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DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Économie

Assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling

Report by the Ministry of the Economy, Luxembourg

in fulfilment of the notification obligation under Article 14 of Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency.

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1 Introduction

Article 14 of Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency states that all Member States shall carry out an assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling. The aim of the study, therefore, is to determine the current state of the art and possible future developments, based on existing analyses of the potential for cogeneration and district heating, and to calculate the economic potential on the basis of a cost-benefit analysis.

The investigation will first consider historical developments and identify the extent to which cogeneration technology is already being used to cover the demand for heat. This will involve looking at the building sector as well as developments in the industrial sector, where cogeneration technologies are used to provide process heat.

The potential for expansion of cogeneration in the future is based on the current and expected heating demand. In the context of the study, therefore, future demand both in the building sector and in industry will be estimated and forecast. These analyses are based on current energy balances for Luxembourg and break down heating demand by sector as well as by geographical region. Heat density and therefore the regional distribution of possible heat sinks and heat sources are important considerations when assessing the economic efficiency of cogeneration systems. Where possible, therefore, regional evaluations are carried out at municipal level and these are also presented in the form of heat maps.

Knowledge of the regional distribution of heat sinks and heat sources as well as the existing heating infrastructure forms the basis for determining and assessing the economically realisable potential for cogeneration technologies based on a cost-benefit analysis. The possible alternative approaches to heating supply are extremely relevant in this assessment. Due to the comparatively high proportion of new buildings expected among Luxembourg’s building stock, there could be greater opportunities here for implementing new heating supply systems.

The results of the assessment of the economic potential form the basis for possible recommendations for action and strategies for the future coverage of Luxembourg’s heating demand. When determining policy-related recommendations for action, other mandatory targets such as reduction of CO_2 emissions, increasing the proportion of renewable energies and increasing energy efficiency must be taken into account. In this regard, the particular situation in Luxembourg needs to be considered, namely the fact that, based on the territorial principle, an increase in national electricity production will initially lead to an increase in national CO_2 emissions if these plants do not fall within the emissions trading system and at the same time they supplant electricity imports.

In addition to these interrelationships with other mandatory targets, there is also the question of what path dependencies exist if coverage of the heating demand is in future to be characterised by high efficiency standards and an increasing distribution of electric heat pumps in an energy system strongly dominated by renewable energies. As a result of the high proportion of new buildings, it may be that changes to, and adaptation of, the heating supply could progress more rapidly here than in other countries where the rate of construction of new buildings is lower.

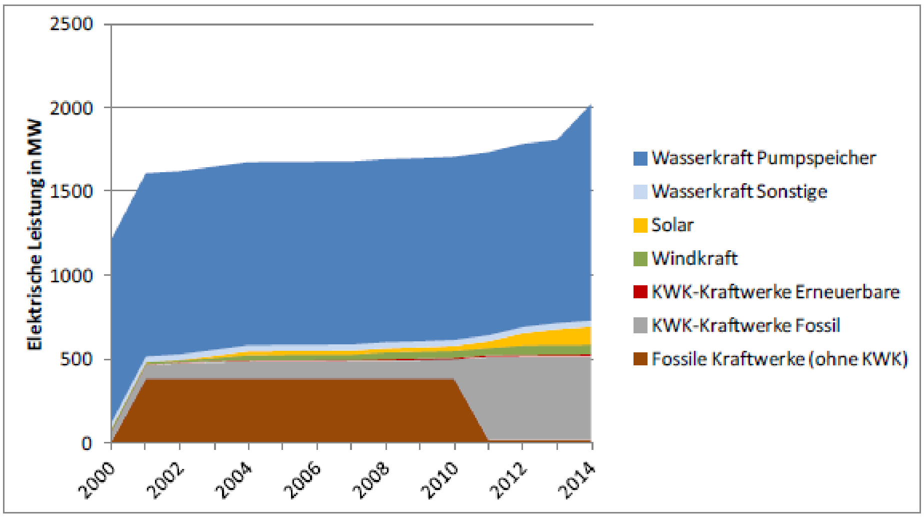
The following sections address the above questions and thus provide a comprehensive assessment of the potential for high-efficiency cogeneration installations as required by Article 14 of Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency.

2 History of cogeneration

2.1 Installed electric and thermal capacity

The Vianden pumped storage power plant and, until recently, the TwinErg combined cycle (CC) power plant in Esch-Alzette, which together had an electricity-generating capacity of over 1 600 MW, have been responsible for a large proportion of the electricity generated in Luxembourg. The TwinErg combined cycle power plant was decommissioned in the middle of 2016, however. In recent years, other industrial cogeneration installations have also been decommissioned and so only smaller cogeneration installations that are almost exclusively heat led are in operation in Luxembourg. Most of these plants run on fossil fuels (natural gas), but a few also run on renewable energy sources (wood pellets).

The expansion of cogeneration in Luxembourg in recent years has taken place in these smaller plants in particular. TwinErg's heat extraction was put into operation in 2008 with a total extractable capacity of 28 MW_{th}, and until 2015 it continually increased up to a total load of 12 MW_{th}, supplying district heating to the area of Belval West (Agora). The cogeneration part of the power station was included in the statistical data on installed cogeneration capacity that were published in the past. In their published form, however, these data had very limited informative value and so Statec (National Institute of Statistics and Economic Studies of the Grand Duchy of Luxembourg) made a retrospective amendment. For this reason, the fossil fuel-based cogeneration capacity of 491 MW in 2011 should be viewed with discrimination (see Figure 1). In total, approximately 507 MW of electrical cogeneration capacity is shown for 2014 in the current statistics, of which approximately 14 MW uses renewable energies.



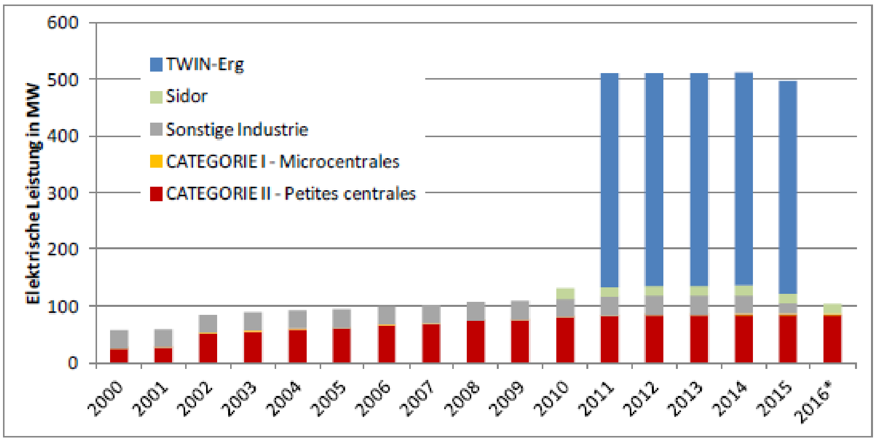
Source: Statec A4201

Elektrische Leistung in MW	Electrical capacity in MW
Wasserkraft Pumpspeicher	Hydroelectric power, pumped storage
Wasserkraft Sonstige	Hydroelectric power, other
Solar	Solar
Windkraft	Wind
KWK-Kraftwerke Erneuerbare	Cogeneration installations, renewable
KWK-Kraftwerke Fossil	Cogeneration installations, fossil
Fossile Kraftwerke (ohne KWK)	Fossil fuel-based power plants (with no cogeneration)

Figure 1: Changes in installed electrical power generation capacity according to technology from 2000 to 2014

The proportion of the installed capacity provided by cogeneration in the current statistics is therefore approximately 25 % in 2014. Since the mid-1990s there have also been several industrial cogeneration installations in the single-figure MW range that were used to provide process heat. These plants have been decommissioned in recent years, however, because they were not economically viable. As a result of the closures that have taken place since 2014, however, the proportion of the installed electrical capacity represented by cogeneration in Luxembourg has fallen significantly.

In the small plant sector, since 2000 a total of 117 cogeneration installations have been built on 86 sites with a mean electrical capacity of a few hundred kW, increasing the installed capacity from approximately 25 MW to 85 MW (see Figure 2). There have also been an additional 39 plants in the micro cogeneration sector, each with less than 100 kW, bringing the capacity to just below 1 MW. As a rule, the installations use natural gas as fuel. Finally, it should be mentioned that in 2010 the existing waste incineration plant (SIDOR) was refurbished and extended. It generates electricity and can also extract heat. Heat extraction is planned here to supply a nearby city quarter (Cloche d'Or).

