	**2010**	**2025**
Baseline Scenario	226 296 000	231 667 000	233 497 000	232 837 000	6 540 000	2.9	**100.0**	**100.0**
1. Legislators, senior officials and managers	19 564 000	20 474 000	21 190 000	21 644 000	2 079 000	10.6	8.6	9.3
2. Professionals	33 622 000	35 095 000	35 939 000	36 319 000	2 698 000	8.0	14.9	15.6
3. Technicians and associate professionals	37 742 000	40 543 000	42 486 000	43 773 000	6 031 000	16.0	16.7	18.8
4. Clerks	24 303 000	23 423 000	22 373 000	21 308 000	-2 995 000	-12.3	10.7	9.2
5. Service workers and shop and market sales workers	30 454 000	31 291 000	31 361 000	30 951 000	497 000	1.6	13.5	13.3
6. Skilled agricultural and fishery workers	9 314 000	9 111 000	8 662 000	8 238 000	-1 075 000	-11.5	4.1	3.5
7. Craft and related trades workers	28 978 000	27 981 000	27 133 000	26 127 000	-2 851 000	-9.8	12.8	11.2
8. Plant and machine operators and assemblers	17 802 000	17 950 000	17 579 000	17 000 000	-802 000	-4.5	7.9	7.3
9. Elementary occupations	23 286 000	24 663 000	25 693 000	26 451 000	3 164 000	13.6	10.3	11.4

Notes: Armed Forces have been included in overall totals but data for this group have not been presented in the table.

Scenario results Trends in skill demand are affected only to a modest extent by the different scenarios examined in this report. Table 7.2 and Figure 7.2 show the extent to which levels of employment in each occupational group differ by scenario compared with those in the Baseline. So, for example, under the Energy Efficiency scenario there will be 78000 more jobs in the legislators, senior officials and managers occupational group by 2025.

It is clear that under all of the scenarios employment in each occupational group will be greater than under the baseline, except in the case of skilled agricultural workers and fishery workers. This brings about a relatively favourable outcome with respect to higher-level occupations (managers, professionals, and associate professionals) and skilled trades workers. In other words, under each of the energy scenarios there is a relatively positive impact on skill levels. As noted in previous chapters this is likely to result at least in part from relatively strong employment growth in the engineering and manufacturing sectors under each of the scenarios relative to the baseline.

It is under the S3 High Renewables scenario that employment levels will be highest by 2025 resulting in additional demand, in particular, for people working in professional and associate professional occupations, and craft and related workers. In the latter occupational group, an additional 371000 jobs are projected, compared with the baseline. Under the S4 Delayed CCS scenario, there will be less growth among craft and skilled trades workers than in any other scenario, compared with the baseline (270000). The relatively high growth under the S3 High Renewables scenario is for associate professional occupations, an additional 369000 jobs. Even under the S1 Energy Efficiency scenario, where there will the lowest level of employment growth relative to the baseline for this occupational group, an additional 186000 jobs will be created by 2025.

Overall, the differences between the various scenarios and the baseline are modest. For example, in a labour market containing around 235m people in employment by 2025, with approximately 22m people employed as legislators, senior officials and managers, an additional 179000 jobs will be created in this occupational group under the S3 High Renewables scenario (i.e. an increase of around 0.08%). Nevertheless, the evidence points to the various scenarios bringing about an increase in relatively high-skilled occupations, and increased growth in relatively well paid jobs.

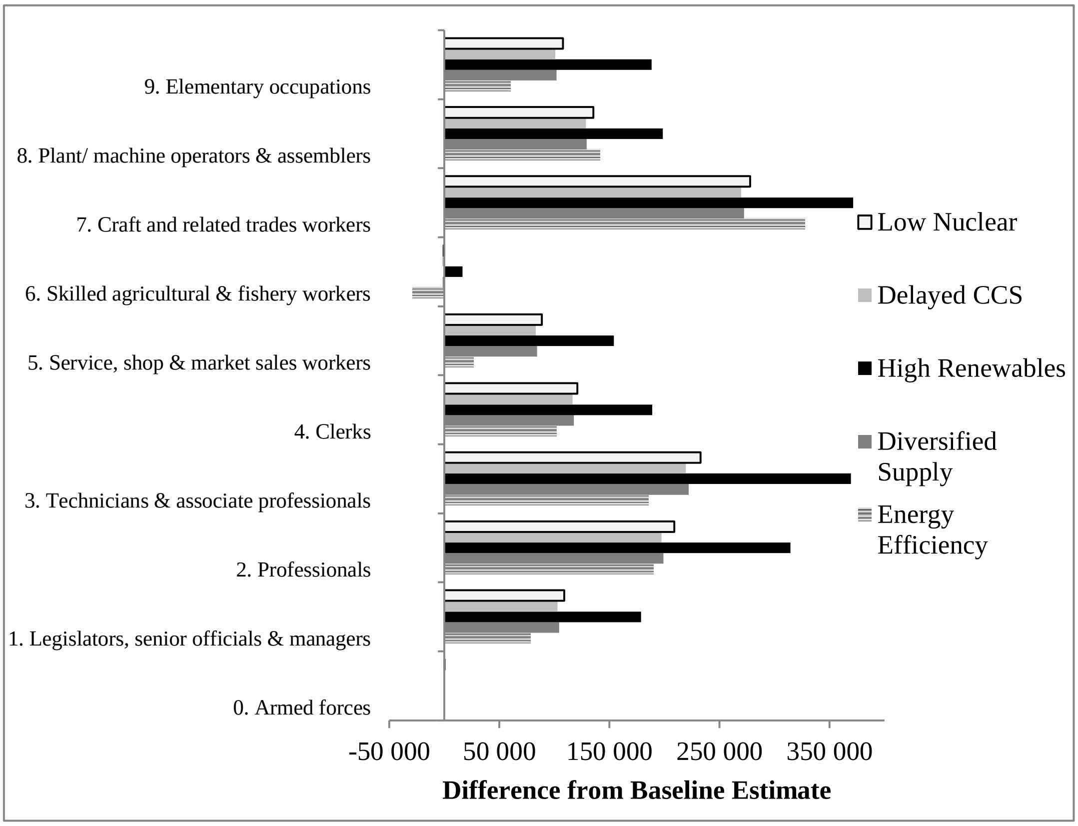
Table 7.2 shows the relative importance of craft and related trades workers. This is consistent with other data which suggest that many jobs related to the greening of the economy are ‘green-collar’ ones (Muro et al., 2011), and are of the kind that in the past would have been regarded as manual, or blue collar ones. This in part reflects the nature of the work that results from a greening of the economy, such as manufacture and installation of wind turbines, retro-fitting buildings to improve their energy efficiency, the development of more fuel efficient vehicles, etc.

Table 7.2: Differences from the Baseline in levels of employment by occupation by 2025

	Scenarios				
	Energy Efficiency	Diversified Supply	High RES	Delayed CCS	Low Nuclear
1. Legislators, senior officials and managers	78 000	104 000	179 000	103 000	109 000
2. Professionals	190 000	199 000	315 000	197 000	209 000
3. Technicians and associate professionals	186 000	222 000	369 000	220 000	233 000
4. Clerks	102 000	118 000	189 000	116 000	121 000
5. Service workers and shop and market sales workers	27 000	84 000	154 000	83 000	89 000
6. Skilled agricultural and fishery workers	-29 000	-2 000	17 000	-2 000	-1 000
7. Craft and related trades workers	328 000	272 000	371 000	270 000	278 000
8. Plant and machine operators and assemblers	142 000	129 000	198 000	129 000	135 000
9. Elementary occupations	60 000	102 000	188 000	101 000	108 000

Notes: Armed Forces have been included in overall totals but data for this group are not presented in the table.

Figure 7.2: Differences from the Baseline in levels of employment by occupation by 2025



Focusing now just on the relatively high skilled jobs, Table 7.3 shows the projected growth in the number of such jobs under each scenario compared to the baseline. S3 High Renewables has higher requirements than the other scenarios.

Table 7.3: Differences from the Baseline in levels of employment by occupation by 2025 for relatively high skilled occupations

	S1: Energy Efficiency	S2: Diversified Supply	S3: High Renewables	S4: Delayed CCS	S5: Low Nuclear
Managers, professionals, and associate profs.	454 000	525 000	863 000	520 000	551 000
Skilled trades	328 000	272 000	371 000	270 000	278 000
Total	782 000	797 000	1 234 000	790 000	829 000

Focusing on higher level occupations (i.e. managers, professionals, and associate professionals), Table 7.4 shows for each member of the EU28, the difference in percentage points between the employment growth projected for higher level occupations between 2010 and 2025 under the baseline and under each of the other scenarios. If one looks at the High Renewables scenario it is noticeable that in general the percentage point difference between this scenario and the baseline reveals a consistent pattern across countries in that it shows relatively high employment growth. But there are exceptions, particularly in Belgium, France, Latvia, and Austria where the percentage point difference is smaller than the EU28 average. Clearly, the results are affected by features specific to particular countries. With the exception of Austria, these are all countries where the shares of people working in higher level occupations are slightly higher than the EU28 average. This might limit the capacity of policies to bring about further increases in the take-up of renewable technologies. But this is a speculative suggestion. The subject requires further analysis at national level. The key issue is that the impact of the various scenarios on occupational employment varies, at the margin, between Member States. The relative impact of the various scenarios is stronger in some Member States than others.

Table 7.4: Projected growth in the number of people employed in higher level occupations between 2010 and 2025: Percentage point difference from the Baseline

	S1 Energy Efficiency	S2 Diversified Supply	S3 High Renewable	S4 Delayed CCS	S5 Low Nuclear
EU28	0.5	0.6	0.9	0.6	0.6
1. Belgium	0.0	0.1	0.3	0.1	0.1
2. Bulgaria	0.6	0.8	1.2	0.8	0.9
3. Czech Republic	1.1	1.1	1.7	1.1	1.2
4. Denmark	1.2	1.0	1.6	1.0	1.0
5. Germany	0.5	0.5	0.6	0.5	0.5
6. Estonia	1.1	0.9	1.2	0.9	0.9
7. Ireland	0.5	0.6	1.2	0.6	0.7
8. Greece	1.4	1.2	1.6	1.2	1.2
9. Spain	0.7	0.8	1.1	0.8	0.7
10. France	0.5	0.5	0.5	0.5	0.5
11. Italy	0.4	0.6	1.1	0.6	0.6
12. Cyprus	0.7	1.3	2.6	1.2	1.3
13. Latvia	-0.3	0.1	0.1	0.1	0.1
14. Lithuania	0.4	0.6	0.8	0.6	0.7
15. Luxembourg	1.8	1.2	1.8	1.2	1.3
16. Hungary	1.0	1.4	2.7	1.3	1.4
17. Malta	0.8	0.9	1.0	0.9	0.9
18. Netherlands	1.1	0.9	1.4	0.9	0.9
19. Austria	-0.3	0.1	0.3	0.0	0.1
20. Poland	0.6	0.7	1.3	0.7	0.8
21. Portugal	0.6	0.5	0.7	0.5	0.6
22. Romania	1.0	1.0	1.4	1.0	1.1
23. Slovenia	1.9	1.5	1.9	1.6	2.4
24. Slovakia	0.5	0.6	1.0	0.6	1.2
25. Finland	1.2	1.1	1.4	1.1	1.1
26. Sweden	0.2	0.3	0.5	0.3	0.3
27. United Kingdom	-0.1	0.3	0.8	0.3	0.3
28. Croatia	0.7	0.7	1.6	0.7	0.8

Qualifications

An alternative way of looking at skill demand is with reference to the qualification profile of those in employment. Qualification levels have been calculated according to the highest qualification attained by those in employment with the following three levels of education:

- High: tertiary level
- Medium: upper-secondary / post-secondary, non-tertiary
- Low: below upper-secondary level

Figure 7.3 shows how the occupational profile is projected to change in the baseline. It shows, consistently with the findings relating to the changing occupational structure, an increase – in both absolute and proportionate terms – in the number of people qualified at the highest level. Under each of the scenarios, there will be an increase in the number of people employed at each qualification level but especially at the medium level (see Figure 7.4). But again the differences from the baseline under each scenario are small.

Figure 7.3: Changes in qualification levels between 2010 and 2025 in the Baseline

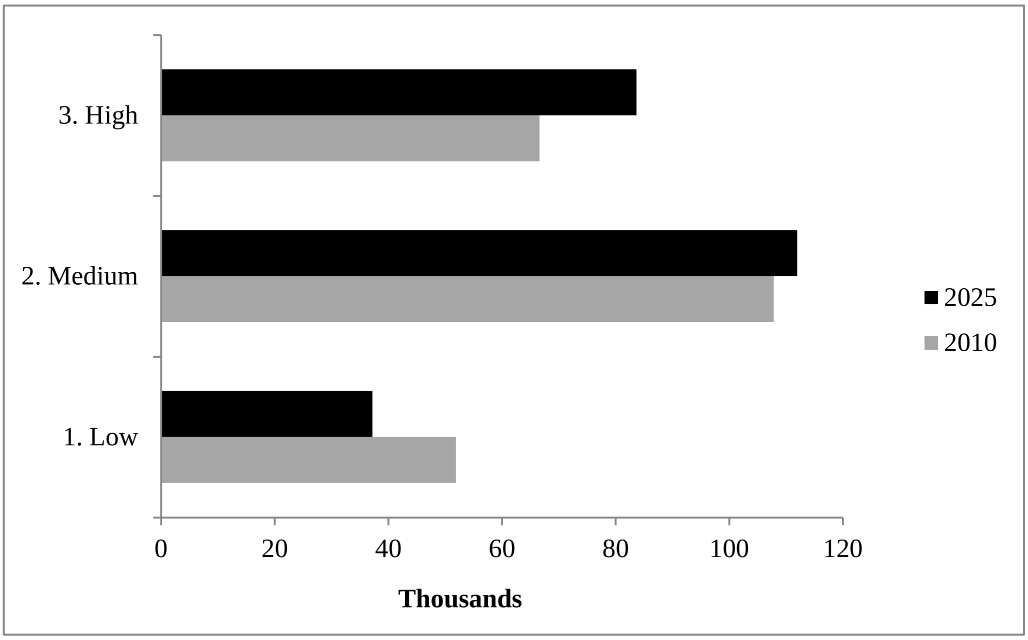
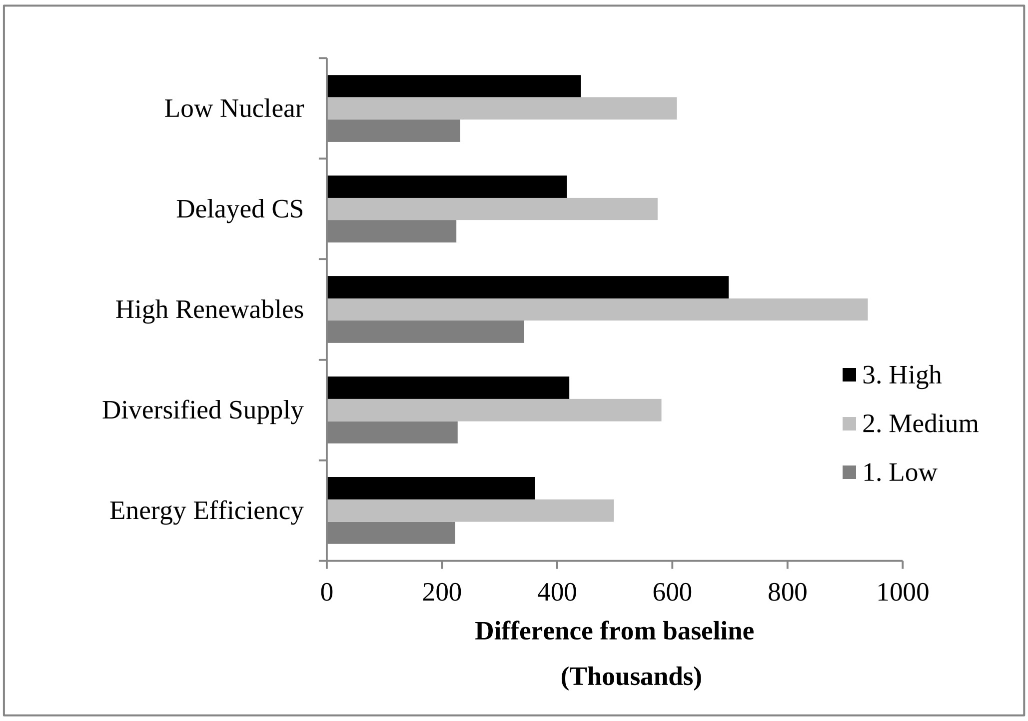


Figure 7.4: Differences from the Baseline by 2025 in levels of employment by qualification level



7.3 Qualitative outcomes

The results under the various scenarios indicate that they will all increase the demand for people to work in relatively high skilled jobs, i.e. in managerial, professional, associate professional, and craft and skilled trades occupations. At its highest under the S3 High Renewables scenario the increased demand will result in the employment of around 1.2m more people in these occupations in 2025 than under the baseline, and at its lowest, around three quarters of a million more under the S1 High Energy Efficiency scenario. As noted elsewhere in this report the increased demand for skills will be driven in large measure through the impact on employment in the engineering and construction sectors.

When we are looking at occupational demand, and are interested in the extent to which environmental and energy policies are related to the creation of high-skill, high-wage employment, we need to consider how far:

i. change takes place within the existing occupational distribution of jobs, in other words, the extent to which there is a re-distribution of existing jobs across the occupational structure
ii. the content of jobs changes such that (a) the types of tasks people are expected to carry out within a given occupation change, or (b) new jobs or occupations are created

In relation to (i), occupational demand will be driven in large measure by change in the sectoral demand for labour. The projections of future occupational demand provided in this chapter show the extent to this kind of expected change. In relation to (ii) there is a need to glean evidence from a number of sources which have looked, in detail, at the new types of skill needed within existing occupations and, importantly, the emergence of new occupations as a consequence of the economy's greening.

Change in the existing occupational structure

The evidence in the preceding chapters, which is consistent with many other studies of the changing demand for labour resulting from environmental policy (e.g. Cambridge Econometrics, 2011), suggests that there are distinct sectoral effects. These can be summarised with respect to:

- **sectors expected to experience employment decline:**
  - energy production sectors which are dependent upon fossil fuels (e.g. coal-fired power stations)
  - industrial production which is relatively dependent upon energy consumption (e.g. metals processing)
- **sectors expected to make employment gains:**
  - industrial production related to energy conservation / renewable energy production
  - the renewable energy sector
  - services related to energy conservation (e.g. construction services, environmental services, etc.)

The impacts of the above changes are likely to be uneven across the EU. In many Member States, there are regional concentrations of energy producers and heavy industry. In particular, there are parts of eastern Europe which are particularly dependent upon coal as a source of energy (OECD, 2009b). In countries, such as France with its relatively well developed nuclear sector, or the Nordic countries with the availability of hydro-electric energy production, there is potentially less impact from policies to reduce GHG. The importance of the sectoral changes for occupations is that jobs in energy and heavy industry are often relatively well paid and skilled. Consequently, the loss of such jobs may have an adverse impact on the skill structure of a country or region, at least over the short term, but this depends on the type of jobs which replace them. This was observed, to some extent, in those parts of western Europe where the masked decline of employment in traditional, often energy-intensive industries, during the late 1970s and 1980s led, during a transitional period, to a marked downturn in employment opportunities for skilled trades workers – mainly men – in some regional economies (e.g. north-east England).

While employment in traditional industrial sectors may decline slightly more rapidly than in other sectors, depending upon the mix of policies adopted, there is also evidence that these same policies can provide opportunities for employment growth in skilled jobs. This has been observed in several countries. In Denmark, for example, there is evidence that shipbuilders have been able to transfer their skills into the production of offshore wind turbines (Strietska-Ilina et al., 2011). For example, the closing of the Lindoe Shipyard in Southern Denmark in 2009 led, with assistance from the public authorities, to the emergence of an offshore renewable energy facility which was able to make use of the skills of the workforce and the existing facilities, including docks, production and storage facilities, cranes and lifting facilities (Strietska-Ilina et al., 2011, p. 268). Similarly, the need to reduce GHG from vehicles has led to investments in electric powered cars which have resulted in benefits to regional economies for example in the north-east of England where Nissan has invested in the production of electric cars (Strietska-Ilina et al., 2011, p 426). These types of development have increased the demand for both skilled trades jobs – often referred to as green-collar occupations – alongside professional and associate professional, occupations often linked to research and development. They also potentially lead to a demand for new skills to augment traditional engineering ones.

The renwables energy sector has been identified as one with considerable potential for employment growth. Evidence from Germany (O'Sullivan, et al., 2011) and the UK (CE/IER/IFF, 2010) suggests that the renewables sector has created a strong demand for skilled labour. Again the demand is for green-collar and professional / associate professional level skills. These too are often regionally specific with the production of wind turbines taking place in areas with a tradition of marine and offshore engineering (e.g. for oil and gas) producing these. Where the intention is to develop offshore facilities, this has benefited regions which have a history of shipbuilding. Finally, jobs are also created in those regions where there is a plentiful supply of wind; these areas are not always well populated which can create problems related to skills supply.

Evidence from the USA suggests that there are likely to be agglomerative benefits here.

New skills for new jobs

The most systematic attempt to analyse the impact of green policy on job content has been produced by the 0*NET system in the US (see Dierdorff et al., 2009; 2011). A distinction is made between:

Green Increased Demand Occupations where there is an increased demand for people in existing occupations, where the work context may change but there are no significant changes in the work undertaken in the occupation. An example is the increased demand for electrical power line installers and repairers related to energy efficiency and infrastructure upgrades.

Green Enhanced Skills Occupations where green economy activities and technologies result in a significant change to the work and worker requirements of an existing occupation. An example is the occupation architect, where greening requires increased knowledge of energy-efficient materials and construction, as well as skills associated with integrating green technology into the aesthetic design of buildings.

New and Emerging Green Occupations[47] where **t**he impact of green economy activities and technologies is sufficient to create the need for unique work and worker requirements, resulting in the generation of a new occupation. This new occupation could be entirely novel, or it could be 'born' from an existing occupation. An example would be solar system technicians who must be able not only to install new technology, but also to determine how this technology can best be used on a specific site.

Source: Dierdoff et al., 2009

Dierdorff et al. (2011) analyse the emerging skill needs in a range of sectors resulting from a greening of the US economy. In particular, a number of occupations are identified in the renewable energy sector where an increase / decrease in demand are expected over the medium term, and the new skills which will emerge are identified. The only existing occupations which are expected to show faster-than-average employment growth over the medium term are civil engineers and nuclear engineers, but attention is also drawn to new skill needs emerging related to installers of wind and solar energy devices, the operation of hydroelectric plants, wind engineers, and engineers engaged in hydropower, solar, and biomass. Looking at the impact on other sectors, attention is drawn to the need for engineers with experience of working with fuel cells in the automotive sector. This will result in the content of existing jobs changing but also in demand for new skills related specifically to battery or cell technology. In the green construction sector, there is also likely to be an increased demand for those in the sector to be aware of energy-efficiency requirements, which is also likely to result in demand for energy auditors and energy engineers.

The key point is that, at a relatively high level of aggregation, the statistics on occupational change can disguise some of the change which is taking place at a local level or within an occupation.

General Impacts on Job Content

A greater impact is likely to be felt from the effects of green / energy policy on jobs in general (Dierdorff, et al., 2009; 2011; Cambridge Econometrics, 2011). This arises from an increasing demand for generic skills (e.g. being aware of ways of conserve energy) and being able to apply existing technical skills within a green context (such as applying turbine technologies to renewables onshore and offshore or the ability of construction workers to apply their skills to retrofitting buildings) (Cedefop, 2010). This would imply that there is a substantial demand for continuing vocational

[47] The following link provides a list of new and emerging occupations: http://www.onetcenter.org/green/emerging.html

education and training assist people to apply their existing technical skills within a green context.

Regional impact

The argument in this chapter has indicated that there is likely to be a strong regional element to the occupational change projected to take place in the period to 2025. A number of observations can be made here:

- The impact of policy on the demand for skills will be felt across all areas to some degree. While there are likely to be opportunities relating to employment in all areas, for example, waste management, and installation of renewable energy technologies, some localities are better placed to take advantage of future developments.
- Greening of the economy is likely to favour those areas which have already developed a strong presence in the production of renewable technologies (e.g. in Denmark and Germany). It is likely to be the renewable technology sector which will show strong employment growth over the medium term and it is likely that the areas which already have the production capacity will benefit most from this development (Muso et al., 2011; CE/IER/IFF, 2010).
- Related to the above, there are likely to be increasing employment opportunities in those areas which are favourably disposed to the production of renewable energy or in facilitating the construction of renewable energy installations, for example, where there already is an infrastructure related to the construction of offshore installations.
- More widely, there is already evidence that certain areas are developing expertise in specialist technologies, such as the production and development of electric vehicles. Future developments are likely to further favour these areas.
- Areas which are dependent upon energy-intensive production or are engaged in the development of relatively less clean forms of energy will, at least over the short term, other things being equal, fare less well with respect to future employment growth.

Social equity and income

There are also social equity issues to consider given the changes in the occupational structure projected under the baseline and other scenarios. Potentially, other things being equal, the combination of sectoral and occupational change may disadvantage certain groups in the labour market. Attention has been drawn to the fact that the direction of occupational change potentially disadvantages women insofar as they are less well represented in: (a) some of the higher level occupations where growth is projected under all of the scenarios (Cambridge Econometrics, 2011); and (b) in the construction and engineering industries where greening is expected to create a substantial number of jobs (Gausus et al., 2012; Stevens, 2009). Caution is required in the interpretation of this trend from an energy policy perspective. Projected future occupational change is driven by many factors, among which the potential impact of future energy policy is likely to be small. The key finding is that the energy scenarios tend to marginally increase the demand for people to work in occupations and sectors where women have a relatively small share of the workforce compared to men.

In relation to income levels, the increased demand for enhanced skills likely under many of the scenarios will, other things being equal, have a positive impact on wage levels. There needs to be a qualification here in relation to the capacity of national education and training systems to produce the skills which energy policy is likely to create a demand for. The evidence indicates that in some countries a substantial increase in the demand for people at professional, associate professional, and craft /

skilled trades levels may result in supply failing to keep pace with demand (CE / IER / IFF, 2010; Ecorys, 2008).

7.4 Conclusions

Future skill demand – as measured by occupational change – is driven by a large number of factors including globalisation and technological change. Changes in energy policy have the potential to influence technological change where it leads, for instance, to the construction of new energy plants (e.g. nuclear and renewable ones) and to the introduction of new, more energy-efficient production systems across all sectors of the economy. The projections of occupational change to 2025 indicate that, under the various energy scenarios, the long established trend towards an increase in the number of people employed in relatively high-skilled (managerial, professional, associate professional, and craft /skilled trades workers) and low-skilled (elementary occupations) will be slightly strengthened.

Underlying this trend are more specific occupational changes. Policies which, for example, seek to increase output from the renewables or nuclear energy sectors may well create a demand for technology specific skills. The numbers of people required with these skills may be small when compared to the overall level of employment in the EU, but such people can be of critical importance to achieving policy goals. There are also the wider effects of energy policies to consider, namely that they can affect jobs in general insofar as employees need to be able to apply their existing skill sets within a green environment.

8 Conclusions

Introduction

This chapter provides a short comparison of the results from the two models that are presented in Chapters 5 and 6. We first compare the macroeconomic outcomes and then look at employment in more detail.

The models looked at the same set of scenarios, with inputs set to be as consistent as possible, given the models' different specifications. The differences between the two sets of results should therefore represent differences in modelling approach rather than differences in scenario inputs. Nevertheless, there are some cases where the complexity of the scenarios and the different treatment in the models make it difficult to give a simple interpretation of the differences in results.

A description of some of the theoretical differences between the models is provided in Appendix E.

Macroeconomic results

The baseline values used in the two models are shown in Table 8.1.

The scenarios include a combination of positive and negative effects, with the GDP impacts showing the aggregation of these different effects. Both models show that overall the scenarios will have a modest impact on GDP. The results from the E3ME model suggest that GDP could increase by up to 3% by 2050 (of which up to 1% is attributable to the oil price effect), while GEM-E3 suggests a reduction in GDP of up to 1%. This is shown in Table 8.2.

Table 8.1: EU28 Baseline results in 2050

	E3ME	GEM-E3
GDP	22 985	27 215
Household consumption	12 967	16 499
Investment	5 357	5 005
Exports	4 432	4 267
Imports	4 258	4 340
Employment	218.5	220.7

Notes: GDP and components are €2005m, employment in million persons.
Sources: E3ME and GEM-E3 models.

Table 8.2: Comparison of the two models' results for the impacts on GDP in the scenarios

	S1	S2	S3	S4	S5
			% difference in GDP from CPI baseline in 2050		
E3ME	2.9	2.3	2.0	2.2	2.2
GEM-E3	-0.6	-0.8	-0.8	-0.9	-0.7

Sources: E3ME and GEM-E3 models.

The difference in results between the models is around 3-4% of GDP in 2050. The breakdown by final expenditure component does not differ greatly across scenarios; Table 8.3 presents the breakdown for S2, the diversified supply technologies scenario. While the differences in consumption largely reflect changes going on elsewhere in the economy, there are two key differences in the results:

- The E3ME results show a much larger increase in total investment. This is largely due to the differences in assumptions about 'crowding out' of investment. In the sensitivity test using E3ME where full crowding out was assumed, investment was almost unchanged from baseline. The difference in investment accounts for around 20% of the total difference in GDP.
- There is a large difference in the results for competitiveness and international trade. In the results for GEM-E3, exports decrease and imports decrease, for various reasons. Firstly, GEM-E3 assumes that, globally, the policies that promote low carbon technologies must come at a cost in the form of lower GDP, and this depresses the market for EU exports. Secondly, the GEM-E3 scenarios were designed so that extra investment in the EU could not be financed by a larger current account deficit, and so these scenarios include an increase in the terms of trade to keep the current account as a percentage of GDP unchanged. E3ME does not make that assumption. Thirdly, although both models treat the loss of competitiveness that results from the carbon prices imposed in the scenarios (and also increases in biofuel imports), these effects are very limited in E3ME, and are balanced by the reductions in fossil fuel imports. This accounts for around 60% of the total difference in GDP.

The remaining difference is due to endogenous effects on household incomes and expenditure.

Table 8.3: Comparison of the two models' results for the impacts on final expenditure components in the S2 scenario

	E3ME	GEM-E3
	% difference in GDP from CPI baseline in 2050	
GDP	2.3	-0.9
Household consumption	1.5	-0.3
Investment	4.0	1.6
Exports	0.4	-3.2
Imports	0.0	2.0

Sources: E3ME and GEM-E3 models.

Employment results

Aggregate employment results

The employment results are also the result of a set of complex interactions. Employment in the models is determined by a combination of:

- structural change
- the revenue recycling

- aggregate GDP effects
- reaction in the labour market

Despite the differences in GDP results, both models show positive results for employment and both models show quite consistent impacts across scenarios. The E3ME sensitivity analysis showed that the revenue recycling (and choice of method applied) was an important determinant of final outcomes. While this was also a factor in the GEM-E3 results, it appears to be less prominent in the results.

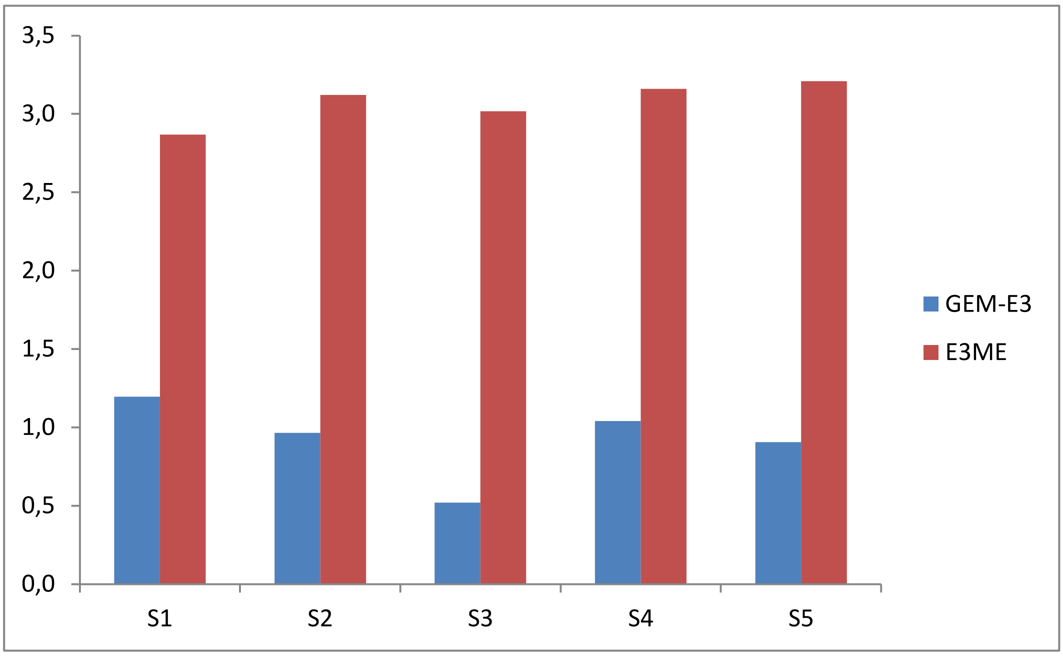
It is also important to note the differences in how labour supply and wages are determined in the models. For both models, employment results depend upon the stock of available labour; if there are not spare labour resources available then boosts to labour demand will push up wages rather than employment levels.

Table 8.4: Comparison of the Models' Employment Results (% from CPI, 2050)

	S1	S2	S3	S4	S5
E3ME	1.3	1.4	1.4	1.4	1.5
GEM-E3	0.5	0.5	0.2	0.6	0.5

Sources: E3ME and GEM-E3 models.

Figure 8.1: EU28 Absolute Change in Employment from Baseline in 2050, m



Sectoral employment

The results for sectoral employment are quite similar in pattern between the two models, although different in magnitude. Both models show gains principally in the construction and engineering sectors, resulting from the higher levels of investment and new products. In other sectors, the results for employment typically follow those for output in the same sector. Two differences in particular stand out.

- In the energy-intensive sectors, E3ME results suggest there will be an increase in employment overall due to a greater demand for inputs to construction, while in GEM-E3 the competitiveness effects (from the carbon prices) outweigh this, leading to a reduction overall.

- In the agriculture sector the GEM-E3 results show a large increase in employment, while results from E3ME are in line with other sectors. The reason for this is the more advanced treatment of biofuels in GEM-E3 which captures these feedback effects explicitly.

Skill base Both models suggest that there will not be much change in the structure of employment in terms of skills requirements in the scenarios. In both cases there is very little difference from the baseline for the share of high and low-skilled workers. This is consistent with previous findings.

Power sector employment Employment in the electricity sector is determined by a combination of the input assumptions on the electricity fuel mix (consistent between the models) and the different coefficients used to determine number of jobs per unit of generation capacity. The differences in results between the two models are therefore due to the choices of coefficients used rather than any differences in modelling specification (see Table 8.5 for baseline values).

The main difference between the two sets of model results is the large value for solar-related employment in the E3ME results. This is due to a combination of a large coefficient (jobs/GW, based on the 2010 data from Chapter 2, without any efficiency gains), and a large expansion of solar capacity in the baseline. When the sensitivity of this assumption was tested for the scenarios it was found to have minimal impact at macro level.

Table 8.5: EU28 Baseline Power Sector Employment in 2050, m

	E3ME	GEM-E3
Conventional	0.25	0.17
Hydro	0.03	0.05
Nuclear	0.14	0.15
Solar	1.19	0.27
Wind	0.36	0.28
Geothermal	0.00	-
Biomass	0.04	0.07
Tidal	0.03	-

Sources: E3ME and GEM-E3 models.

Revenue recycling options The E3ME results show that the choice of revenue recycling method can have a significant impact on the results. This has not, however, come through in the GEM-E3 results. The impacts of the choice of recycling method will also to some extent depend on the models' labour market specifications and the available labour resources in the economy.

Summary In summary, there are both similarities and differences in the models' results.

E3ME predicts a more positive outcome for GDP and employment, which is mainly due to two key factors.

- E3ME assumes that it is possible to have a large increase in investment in energy infrastructure without diverting investment from elsewhere. In contrast, GEM-E3 assumes a crowding-out effect, meaning that there are reductions in other types of investment.
- The two models suggest different outcomes in terms of international trade, with there being much stronger competitiveness effects in GEM-E3. This is at least in part due to a difference in elasticities (i.e. the reaction to net trade in response to price changes) rather than model specification.