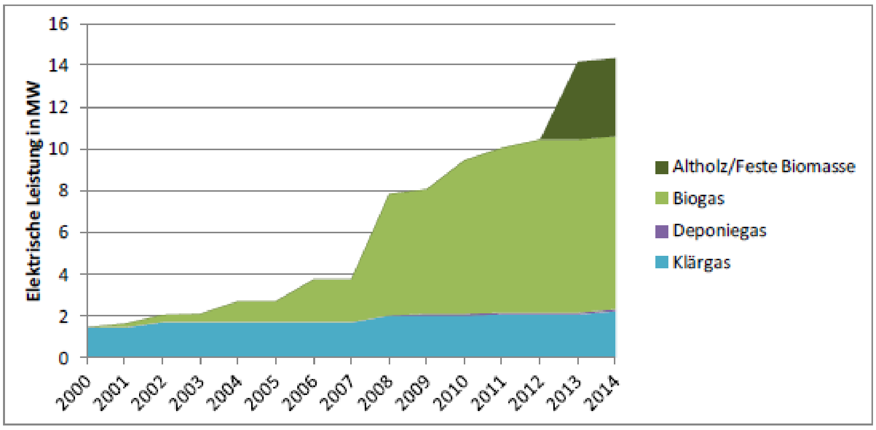


Source: WiMi Lux 2016, ILR 2016 (*2016, estimated)

Elektrische Leistung in MW	Electrical capacity in MW
TWIN-Erg	TWIN-Erg
Sidor	Sidor
Sonstige Industrie	Other industry
CATEGORIE I -Microcentrales	CATEGORY I – Micro plants
CATEGORIE II - Petites centrales	CATEGORY II – Small plants

Figure 2: Changes in installed electrical capacity in fossil fuel-based cogeneration installations from 2000 to 2016

There has been further expansion of cogeneration in the renewable cogeneration installation sector, where the installed capacity of biogas plants with heat recovery increased to approximately 8.3 MW in 2014 (see Figure 3) and includes around 25 installations with a mean electrical capacity of 300 kW. In 2013 a larger cogeneration installation with a capacity in the MW range was installed using waste wood as fuel. The installed capacity of landfill and sewage gas plants has barely increased and in 2014 was approximately 2.3 MW.



Source: WiMi Lux 2016

Elektrische Leistung in MW	Electrical capacity in MW
Altholz/Feste Biomasse	Waste wood/solid biomass
Biogas	Biogas
Deponiegas	Landfill gas
Klärgas	Sewage gas

Figure 3: Changes in installed electrical capacity in renewable cogeneration installations from 2000 to 2014

Based on Eurostat data (Eurostat 2015) and the installed electrical capacities, the thermal capacities of the cogeneration installations can be estimated using typical power to heat ratios. Local and district heating networks that have heat generators only and do not produce electricity are also operated in Luxembourg. In addition to the cogeneration heat capacity of approximately 105 MW, more than 320 MW are installed in pure heat generators (typically boilers) and therefore the total thermal capacity in the district heating network is more than 430 MW (see Table 1).

Table 1: Installed electrical and thermal cogeneration capacity and pure heat generators in district heating networks

	Electricity from cogeneration	**Heat from cogeneration**	**Power to heat ratio**	**Pure heat generators**	**Heat total**
	in kW	in kW		in kW	in kW
Sidor	17 500*	Planned (18 000)		Planned > 30 000	Planned > 40 000
Small heating plants (cat. II)	85 130	105 100	0.81	> 320:000	> 430 000
Micro cogeneration units (cat. I)	919	1 670	0.55		
Biomass	14 354	48 060	0.29		

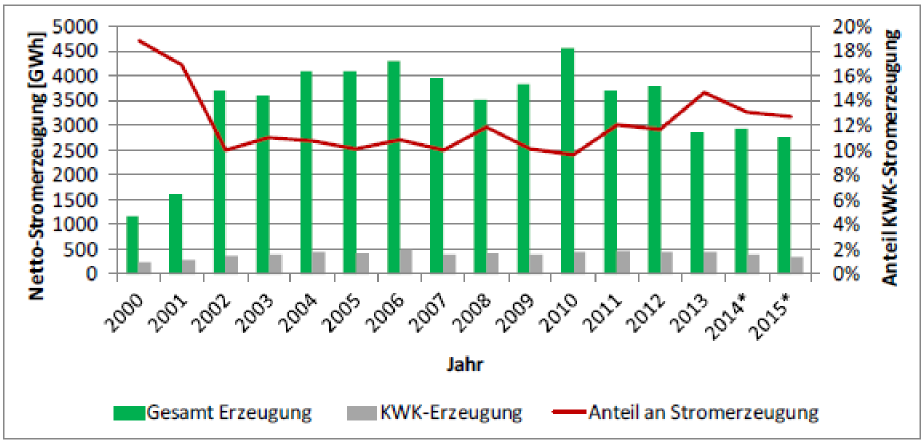
* with no heat extraction, source: ILR 2016, WiMi Lux 2016

Taking into account the combined heat capacity in heating plants of approximately 106 MW as well as the industrial cogeneration installations and TwinErg, which together account for a total of approximately 800 MW, approximately 900 MW of combined thermal capacity was identified by Eurostat for Luxembourg in 2013. TwinErg's share needed statistical qualification, however, as the heat capacity made available was less than 5 % of the total extractable heat capacity of the TwinErg power station. As a result of the decommissioning of the industrial cogeneration installations (CEDUCO, CEGYCO) and TwinErg, the thermal capacity has reduced considerably.

2.2 Electricity from cogeneration and the production of heat

In 2013 cogeneration produced a total of approximately 424 GWh (Eurostat 2015) and in 2014 it was approximately 384 GWh (ILR 2016). Due to Eurostat's inclusion of the non-combined generation of electricity in cogeneration installations in its designation of cogeneration, an exact estimate of the production for 2014 based on the Eurostat data has not yet been possible[1]. The proportion of the total electricity production represented by electricity from cogeneration was around 15 % in 2013, having increased slightly since 2010 (see Figure 4). However, this is largely due to the decrease in total electricity production, while electricity from cogeneration remained roughly the same. Since then the percentage as well as the absolute quantity of electricity from cogeneration has decreased, as the utilisation of industrial plants in particular initially declined and now the plants have been completely decommissioned.

Overall, it appears that electricity from cogeneration was produced at a level of between 390 and 470 GWh during the period from 2005 to 2010 and since 2011 it has fallen from approximately 450 GWh to an estimated 350 GWh/a in 2015. One of the main reasons for this is the decline in industrial cogeneration installations, which were no longer in operation in 2015.



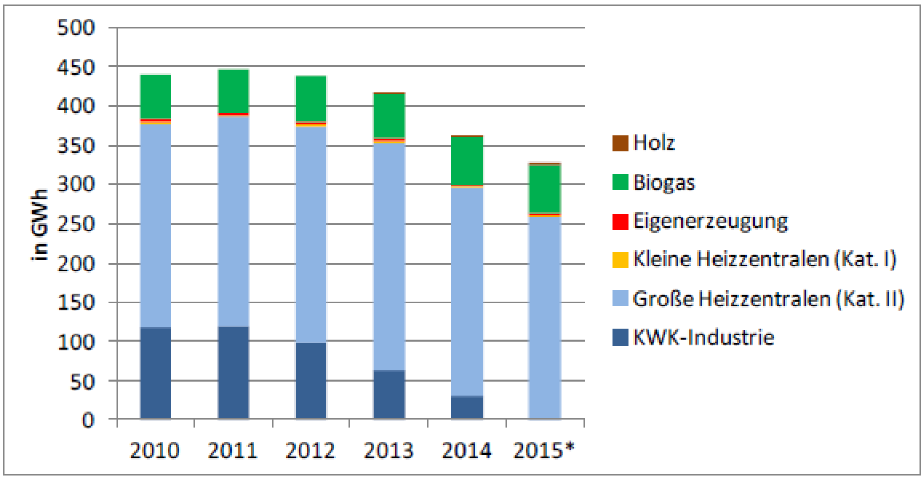
Source: Eurostat 2015, Statec A4203, ILR 2016

Anteil KWK-Stromerzeugung	Percentage of electricity from cogeneration
Netto-Stromerzeugung [GWh]	Net electricity production [GWh]
Jahr	Year
Gesamt Erzeugung	Total production
KWK-Erzeugung	Cogeneration
Anteil an Stromerzeugung	Percentage of electricity production

Figure 4: Combined electricity production from cogeneration installations, total electricity production and percentage of cogeneration from 2000 to 2014

Historically, electricity production was dominated by the industrial cogeneration installations and the small plants. From 2011 onwards, however, industrial cogeneration declined dramatically and in 2015 it was completely shut down (see Figure 5). In 2013 the proportion of biogas cogeneration was just 13 % of the total amount of electricity from cogeneration or approximately 56 GWh (status in 2014: 61 GWh). This means that biogas plants achieved approximately 6 200 full load hours in 2013 and therefore run considerably longer than gas-based cogeneration installations. Cogeneration installations running on waste wood generated just 0.2 GWh in 2013 and approximately 1.8 GWh in 2014. Publications by the regulatory authority, the ILR [Institut Luxembourgeois de Régulation], give a figure for electricity generation by biogas cogeneration in 2015 of 61.5 GWh. For electricity generation plants running on waste wood, no information on combined generation was available and therefore the values have been estimated based on those of the previous year.

[1] Electricity produced in cogeneration installations (including the non-combined portion): 1 478 GWh (2013)/1 534 GWh (2014).



Source: ILR 2016, Statec 4203

in GWh	in GWh
Holz	Wood
Biogas	Biogas
Eigenerzeugung	Own generation
Kleine Heizzentralen (Kat. I)	Small heating plants (cat. I)
Große Heizzentralen (Kat. II)	Large heating plants (cat. II)
KWK-Industrie	Cogeneration industry

Figure 5: Electricity from cogeneration according to installation type from 2010 to 2015

In order to estimate the heat generated from cogeneration installations, the power to heat ratios and load periods for 2015 were estimated. The electricity from cogeneration of approximately 325 GWh therefore has a corresponding heat generation of approximately 527 GWh (see Table 2). This is generated by small plants in particular, which mainly comprise block-type thermal power plants. Industrial cogeneration installations that were used in the rubber industry and the chemicals industry have now been decommissioned. In the biomass sector, a greater amount of heat is generated than electricity due to the use of steam turbines to generate electricity in the wood waste recovery sector. These installations have very low power to heat ratios and therefore produce considerably more heat than electricity.