When considering employment impacts, it is also important to take into account how the models treat labour supply and wage formation. This is particularly true when unemployment rates are relatively low, when increases in labour demand tend to lead to higher wage rates rather than higher levels of employment.

Both models suggest that the employment effects will be quite similar in all the scenarios. They also predict that the largest increases in jobs will be in construction and in sectors that produce new equipment.

9 References

Appendix B contains a summary of the main reports and papers that were used in the literature review.

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10 Appendices

Appendix A: Further Data Results

This appendix provides EurObserv’ ER data on the employment breakdown between manufacturing, distribution, installation, operation and maintenance (O&M)

NC 221115 Electric power generation, wind

WIND	2007	2008	2009	2010
Austria	55% manufacturing and installation, 45% in O&M	55% manufacturing, distribution and installation 45% O&M	90% manufacturing 10% O&M	90% manufacturing, 10% 0&M
Denmark		75% manufacturing 10% distribution, 15% O&M	85% manufacturing 15% O&M	
Finland			95% manufacturing 5% installation	90% manufacturing, 10% Installation and 0&M
France	3% manufacturing 90% distribution and installation, 7% O&M	30% manufacturing 65% study and installation 5% O&M	50% manufacturing 40% installation 10% O&M	
Germany	35% manufacturing 65% distribution and O&M	80% manufacturing, distribution and installation 20% O&M	85% manufacturing (also for export) and installation 15% O&M	85% manufacturing, 15% 0&M
Italy		17% manufacturing 48% development and construction, 35% O&M	20% manufacturing 50% installation 30% O&M	20% manufacturing, 50% Installation, 30% 0&M
Netherlands	75% manufacturing 10% distribution and installation, 15% O&M			
Poland		25% manufacturing and distribution 60% installation, 15% O&M	75% manufacturing 10% installation 15% O&M	75% manufacturing, 10% Installation, 15% 0&M
Spain	40% manufacturing 60% distribution, installation and O&M	32% manufacturing and distribution, 38% installation, 30% O&M	30% manufacturing (components and turbines) 40% installation 30% O&M and services	30% manufacturing of components and turbines, 40% Installation, 30% 0&M and services
United Kingdom		20% manufacturing 40% installation, 40% O&M	20% manufacturing 40% installation 40% O&M	45% plannification and development, 28% manufacturing and installation, 27% 0&M

Sources: EurObserv’ER, « The State of renewable energies in Europe », 2008, 2009, 2010 and 2011

NC 221114 Electric power generation, solar

Solar - PV	2007	2008	2009	2010
Austria	70% manufacturing 30% distribution, O&M and R&D	33% production 55% distribution and installation, 12% R&D	45% manufacturing, production and R&D 55% distribution and installation	45% manufacturing, 55% Distribution and installation
Belgium				3% manufacturing, 87% Distribution and installation
Bulgaria			20% manufacturing and installation 80% O&M	20% manufacturing and installation, 80% O&M
Czech Republic			25% installation 75% O&M	25% manufacturing, 75% O&M
Denmark		10% R&D, 80% manufacturing 10% distribution and installation	80% manufacturing 10% installation 10% R&D	80% manufacturing, 10% Installation, 10% R&D
France	15% manufacturing 85% distribution and installation	15% manufacturing 85% distribution and installation	15% manufacturing 85% installation and O&M	13% manufacturing, 87% Installation and O&M
Germany	46% manufacturing 54% distribution, installation and O&M	55% manufacturing 10% distribution 35% installation	50% manufacturing 40% installation 10% O&M, sales and trade	50% manufacturing, 40% Installation 10% O&M
Italy			30% manufacturing 55% installation 15% O&M and R&D	30% manufacturing, 55% Installation, 15% 0&M
Netherlands	50% manufacturing 45% distribution and installation, 5% O&M	50% manufacturing 50% distribution and installation	50% manufacturing 50% distribution and installation	50% manufacturing, 50% Distribution and installation
Poland	50% distribution and installation, 50% O&M	100% distribution and installation	25% manufacturing 50% installation 25% O&M	
Slovenia	65% manufacturing 30% distribution and installation, 5% O&M	100% distribution and installation	40% manufacturing 60% installation and O&M	40% manufacturing, 60% Installation and O&M
Spain	20% manufacturing 70% distribution and installation, 10% O&M	20% manufacturing 80% distribution and installation	20% manufacturing 80% distribution and installation	20% manufacturing, 80% Distribution and installation
Sweden		95% manufacturing and R&D 5% distribution and installation	95% manufacturing 5% distribution and installation	95% manufacturing, 5% Distribution and installation

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008, 2009, 2010 and 2011

NC 221114 Electric power generation, solar

Solar - thermal	2007	2008	2009	2010
Austria		37% manufacturing 32% sales 31% system design and installation	40% manufacturing 30% sales 30% installation and O&M	30% manufacturing, 30% sales, 40% Installation and O&M
Belgium			10% manufacturing 80% distribution and installation 10% O&M	10% manufacturing, 80% Distribution and installation, 10% O&M
Bulgaria			50% manufacturing 40% installation 10% O&M	
Denmark		40% manufacturing 60% distribution and installation	40% manufacturing 60% distribution and installation	40% manufacturing, 60% Distribution and installation
Finland				100% Installation
France	15% manufacturing 75% distribution and installation, 10% O&M	65% manufacturing 25% distribution and installation 10% O&M	65% manufacturing 25% distribution and installation 10% O&M	
Germany	85% manufacturing 15% distribution and O&M	30% manufacturing 35% distribution and marketing 35% system design, installation, O&M	30% manufacturing 35% distribution and marketing 35% installation and O&M	30% manufacturing, 35% Distribution and marketing, 35% Installation and O&M
Hungary			16% manufacturing 67% installation 17% O&M	
Ireland			Mainly installation	Mainly installation
Italy		30% manufacturing 70% distribution and installation	30% manufacturing 70% distribution and installation	30% manufacturing, 70% Distribution and installation
Luxembourg		100% distribution and installation	Only installation	100% Installation
Netherlands		34% manufacturing 66% distribution and installation	35% manufacturing 65% distribution and installation	
Poland	10% manufacturing 75% distribution and installation, 15% O&M	34% manufacturing 66% distribution and installation	30% manufacturing 45% installation 25% O&M	30% manufacturing, 45% Installation, 25% O&M
Slovakia		100% distribution and installation	Only installation	100% Installation
Spain		20% manufacturing 80% sales, system design and installation	60% manufacturing 40% installation 10% O&M	30% manufacturing, 15% Distribution, 45% Installation, 10% O&M
Sweden		20% manufacturing 80% distribution and installation	20% manufacturing 80% distribution and installation	20% manufacturing, 80% Distribution and installation

Solar - thermal	2007	2008	2009	2010
United Kingdom		35% manufacturing 65% distribution and installation	35% manufacturing 65% distribution and installation	35% manufacturing, 65% Distribution and Installation

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008, 2009, 2010 and 2011

NC 221111 Power generation, hydroelectric

Small hydropower	2007	2008
Austria		40% manufacturing 10% installation 50% O&M
Finland		66% manufacturing 34% O&M
France	15% manufacturing, distribution and installation; 85% O&M	10% manufacturing and installation 90% O&M
Germany	55% manufacturing 45% O&M	75% manufacturing 10% installation 15% O&M
Italy		60% manufacturing 25% installation 15% O&M
Luxembourg		100% O&M
Poland		90% manufacturing 5% installation 5% O&M
Sweden		15% manufacturing 65% installation 15% O&M
United Kingdom		90% manufacturing 5% installation 5% O&M

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008 and 2009

NC 221116 Electric power generation, geothermal

Geothermal energy	2007	2008
France	40% manufacturing 55% distribution and installation, 5% O&M	40% manufacturing, 50% distribution and installation, 10% O&M
Germany	90% manufacturing 10% distribution and O&M	95% manufacturing 5% distribution and O&M

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008 and 2009

NC 221117 Biomass electric power generation

Solid biomass	2007	2008
France	20% manufacturing, 45% distribution and installation, 35% O&M	80% manufacturing, distribution and installation, 20% O&M
Germany	45% manufacturing, 55% distribution, installation and O&M	40% Wood fuel supply, 45% manufacturing and distribution, 15% O&M
Slovenia	80% manufacturing, distribution and installation; 20% O&M	

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008 and 2009

NC 221117 Biomass electric power generation

Biogas	2007	2008
Austria	65% manufacturing and installation, 35% O&M	
France	90% manufacturing, distribution and installation; 10% O&M	90% distribution and installation, 10% O&M
Germany	65% manufacturing 35% distribution, installation and O&M	48% waste sectors 22% manufacturing, distribution and installation, 30 % O&M
Slovakia		5% manufacturing 90% distribution and installation, 5% O&M

Sources: EurObserv'ER, « The State of renewable energies in Europe », 2008 and 2009

Appendix B: Summary of Reviewed Literature

Name of study and authors	Date of publication	Summary
The outlook to 2050		
Analysis of the EU's Energy Roadmap 2050 Scenarios, Foster H., Healy, S., Loreck C., Matthes, F., Fischedick, M., Lechtenböhmer, S., Samadi, S., Venjakob,. J	2012	The paper summarises various analyses done based on the scenarios published in the Energy Roadmap 2050. The report looks at different emission trajectories, electricity production mixes and electricity consumption.
Decarbonisation Scenarios Leading to the EU Energy Roadmap 2050, Foster H., Healy, S., Loreck C., Matthes, F., Fischedick, M., Lechtenböhmer, S., Samadi, S., Venjakob,. J	2012	The study presents results of an in-depth analysis of six mitigation scenarios drawn from three important background studies done for Energy Roadmap 2050: Greenpeace (2010), Eurelectric (2009) and the European Climate Foundation (ECF) (2010) respectively (all three studies are listed in this table). The report looks at different emission trajectories, electricity production mixes and electricity consumption.
Global Europe 2050, European Commission, DG Research and Innovation	2012	The report presents three key scenarios describing different pathways that Europe could choose to follow over the decades to come. The report focuses issues regarding population, sustainable resources, developing clean energy supplies, innovation and climate change.
Roadmap 2050. Financing for a Zero-carbon Power Sector in Europe, European Climate Foundation	2012	The report presents views from the financial community on some of the key issues in the energy debate, looking at trends in the financial and power sector, with a specific focus on low-carbon power generation.
The EU Decarbonisation Roadmap 2050: What Way to Walk?, Hübler, M., Löschel, A., ZEW Discussion Papers	2012	The study presents detailed CGE (Computable General Equilibrium) analysis of the EU Decarbonisation Roadmap 2050 on a macroeconomic and sectoral level, the report distinguishing between 24 production sectors, of which seven are energy-intensive sectors.
Investment and Employment from Large-scale Photovoltaics up to	2012	The paper provides an analysis of current developments in photovoltaics and

2050, Grossmann, W., •. Steininger, K.W., • Schmid, C., Grossmann, I.		assesses the ensuing amounts of investment and employment for a range of sizes of the solar energy sector.
Socio-Economic Role of Nuclear Energy to Growth and Jobs in the EU for Time Horizon 2020-2050, European Commission DG Energy	2012	The paper presents an analysis of the impact of the contribution of nuclear energy to the low-carbon energy mix will have in terms of job creation and growth.
The EU 2050 Low-carbon Energy Future: Visions and Strategies, EUI Working Papers, Robert Shuman Centre for Advanced Studies	2011	The aim of this paper is to identify the main challenges regarding the achievement of a low-carbon energy system in the EU 2050. The five main areas it covers are: energy efficiency, GHG emissions, renewable energy, energy infrastructure and energy markets.
Energy Roadmap 2050 Impact Assessment and Scenario Analysis, European Commission DG Energy	2011	The report contains a detailed analysis of the shift to a low-carbon energy system in the EU by 2050. The report focuses on the following specific objectives: deep reductions of greenhouse gas emissions, reducing vulnerability to oil shocks and other energy security concern and reaping opportunities for sustainable growth and jobs (related to new low carbon technologies), while taking into account wider sustainability and resource efficiency considerations.
A Roadmap for Moving to a Competitive Low-carbon Economy in 2050, European Commission, DG Climate Action	2011	The report presents analyses of several possible scenarios that achieve an 80% reduction in CO_2 emissions by 2050 compared to 1990 levels in the EU in a cost-effective manner, while also maximising benefits for EU manufacturing industries.
Transition Towards a Low-carbon Energy System by 2050: What Role for the EU? Final Report, THINK	2011	This report gives recommendations for the 2050 Energy Roadmap, following the European Council's target to reduce greenhouse gas emissions 80 to 95% below 1990 levels by 2050.
Energy Technology Perspectives. Scenarios & Strategies to 2050, IEA	2010	The report focuses on scenarios to a low-carbon future, focusing on enhancing energy security and economic development.

Roadmap 2050. A Practical Guide to a Prosperous, Low-carbon Europe, European Climate Foundation	2010	The report provides a technical and economic assessment of a set of decarbonisation pathways, as well as policy and regulatory implications.
The World Economy in 2050: A Tentative Picture, Fouré,J., Bénassy-Quéré, A., Fontagné, L. CEPII Working Paper	2010	The paper presents growth scenarios for 128 countries to 2050, based on a three-factor production function that includes capital, labour and energy.
Power Choices. Pathways to Carbon-neutral Electricity in Europe by 2050. Full Report, Eurelectric	2009	The study uses the PRIMES energy model to examine different scenarios that achieve a 75% reduction in greenhouse gases emissions across the entire EU by 2050. The study focuses on different mixes of energy technologies, including renewables.
Other studies on energy efficiency		
A Resource-Efficient Europe. Flagship Initiative of the Europe 2020 Strategy, European Commission http://ec.europa.eu/resource-efficient-europe/index_en.htm	2011	This is an initiative for a resource-efficient Europe under the Europe 2020 strategy. The report supports the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth.
Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. Final Report, Fraunhofer and partners for the European Commission DG Energy and Transport	2009	The main focus of the report is to provide the analytic basis for an in-depth discussion of economic energy efficiency potentials in the different energy-end uses. The study provides estimates energy savings potentials for each EU27 Member State, other EEA countries and Croatia.
Energy Efficiency Economics and Policy, Gillingham, K., Newell, R.G., Palmer, K.	2009	The study reviews economic concepts underlying consumer decision-making in energy efficiency and conservation and examines related empirical literature. In particular, it focuses on the range of market barriers, market failures, and behavioural failures that have been cited in the energy efficiency context.
Renewable Energy and Energy Efficiency: Economic Drivers for the 21st Century, Bezdek**,** R.,	2007	The study looks at the impact of renewable and energy efficiency industry on the economy of the US.
Overall Impact Assessment of Current Energy Efficiency Policies and Potential. 'Good Practice Policies, AID - EE	2007	The study outlines the results of the overall impact assessment of current energy efficiency policies and potential 'good practice' policies in the EU.

		The focuses on the industrial, residential, tertiary and transport sectors.
The Experience with Energy Efficiency Policies and Programmes in IEA Countries. Learning from the Critics, IEA Information Paper	2005	The goal of this paper is to compile, categorise and then evaluate criticisms of energy efficiency policies in IEA countries.
Energy Pricing		
The Effect of Energy Prices on Operation and Investment in OECD Countries: Evidence from the Vintage Capital Model, Steinbuks, J., Meshreky, A., Neuhoff, K..	2009	This paper analyzes the effect of energy prices on energy efficiency, separately accounting for operational and investment choices in different sectors. The study focuses on the manufacturing, commerce, transport and agriculture sectors.
Impacts of the German Support for Renewable Energy on Electricity Prices, Emissions and Firms, Traber, T., Kemfert C.	2007	The paper aims to find the total effect of the German renewable policies on electricity prices using quantitative electricity market model.
First evidence of Asymmetric Cost Pass-through of EU Emissions Allowances: Examining Wholesale Electricity Prices in Germany, Zachmann, G., von Hirschhausen, C.R.	2007	This paper looks at asymmetric cost pass-through rates between CO_2-emissions prices and electricity wholesale prices.
Other studies on renewables		
Power Perspectives 2030. On the Road to a Decarbonised Power Sector, ECF, McKinsey, KEMA, Imperial College London, RAP and E3G	2011	The report looks at the transition to a zero-carbon power sector, focusing on the 2030 horizon and closely follows the sectoral emissions trajectory set out by the European Commission's 8th March 2011 communication on a roadmap for a low-carbon competitive economy by 2050, which indicates a CO_2 emissions reduction range of ±60% in the power sector in 2030.
Economic Effects of Renewable Energy Expansion: A Model-Based Analysis for Germany, Blazejczak, J., Braun, F.G., Edler, D. Schill, W.P	2011	This paper analyses and quantifies the net balance of economic effects associated with renewable energy deployment in Germany until 2030. The model used in the analysis is the 'Sectoral Energy-Economic Econometric Model' (SEEEM). The disaggregated economic results are presented at a 7-sector split.
Working for a Green Britain Volume 2 - July 2011, Cambridge Econometrics, University of Warwick Institute for Employment Research	2011	The study looks at current and future employment and skills associated with the development of the UK wind and marine energy industries over the

(IER) and IFF Research. Study done for RenewableUK		period 2010 to 2021.
Energy Revolution. Towards a Fully Renewable Energy Supply in the EU27, Greenpeace and EREC	2010	The study focuses on the impact of green energy investment on issues such as energy security, stability of supply, growing demand, employment and the urgent need to cut emissions and head off climate change.
EmployRES: The Impact of Renewable Energy Policy on Economic Growth and Employment in the European Union. Final Report, Fraunhofer ISI and partners	2009	This report presents a complete analysis of the employment and economic growth impacts of renewable energies, covering past, present and future prospects.
The Economic Benefits of Investing in Clean Energy. How the Economic Stimulus Programme and New Legislation Can Boost U.S. Economic Growth and Employment, Pollin, R., Heintz, J., d Garrett-Peltier, H.	2009	This paper examines these broader economic considerations with respect to two US government initiatives focused on clean energy passed in 2009.
Study of the Effects on Employment of Public Aid to Renewable Energy Sources, Álvarez, G.C., Jara, R.M., Julián, J.R.R., Bielsa, J.I.G.	2009	The study looks at the actual performance and impact of the Spanish/EU-style green jobs policies that have been implemented.
Economic Impacts from the Promotion of Renewable Energies: The German Experience, Rheinisch-Westfälisches Institut für Wirtschaft sforschung	2009	This paper reviews the Renewable Energy Sources Act (EEG), focusing on its costs and the associated implications for job creation and climate protection in Germany.
The Economic Effects of the EU Biofuel Target, Kretschmer, B., Narita, D.,Peterson, S.	2009	The study uses the model DART to assess the economic impacts and optimality of the different aspects of the EU climate package, with the focus on the 10% biofuel target in the EU. In particular the study looks at the development in the biofuel sectors, the effects on agricultural production and prices and finally overall welfare implications.
Employment Impacts of EU Biofuels Policy: Combining Bottom-up Technology Information and Sectoral Market Simulations in an Input-output Framework, Neuwahl, F., Löschel, A., Mongelli, I., Delgado, L., ZEW Discussion Paper	2008	This paper analyzes the employment consequences of policies aimed to support biofuels in the EU. The results are also presented at a sectoral level, using an eight sector split.
Other studies with a focus on nuclear energy		
Economic Effects of a Nuclear Phase-out Policy: A CGE Analysis,	2012	The paper investigates the long-run consequences of a phase-out of nuclear

Bretschger, L., Ramer, R., Zhang,L.		energy for the Swiss economy using the CITE model. Disaggregated economic results are presented at a 13-sector split.
On the Causal Dynamics between Emissions, Nuclear Energy, Renewable Energy, and Economic Growth, Apergis N., Payne J.E., Menyah, K., Wolde-Rufael, Y.	2010	This paper examines the causal relationship between CO_2 emissions, nuclear energy consumption, renewable energy consumption, and economic growth for a group of 19 developed and developing countries using a panel error correction model.
Other energy policy studies		
Insufficient Climate Policy Integration in EU Energy Policy: The Importance of the Long-term Perspective, Dupont, C., Oberthür,S.	2011	This article assesses and explains the level of climate policy integration (CPI) in the EU's energy sector, and takes issue with the assumption that a high level of CPI has been achieved in this case.
Climate, Energy Security and Innovation. An assessment of EU Energy Policy Objectives, ECN and Netherland Environmental Assessment Agency	2008	The study discusses possible trade-offs and synergies between the three main objectives of EU's energy policies: mitigation of climate change, the security of energy supply, and the promotion of the competitiveness of the EU economy.
Future Value of Coal Carbon Abatement Technologies to UK Industry. Final Report to the Department of Energy and Climate Change, AEA	2008	The report provides projections of the possible value to UK business of coal-related carbon abatement technologies (CATs) to 2030 under different scenarios.
Renewable Energy Sector in the EU: Its Employment and Export Potential. A Final Report to DG Environment, ECOTEC	2008	This report provides an overview of the current status of renewable energy developments in the EU, together with an assessment of employment, manufacturing activity and export markets
Labour market, climate change policies and the energy sector		
Study for Intelligent Energy Europe, Observ'ER and partners http://www.eurobserv-er.org/default.asp	2012	The website contains a database on the job impact of RES investment. It also monitors and analyzes the development of renewable energy sectors in the EU.
OECD: The Jobs Potential of a Shift Towards a Low-carbon Economy, OECD Green Growth Papers	2012	This report provides guidance for how best labour market and skill development policy can contribute to an efficient and fair transition to a low-carbon and resource efficient economy.

OECD: Enabling Local Green Growth: Addressing Climate Change Effects on Employment and Local Development, OECD Green Growth Strategy	2012	This report is concerned with challenges regarding local economic activity, employment and skills in response to climate change. The findings indicate that in the process of shifting economies from high to low-carbon activities many jobs will be restructured involving upgrading of existing skills.
The Challenges of Determining the Employment Effects of Renewable Energy, Lambert, T.J., SILVA, P.P.	2012	This paper discusses various factors that influence the analysis of renewable energy and its impact on employment indicating the advantages and disadvantages of each alternative and the factors that should be considered when studying the relationship between renewable energy and employment.
Issues in Estimating the Employment Generated by Energy Sector Activities, Bacon, R., KOJIMA, M.	2011	This paper reviews the issues in estimating the employment effects of changes in energy sector activities and discusses the bottom-up and top-down methodologies widely used for estimating employment levels.
Direct Employment in the Wind Energy Sector: An EU Study, Blanco, M.I., Rodrigues, G.	2011	This paper presents estimates of direct wind energy employment in all EU countries, gathered for the first time. The authors analyse aspects such as gender distribution and company profiles. Results show that wind energy deployment creates a significant number of jobs and does so at a time when other energy sectors are shrinking.
Job Retention in the British Offshore Sector through Greening of the North Sea Energy Industry, Esteban, M., Leary, D., Zhang, Q., Utama, A., Tezuka, T., Nishihara, K.	2011	This paper looks at the possibility of the UK generating energy from sea areas (wind, tides and waves). It also contains an assessment of the decline in the number of people employed in oil related jobs in the North Sea and the gap that this could create in the UK's economy. The paper also investigates the effect of gradually transforming the UK's oil and gas sector into offshore renewables.
Local Impact of Renewables on Employment: Assessment Methodology and Case Study, Sastresa, E.L., Uso, A., Bribia, I.Z., Scarpellini, S.	2010	This paper assesses the socio-economic impacts of establishing renewable energy on a regional scale, with a particular on job creation.
Low-carbon Jobs in an Interconnected World: Literature Review, Global Climate Network	2010	This paper focuses on the emerging debate concerning the creation of low-carbon jobs.
Green Jobs in Germany and the UK. Conference Report., Anglo-	2009	The study looks at the economic impact of the changeover to sustainable and

German Foundation		environmentally-friendly manufacturing in Germany and the UK.
Creating Jobs & Growth. The German Green Experience, Deutsche Bank	2009	The study presents a snapshot of Germany's renewable energy supply, its impact on job creation and investment and its legislative history.
Energy Sector Jobs to 2030: A Global Analysis, Rutovitz, J., Atherton, A. final report for Greenpeace	2009	This report presents an analysis of the potential job creation associated with the two scenarios to 2030. Only direct employment associated with electricity production is calculated, including jobs in fuel production, manufacturing, construction, and operations and maintenance.
Green Policies and Jobs: A Double dividend?, ILO	2009	The report focuses on whether green policies can possibly produce a double dividend, in terms of both environmental and social goals. The study focuses on the employment opportunities and challenges in switching to a low-carbon economy.
The Future's Green: Jobs and the UK Low-carbon Transition, Bird, J., Lawton,K.	2009	This report sets out to investigate what impact the transition to a low-carbon economy could have on jobs and employment in the UK and to identify ways in which opportunities can be taken and threats minimised.
Low-carbon Jobs for Europe. Current Opportunities and Future Prospects, WWF	2009	The report assesses the impact of green policies on employment in the EU.
Low-Carbon Cluster. Sector Skills Assessment Report. Asset Skill and partners	2009	The report focuses on various low-carbon cluster aspects, such as drivers, range and scope of low-carbon technologies and current and future skills issues.
Wind at Work: Wind Energy and Job Creation in the EU, European Wind Energy Association	2009	This report summarizes the employment effects of wind energy sector development in EU. The report also looks at methodological alternatives to estimating the employment effects of wind energy generation.
Green Jobs. Towards Decent Work in a Sustainable, Low-carbon World. Policy Messages and Main Findings for Decision Makers, UNEP	2008	The report looks at the creation of green jobs, where the new jobs are created and the skills required.
Climate Change and Employment. Impact on Employment in the European Union-25 of Climate Change and CO_2 Emission Reduction Measures by 2030, European Trade Union Confederation (ETUC) and	2007	This study provides an analysis of the potential costs and benefits for employment of the policies and measures against climate change as well as of the manifestations of the consequences of climate change in Europe.

partners		
Climate Change, Innovation and Jobs, Fankhauser, S., Sehilleier, F., Stern, N.	2008	This paper discusses the employment effects of climate policy. The paper looks short and long-term effects and implications for policy, job creation and growth.
Impact on Activity and Employment of Climate Change and Greenhouse Mitigation Policies in the Enlarged Europe. Final Country Report: Germany, ETUC and Social Development Agency	2006	The report summarises opinions and expectations, existing reports and studies on the impact of climate mitigation policies on employment in Germany.
Other studies related to climate change and green policies		
Global Research: Building a Green Recovery, HSBC	2009	The report provides an analysis of the impact of fiscal stimulus packages with green focus.
Climate Change Impacts in Europe. Final report of the PESETA Research Project, JRC	2009	The aim of the PESETA research project is s to provide to a better understanding of the possible physical and economic impacts induced by climate change in Europe over the 21st century in the following aspects: agriculture, river basin floods, coastal systems, tourism, and human health.

Appendix C: Sensitivity Analysis and Additional Results

C.1 Sensitivity analysis results from E3ME

Sensitivity analysis: Higher GDP growth

EU28 summary of results, % difference from baseline, 2050

	S1	S2	S3	S4	S5
GDP	2.7	1.9	1.7	1.8	1.6
Consumption	1.4	1.4	1.1	1.4	1.3
Investment	6.8	3.7	3.1	3.6	3.6
Exports (extra-EU)	0.0	0.0	-0.1	0.0	-0.1
Imports (extra-EU)	0.6	0.2	-0.3	0.2	0.5
Consumer Price Index	-0.01	-0.05	0.5	0.08	0.28

Sources: E3ME, Cambridge Econometrics.

EU28 Employment by sector, % difference from baseline

	S1	S2	S3	S4	S5
Agriculture	1.3	1.7	1.7	1.7	1.9
Extraction Industries	0.0	0.0	0.0	0.0	0.0
Basic manufacturing	2.5	2.0	2.1	2.1	2.1
Engineering and transport equipment	5.1	5.6	5.6	5.5	5.8
Utilities	0.0	0.0	0.0	0.0	0.0
Construction	2.7	2.4	2.2	2.4	2.4
Distribution and retail	1.2	1.1	1.0	1.1	1.1
Transport	0.3	0.6	0.7	0.6	0.8
Communications	2.6	2.2	2.2	2.3	2.3
Business services	0.9	0.9	0.9	0.9	0.9
Public services	0.4	0.8	0.8	0.9	0.9

Sources: E3ME, Cambridge Econometrics.

Power sector employment, EU28, 2050

	BASE	S1	S2	S3	S4	S5
Conventional	251	75	110	45	72	146
Hydro	32	32	32	32	32	32
Nuclear	136	84	111	25	131	17
Solar	1185	1672	1775	2866	1764	1901
Wind	355	446	485	749	497	532
Geothermal	3	4	5	9	6	6
Biomass	35	41	41	47	43	43

Tidal	32	40	41	72	40	49

Sources: E3ME, Cambridge Econometrics.

EU28 Change in Unemployment, EU, 2050

Scenario	Change in Unemployment, 000s
Energy Efficiency (S1)	-1637
Diversified Supply (S2)	-1626
High Renewables (S3)	-1721
Delayed CCS (S4)	-1666
Low Nuclear (S5)	-1754

Sources: E3ME, Cambridge Econometrics.

Sensitivity analysis: Inestment 'crowding out'

EU28 summary of results, % difference from baseline, 2050

	S1	S2	S3	S4	S5
GDP	1.1	1.1	0.9	1.1	1.1
Consumption	0.5	0.9	0.6	0.8	0.9
Investment	0.5	0.1	-0.6	0.1	0.0
Exports (extra-EU)	0.3	0.3	0.1	0.3	0.1
Imports (extra-EU)	-1.2	-1.0	-1.6	-1.1	-1.2
Consumer Price Index	-0.3	-0.5	0.2	-0.3	-0.1

Sources: E3ME, Cambridge Econometrics.

EU28 Employment by sector, % difference from baseline

	S1	S2	S3	S4	S5
Agriculture	1.6	1.8	1.8	1.9	2.1
Extraction Industries	0.0	0.0	0.0	0.0	0.0
Basic manufacturing	0.8	1.1	1.1	1.1	1.2
Engineering and transport equipment	-0.8	0.2	0.1	0.2	0.3
Utilities	0.0	0.0	0.0	0.0	0.0
Construction	2.0	2.2	2.0	2.2	2.2
Distribution and retail	-0.1	0.4	0.2	0.4	0.4
Transport	-0.3	0.4	0.4	0.5	0.6
Communications	1.1	1.3	1.2	1.3	1.4
Business services	0.4	0.7	0.7	0.7	0.7
Public services	0.2	0.8	0.8	0.8	0.8

Sources: E3ME, Cambridge Econometrics.

Power sector employment, EU28, 2050

	BASE	S1	S2	S3	S4	S5
Conventional	251	75	110	45	72	146
Hydro	32	32	32	32	32	32
Nuclear	136	84	111	25	131	17
Solar	1,185	1,672	1,775	2,866	1,764	1,901
Wind	355	446	485	749	497	532
Geothermal	3	4	5	9	6	6
Biomass	35	41	41	47	43	43
Tidal	32	40	41	72	40	49

Sources: E3ME, Cambridge Econometrics.

EU28 Change in Unemployment, EU, 2050

Scenario	Change in Unemployment, 000s
Energy Efficiency (S1)	-508
Diversified Supply (S2)	-884
High Renewables (S3)	-1,093
Delayed CCS (S4)	-933
Low Nuclear (S5)	-1,117

Sources: E3ME, Cambridge Econometrics.

Sensitivity analysis: coefficients similar to fossil fuels

EU28 summary of results, % difference from baseline, 2050

	S1	S2	S3	S4	S5
GDP	2.9	2.2	1.9	2.2	2.1
Consumption	1.2	1.4	1.0	1.4	1.3
Investment	7.4	4.0	3.3	3.9	3.8
Exports (extra-EU)	0.4	0.4	0.1	0.3	0.2
Imports (extra-EU)	0.5	0.0	-0.6	-0.1	-0.2
Consumer Price Index	-0.3	-0.5	0.2	-0.3	-0.1

Sources: E3ME, Cambridge Econometrics.

EU28 Employment by sector, % difference from baseline

	S1	S2	S3	S4	S5
Agriculture	1.4	1.7	1.7	1.7	1.9
Extraction Industries	0.0	0.0	0.0	0.0	0.0
Basic manufacturing	2.6	2.2	2.2	2.2	2.3
Engineering and transport equipment	1.8	1.8	1.7	1.7	1.8
Utilities	0.0	0.0	0.0	0.0	0.0
Construction	2.7	2.6	2.4	2.7	2.6

Distribution and retail	1.5	1.4	1.2	1.4	1.4
Transport	1.2	1.5	1.5	1.6	1.7
Communications	2.8	2.5	2.4	2.5	2.6
Business services	1.0	1.1	1.1	1.2	1.1
Public services	0.4	0.9	0.9	0.9	0.9

Sources: E3ME, Cambridge Econometrics.

Power sector employment, EU28, 2050

	BASE	S1	S2	S3	S4	S5
Conventional	251	75	110	45	72	146
Hydro	32	32	32	32	32	32
Nuclear	136	84	111	25	131	17
Solar	1,185	255	271	438	269	290
Wind	355	446	485	749	497	532
Geothermal	3	1	1	1	1	1
Biomass	35	41	41	47	43	43
Tidal	32	6	6	11	6	8

Sources: E3ME, Cambridge Econometrics.

EU28 Change in Unemployment, EU, 2050

Scenario	Change in Unemployment, 000s
Energy Efficiency (S1)	-724
Diversified Supply (S2)	-862
High Renewables (S3)	-883
Delayed CCS (S4)	-913
Low Nuclear (S5)	-937

Sources: E3ME, Cambridge Econometrics.

Sensitivity analysis:Coefficients similar to wind

EU28 summary of results, % difference from baseline, 2050

	S1	S2	S3	S4	S5
GDP	2.9	2.2	1.9	2.2	2.1
Consumption	1.2	1.4	1.0	1.4	1.3
Investment	7.4	4.0	3.3	3.9	3.8
Exports (extra-EU)	0.4	0.4	0.1	0.3	0.2
Imports (extra-EU)	0.5	0.0	-0.6	-0.1	-0.2
Consumer Price Index	-0.3	-0.5	0.2	-0.3	-0.1

Sources: E3ME, Cambridge Econometrics.

EU28 Employment by sector, % difference from baseline

	S1	S2	S3	S4	S5
Agriculture	1.4	1.7	1.7	1.7	1.9
Extraction Industries	0.0	0.0	0.0	0.0	0.0
Basic manufacturing	2.6	2.2	2.2	2.2	2.3
Engineering and transport equipment	1.8	1.8	1.7	1.7	1.8
Utilities	0.0	0.0	0.0	0.0	0.0
Construction	2.7	2.6	2.4	2.7	2.6
Distribution and retail	1.5	1.4	1.2	1.4	1.4
Transport	1.2	1.5	1.5	1.6	1.7
Communications	2.8	2.5	2.4	2.5	2.6
Business services	1.0	1.1	1.1	1.2	1.1
Public services	0.4	0.9	0.9	0.9	0.9

Sources: E3ME, Cambridge Econometrics.

Power sector employment, EU28, 2050

	BASE	S1	S2	S3	S4	S5
Conventional	251	75	110	45	72	146
Hydro	32	32	32	32	32	32
Nuclear	136	84	111	25	131	17
Solar	1,185	346	367	593	365	393
Wind	355	446	485	749	497	532
Geothermal	3	1	1	2	1	1
Biomass	35	56	55	63	58	58
Tidal	32	8	8	15	8	10

Sources: E3ME, Cambridge Econometrics.

EU28 Change in Unemployment, EU, 2050

Scenario	Change in Unemployment, 000s
Energy Efficiency (S1)	-725
Diversified Supply (S2)	-861
High Renewables (S3)	-887
Delayed CCS (S4)	-914
Low Nuclear (S5)	-938

Sources: E3ME, Cambridge Econometrics.

Sensitivity analysis: Income tax resutctions

EU28 summary of results, % difference from baseline, 2050

	S1	S2	S3	S4	S5
GDP	3.0	2.7	2.6	2.7	2.7
Consumption	1.4	2.1	2.0	2.1	2.1
Investment	7.4	4.5	4.0	4.5	4.4
Exports (extra-EU)	0.5	0.4	0.2	0.3	0.2
Imports (extra-EU)	0.5	0.3	-0.2	0.2	0.2
Consumer Price Index	-0.2	-0.4	0.3	-0.2	0.0

Sources: E3ME, Cambridge Econometrics.