Table 2: Electrical and thermal capacity and electricity and heat generation by cogeneration installations by area of application for 2015

2015	**Electrical capacity** P(el) [kW]	**Thermal capacity** P(th) [kW]	**Number**	**Capacity utilisation electricity 2015** [h]	**Electricity** MWh	**Heat** MWh
TwinErg cogeneration	376 000 Decommissioned 2016	n/a			n/a	n/a
Sidor	17 500	up to now no heat extraction				
Cogeneration industry	Decommissioned in 2015 2014: 15 800	2014: 33 200	2			
Own consumption	2 560	3 500	1	1 624	4 159	5 686
Small heating plants (cat. II)	85 130	105 100	87	3 033	258 209	318 777
Micro cogeneration (cat. I)	919	1 670	43	1 987	1 826	3 320
Biomass	15 818	48 060	36	3 888	61 500	205 000
Total (without/with TwinErg/Sidor)	**104 427** **497 677**	**158 330**	**168**		**325 694**	**532 783**
for information EUROSTAT 2013	*507 000*	*912 000*			*424 000*	*938 000*

Source: Eurostat 2015, Statec A4203, ILR 2016

3 Starting point and framework data

3.1 Energy balance in Luxembourg

The starting point for estimating the potential coverage of the heating demand by cogeneration installations is the current final energy demand in Luxembourg. In 2014 the final energy demand in Luxembourg was approximately 47 TWh, of which approximately 7 TWh was consumed in the industrial sector, approximately 29 TWh in the transport sector and 10 TWh in all other sectors (Table 3). Most of the final energy demand in the transport sector is a result of fuel exports, which in 2014 were approximately 20 TWh. Sectors that are suitable for cogeneration installations include, in particular, the industrial sector and, via a district heating supply, also households and the commercial sector.

Table 3: Energy balance 2014 for the industrial, transport and other sectors

	Final energy balance Luxembourg 2014					
	Industry	**Transport**	**Agriculture**	**Households**	**Commercial**	**Total**
	Data in GWh					
Electricity demand	3 175	123	40	942	1 948	6 227
Mineral oil; crude oil	122	28 255	0	1 719	588	30 684
Natural gas	2 543	0	0	2 596	1 175	6 314
Solid fuels	615			6	0	621
Biomass + waste-derived fuels	507	812	30	270	26	1 644
Heat	157	0	0	69	839	1 065
Total	**7 119**	**29 189**	**70**	**5 601**	**4 575**	**46 555**

Source: Statec A4100

In the final energy balance, heat is also identified as an energy source, which includes all heat made available via a heating network. In addition to heat from cogeneration, this also includes non-combined heat generation. Heat from cogeneration in the industrial sector that is used by the industry itself and is not delivered to other heat users via a heating network is not included. The greatest contribution to the final energy demand is provided by heat in the commercial sector with approximately 840 GWh, which represents approximately 30 % of the final energy demand (excluding electricity). In the household and industrial sectors the proportion is very much lower at significantly less than 5 %.

3.2 Technical and economic performance indicators for cogeneration installations

In order to calculate the economic efficiency of cogeneration installations in the industrial sector and in relation to local and district heating, individual reference installations were defined (see Tables 4 and 5). The costs of cogeneration technologies include the capital investment (including peripheral equipment and structural measures), variable operating costs (fuel costs, auxiliary materials) and fixed operating costs (staff, administration, insurance).

Table 4: Technical and economic performance indicators for cogeneration installations of capacity class (1)

Performance indicators	**Unit**	**CC cogeneration installation**	**CC cogeneration installation**	**CC cogeneration installation**	**CC cogeneration installation**	**Block type**	**GT**
Capacity [MW]	MW (el)	**450**	**200**	**100**	**20**	**10**	**10**
el. efficiency	%	55	50	45	35	46	30
th. efficiency	%	33	38	43	53	42	55
Efficiency total	%	88	88	88	88	88	85
Investment incl. planning	EUR/kW	1 100	1 200	1 300	1 300	700	800
Fixed operating costs	EUR/kW/a	16	16	16	20	9	16
Other variable costs	EUR/MWh	1.5	1.5	1.8	4	6	6

Source: Prognos AG, 2014

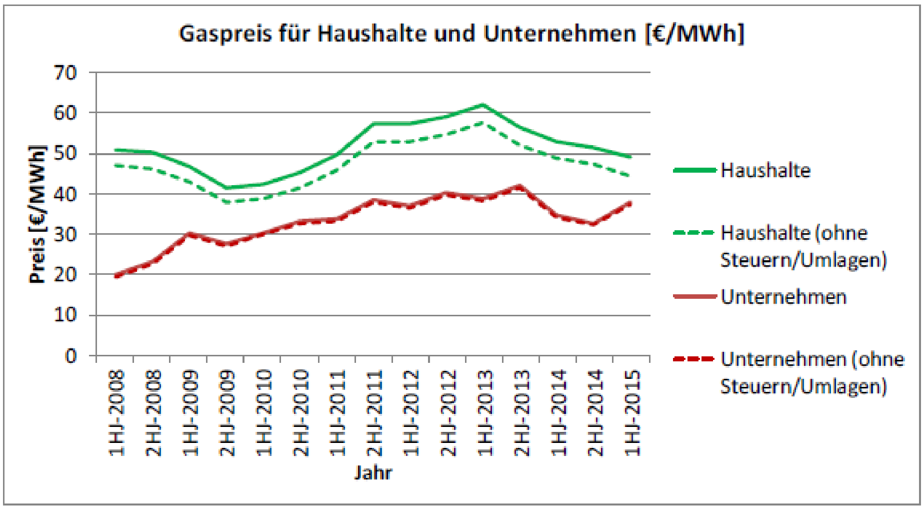
Table 5: Technical and economic performance indicators for cogeneration installations of capacity class (2)

Performance indicators	**Unit**	**ST**	**Block type**	**Block type**	**Block type**	**Block type**	**Block type**
Capacity [MW]	MW (el)	**5**	**2**	**0.5**	**0.05**	**0.005**	**0.001**
el. efficiency	%	25	42	39	34	27	26
th. efficiency	%	60	48	51	57	66	66
Efficiency total	%	85	90	90	91	93	92
Investment incl. planning	EUR/kW	1 500	850	1 300	2 750	5 300	15 000
Fixed operating costs	EUR/kW/a	10	10	15	30	110	280
Other variable costs	EUR/MWh	8	9	13	25	40	60

Source: Prognos AG, 2014

3.3 Other framework data and energy source price trends

The electricity and gas prices that the respective users have to pay form the key basis for assessing the economic efficiency of cogeneration installations. The gas price paid by the final customer initially fell as a result of the economic crisis and then rose again between 2010 and 2013 to a level of approximately EUR 60/MWh. Since 2013, gas prices paid by final customers have fallen again and are currently around EUR 50/MWh (see Figure 6). For enterprises, gas prices are lower than the level for households due to the higher purchase volume and lower distribution costs, and in the first half of 2015 they were approximately EUR 37/MWh. Charges and taxes are also considerably lower than for households.



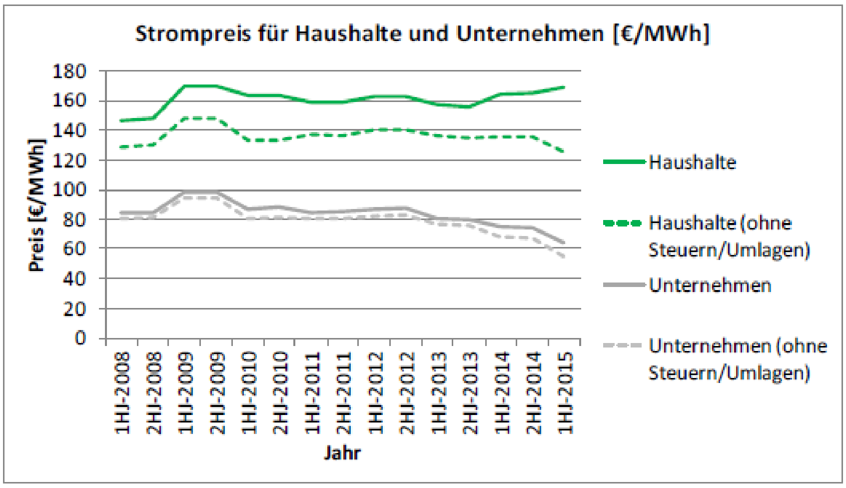
Source: Statec A4503

Gaspreis für Haushalte und Unternehmen [€/MWh]	**Gas price for households and enterprises [EUR/MWh]**
Preis [€/MWh]	**Price [EUR/MWh]**
Jahr	**Year**
Haushalte	Households
Haushalte (ohne Steuern/Umlagen)	Households (without taxes/charges)
Unternehmen	Enterprises
Unternehmen (ohne Steuern/Umlagen)	Enterprises (without taxes/charges)

Figure 6: Gas price trend for households and enterprises from 2008 to 2015

The price of electricity for households in Luxembourg was approximately EUR 160/MWh for several years but in 2015 it rose slightly to around EUR 170/MWh due to increases in charges and taxes (see Figure 7). For enterprises, the price of electricity has been falling since 2009 and in 2015 it was around EUR 64/MWh. The taxes/charges included in the price of electricity are considerably lower for enterprises than for households, too.

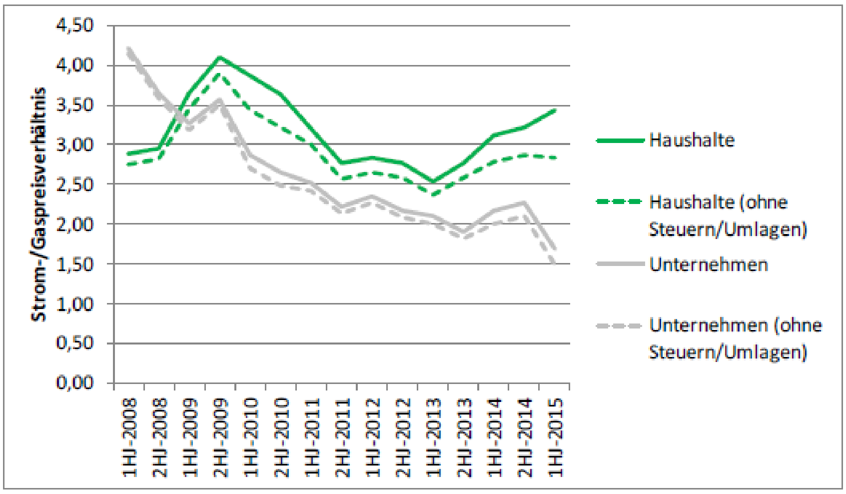
For the economic efficiency of cogeneration installations that use natural gas as fuel, the relationship between gas and electricity prices is crucial. If electricity prices rise more sharply than gas prices, the economic efficiency of natural gas-based cogeneration installations improves. If it is only the gas prices that increase and electricity prices remain constant or even fall, as has been the case in Luxembourg in recent years, the economic efficiency of natural gas-based cogeneration installations decreases (see Figure 8). This has been the case in particular for enterprises.



Source: Statec A4502

Strompreis für Haushalte und Unternehmen [€/MWh]	**Electricity price for households and enterprises [EUR/MWh]**
Preis [€/MWh]	**Price [EUR/MWh]**
Jahr	**Year**
Haushalte	Households
Haushalte (ohne Steuern/Umlagen)	Households (without taxes/charges)
Unternehmen	Enterprises
Unternehmen (ohne Steuern/Umlagen)	Enterprises (without taxes/charges)

Figure 7: Electricity price trend for households and enterprises from 2008 to 2015

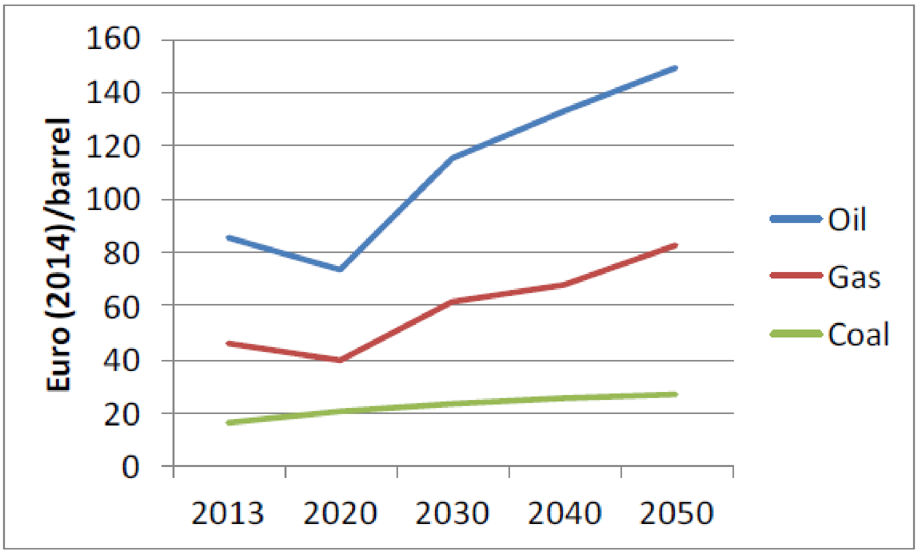


Source: own calculations based on Statec A4502/3

Strom-/Gaspreisverhältnis	**Electricity/gas price ratio**
Haushalte	Households
Haushalte (ohne Steuern/Umlagen)	Households (without taxes/charges)
Unternehmen	Enterprises
Unternehmen (ohne Steuern/Umlagen)	Enterprises (without taxes/charges)

Figure 8: Trend in the ratio of electricity price to gas price for households and enterprises from 2008 to 2015

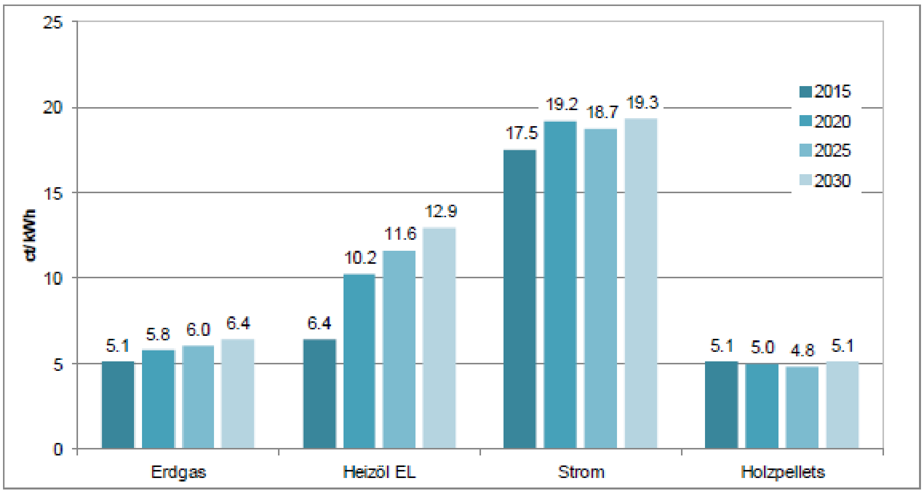
For future changes in energy source prices, the scenario set out in the IEA World Energy Outlook 2015 (WEO 2015) and calculations by the European Commission (Primes 2014) are used as a basis and it is assumed that prices of energy sources (see Figure 9) and prices for emissions certificates will rise in the medium term (EEA: EUR 31/t in 2030, EUR 87/t in 2050).



Source: derived from WEO 2015, Primes 2014

Figure 9: Evolution of energy source prices (cross-border) to 2050

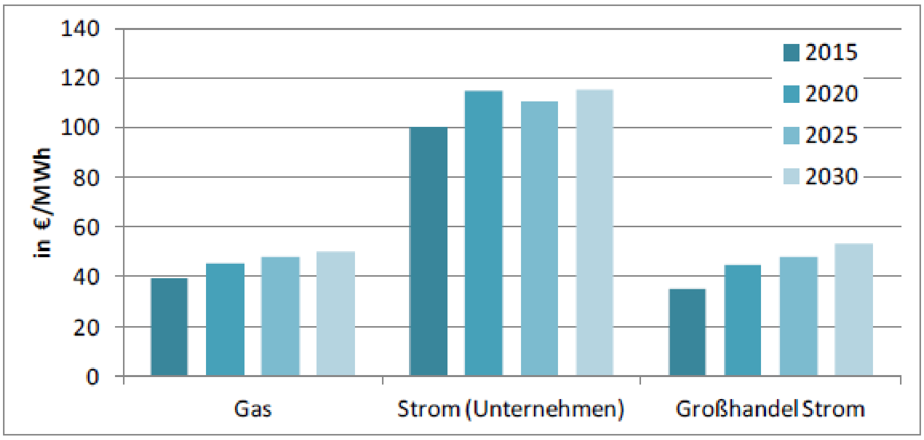
The trend in electricity prices at the level of the final customer is derived using the European Commission's reference scenario (Primes 2014). Prices for household customers will rise by 2030 to EUR 193/MWh (Figure 10) and for industrial customers to EUR 115/MWh (see Figure 11) in each case with taxes and fees.



Source: derived from WEO 2015, Primes 2014

Erdgas	Natural gas
Heizöl EL	Fuel oil EL
Strom	Electricity
Holzpellets	Wood pellets
ct/kWh	**euro cents/kWh**

Figure 10: Assumed energy price trend for household customers up to 2030



Source: derived from WEO 2015, Primes 2014

Gas	Gas
Strom (Unternehmen)	Electricity (enterprises)
Großhandel Strom	Wholesale electricity
in €/MWh	**in EUR/MWh**

Figure 11: Gas and electricity trend for enterprises and evolution of the wholesale price of electricity

3.4 Current measures to promote cogeneration

Current conditions for funding include the following laws and ordinances, under which cogeneration installations can be supported or subsidised:

1. Feed-in tariffs for installations supplied from renewable energies: '*Grand Ducal Regulation of 1 August 2014 on the generation of electricity based on renewable energy sources*' (RGD 2014);
2. Feed-in tariffs for installations based on fossil energy sources: '*Grand Ducal Regulation of 26 December 2012 on the generation of electricity based on high-efficiency cogeneration*' (RGD 2012);
3. Investment grants at municipal level: '*Law of 31 May 1999 establishing a fund for the protection of the environment*', as amended (FPE 1999).