EU28 Employment by sector, % difference from baseline

	S1	S2	S3	S4	S5
Agriculture	1.3	1.5	1.5	1.6	1.7
Extraction Industries	0.0	0.0	0.0	0.0	0.0
Basic manufacturing	2.5	2.3	2.3	2.3	2.4
Engineering and transport equipment	2.0	1.8	1.6	1.7	1.8
Utilities	0.0	0.0	0.0	0.0	0.0
Construction	2.0	1.1	0.8	1.0	0.9
Distribution and retail	1.4	1.7	1.6	1.7	1.7
Transport	1.1	1.4	1.3	1.4	1.6
Communications	2.9	2.7	2.6	2.7	2.8
Business services	0.9	1.2	1.1	1.2	1.2
Public services	0.4	0.8	0.7	0.8	0.8

Sources: E3ME, Cambridge Econometrics.

Power sector employment, EU28, 2050

	BASE	S1	S2	S3	S4	S5
Conventional	251	75	110	45	72	146
Hydro	32	32	32	32	32	32
Nuclear	136	84	111	25	131	17
Solar	1,185	1,672	1,775	2,866	1,764	1,901
Wind	355	446	485	749	497	532
Geothermal	3	4	5	9	6	6
Biomass	35	41	41	47	43	43
Tidal	32	40	41	72	40	49

Sources: E3ME, Cambridge Econometrics.

EU28 Change in Unemployment, EU, 2050

Scenario	Change in Unemployment, 000s
Energy Efficiency (S1)	-713
Diversified Supply (S2)	-990
High Renewables (S3)	-1,104
Delayed CCS (S4)	-1,028
Low Nuclear (S5)	-1,106

Sources: E3ME, Cambridge Econometrics.

Sensitivity analysis: VAT reductions

EU28 summary of results, % difference from baseline, 2050

	S1	S2	S3	S4	S5
GDP	2.9	2.6	2.5	2.6	2.6
Consumption	1.2	1.9	1.6	1.9	1.8
Investment	7.3	4.5	4.1	4.6	4.5
Exports (extra-EU)	0.4	0.3	0.1	0.3	0.2
Imports (extra-EU)	0.5	0.2	-0.3	0.2	0.1
Consumer Price Index	-0.3	-1.5	-1.0	-1.4	-1.3

Sources: E3ME, Cambridge Econometrics.

EU28 Employment by sector, % difference from baseline

	S1	S2	S3	S4	S5
Agriculture	1.1	1.1	1.1	1.1	1.3
Extraction Industries	0.0	0.0	0.0	0.0	0.0
Basic manufacturing	2.4	2.0	2.0	2.1	2.1
Engineering and transport equipment	1.9	1.4	1.2	1.4	1.4
Utilities	0.0	0.0	0.0	0.0	0.0
Construction	2.3	1.8	1.7	1.8	1.8
Distribution and retail	1.4	1.4	1.3	1.4	1.4
Transport	1.0	1.1	1.0	1.2	1.2
Communications	2.8	2.4	2.4	2.4	2.5
Business services	1.1	1.0	0.9	1.0	1.0
Public services	0.5	0.7	0.6	0.7	0.7

Sources: E3ME, Cambridge Econometrics.

Power sector employment, EU28, 2050

	BASE	S1	S2	S3	S4	S5
Conventional	251	75	110	45	72	146
Hydro	32	32	32	32	32	32

Nuclear	136	84	111	25	131	17
Solar	1,185	1,672	1,775	2,866	1,764	1,901
Wind	355	446	485	749	497	532
Geothermal	3	4	5	9	6	6
Biomass	35	41	41	47	43	43
Tidal	32	40	41	72	40	49

Sources: E3ME, Cambridge Econometrics.

EU28 Change in Unemployment, EU, 2050

Scenario	Change in Unemployment, 000s
Energy Efficiency (S1)	-838
Diversified Supply (S2)	-584
High Renewables (S3)	-628
Delayed CCS (S4)	-637
Low Nuclear (S5)	-621

Sources: E3ME, Cambridge Econometrics.

C.2 GEM-E3 additional results from the main scenarios

S2: Diversified supply technologies

Macro aggregates (EU28)

Diversified Supply Technologies, % change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Gross Domestic Product	-0.01	-0.38	-0.96	-0.80	-0.59
Investment	-0.03	0.12	0.41	1.64	0.43
Private Consumption	-0.01	0.01	-0.52	-0.35	-0.24
Exports	-0.24	-2.17	-3.41	-3.21	-2.41
Imports	-0.22	0.65	0.90	1.97	0.87
Terms of Trade	-0.03	1.61	2.35	2.69	-

Source GEME3

Sectoral production (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Agriculture	-0.15	-0.81	-1.94	23.29	3.96
Ferrous and non ferrous metals	0.39	-0.34	-1.91	-4.20	-1.13
Chemical Products	0.78	-0.26	-2.46	-2.86	-1.03
Other energy intensive	-0.03	-0.09	-0.76	-1.19	-0.47
Electric Goods	-0.57	1.51	3.56	2.86	1.54
Transport equipment	-0.28	-1.72	-1.81	-1.85	-1.34
Other Equipment Goods	-0.24	0.13	0.98	2.53	0.68

Consumer Goods Industries	-0.10	-0.39	-1.23	-1.03	-0.74
Construction	-0.03	1.58	2.92	2.38	1.65
Transport Services	0.17	-1.51	-2.94	-2.04	-1.54
Market & Non-Market Services	-0.07	-0.11	-0.59	-0.68	-0.41

Source GEME3

Employment (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Employment (employee hours)	-0.046	0.077	0.013	0.516	0.118

Source GEME3

Sectoral employment (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Agriculture	0.00	-0.35	-1.73	15.20	2.47
Ferrous and non ferrous metals	-0.04	-0.64	-1.75	-5.28	-1.21
Chemical Products	0.49	-0.06	-0.89	-3.11	-0.43
Other energy intensive	-0.31	-0.23	-0.80	-2.15	-0.68
Electric Goods	-0.28	2.15	4.00	2.06	1.66
Transport equipment	-0.15	-0.84	-0.42	-1.33	-0.56
Other Equipment Goods	-0.12	0.33	0.32	1.18	0.28
Consumer Goods Industries	0.17	0.29	-0.85	-1.27	-0.37
Construction	-0.03	1.58	2.98	1.43	1.47
Transport Services	0.15	-0.41	-0.42	0.15	-0.10
Market & Non-Market Services	-0.06	-0.04	-0.25	-0.40	-0.18

Source GEME3

Employment in the power generation sectors (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Coal fired	-1.18	-11.11	-83.54	-99.67	-31.83
Oil fired	-0.37	-7.08	-55.32	-99.34	-49.51
Gas fired	-0.10	14.72	-39.46	-96.19	-24.55
Nuclear	0.36	11.04	1.09	-3.19	2.35
Biomass	0.07	3.86	18.78	22.80	12.77
Hydro electric	0.16	1.39	-1.64	9.11	1.44
Wind	-0.17	-4.31	38.07	52.01	24.77
PV	-0.21	-14.36	43.19	78.25	36.90

Source GEME3

S4: Delayed CCS

Macro aggregates (EU28)

Delayed CCS, % change from BA	2020	2030	2040	2050	Cumulative 2015-2050

Gross Domestic Product	-0.01	-0.40	-1.02	-0.87	-0.67
Investment	-0.03	0.09	0.40	1.50	0.36
Private Consumption	-0.01	-0.01	-0.53	-0.38	-0.31
Exports	-0.24	-2.19	-3.72	-3.44	-2.70
Imports	-0.22	0.64	0.88	1.93	0.80
Terms of Trade	-0.03	1.61	1.80	2.26	-

Source GEME3

Sectoral production (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Agriculture	-0.13	-0.79	-1.81	22.84	3.86
Ferrous and non ferrous metals	0.39	-0.36	-2.19	-4.22	-1.41
Chemical Products	0.78	-0.27	-2.60	-2.92	-1.28
Other energy intensive	-0.03	-0.09	-0.89	-1.29	-0.63
Electric Goods	-0.56	1.55	3.10	2.08	1.38
Transport equipment	-0.28	-1.71	-1.90	-1.73	-1.41
Other Equipment Goods	-0.24	0.09	0.63	2.01	0.45
Consumer Goods Industries	-0.09	-0.38	-1.24	-1.07	-0.76
Construction	-0.03	1.58	2.98	2.15	1.62
Transport Services	0.17	-1.63	-3.51	-2.27	-2.17
Market & Non-Market Services	-0.07	-0.11	-0.60	-0.75	-0.43

Source GEME3

Employment (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Employment (employee hours)	-0.045	0.057	0.132	0.552	0.111

Source GEME3

Sectoral employment (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Agriculture	0.06	-0.36	-1.52	15.02	2.46
Ferrous and non ferrous metals	-0.04	-0.81	-1.57	-5.17	-1.34
Chemical Products	0.49	-0.38	0.01	-2.54	-0.40
Other energy intensive	-0.31	-0.36	-0.34	-1.98	-0.66
Electric Goods	-0.27	2.17	3.52	0.96	1.53
Transport equipment	-0.15	-0.86	-0.02	-0.98	-0.46
Other Equipment Goods	-0.12	0.22	0.33	0.41	0.11

Consumer Goods Industries	0.16	0.26	-0.41	-1.03	-0.23
Construction	-0.04	1.58	3.26	1.50	1.51
Transport Services	0.15	-0.40	-0.01	0.26	-0.18
Market & Non-Market Services	-0.06	-0.04	-0.15	-0.34	-0.17

Source GEME3

Employment in the power generation sectors (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Coal fired	-1.49	-11.21	-82.18	-99.67	-31.56
Oil fired	-0.37	-8.10	-59.52	-99.17	-50.50
Gas fired	-0.25	14.17	-31.62	-94.67	-20.39
Nuclear	0.13	9.77	21.33	19.53	11.42
Biomass	0.01	3.37	25.22	35.07	16.58
Hydro electric	-0.49	1.18	3.65	11.91	3.16
Wind	-0.33	-4.94	48.89	58.77	30.00
PV	-0.31	-14.98	55.87	86.60	44.53

Source GEME3

S5: Low Nuclear

Macro aggregates (EU28)

Low Nuclear, % change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Gross Domestic Product	-0.01	-0.48	-1.01	-0.80	-0.65
Investment	-0.03	0.03	0.29	1.59	0.34
Private Consumption	-0.01	-0.14	-0.63	-0.39	-0.35
Exports	-0.24	-2.20	-3.29	-3.11	-2.36
Imports	-0.22	0.56	0.75	1.86	0.77
Terms of Trade	-0.03	1.58	2.95	3.39	-

Source GEME3

Sectoral production (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Agriculture	-0.14	-0.98	-1.80	23.44	3.92
Ferrous and non ferrous metals	0.39	-0.60	-2.40	-4.37	-1.36
Chemical Products	0.78	-0.57	-2.98	-3.14	-1.31
Other energy intensive	-0.03	-0.22	-1.11	-1.42	-0.65
Electric Goods	-0.57	1.88	3.80	3.27	1.81
Transport equipment	-0.29	-1.81	-1.83	-1.71	-1.34
Other Equipment Goods	-0.25	0.09	0.88	2.47	0.62
Consumer Goods Industries	-0.10	-0.44	-1.24	-1.10	-0.78
Construction	-0.03	1.69	2.50	2.12	1.54
Transport Services	0.17	-1.57	-2.61	-1.85	-1.44
Market & Non-Market Services	-0.07	-0.14	-0.55	-0.65	-0.41

Source GEME3

Employment (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Employment (employee hours)	-0.045	-0.040	-0.187	0.472	0.020

Source GEME3

Sectoral employment (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Agriculture	0.07	-0.61	-2.26	14.45	2.12
Ferrous and non ferrous metals	-0.05	-0.94	-2.28	-5.40	-1.44
Chemical Products	0.49	-0.49	-1.57	-3.35	-0.75
Other energy intensive	-0.31	-0.33	-1.13	-2.28	-0.82
Electric Goods	-0.27	2.80	4.73	3.29	2.25
Transport equipment	-0.16	-1.00	-0.87	-1.56	-0.76
Other Equipment Goods	-0.13	0.46	0.96	3.15	0.75
Consumer Goods Industries	0.16	0.27	-1.03	-1.44	-0.45
Construction	-0.04	1.47	2.26	0.89	1.18
Transport Services	0.14	-0.73	-0.76	0.17	-0.29
Market & Non-Market Services	-0.06	-0.12	-0.30	-0.37	-0.22

Source GEME3

Employment in the energy sectors (EU28)

% change from BA	2020	2030	2040	2050	Cumulative 2015-2050
Coal fired	-1.30	-6.19	-90.86	-99.71	-30.78
Oil fired	-0.37	0.20	-41.22	-97.03	-41.82
Gas fired	-0.16	21.61	-29.96	-92.97	-19.27
Nuclear	0.28	-8.99	-73.99	-81.90	-41.05
Biomass	0.14	2.93	16.03	22.93	12.39
Hydro electric	-0.45	-1.20	-5.86	7.27	-0.93
Wind	-0.14	-5.92	36.02	62.59	26.48
PV	-0.14	-14.68	36.24	76.19	33.28

Source GEME3

Employment by Member State, cumulative change from BA 2015-2050, in %

	S1	S2	S3	S4	S5
Austria	0.25	0.26	0.01	0.17	0.22
Belgium	0.38	0.45	0.33	0.16	0.42
Bulgaria	0.33	0.03	0.41	0.06	-0.35
Croatia	0.25	0.40	0.24	0.46	-0.02
Cyprus	0.38	0.36	0.27	0.30	0.36
Czech Republic	0.53	0.47	-0.08	0.63	-0.60
Denmark	0.01	-0.01	-0.01	-0.01	-0.01
Estonia	0.68	0.68	0.61	0.67	0.69
Finland	0.00	0.12	0.04	-0.03	0.02
France	0.01	0.01	-0.01	0.00	-0.01
Germany	0.01	0.01	0.00	0.00	0.01
Greece	0.39	0.28	0.12	0.14	0.25
Hungary	0.55	0.57	0.12	0.69	-0.14
Ireland	0.01	0.06	0.07	-0.09	0.08
Italy	0.002	0.00	-0.01	-0.01	0.00
Latvia	1.16	1.03	1.08	0.73	0.97
Lithuania	0.23	0.21	-0.10	0.27	-1.66
Luxembourg	0.01	-0.02	-0.01	-0.02	-0.02
Malta	0.96	0.88	0.24	0.71	0.80
Netherlands	0.11	0.11	0.06	0.10	0.10
Poland	0.42	0.12	-0.16	0.37	-0.08
Portugal	0.60	0.48	0.19	0.32	0.64
Romania	0.01	-0.03	-0.08	-0.05	-0.06
Slovakia	0.39	0.66	0.00	0.72	-0.48
Slovenia	0.39	0.49	0.13	0.39	-0.18
Spain	0.43	0.25	-0.03	0.16	0.21
Sweden	0.21	0.21	-0.02	0.20	0.07
United Kingdom	0.007	0.0039	0.001	0.0021	0.0015

Employment by Member State, difference from BA in 2050, in thousand persons

	S1	S2	S3	S4	S5
Austria	18.65	17.01	-11.08	15.59	19.45
Belgium	50.02	55.23	35.91	54.22	57.20
Bulgaria	49.56	58.51	23.91	62.53	66.91
Croatia	32.57	26.23	20.87	24.75	22.71
Cyprus	2.88	2.90	2.16	2.85	2.94
Czech Republic	68.98	70.44	6.12	84.56	15.45
Denmark	0.56	-0.71	-1.54	-0.79	-0.73
Estonia	6.87	6.87	6.86	6.86	6.88
Finland	14.93	12.58	9.95	6.73	15.35
France	0.52	-1.35	-9.17	-2.25	-4.49
Germany	18.00	17.53	4.75	17.28	16.05
Greece	79.46	76.81	45.76	77.45	78.02
Hungary	49.83	42.24	-20.48	68.10	-6.17
Ireland	9.39	9.99	8.49	11.26	13.27

Italy	1.41	-0.08	-5.65	-7.52	-0.57
Latvia	25.30	23.49	24.38	21.28	23.59
Lithuania	16.16	16.07	16.24	16.26	-10.06
Luxembourg	-0.04	-0.05	-0.02	-0.04	-0.04
Malta	2.61	2.55	0.08	2.70	3.40
Netherlands	-5.68	-12.46	-22.70	-5.30	-12.17
Poland	330.30	331.25	182.91	386.94	409.58
Portugal	72.57	62.67	13.87	56.17	76.07
Romania	7.58	7.33	-10.91	5.58	2.46
Slovakia	27.81	33.95	-4.25	44.82	0.54
Slovenia	6.07	7.21	-1.74	8.19	-0.40
Spain	289.31	269.86	167.95	257.61	266.36
Sweden	13.83	13.88	-20.22	13.47	-10.80
United Kingdom	7.20	7.52	3.75	8.60	8.64

C.3 Sensitivity analysis from GEM-E3

Alternative recycling options of carbon tax revenues

Macro aggregates EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Gross Domestic Product	-0.69	-0.69	-0.81	-0.79	-0.75
Investment	0.13	0.14	0.35	0.03	0.04
Private Consumption	-0.31	-0.32	-0.55	-0.39	-0.43
Exports	-2.49	-2.54	-2.85	-2.83	-2.50
Imports	0.81	0.73	0.58	0.65	0.62
Terms of Trade	-	-	-	-	-

Source GEME3

Sectoral production EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	4.0	3.8	3.9	3.7	3.8
Ferrous and non ferrous metals	-1.1	-1.3	-1.9	-1.6	-1.5
Chemical Products	-1.0	-1.1	-1.7	-1.4	-1.4
Other energy intensive	-0.4	-0.6	-1.0	-0.8	-0.8
Electric Goods	1.8	1.4	0.9	1.2	1.6
Transport equipment	-1.5	-1.5	-2.0	-1.6	-1.5
Other Equipment Goods	0.4	0.5	0.3	0.2	0.4
Consumer Goods Industries	-0.8	-0.8	-1.0	-0.9	-0.9
Construction	2.1	1.4	1.4	1.3	1.3
Transport Services	-1.4	-1.6	-2.2	-2.2	-1.5
Market Services & Non-Market Services	-0.4	-0.5	-0.6	-0.5	-0.5

Source GEME3

Sectoral Employment EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	2.3	2.3	2.3	2.3	1.9
Ferrous and non ferrous metals	-1.0	-1.4	-1.9	-1.6	-1.7
Chemical Products	0.0	-0.6	-1.2	-0.6	-0.9
Other energy intensive	-0.5	-0.9	-1.2	-0.9	-1.0
Electric Goods	1.6	1.4	1.2	1.3	2.0
Transport equipment	-0.7	-0.8	-1.1	-0.7	-1.0
Other Equipment Goods	-0.1	0.0	0.2	-0.3	0.4
Consumer Goods Industries	-0.4	-0.6	-0.5	-0.5	-0.7
Construction	1.9	1.2	1.1	1.2	0.9
Transport Services	-0.1	-0.2	-0.4	-0.3	-0.4
Market Services & Non-Market Services	-0.2	-0.3	-0.3	-0.3	-0.3

Source GEME3

Employment in power generation EU28, 2050 (in ‘000s persons)

	BASE	S1	S2	S3	S4	S5
Conventional (incl. CCS)	312.6	121.7	154.1	83.6	95.8	209.4
Nuclear	148.4	122.1	143.3	41.9	176.9	26.8

Biomass	66.4	88.5	81.4	79.9	89.5	81.5
Hydro electric	46.5	53.3	50.7	45.9	51.9	49.8
Wind	282.0	413.2	428.1	562.6	447.0	457.8
PV	272.2	495.9	484.3	835.7	506.7	478.6

Source GEME3

Employment (in million hours), % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Employment	0.064	0.001	-0.121	-0.032	-0.110

Source GEME3

Flexible EU current account

Macro aggregates EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Gross Domestic Product	-0.57	-0.59	-0.70	-0.67	-0.64
Investment	1.14	0.99	1.17	0.81	0.91
Private Consumption	0.70	0.51	0.24	0.29	0.42
Exports	-4.36	-4.08	-4.28	-4.03	-4.05
Imports	3.46	2.94	2.63	2.43	2.87
Terms of Trade	-	-	-	-	-

Source GEME3

Sectoral production EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	3.8	3.7	3.7	3.6	3.6
Ferrous and non ferrous metals	-1.8	-1.8	-2.4	-1.9	-2.1
Chemical Products	-1.7	-1.7	-2.2	-1.8	-2.0
Other energy intensive	-0.2	-0.4	-0.8	-0.6	-0.6
Electric Goods	-0.4	-0.4	-0.8	-0.2	-0.2
Transport equipment	-2.4	-2.2	-2.7	-2.1	-2.2
Other Equipment Goods	-0.9	-0.6	-0.6	-0.6	-0.7
Consumer Goods Industries	-0.9	-1.0	-1.1	-0.9	-1.0
Construction	3.0	2.1	2.2	2.0	2.0
Transport Services	-1.3	-1.5	-2.2	-2.2	-1.4
Market Services & Non-Market Services	0.0	-0.2	-0.3	-0.2	-0.2

Source GEME3

Sectoral Employment EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	2.4	2.3	2.3	2.3	1.9
Ferrous and non ferrous metals	-1.8	-1.9	-2.3	-1.9	-2.2
Chemical Products	-0.9	-1.2	-1.7	-1.0	-1.6
Other energy intensive	-0.3	-0.7	-0.9	-0.7	-0.8
Electric Goods	-0.6	-0.3	-0.3	0.0	0.2
Transport equipment	-1.7	-1.5	-1.6	-1.2	-1.7

Other Equipment Goods	-1.5	-1.1	-0.5	-0.9	-0.6
Consumer Goods Industries	-0.6	-0.6	-0.5	-0.4	-0.7
Construction	2.6	1.9	1.7	1.8	1.6
Transport Services	0.0	-0.1	-0.3	-0.2	-0.3
Market Services & Non-Market Services	0.0	0.0	-0.1	-0.1	-0.1

Source GEME3

Employment in power generation EU28, 2050 (in '000s persons)

	BASE	S1	S2	S3	S4	S5
Conventional (incl. CCS)	312.6	127.0	160.9	85.5	99.2	218.6
Nuclear	148.4	124.1	145.3	42.4	179.3	27.2
Biomass	66.4	89.4	82.2	80.6	90.3	82.3
Hydro electric	46.5	54.0	51.3	46.4	52.5	50.4
Wind	282.0	417.3	431.8	566.9	450.8	461.3
PV	272.2	503.1	490.6	844.7	512.9	484.8

Source GEME3

Employment (in million hours), % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Employment	0.194	0.136	0.029	0.120	0.034

Source GEME3

Flexible EU current account and alternative recycling options of carbon tax revenues

Macro aggregates EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Gross Domestic Product	-0.72	-0.75	-0.86	-0.84	-0.80
Investment	0.53	0.38	0.56	0.19	0.30
Private Consumption	0.25	0.08	-0.22	-0.10	-0.01
Exports	-3.81	-3.56	-3.73	-3.62	-3.56
Imports	2.44	1.98	1.63	1.58	1.93
Terms of Trade	-	-	-	-	-

Source GEME3

Sectoral production EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	3.7	3.6	3.7	3.6	3.6
Ferrous and non ferrous metals	-1.6	-1.7	-2.3	-1.9	-2.0
Chemical Products	-1.6	-1.6	-2.0	-1.7	-1.9
Other energy intensive	-0.4	-0.6	-1.0	-0.8	-0.8
Electric Goods	0.2	0.1	-0.2	0.2	0.3
Transport equipment	-2.2	-2.1	-2.5	-2.1	-2.1
Other Equipment Goods	-0.7	-0.4	-0.4	-0.5	-0.5
Consumer Goods Industries	-0.9	-1.0	-1.1	-1.0	-1.0
Construction	2.4	1.6	1.6	1.5	1.5

Transport Services	-1.4	-1.6	-2.3	-2.3	-1.5
Market Services & Non-Market Services	-0.3	-0.4	-0.5	-0.5	-0.4

Source GEME3

Sectoral Employment EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	2.3	2.2	2.2	2.2	1.8
Ferrous and non ferrous metals	-1.6	-1.8	-2.2	-1.9	-2.1
Chemical Products	-0.7	-1.0	-1.6	-0.9	-1.4
Other energy intensive	-0.5	-0.9	-1.2	-0.9	-1.0
Electric Goods	0.1	0.3	0.2	0.4	0.7
Transport equipment	-1.6	-1.5	-1.7	-1.3	-1.7
Other Equipment Goods	-1.3	-1.0	-0.6	-1.1	-0.7
Consumer Goods Industries	-0.6	-0.8	-0.7	-0.6	-0.9
Construction	2.2	1.4	1.3	1.4	1.1
Transport Services	-0.1	-0.2	-0.4	-0.3	-0.4
Market Services & Non-Market Services	-0.1	-0.2	-0.2	-0.2	-0.2

Source GEME3

Employment in power generation EU28, 2050 (in '000s persons)

	BASE	S1	S2	S3	S4	S5
Conventional (incl. CCS)	312.6	126.5	160.3	85.3	98.9	217.8
Nuclear	148.4	123.7	144.9	42.3	178.8	27.1
Biomass	66.4	89.1	81.9	80.3	90.0	82.1
Hydro electric	46.5	53.9	51.1	46.3	52.4	50.3
Wind	282.0	416.1	430.5	565.4	449.5	460.0
PV	272.2	501.4	488.9	842.1	511.1	483.1

Source GEME3

Employment (in million hours), % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Employment	0.086	0.010	-0.112	-0.027	-0.097

Source GEME3

Weak response of international fossil fuel prices to global decarbonisation

Macro aggregates EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Gross Domestic Product	-0.70	-0.66	-0.78	-0.74	-0.72
Investment	0.23	0.26	0.45	0.19	0.17
Private Consumption	-0.18	-0.41	-0.64	-0.47	-0.52
Exports	-2.87	-2.30	-2.62	-2.59	-2.25
Imports	0.46	0.53	0.39	0.47	0.42
Terms of Trade	-	-	-	-	-

Source GEME3

Sectoral production EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	4.6	3.9	4.0	3.8	3.9

Ferrous and non ferrous metals	0.3	-0.8	-1.5	-1.1	-1.1
Chemical Products	0.1	-0.5	-1.1	-0.8	-0.8
Other energy intensive	0.4	-0.5	-0.9	-0.7	-0.7
Electric Goods	0.6	1.2	0.7	1.1	1.5
Transport equipment	-1.2	-1.5	-2.1	-1.6	-1.5
Other Equipment Goods	-0.3	0.5	0.3	0.2	0.4
Consumer Goods Industries	-0.5	-0.9	-1.0	-0.9	-0.9
Construction	2.1	1.5	1.5	1.5	1.4
Transport Services	-2.7	-1.4	-2.1	-2.1	-1.3
Market Services & Non-Market Services	-0.3	-0.5	-0.6	-0.5	-0.5

Source GEME3

Sectoral Employment EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	2.8	2.4	2.4	2.4	2.0
Ferrous and non ferrous metals	0.1	-0.9	-1.4	-1.1	-1.2
Chemical Products	-0.8	0.0	-0.6	0.0	-0.4
Other energy intensive	0.1	-0.7	-1.0	-0.7	-0.9
Electric Goods	0.7	1.4	1.2	1.3	1.9
Transport equipment	-0.6	-0.8	-1.1	-0.7	-1.0
Other Equipment Goods	-0.3	0.0	0.3	-0.1	0.4
Consumer Goods Industries	-0.7	-0.5	-0.5	-0.4	-0.6
Construction	2.1	1.3	1.2	1.4	1.0
Transport Services	-0.1	0.0	-0.2	-0.1	-0.2
Market Services & Non-Market Sevices	-0.5	-0.3	-0.3	-0.3	-0.3

Source GEME3

Employment in power generation EU28, 2050 (in '000s persons)

	BASE	S1	S2	S3	S4	S5
Conventional (incl. CCS)	312.6	132.8	152.0	83.5	95.3	205.9
Nuclear	148.4	133.1	143.3	41.9	177.1	26.7
Biomass	66.4	95.4	81.5	80.2	89.7	81.5
Hydro electric	46.5	58.0	50.7	46.0	52.0	49.8
Wind	282.0	449.9	428.0	563.7	447.2	457.7
PV	272.2	538.3	482.9	836.2	506.2	477.0

Source GEME3

Employment (in million hours), % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Employment	-0.067	0.031	-0.072	0.032	-0.083

Source GEME3

Higher GHG mitigation policies from non - EU countries

Macro aggregates EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Gross Domestic Product	-0.44	-0.45	-0.60	-0.55	-0.51

Investment	0.54	0.54	0.71	0.44	0.45
Private Consumption	-0.09	-0.11	-0.36	-0.19	-0.21
Exports	-4.02	-4.09	-4.49	-4.43	-4.08
Imports	-1.00	-1.10	-1.30	-1.20	-1.22
Terms of Trade	-	-	-	-	-

Source GEME3

Sectoral production EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	4.8	4.7	4.7	4.5	4.6
Ferrous and non ferrous metals	4.1	3.9	3.2	3.6	3.7
Chemical Products	6.2	6.1	5.5	5.8	5.8
Other energy intensive	1.8	1.6	1.2	1.4	1.4
Electric Goods	-3.9	-4.3	-4.9	-4.5	-4.1
Transport equipment	-4.4	-4.3	-4.9	-4.4	-4.3
Other Equipment Goods	-1.3	-1.2	-1.4	-1.5	-1.3
Consumer Goods Industries	-1.0	-1.0	-1.2	-1.1	-1.1
Construction	2.3	1.7	1.7	1.6	1.6
Transport Services	1.6	1.3	0.6	0.6	1.4
Market Services & Non-Market Services	-0.9	-0.9	-1.0	-1.0	-0.9

Source GEME3

Sectoral Employment EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	2.8	2.9	2.8	2.8	2.5
Ferrous and non ferrous metals	3.9	3.5	3.0	3.3	3.2
Chemical Products	6.1	5.6	4.9	5.6	5.3
Other energy intensive	1.5	1.1	0.8	1.1	1.0
Electric Goods	-3.8	-4.0	-4.2	-4.1	-3.4
Transport equipment	-3.3	-3.3	-3.6	-3.2	-3.5
Other Equipment Goods	-1.8	-1.6	-1.4	-1.8	-1.1
Consumer Goods Industries	-0.8	-0.9	-0.8	-0.8	-1.0
Construction	2.1	1.5	1.3	1.5	1.2
Transport Services	2.2	2.1	1.9	2.0	1.9
Market Services & Non-Market Services	-0.5	-0.6	-0.6	-0.6	-0.6

Source GEME3

Employment in power generation EU28, 2050 (in '000s persons)

	BASE	S1	S2	S3	S4	S5
Conventional (incl. CCS)	312.6	123.1	156.1	82.9	97.3	211.9
Nuclear	148.4	124.6	146.1	42.3	181.0	27.1
Biomass	66.4	90.7	83.4	81.7	91.6	83.4
Hydro electric	46.5	54.2	51.5	46.4	52.8	50.6
Wind	282.0	422.9	437.9	571.9	456.5	469.6
PV	272.2	503.9	492.2	842.3	514.7	487.3

Source GEME3

Employment (in million hours), % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Employment	0.055	0.012	-0.121	-0.008	-0.101

Source GEME3

Low responsiveness of labour market

Macro aggregates EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Gross Domestic Product	-0.57	-0.56	-0.72	-0.66	-0.64
Investment	0.45	0.46	0.62	0.38	0.36
Private Consumption	-0.20	-0.21	-0.48	-0.28	-0.34
Exports	-2.35	-2.40	-2.72	-2.69	-2.36
Imports	0.97	0.89	0.73	0.81	0.78
Terms of Trade	-	-	-	-	-

Source GEME3

Sectoral production EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	4.1	4.0	4.0	3.9	3.9
Ferrous and non ferrous metals	-0.9	-1.1	-1.8	-1.4	-1.3
Chemical Products	-0.9	-1.0	-1.6	-1.3	-1.3
Other energy intensive	-0.2	-0.4	-0.9	-0.6	-0.6
Electric Goods	2.0	1.6	1.1	1.4	1.8
Transport equipment	-1.3	-1.3	-1.9	-1.4	-1.3
Other Equipment Goods	0.6	0.7	0.5	0.5	0.6
Consumer Goods Industries	-0.6	-0.7	-0.9	-0.7	-0.8
Construction	2.3	1.7	1.7	1.6	1.6
Transport Services	-1.3	-1.5	-2.2	-2.2	-1.4
Market Services & Non-Market Services	-0.3	-0.4	-0.5	-0.4	-0.4

Source GEME3

Sectoral employment EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	2.5	2.5	2.4	2.5	2.1
Ferrous and non ferrous metals	-0.8	-1.2	-1.7	-1.3	-1.5
Chemical Products	0.2	-0.4	-1.0	-0.3	-0.8
Other energy intensive	-0.2	-0.6	-0.9	-0.6	-0.8
Electric Goods	1.9	1.7	1.5	1.6	2.2
Transport equipment	-0.5	-0.5	-0.9	-0.4	-0.8
Other Equipment Goods	0.2	0.3	0.6	0.2	0.7
Consumer Goods Industries	-0.2	-0.3	-0.3	-0.2	-0.5
Construction	2.2	1.5	1.3	1.6	1.2
Transport Services	0.1	0.0	-0.3	-0.1	-0.3
Market Services & Non-Market Services	-0.1	-0.1	-0.2	-0.1	-0.2

Source GEME3

Employment in power generation EU28, 2050 (in '000s persons)

	BASE	S1	S2	S3	S4	S5
Conventional (incl. CCS)	312.6	122.4	155.1	84.0	96.6	210.6
Nuclear	148.4	122.6	143.9	42.0	177.7	26.9
Biomass	66.4	88.8	81.7	80.1	89.9	81.7
Hydro electric	46.5	53.5	50.8	46.0	52.1	50.0
Wind	282.0	414.2	429.1	563.7	448.1	458.8
PV	272.2	497.6	486.0	838.2	508.7	480.3

Source GEME3

Employment (in million hours), % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Employment	0.221	0.160	0.009	0.149	0.012

Source GEME3

High responsiveness of labour market

Macro aggregates EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Gross Domestic Product	-0.63	-0.61	-0.72	-0.69	-0.65
Investment	0.36	0.40	0.61	0.33	0.33
Private Consumption	-0.28	-0.27	-0.48	-0.33	-0.36
Exports	-2.38	-2.43	-2.73	-2.71	-2.37
Imports	0.94	0.86	0.72	0.79	0.77
Terms of Trade	-	-	-	-	-

Source GEME3

Sectoral production EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Agriculture	4.0	3.9	4.0	3.8	3.9
Ferrous and non ferrous metals	-1.0	-1.2	-1.8	-1.4	-1.4
Chemical Products	-0.9	-1.1	-1.6	-1.3	-1.3
Other energy intensive	-0.3	-0.5	-0.9	-0.7	-0.7
Electric Goods	1.9	1.5	1.1	1.3	1.8
Transport equipment	-1.4	-1.4	-1.9	-1.4	-1.3
Other Equipment Goods	0.5	0.6	0.5	0.4	0.6
Consumer Goods Industries	-0.7	-0.8	-0.9	-0.8	-0.8
Construction	2.3	1.6	1.7	1.6	1.5
Transport Services	-1.3	-1.6	-2.2	-2.2	-1.5
Market Services & Non-Market Services	-0.4	-0.4	-0.5	-0.4	-0.4

Source GEME3

Sectoral employment EU28, % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5

Agriculture	2.4	2.4	2.5	2.4	2.1
Ferrous and non ferrous metals	-0.9	-1.3	-1.7	-1.4	-1.4
Chemical Products	0.0	-0.5	-1.0	-0.5	-0.7
Other energy intensive	-0.4	-0.7	-0.9	-0.7	-0.8
Electric Goods	1.7	1.6	1.5	1.5	2.3
Transport equipment	-0.6	-0.6	-0.8	-0.5	-0.7
Other Equipment Goods	0.0	0.2	0.6	0.0	0.8
Consumer Goods Industries	-0.4	-0.4	-0.3	-0.3	-0.4
Construction	2.0	1.4	1.4	1.5	1.2
Transport Services	-0.1	-0.2	-0.3	-0.2	-0.3
Market Services & Non-Market Services	-0.2	-0.2	-0.2	-0.2	-0.2

Source GEME3

Employment in power generation EU28, 2050 (in '000s persons)

	BASE	S1	S2	S3	S4	S5
Conventional (incl. CCS)	312.6	121.5	154.2	83.9	96.0	209.5
Nuclear	148.4	122.2	143.5	42.0	177.1	26.9
Biomass	66.4	88.5	81.5	80.1	89.6	81.6
Hydro electric	46.5	53.4	50.7	46.0	52.0	49.9
Wind	282.0	413.4	428.3	563.4	447.4	458.2
PV	272.2	496.1	484.7	837.5	507.4	479.1

Source GEME3

Employment (in million hours), % change from BA (cumulative 2015-2050)

	S1	S2	S3	S4	S5
Employment	0.100	0.077	0.011	0.072	0.021

Source GEME3

Appendix D: Employment Coefficients

This appendix presents results from the main report in coefficient form. The main coefficients that we look at are:

- The power sector: Number of jobs per GW of installed capacity
- Macroeconomic relationships: Number of jobs per unit of spending

These are described below.