Re 1.

For feeding in heat from biogas and solid biomass, installations receive a payment for the heat of EUR 30/MWh provided minimum sales quotas for the sale of heat are met. These quotas are between 25 % (years 1 to 3) and 50 % (from year 4) for biogas plants and 35 % and 75 %, respectively for solid biomass. The quantity of electricity generated is also subsidised (RGD 2014). Furthermore, if lower minimum sales quotas are met (40 % and 65 % from year 4 onwards), a reduced heat premium of EUR 15/MWh can be received.

Re 2.

Existing installations commissioned by 1 July 2014 receive a subsidy for the quantity of electricity generated, which for category I plants (1 to 150 kW) is 7.3 euro cents/kWh. Larger installations of category II (150 kW) receive a subsidy of 7 euro cents/kWh if they feed in power between 6.00 and 22.00 (remuneration, day) and 3 euro cents/kWh during the remaining hours (remuneration, night). In addition, only category II installations commissioned before 1 July 2014 can receive the subsidy. By way of deviation from this, installations commissioned before 1 July 2013 receive a lower subsidy during the day of 5.7 euro cents/kWh (remuneration, day), but receive an additional performance fee of EUR 111.55/kW per year. The funding period starts from the time of the first feed in and lasts for a period of 20 years. Both the energy prices and the performance prices (category II only) are adjusted in line with inflation and the evolution of the gas price.

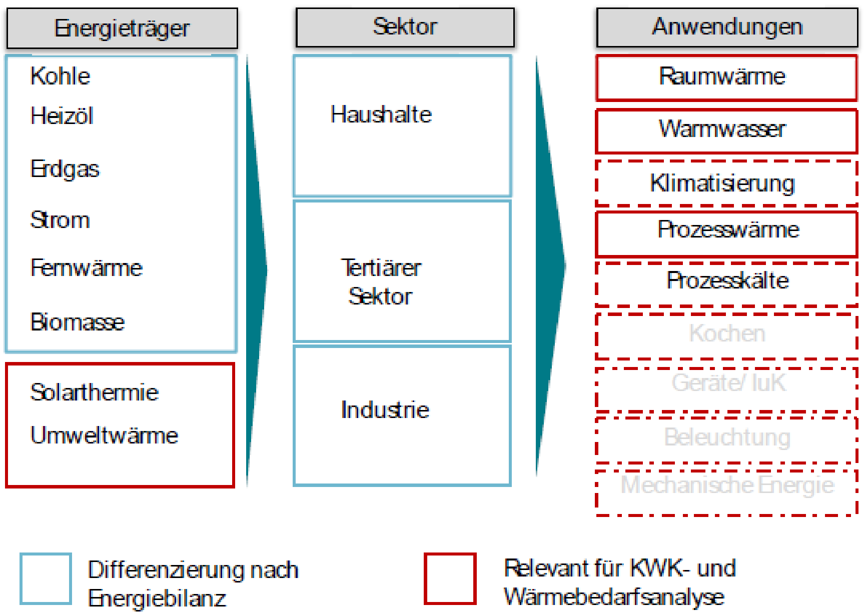
Re 3.

For municipalities, investment grants of up to 30 % can be paid from the fund for the protection of the environment if they install a local heating installation based on renewable energies (‘*Circular No 3178 to municipal administrations, confederations of municipalities and public institutions under the supervision of municipalities*’, FPE 1999).

It is currently the case, therefore, that new cogeneration installations are only eligible for subsidies if they use renewable energies as fuel. Cogeneration installations based on fossil fuels, in particular natural gas, are only subsidised as existing installations. New installations are not eligible for funding.

4 Description of the heating and cooling demand and the building stock

From the energy balance, the primary energy consumption and final energy consumption in the household, industry and tertiary sector, including agriculture, are known. To assess the cogeneration potential, however, a breakdown according to end use is necessary in order to determine heating demand (Figure 12).

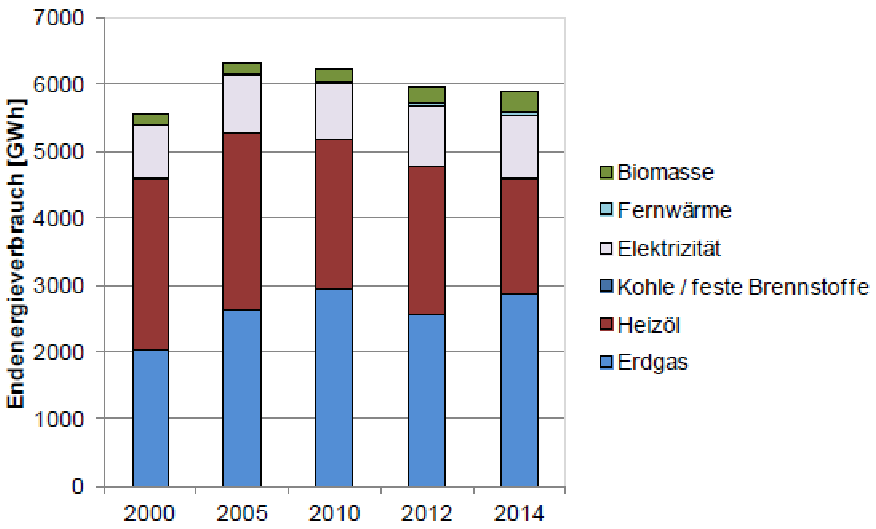


Energieträger	Source of energy
Kohle	Coal
Heizöl	Fuel oil
Erdgas	Natural gas
Strom	Electricity
Fernwärme	District heating
Biomasse	Biomass
Solarthermie	Solar energy
Umweltwärme	Ambient heat
Sektor	Sector
Haushalte	Households
Tertiärer Sektor	Tertiary sector
Industrie	Industry
Anwendungen	End use
Raumwärme	Space heating
Warmwasser	Hot water
Klimatisierung	Air conditioning
Prozesswärme	Process heating
Prozesskälte	Process cooling
Kochen	Cooking
Geräte/IuK	Equipment/IT & telecom.
Beleuchtung	Lighting
Mechanische Energie	Mechanical energy
Differenzierung nach Energiebilanz	Breakdown according to energy balance
Relevant für KWK- und Wärmebedarfsanalyse	Relevant for cogeneration and heating demand analysis

Figure 12: Context: final energy balance and relevant end-use volumes for the heating demand analysis

4.1 Heating and cooling demand in the residential and non-residential buildings sectors

The definition of the heating demand of buildings is derived from the final energy demand for space heating and hot water. In a sectoral breakdown, this can be derived from the energy demand of private households and the tertiary sector. In the industrial sector, however, separation of space and process heating demand is only possible to a limited extent and therefore these are presented together in the following section. Figure 13 shows the changes in the total final energy demand for households. Final energy demand displays a downward trend for the years shown. One of the reasons for this is an increase in building efficiency and an improvement in heating supply technologies. Climatic conditions in the years in question should also be taken into account, as they contribute to changes in final energy demand. The total final energy consumption of private households in 2014 was 5.9 TWh, with only 1.2 % of this coming from local and district heating.

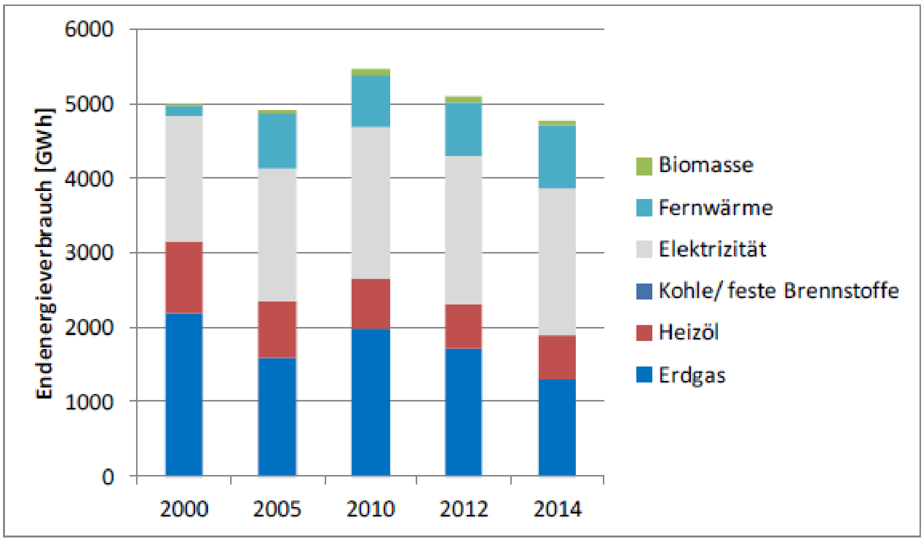


Source: Statec (2015)

Endenergieverbrauch [GWh]	Final energy consumption [GWh]
Biomasse	Biomass
Fernwärme	District heating
Elektrizität	Electricity
Kohle / feste Brennstoffe	Coal/solid fuels
Heizöl	Fuel oil
Erdgas	Natural gas

Figure 13: Changes in the final energy demand of households

At 17.5 %, however, the proportion represented by local and district heating in the tertiary sector is considerably higher (Figure 14). In total, the final energy demand in the tertiary and agricultural sector was 4.8 TWh in 2014, of which approximately 0.8 TWh was provided by local and district heating.