D.1 Power sector results

Figures used in E3ME

The coefficients for the power sector are derived from the tables in Chapter 2 of the main report. In particular figures are taken from Tables 2.19 and 2.20 (number of jobs) and Table 2.2 (installed capacity). The ratios from these figures are given in Table D1. Data are for 2010.

	MW Capacity	Jobs	Ratio
Conventional	480142	187290	390.1
Hydro	147344	34120	231.6
Nuclear	131715	128233	973.6
Solar	29879	76605	2563.8
Wind	84668	46015	543.5
Geothermal	767	6033	7865.7
Biomass	28670	112141	3911.4
Tidal	241	67	278.0

Sources: See Chapter 2.

The ratios suggest a labour intensity for wind that is slightly higher than that for conventional electricity generation. Other renewables (except hydro) have much higher ratios but these are related to quite small existing sample sizes. The ratio for nuclear is more than twice that for conventional power.

These employment ratios were used in the modelling with E3ME. They were not changed over time, but it is assumed that the ratios for solar and geothermal (and tidal) fall into line with the ratio for wind, and the ratio for biomass becomes the same as that for conventional fuels.

In the sensitivity testing, we tested one option where all renewables except wind and hydro used the same ratios as wind, and one where they were the same as conventional electricity generation.

Figures used in GEM-E3

A similar set of ratios was used in the GEM-E3 model, although a different source was used, as they were set before the beginning of the project based on another source. The figures are shown in the table below (same units).

The figures are quite similar, although generally smaller in magnitude. It should also be noted that the figures in the table below include more sensible estimates for technologies that are not yet established, meaning that further assumptions (like those made for E3ME) are not required.

	Ratio, jobs per installed capacity
Coal & Coke	590
Oil	770
Gas	770
Nuclear	700
Solar	520
Wind	240
Geothermal	1720
Biomass	1370
Hydro	480

Sources: Wei et al (2010).

D.2 Macroeconomic coefficients from E3ME

Table 5.5 in the main report provides estimate of short-term employment gains from injecting €100bn into the European economy in various different ways. These coefficients were derived by running some additional modelling scenarios. In each case a shock to the model was entered in 2013 and then gradually scaled up so that in 2020 the value of the input is €100bn in 2008 prices.

The €100bn was spread across Europe so that:

- Tax rates were reduced proportionately until revenues fell by €100bn. This approach was used for employers social security contributions, income tax rates and standard VAT rates.
- The carbon tax rate was set at a rate to raise €100bn in the year 2020. It was applied to all sectors in all Member States except the power sector.
- The investment was added to public investment in proportion to Member States' existing investment expenditure. The total sum spent in 2020 was €100bn.

The carbon tax raises revenue rather than putting it back into the economy, and therefore has a negative effect.

There is no revenue recycling in this exercise.

The coefficients are for the current EU27 and do not include Croatia. The reason for this is that economic data for Croatia are still incomplete, so including Croatia could increase the range of uncertainty in the results. However, the same ratios could be applied to Croatia.

The results are presented again below. The figures represent total change in employment in Europe compared to the baseline position in 2020 with no additional input.

Expenditure	Additional Jobs for €100bn spend
Carbon tax*	-182,406
Employers' social contributions	815,443
Public investment	708,441
Income taxes	221,484
VAT	291,730

Notes: Table shows additional jobs created in 2020 for €100bn (2008 prices), stepped up gradually over time. * The carbon tax is applied to the non-power sector and raises, rather than spends, revenue. See Appendix D for details.
Sources: E3ME, Cambridge Econometrics.

In terms of magnitude the carbon tax has the smallest impact on the total number of jobs. This is partly due to the relatively low labour intensity of the energy supply sectors that are most affected by the tax, but also the fact that most of Europe's energy is imported. A substantial proportion of the jobs that might be lost are therefore in non-European countries.

The largest coefficient relates to reductions in employers' social security contributions. This makes intuitive sense as it affects labour costs directly. The modelling results show an increase of just over 800,000 jobs.

The coefficient for public investment is almost as large, at just over 700,000 jobs. This is a result similar to the one found in Cambridge Econometrics et al (2011) when the two methods of revenue recycling produced similar results. The main reason for the positive result is that much of the investment spending must be made locally (e.g. construction costs) so there is a large domestic benefit.

The other options have more moderate impacts on jobs.

Longer-term impacts

It is important to bear in mind that the labour market is highly dynamic and there are often lagged effects in employment levels, for example due to restrictions in hiring and firing. Thiscan vary between sectors and it can mean that simple coefficients can give a misleading impression of outcomes.

To some extent this is presented in the sensitivity results in the main report; although the scenarios where revenues are used to reduce employers' social security contributions produce the best results in terms of job creation, the picture is not as clear when considering the other options. For example, the employment gains in the scenarios with lower VAT rates are smaller than those with reductions in income tax rates. While this may seem to contradict the pattern in the table above, it indicates the difference between long and short –term outcomes, as well as possible interaction between the different instruments[48] and some modelling assumptions.

It should also be noted that the scenarios include a range of different inputs, with different carbon prices and electricity prices. This can make a direct comparison of this sort quite difficult to carry out.

[48] For example, the carbon price in the scenarios is fixed in nominal terms, so the reduced VAT rate (which lowers general inflation) effectively increases the carbon price in real terms, leading to a small negative impact.

Appendix E: Model Descriptions

E.1 Introduction

This section contains the model descriptions for E3ME and GEM-E3 as well as an analysis of the main differences between the two models.

E.2 E3ME model description

This section describes the macroeconomic E3ME model and summarises how it will be applied in the study. The model will be the principle tool used to assess indirect and macroeconomic costs and benefits, including employment impacts.

Introduction to E3ME

While it is clearly necessary to apply a modelling approach to the tasks, E3ME is particularly well suited because:

- it covers each of the European Member States at national level
- it has a detailed sectoral specification
- it has been applied extensively at European level before, for a variety of clients
- its econometric specification provides a strong empirical grounding
- it has a detailed treatment of labour market effects
- it incorporates physical flows of energy in its structure

A general model description is also provided in the appendix and further information, including the full model manual, is available online at www.e3me.com.

Economic pedigree and recent applications

E3ME is a computer-based model of Europe's economies, linked to their energy systems and the environment. The model was originally developed through the European Commission's research framework programmes in the 1990s and is now widely used in collaboration with a range of European institutions for policy assessment, for forecasting and for research purposes.

Examples of recent studies that have made use of the E3ME model include:

- input to the Impact Assessment of the proposed Energy Efficiency Directive[49] (DG Energy)
- input to Impact Assessment of the proposed revised Energy Taxation Directive[50] (DG TAXUD)
- Sustainability and Green Jobs[51] (DG Employment)
- the EU's current projections of labour skills supply and demand[52] (CEDEFOP)
- assessment of green fiscal stimulus packages in Europe[53] (DG Environment)

In addition, the E3MG model, which is identical in structure to E3ME, but covers the whole world (although not the EU Member States at national level) contributed to the European Commission's communication on moving beyond the 20% GHG reduction target.

[49] http://ec.europa.eu/energy/efficiency/eed/eed_en.htm

[50] http://ec.europa.eu/taxation_customs/taxation/excise_duties/energy_products/legislation/index_en.htm

[51] http://ec.europa.eu/social/BlobServlet?docId=7436&langId=en

[52] http://www.cedefop.europa.eu/EN/publications/15540.aspx

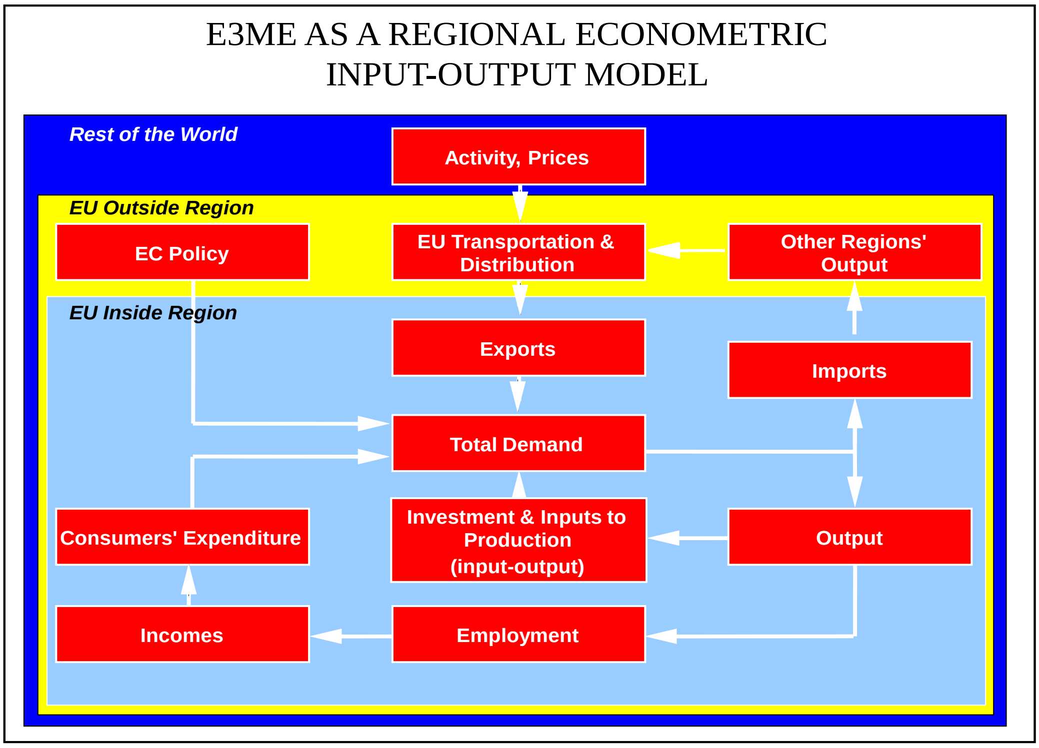
[53] http://ec.europa.eu/environment/enveco/memberstate_policy/pdf/green_recovery_plans.pdf

Economic structure

The economic structure of E3ME is based on the system of national accounts, as defined by ESA95 (European Commission, 1996). Figure A1 provides a summarised graphical representation of the main economic flows for a single European country. Short-term multiplier effects occur through the various interdependencies and feedback loops that are present in the model structure.

The labour market is also covered in detail, with estimated sets of equations for labour demand, supply, wages and working hours. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

Figure A1: E3ME Economic Structure

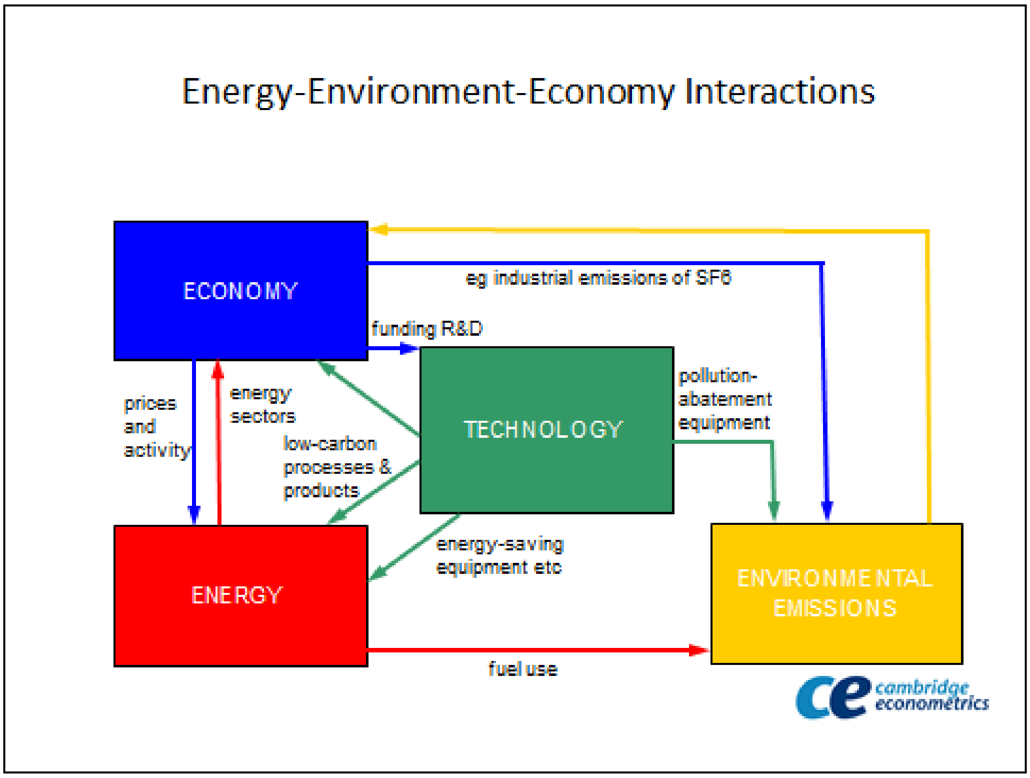


Energy and Environment linkages

Figure A2 shows the main modules in E3ME. The economy and energy demand are closely linked; economic activity creates the demand for energy, but energy consumption also affects the economy through output in the energy production and distribution sectors (e.g. electricity sector, oil and gas sector). Most environmental emissions are caused by fuel combustion (modelled as a fixed coefficient) but there are also direct economy-emission linkages through process emissions.

Technology, which is endogenous in E3ME, can affect many of these relationships. For example, the use of energy-efficient vehicles allows an increase in economic production without an increase in energy consumption and emissions. Some particular technologies like CCS or renewables allow energy consumption to increase without increasing emissions.

Figure A2: E3ME Modules



The main dimensions of the model

The main dimensions of the model are:

- 33 countries (the EU27 Member States, Norway and Switzerland and four candidate countries)
- 69 economic sectors, defined at the NACE (rev2) 2-digit level, linked by input-output relationships
- 43 categories of household expenditure
- 13 types of household, including income quintiles and socio-economic groups such as the unemployed, inactive and retired, plus an urban/rural split
- 19 different users of 12 different fuel types
- the 6 Kyoto GHGs; other emissions where available

How the model will be applied: Baseline and scenarios

Policies are simulated in E3ME using a scenario-based approach. For this study the scenarios will be *ex ante*, covering the period up to 2050. This means that a baseline forecast is required, which will be matched to that in the Energy Roadmap.

The scenario inputs will be developed in discussion with DG Energy and will match those used in the GEM-E3 model (see Appendix C). The results from the scenarios will be compared to the baseline solution with the difference between the two being the policy impacts.

Expected model outputs

E3ME is capable of producing a broad range of economic and environmental indicators. The following list provides a summary of the most common outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)

- sectoral output and GVA, wages, prices, investment, trade and competitiveness effects
- consumer prices and expenditures, and implied household distributional effects (from which welfare can be estimated)
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices
- CO_2 emissions by sector, GHG emissions
- material demands

Each of these is produced at the Member State level annually up to 2050, although usually specific years of interest are chosen for presentational purposes. The exact specification of the outputs will be discussed with the DG Energy

Further information about E3ME, including the full manual, is available at www.e3me.com.

E.3 GEM-E3 model description

Introduction to GEM-E3

The GEM-E3 model is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model which provides details on the macro-economy and its interaction with the environment and the energy system. It is an empirical, large scale model, written entirely in structural form. GEM-E3 allows for a consistent comparative analysis of policy scenarios since it ensures that in all scenarios, the economic system remains in general equilibrium. In addition it incorporates micro-economic mechanisms and institutional features within a consistent macro-economic framework and avoids the representation of behaviour in reduced form. The model is built on rigorous microeconomic foundations and is able to provide is an transparent way insights on the distributional aspects of long-term structural adjustments. The GEM-E3 model is extensively used as a tool of policy analysis and impact assessment.

The model is modularly built allowing the user to select among a number of alternative closure options and market institutional regimes depending on the issue under study. The GEM-E3 model includes projections of full Input-Output tables by country/region, national accounts, employment by economic activity, unemployment rate, balance of payments, public finance and revenues, household consumption, energy use and supply, GHG emissions and atmospheric pollutants.

The version of the GEM-E3 model used for this study simultaneously represents 38 regions and 29 sectors linked through endogenous bilateral trade flows. The model features perfect competition market regimes, discrete representation of power producing technologies, semi-endogenous learning by doing effects, equilibrium unemployment, different labour skills, option to introduce energy efficiency standards, formulates emission permits for GHG and atmospheric pollutants. The environmental module includes flexibility instruments allowing for a variety of options when simulating emission abatement policies, including: different allocation schemes (grandfathering, auctioning, etc.), user-defined bubbles for traders, various systems of exemptions, various systems for revenue recycling, etc.

Its scope is general in two terms: it includes all simultaneously interrelated markets and represents the system at the appropriate level with respect to geography, the subsystem (energy, environment, economy) and the dynamic mechanisms of agent's behaviour.

It formulates separately the supply or demand behaviour of the economic agents which are considered to optimise individually their objective while market derived prices guarantee global equilibrium, allowing the consistent evaluation of distributional effects of policies. It also considers explicitly the market clearing mechanism and the related price formation in the energy, environment and economy markets: prices are computed by the model as a result of supply and demand interactions in the markets and different market clearing mechanisms, in addition to perfect competition, are allowed.

The model formulates production technologies in an endogenous manner allowing for price-driven derivation of all intermediate consumption and the services from capital and labour. In the electricity sector a bottom up approach is adopted for the representation of the different power producing technologies. For the demand-side the model formulates consumer behaviour and distinguishes between durable (equipment) and consumable goods and services.