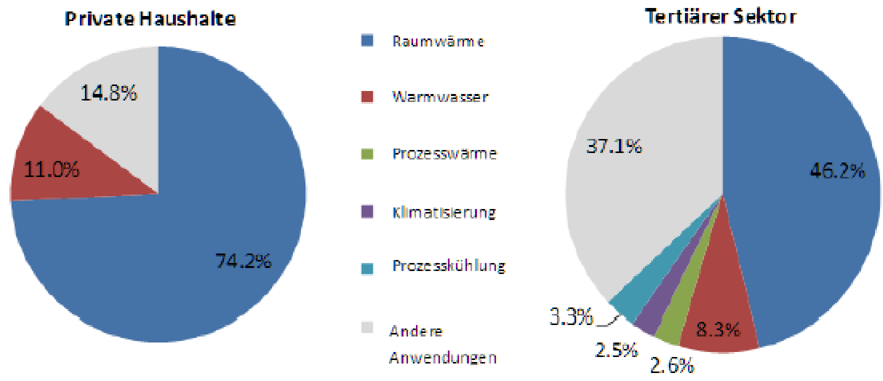


Source: Statec (2015)

Endenergieverbrauch [GWh]	**Final energy consumption [GWh]**
Biomasse	Biomass
Fernwärme	District heating
Elektrizität	Electricity
Kohle / feste Brennstoffe	Coal/solid fuels
Heizöl	Fuel oil
Erdgas	Natural gas

Figure 14: Changes in final energy demand in the tertiary and agricultural sector

A breakdown of the final energy demand by individual areas of end-use that are relevant to the trend in heating demand was carried out in the context of the project ‘Mapping EU heating and cooling supply’ for 2012 for all EU Member States (Fleiter, Steinbach, Ragwitz et al. 2016). It can be seen from the results that around 85 % of the final energy consumption of private households is attributable to the supply of heat (space heating and hot water) (see Figure 15). In the tertiary sector, a considerably lower proportion, at 54.5 %, is attributable to the supply of heat in buildings. In contrast to the industrial sector, the process heating and cooling demand, at around 2.6 %, is less important.

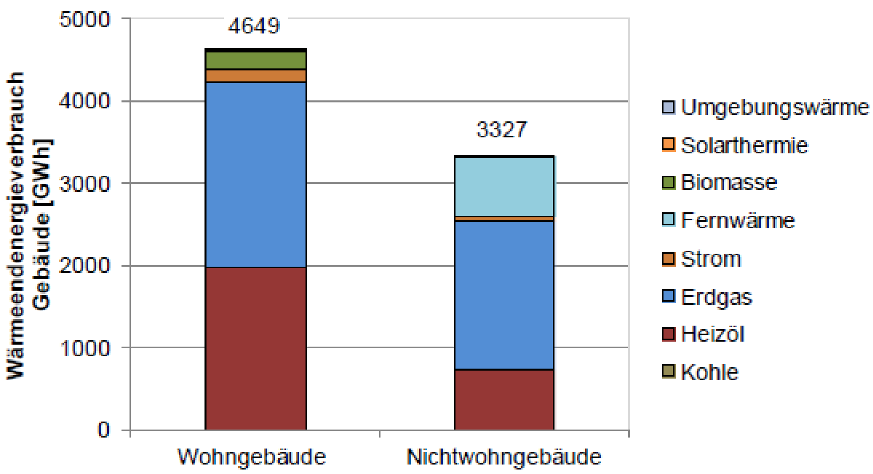


Source: Fleiter, Steinbach, Ragwitz et al. (2016)

Private Haushalte	Private households
Raumwärme	Space heating
Warmwasser	Hot water
Prozesswärme	Process heating
Klimatisierung	Air conditioning
Prozesskühlung	Process cooling
Andere Anwedungen	Other uses
Tertiärer Sektor	Tertiary sector

Figure 15: End-use balance in the heating and cooling sector in Luxembourg in 2012

Figure 16 shows the final thermal energy demand for residential and non-residential buildings (excluding buildings belonging to the industrial sector) in Luxembourg by energy source. This is used as a baseline value for the further modelling of the scenarios relating to the cogeneration potential.



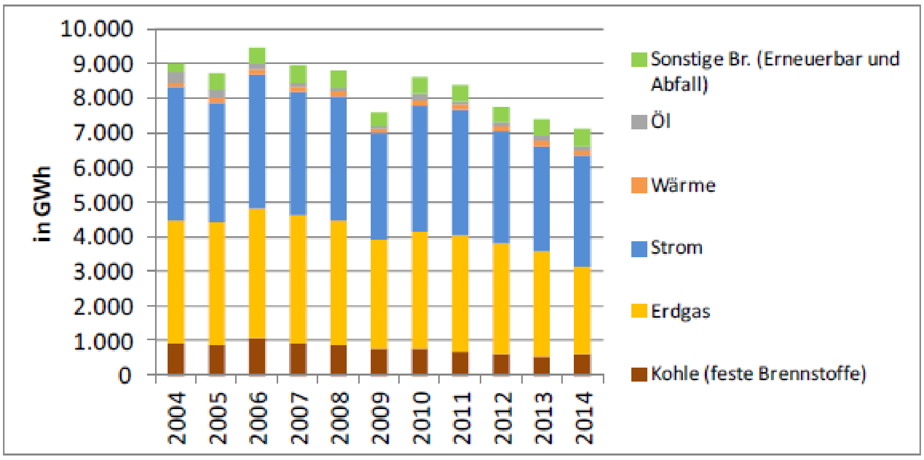
Source: Fleiter, Steinbach, Ragwitz et al. (2016)

Wärmeendenergieverbrauch	**Final thermal energy consumption**
Gebäude [GWh]	**Buildings [GWh]**
Wohngebäude	Residential buildings
Nichtwohngebäude	Non-residential buildings
Umgebungswärme	Ambient heat
Solarthermie	Solar energy
Biomasse	Biomass
Fernwärme	District heating
Strom	Electricity
Erdgas	Natural gas
Heizöl	Fuel oil
Kohle	Coal

Figure 16: Heating demand in residential and non-residential buildings by energy source for 2012

4.2 Heating demand in the industrial sector

The starting point for estimating the heating demand in the industrial sector is the final energy demand in this sector. The final energy demand[2] in the industrial sector in 2014 was 7 119 GWh, making up approximately 15 % of the total final energy demand for Luxembourg (Statec A4100). In the industrial sector it is primarily natural gas and electricity that are used. The proportion of coal products has decreased over the last 14 years and in 2014 made up only around 8 % of the final energy demand. During the economic crisis in 2009 the final energy demand in the industrial sector fell significantly and then briefly stabilised (Figure 17). The final energy demand has been falling continuously since 2010 and in 2013 it fell below the level of 2009.



Source: Energy balance, Statec A4100

in GWh	in GWh
Sonstige Br. (Erneuerbar und Abfall)	Other fuels (renewables and waste)
Öl	Oil
Wärme	Heat
Strom	Electricity
Erdgas	Natural gas
Kohle (feste Brennstoffe)	Coal (solid fuels)

Figure 17: Trend in final energy demand in the industrial sector from 2004-2014

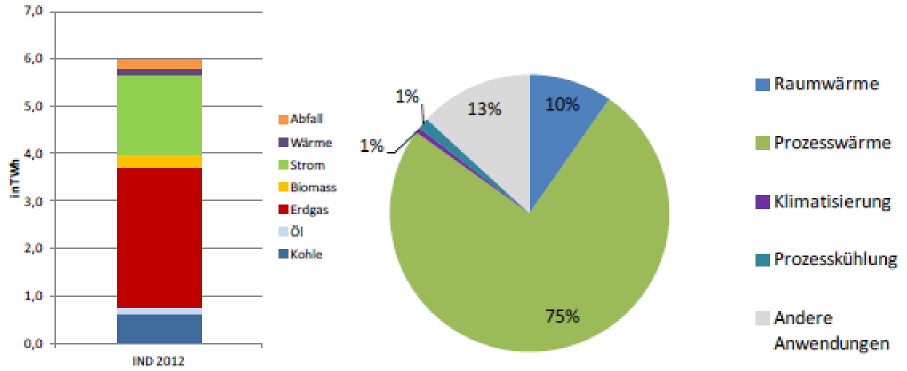
Only a small proportion of the final energy demand is not used for heating applications. This relates in particular to the use of electricity in the industrial sector. An assessment of the types of end use and the fuels used for heating was carried out in the context of the project 'Mapping EU heating and cooling supply' for 2012 for all EU Member States, including Luxembourg (Fleiter, Steinbach, Ragwitz et al. 2016). The end use for the majority of the energy in the industrial sector is process heating. Space heating constitutes approximately 10 % of the final energy demand for industry (see Figure 18).

The final energy demand for industry is therefore almost exclusively used for the supply of heat, apart from a proportion of the electricity demand. The dominant energy source used to cover this fuel-based heating demand is natural gas, at approximately 3 200 GWh. In 2012 approximately 1 700 GWh of electricity were used for the supply of heat, the majority of which was used in the steel industry for process heating in electric arc furnaces. The use of heating from network cogeneration installations was 134 GWh final energy in the industrial sector according to the data in the energy balance.