The model is dynamic, recursive over time, driven by accumulation of capital and equipment. Technology progress is explicitly represented in the production function, either exogenous or endogenous, depending on R&D expenditure by private and public sector and taking into account spillovers effects. Moreover it is based on the myopic expectations of the participant agents.

The GEM-E3 model includes an explicit accounting framework (investment matrix) that decomposes total sectoral investment to specific demand for investment goods. The structure of the investment matrix is based on a reconciliation of data from various sources including the European Wind Energy Association (EWEA, 2009) on PV, biomass and wind investments and the National Renewable Energy Laboratory (NREL) of the US Department of Energy Jobs and Economic Development programme (JEDI) for coal and conventional power generation technologies.

The GEM-E3 model represents public and freight transportation split in three sectors which refer to the transportation mode: land, air and water. Each public/freight transport sub-sector sells services to other production sectors and to households. Transportation using private cars and motorcycles is part of final consumption by households and more specifically it is provided by the durable goods (cars and motorcycles) which are purchased by households.

Households can choose the mix between public transportation and the use of private cars and motorcycles depending on utility, income and relative unit costs. Using private cars entails a cost to the consumer which includes annualised expenditure for acquiring the vehicle and annual expenditures for operation, maintenance and fuelling. Three types of vehicles are represented in the model: conventional, electrical and plug-in hybrid. Each vehicle type has different structures in terms of acquisition and operation costs. Cars are purchased from the transport equipment sector.

- The design of GEM-E3 model has been developed following four main guidelines:
- Model design around a basic general equilibrium core in a modular way so that different modelling options, market regimes and closure rules are supported by the same model specification.
- Fully flexible (endogenous) coefficients in production and in consumer's demand.

- Calibration to a base year data set, incorporating detailed Social Accounting Matrices as statistically observed.
- Dynamic mechanisms, through the accumulation of capital stock.

The GEM-E3 model starts from the same basic structure as the standard World Bank models. Following the tradition of these models, GEM-E3 is built on the basis of a Social Accounting Matrix (SAM). Technical coefficients in production and demand are flexible in the sense that producers can alternate the mix of production not only regarding the primary production factors but also the intermediate goods. Production is modelled through KLEM (capital, labour, energy and materials) production functions involving many factors (all intermediate products and three primary factors –capital, natural resources and labour). At the same time consumers can also endogenously decide the structure of their demand for goods and services. Their consumption mix is decided through a flexible expenditure system involving durable and non-durable goods.

The GEM-E3 model is built in a modular way around its central CGE core. It supports defining several alternative regimes and closure rules without having to re-specify or re-calibrate the model. The most important of these options are presented below:

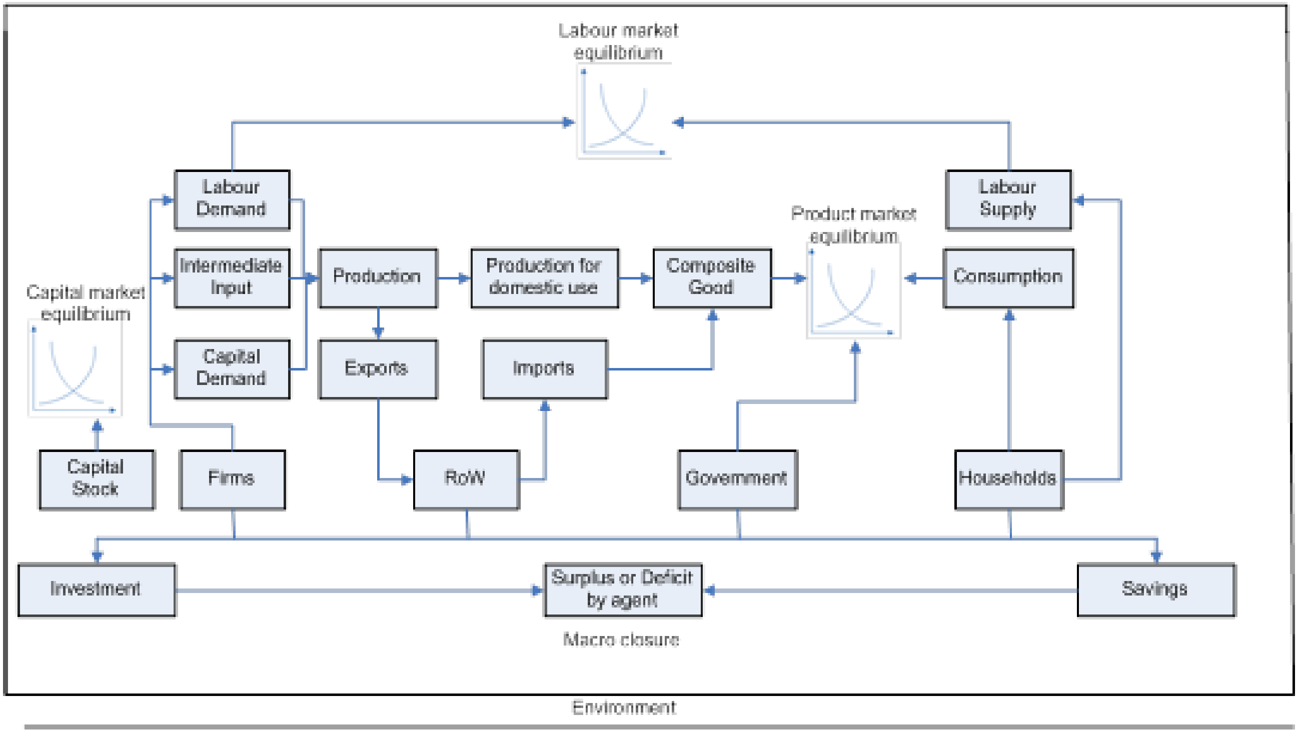
- Capital mobility across sectors and/or countries
- Flexible or fixed current account (with respect to the foreign sector)
- Flexible or fixed labour supply
- Market for pollution permits national/international, environmental constraints
- Fixed or flexible public deficit
- Perfect competition or Nash-Cournot competition assumptions for market competition regimes

The model is not limited to comparative static evaluation of policies. The model is dynamic in the sense that projections change over time. Its properties are mainly manifested through stock/flow relationships, technical progress, capital accumulation and agents' (myopic) expectations.

The model is calibrated to a base year data set that comprises a full Social Accounting Matrices for each country/region represented in the model. Bilateral trade flows are also calibrated for each sector represented in the model, taking into account trade margins and transport costs. Consumption and investment is built around transition matrices linking consumption by purpose to demand for goods and investment by origin to investment by destination. The initial starting point of the model therefore, includes a very detailed treatment of taxation and trade.

Total demand (final and intermediate) in each country is optimally allocated between domestic and imported goods, under the hypothesis that these are considered as imperfect substitutes (the "Armington" assumption). Institutional regimes, that affect agent behaviour and market clearing, are explicitly represented, including public finance, taxation and social policy. The model represents goods that are external to the economy as for example damages to the environment. Figure A3 illustrates the overall structure of the GEM-E3 model.

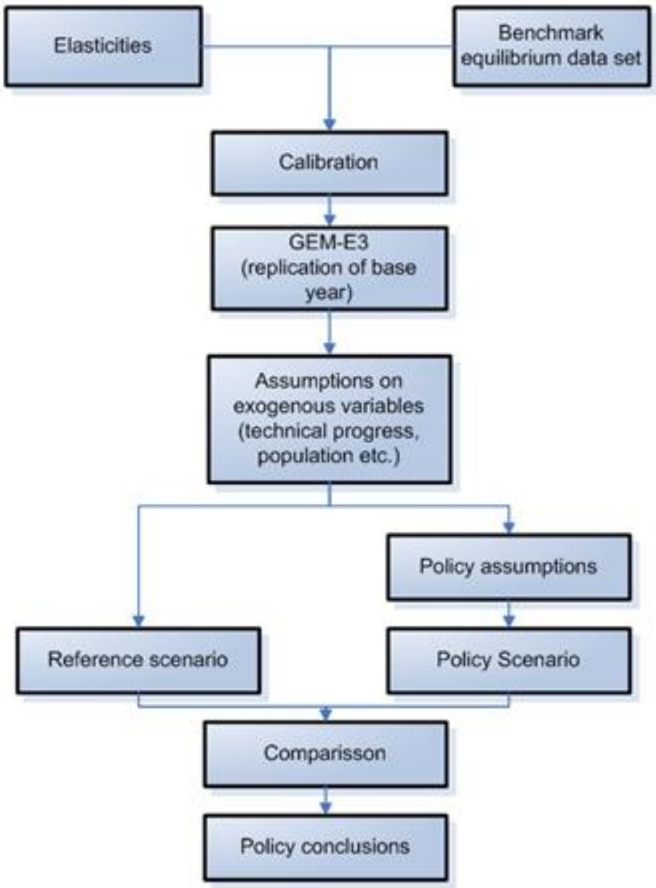
Figure A3: Economic circuit in GEM-E3



The internalisation of environmental externalities is achieved either through taxation or global system constraints, the shadow costs of which affect the decision of the economic agents. In the GEM-E3 model global/regional/sectoral constraints are linked to environmental emissions, changes in consumption or production patterns, external costs/benefits, taxation, pollution abatement investments and pollution permits. The model evaluates the impact of policy changes on the environment by calculating the change in emissions and damages and determines costs and benefits through an equivalent variation measurement of global welfare (inclusive environmental impact).

Once the model is calibrated, the next step is to define a reference case scenario. The reference case scenario includes all already decided policies. The key drivers of economic growth in the model are labour force, total factor productivity and the expectations on sectoral growth. The "counterfactual" equilibria can be computed by running the model under assumptions that diverge from those of the reference scenario. This corresponds to scenario building. In this case, a scenario is defined as a set of changes of exogenous variables, for example a change in the tax rates. Changes of institutional regimes, that are expected to occur in the future, may be reflected by changing values of the appropriate elasticities and other model parameters that allow structural shifts (e.g. market regime). These changes are imposed on top of the assumptions of the reference scenario thereby modifying it. To perform a counterfactual simulation it is not necessary to re-calibrate the model. The different steps for performing a counterfactual simulation in GEM-E3 are depicted in the figure above.

Figure A4: GEM-E3 Baseline and policy scenarios set-up



A counterfactual simulation is characterised by its impact on consumer's welfare or through the equivalent variation of his welfare function. The equivalent variation can be, under reasonable assumptions, directly mapped to some of the endogenous variables of the model such as consumption, employment and price levels. The sign of the change of the equivalent variation gives then a measure of the policy's impact and burden sharing implications. The most important results, provided by GEM-E3, are as follows:

- Dynamic annual projections in volume, value and deflators of national accounts by country.
- Full Input-Output tables for each country/region identified in the model.
- Distribution of income and transfers in the form of a social accounting matrix by country.
- Employment by economic activity and skill and unemployment rate by country.
- Capital and investment by country and sector.
- Greenhouse gasses, atmospheric emissions, pollution abatement capital, purchase of pollution permits and damages.
- Consumption matrix by product and investment matrix by ownership branch.
- Public finance, tax incidence and revenues by country.
- Full bilateral trade matrices.

The model also puts emphasis on:

- The analysis of market instruments for energy-related environmental policy, such as taxes, subsidies, regulations, emission permits etc., at a degree of detail that is sufficient for national, sectoral and World-wide policy evaluation.
- The assessment of distributional consequences of programmes and policies, including social equity, employment and cohesion for less developed regions.

GEM-E3 classifications

Table A1: List of regions

Abbreviation	Country	Abbreviation	Country
AUT	Austria	MLT	Malta
BEL	Belgium	NLD	Netherlands
BGR	Bulgaria	POL	Poland
CYP	Cyprus	PRT	Portugal
CZE	Czech Republic	SVK	Slovakia
DEU	Germany	SVN	Slovenia
DNK	Denmark	SWE	Sweden
ESP	Spain	ROU	Romania
EST	Estonia	HRV	Croatia
FIN	Finland	USA	USA
FRA	France	JPN	Japan
GBR	United Kingdom	CAN	Canada
GRC	Greece	BRA	Brazil
HUN	Hungary	CHN	China
IRL	Ireland	IND	India
ITA	Italy	AUZ	Oceania
LTU	Lithuania	FSU	Russian federation
LUX	Luxembourg	ANI	Rest of Annex I
LVA	Latvia	ROW	Rest of the World

Table A2: List of activities

No.	Activity	No.	Activity (power generation technologies)
1	Agriculture	20	Coal fired
2	Coal	21	Oil fired
3	Crude Oil	22	Gas fired
4	Oil	23	Nuclear
5	Gas	24	Biomass
6	Electricity supply	25	Hydro electric
7	Ferrous and non ferrous metals	26	Wind
8	Chemical Products	27	PV
9	Other energy intensive	28	CCS coal
10	Electric Goods	29	CCS Gas
11	Transport equipment		
12	Other Equipment Goods		
13	Consumer Goods Industries		
14	Construction		

15	Transport (Air)
16	Transport (Land)
17	Transport (Water)
18	Market Services
19	Non Market Services

E.4 Key differences between the models

E3ME and GEM-E3 belong to two different classes of model types: E3ME is an econometric model, while GEM-E3 is a computable general equilibrium (CGE) model. The differences described here reflect differences between the two modelling approaches, rather than peculiarities of these particular models. How these differences might be expected to affect the results is described in the following section.

Optimisation and the relationship between supply and demand

The most important difference between CGE and econometric models is in the treatment of the interaction of supply and demand. In a CGE model, it is assumed that actors within the system behave in an optimal fashion, meaning that an automatic adjustment takes place, typically via a vector of prices, so that supply and demand match and markets clear. When this outcome occurs in all markets simultaneously, there is a 'general' equilibrium within the system as a whole.

In contrast, the econometric model allows for the possibility that only a partial adjustment takes place, the extent of which is determined by econometric evidence based on historical experience. Output is in general determined by the level of demand in the system, which may be less than potential supply. This means that there is not necessarily equilibrium between supply and demand and it is possible for imbalances to build up within the overall system and non-optimal outcomes and behaviour to occur.

Price and wage adjustment

An example of this difference in approach can be found in product markets. In a CGE model, product prices are set so that product demand and supply are matched. The amount that prices must adjust is given by a set of elasticities that determine the responses in demand and supply to a change in price. All available production capacity is therefore used, with producers charging the prices that will optimise their profitability.

In comparison, responses to prices in an econometric model reflect empirical relationships that are estimated based on historical data (see below). These estimates are restricted so that they operate in the expected direction (so e.g. higher prices do not lead to higher demand) but prices will not necessarily change such that product demand meets available supply. It is thus therefore possible to have spare production capacity in the system.

Savings and investment

The way in which the models deal with capital markets is also likely to be highly important for scenarios that have a large amount of investment. In a CGE model there is a constraint on investment, based on the available savings. It means that, all other things being equal, an increase in energy-related investment must be associated with a reduction in productive investment elsewhere.

In the econometric model, however, the assumption is that there is unproductive (i.e. non-optimal) capital available, which may be used for investment in energy-efficient or renewable equipment. It is therefore possible to introduce additional investment to the system, without requiring an increase in savings or a reduction in investment elsewhere.

Parameterisation Here we define parameters as the models' representation of behavioural relationships, such as the response in demand to a change in price, or the rate of substitution between two products. They are also referred to as 'elasticities' because the model functions are usually specified in a form that means that the parameters are interpreted as elasticities (the proportionate response of one variable to a unit percentage change in another).

The two modelling approaches differ in their means of deriving parameters. In the CGE model, values for key parameters are taken from the economic literature and previous studies. Values for the remaining parameters are obtained using a calibration procedure that ensures that the model equations are consistent with the base year data.

In the econometric model, it is also possible to fit parameters to be consistent with previous research but most model parameters are estimated on the basis of historical data using econometric methods. This usually requires time series of historical data from which the econometric estimation method seeks to isolate the effects of one model variable on another.

E.5 Expected influence of these differences on the scenario results

Similarities and differences Before discussing the differences in the modelling approaches, it should be noted that the similarities between the models are also important. Both models use the latest available data from Eurostat[54] and use the same national accounting structure. This means that, for example, both models will show that a policy that leads to a deterioration in net trade will lead to a greater loss of output in countries and sectors that are more exposed to trade.

The main differences are expected to reflect the differences in modelling approach discussed in the previous section. Some of the main ones are described below.

Long and short-term impacts The difference between short and long-term outcomes is often cited when comparing the two modelling approaches. It may be more reasonable to assume that forces that return the economy to equilibrium might take effect not in the short run but in the long run, when there is time for individuals and firms to adapt. Econometric models are therefore typically preferred for short-term analysis.

However, the focus in this study is primarily on long-term outcomes in 2050, so this distinction is less relevant. The CGE model will assume equilibrium in results, while short-run impacts will generally have worked themselves through in the econometric model.

Investment effects Outcomes for investment are likely to be a key difference between results from the two models. In the E3ME results an increase in total investment is a likely outcome in scenarios that require the development and deployment of new energy technologies. In GEM-E3 an increase in energy investment is likely to be countered by a reduction in investment elsewhere, or an increase in savings (and hence lower consumption spending) to match (i.e. a crowding out effect).

[54] In the case of GEM-E3, which requires global data, this is alongside GTAP figures.

As investment is a component of GDP, this will have a direct impact on the economic results. The investment sectors (e.g. engineering, construction) are also labour intensive and with particular skills requirements, so this difference is likely to influence the employment results.

The labour market Historically, the labour market has been a key area of difference between CGE and econometric models. Under standard CGE assumptions, wages (like product prices) will adjust automatically so that labour supply and demand match. This means that it is not possible to have involuntary unemployment in the system. However, more recent developments in CGE modelling, including the GEM-E3 model, allow for unemployment due to labour market frictions.

In the econometric model, wage rates do not automatically adjust to remove involuntary unemployment, either in the short or long run. There may also be a lag in company hiring/firing decisions.

International trade The specification of international trade is quite similar between the two models, so we do not expect this to cause major differences in the long-term results. Our initial assessment suggests that differences in the results are more likely to be the result of variation in the parameters (e.g. import substitution elasticities) than in the structure of the treatment of trade.

It should also be noted that the models have different geographical coverage, with GEM-E3 being global while the current version of E3ME covers just Europe.

Model parameters The previous studies to which parameters in the CGE model are matched typically use an approach that is quite similar to that in the econometric model. Therefore, while there will be differences in individual parameters, this is not expected to lead to a large difference in overall results.