Following the Third National Energy Efficiency Action Plan for Luxembourg (Ministry of the Economy, 2014), the fuel demand (total final energy demand less the final energy demand for electricity) is used as the basis for calculating the heating demand in the industrial sector and

[2] Excluding the final energy demand quota for transport, which is assigned to the industrial sector.

allocated a primary energy factor of 1. Based on the latest energy balances for industry, this results in a fuel-based heating demand of 3 944 GWh in 2014, around 250 GWh less than in 2012.

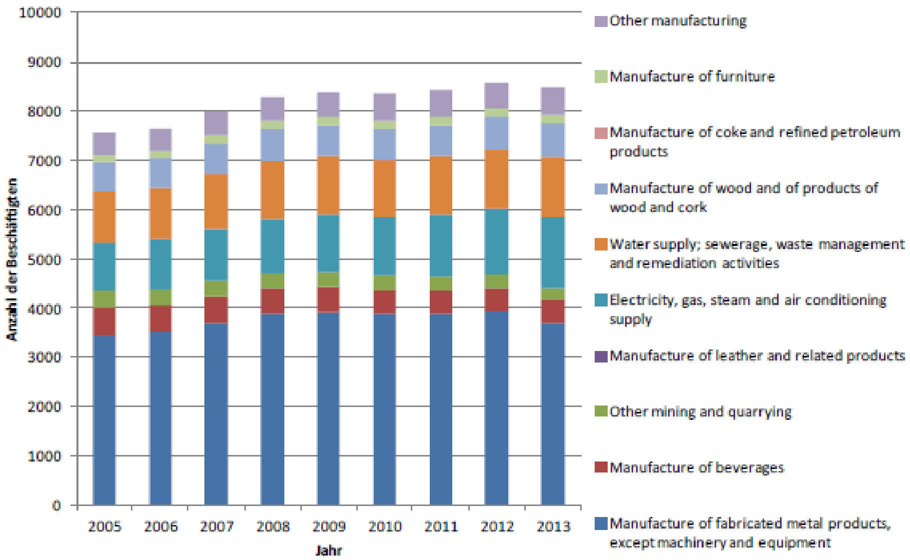


Source: Fleiter, Steinbach, Ragwitz et al. (2016)

IND 2012	IND 2012
in TWh	**in TWh**
Abfall	Waste
Wärme	Heat
Strom	Electricity
Biomass	Biomass
Erdgas	Natural gas
Öl	Oil
Kohle	Coal
Raumwärme	Space heating
Prozesswärme	Process heating
Klimatisierung	Air conditioning
Prozesskühlung	Process cooling
Andere Anwendungen	Other uses

Figure 18: Energy sources and end uses of the heating demand in the industrial sector in 2012

The relevant employment figures for the industrial sector are used as an indicator to estimate the future heating demand in industry. Besides the construction industry, the highest number of workers are employed in the steel and metal industry (see Figure 19). Other important sectors are the food, rubber and plastics industries.



Source: Statec 2013

Anzahl der Beschäftigten	Number of employees
Jahr	Year

Figure 19: Changes in employment figures in the industrial sector from 2005 to 2013

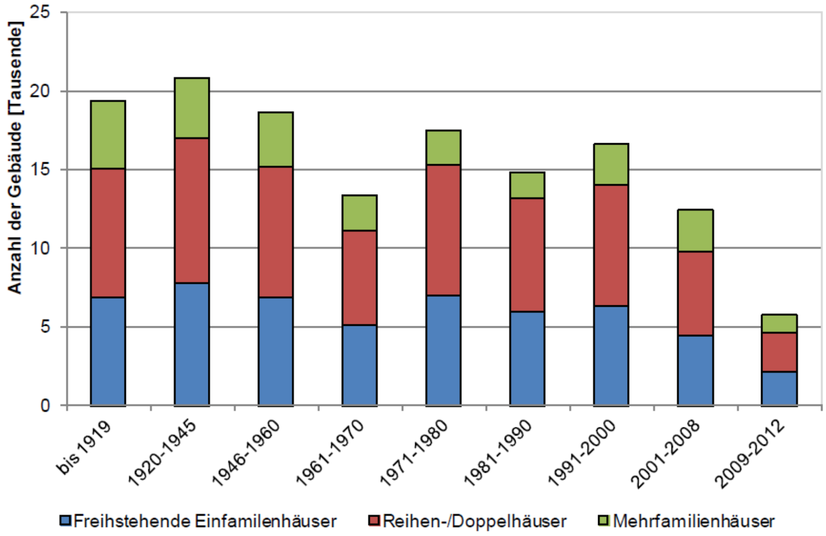
4.3 Description of the building stock in Luxembourg

The potential for the application of cogeneration technologies, both distributed and centralised, in heating networks depends largely on the evolution of the heating demand and heat densities in the building sector. To calculate the potential, therefore, it is essential to map the building stock in as detailed a way as possible at the level of individual buildings as well as in respect of their regional distribution. Table 6 shows the data sources available to enable the creation of a building typology for Luxembourg. A detailed analysis of the building stock and the preparation of a building typology are being carried out within the current ongoing project ‘Szenarien des zukünftigen Energiebedarfs des Gebäudeparks Luxemburgs’ [Scenarios for the future energy demand of Luxembourg’s building stock]. The results were not yet available when this study was prepared.

Table 6: Data sources used to derive the building typology

Data	Differentiation of buildings	Regional resolution	Source
Number of buildings	Types of residential building and age classes	Municipal level	(Statec, 2016a, 2016b, 2011a)
Living area	Types of residential building	Municipal level	(Statec, 2016c)
Heating energy used	Types of residential building	Municipal level	(Statec, 2016d)
Living areas	Types of residential building and age classes	Luxembourg	(Statec, 2011b)
New buildings: number, building volume, area	Types of residential building, types of non-residential building	Luxembourg	(Statec, 2016e)
U values	Building age class	Luxembourg (analogies in some instances)	ENTRANZE / LuxEeB (Atanasiu et al., 2014; Markus Lichtmeß, 2008; Schimschar et al., 2010b; Sebi et al., 2013)
Ground areas, number of buildings	Residential buildings, types of non-residential building with types of use	Geo-referenced building plans	(GeoPortal Luxembourg, 2016)

This is used for modelling the future heating demand as well as to determine the plot ratio. Figure 20 shows the number of residential buildings according to building type and age class aggregated for the whole of Luxembourg. The data are based on the official statistics for residential buildings.



Source: Own calculation based on Statec

Anzahl der Gebäude [Tausende]	**Number of buildings [thousands]**
bis 1919	up to 1919
Freihstehende Einfamilenhäuser	Detached single-family houses
Reihen-/Doppelhäuser	Terraced/semi-detached houses
Mehrfamilienhäuser	Apartment blocks

Figure 20: Number of residential buildings according to building class

As is the case in almost all countries, the data available for residential buildings are better than for non-residential buildings. However, there is a comprehensive breakdown of non-residential buildings as geo-referenced data available with the official building plans held by the land registry, which are made available in connection with the project on the national geoportal of Luxembourg (GeoPortal Luxembourg, 2016). These allow the number and ground areas to be determined, broken down by the different types of non-residential building (see Table 7). To calculate the gross ground areas of the buildings, assumptions were made with regard to the average full storeys, based mainly on Klauß (2010).

Table 7: Non-residential building areas calculated from land registry data

Buildings	Ground area [1 000 m²]*	Number of buildings	Number of full storeys**	Floor area [1 000 m²]
Industrial and commercial buildings	7 038	4 722	1.0	7 038
Agricultural buildings	4 557	7 238	1.6	7 092
Trade and retail buildings	1 613	1 217	1.0	1 613
Educational buildings (schools, universities, etc.)	993	810	2.5	2 482
Offices and administration buildings	537	694	4.5	2 406
Public buildings	518	1 336	4.5	2 332
Sports facilities	435	212	1.0	435
Hospitals/buildings belonging to the healthcare sector	338	422	4.5	1 522
Church and sacred buildings	204	824	1.0	204
Event buildings	194	264	1.5	291
Collective living quarters	175	451	3.0	525
Other buildings	80	244	3.0	241
Buildings of the public emergency services	73	164	2.0	146
Cultural buildings	52	89	4.5	233
Not thermally conditioned	*1 015*	*20 131*		

Source: *Geoportal Luxembourg (2016) *Auswertung Katasterdaten BD-L-TC* [Evaluation of land registry data]; **Own assumptions based on (Klauß, 2010)

In addition to the building areas and types of use, heating demand is determined to a significant extent by the quality of the building envelope. In the model, the building components were described using specific heat transfer coefficients (U values) (see Table 8). For this purpose we referred to the ENTRANZE database, which contains typical U values for individual components for different age classes of buildings in the individual EU Member States (www.entranze.eu). For the more recent building stock built since 2008 reference can be made to the relevant requirements of the Heat Insulation Ordinance and the Energy Saving Ordinance, in which typical U values for the building components can be found.

Table 8: U values for building components of residential buildings since 1995

Ordinance/efficiency class	Year of construction	Wall	Roof	Floor	Windows
WSV95 [Heat Insulation Ordinance]	1995-2007	0.40	0.30	0.50	2.00
LuxEeB Class D	2008-2012	0.32	0.25	0.40	1.50
LuxEeB Class C	2012-2014	0.26	0.23	0.36	1.25
LuxEeB Class B	2015-2016	0.19	0.14	0.24	1.00
LuxEeB Class A	From 2017	0.13	0.11	0.17	0.90
Renovation		0.32	0.25	0.40	1.50

Source: based on (Markus Lichtmeß and Knissel, 2014; Markus Lichtmeß, 2008; Schimschar et al., 2010a)

4.4 Determining the plot ratio per municipality

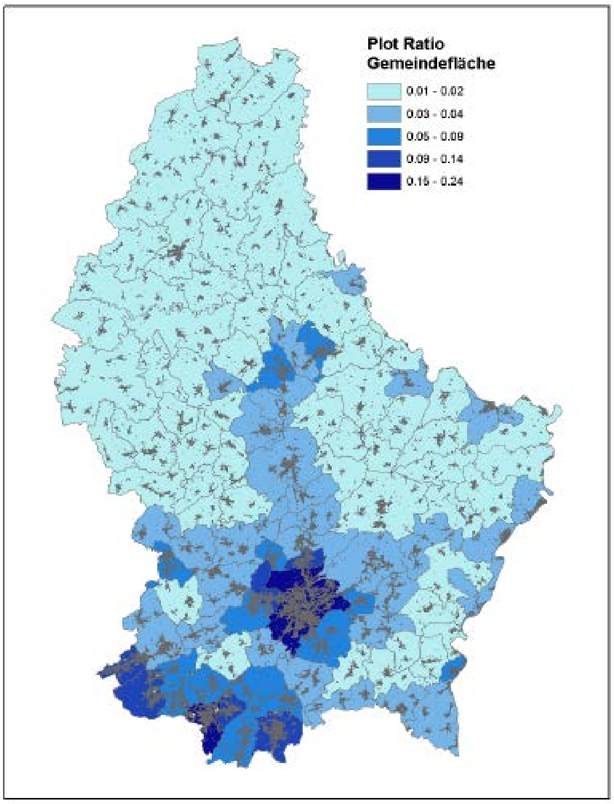
In accordance with the Directive on energy efficiency (Annex VIII), assessment of the national heating and cooling potential for heating network-based supply and the use of cogeneration should identify ‘heating and cooling demand points’. These include municipalities with a plot ratio of at least 0.3. The plot ratio is defined as follows:

$$\frac{Building\ floor\ area}{Land\ area} > 0.3$$

The building floor area comprises the external dimensions of the building in all full storeys (Section 20 BauNVO [Land Use Ordinance]). In this regard, the concept of full storey, which distinguishes the floor area from gross ground area in accordance with DIN 277, is important. This includes the ground areas of all storeys. From this systematic point of view, however, the ratio of living area to floor area can be estimated approximately using the typical conversion factors between living and gross ground area. The floor areas are determined with the aid of the data presented and analyses for the individual municipalities.

For residential buildings, they are determined using the specific living areas per municipality and building type recorded by STATEC. To convert living area to floor area, a factor of 1.6 is applied for single-family houses and 1.7 for apartment blocks. The floor area of non-residential buildings is calculated from the ground area, which is determined by analysing the GIS data, and the assumptions regarding the specific number of full storeys (see Table 7). Whereas the ground areas are therefore available per municipality, the specific number of full storeys is not broken down by municipality, although it is broken down by type of non-residential building. As reference area for the municipality (land area in the municipality), the municipal area can be used. However, this also includes a large proportion of areas that are not residential, industrial or built-up areas, such as woodland and agricultural land.

The assessment shows that, using the selected figures, the plot ratio is not above 0.24 in any municipality. The highest values are obtained for the municipalities of Luxembourg and Esch-sur-Alzette in the south (see Figure 21).



Source: Own calculation based on GeoPortal Luxembourg (2016)

Plot Ratio	Plot ratio
Gemeindefläche	Municipal area

Figure 21: Results for the plot ratio using municipal area as the reference area

5 Assessment of the potential for distributed cogeneration installations in buildings

5.1 Evolution of the heating demand in buildings up to 2030

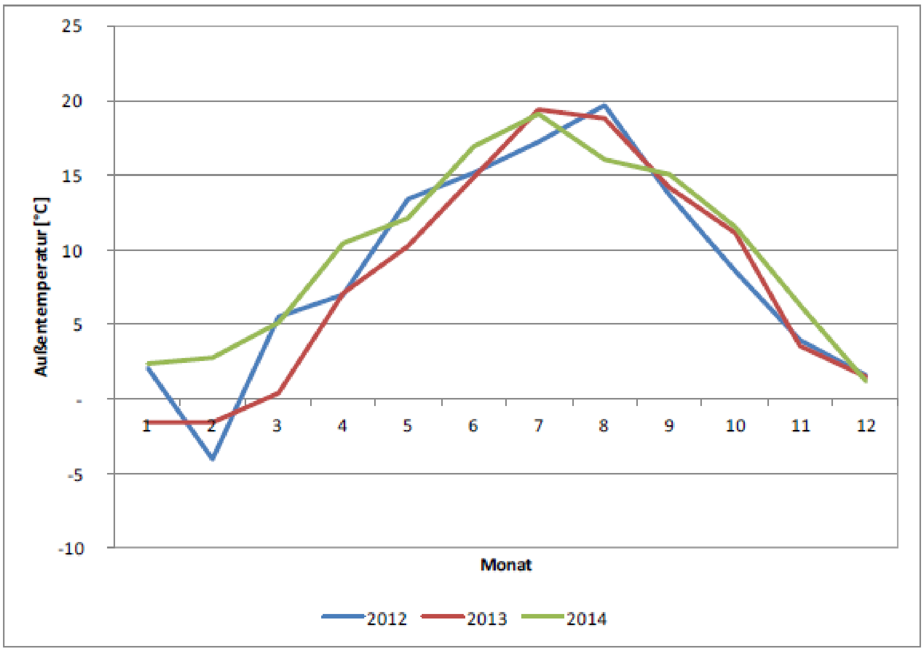
The economic potential for the use of cogeneration installations and heating network-based suppliers depends largely on changes in renovation activities in the building sector and thus the changes in heating demand. Future changes in useful and final energy demand are calculated using the bottom-up simulation model Invert/EE-Lab. The basis for the calculation is the representation of the building stock by reference buildings. The base year used for the simulation is 2012, to which the energy demand in the building sector is calibrated (see 4.1). The simulation period for the scenario is from 2013 to 2030. See the annex for a detailed description of the model.

Changes in heating demand are dependent on the following parameters in particular:

- Climatic influences – changes in average temperatures
- Changes in the rate of construction of new buildings
- Changes in the rate of energy efficiency renovation (how often renovations are carried out)
- Implementation of the deep renovation measures (to what standard the renovation work is carried out)

Whereas the first two points are exogenously determined for the simulation, changes in renovation rates and depths represent output of the model.

Figure 22 shows the average monthly temperatures for 2012 to 2016. For the simulation period up to 2030 a reference climate based on the outdoor temperatures for 2012 is used.



Außentemperatur [°C]	Outdoor temperature [°C]
Monat	Month

Figure 22: Average monthly temperatures for Luxembourg

In addition to the reference climate, future building activity is an important external factor for the scenario. For the model, changes in building stock are exogenously determined and the model calculates endogenously depending on the age of the buildings, the new construction rate and the demolition rate. Changes in building stock are estimated in accordance with the assumptions in the Third National Energy Efficiency Action Plan for Luxembourg (Ministry for the Economy, 2014). This assumes a mean annual new construction rate of 3 % with a demolition rate of 0.85 % for residential buildings and a 2 % new construction rate for non-residential buildings up to 2020. This, from a European perspective, comparatively very high new construction rate continues the current trend of a high level of construction and population growth in Luxembourg up to 2020. There is a distribution function provided in the model which determines the annual new construction and demolition rate based on the stored building stock data, in particular the ages of the buildings and the exogenous specification of general changes in building numbers and useful areas. The model gives a somewhat lower demolition rate, meaning that the mean new construction rate over the period up to 2030 is also slightly lower (see Table 9).

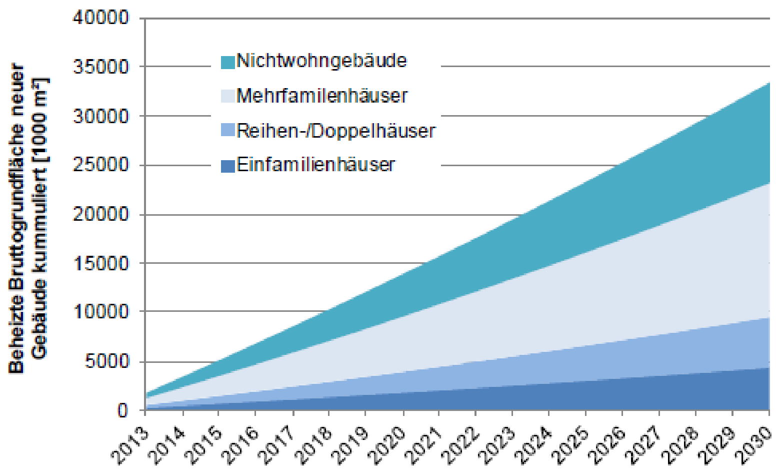
Table 9: Mean new construction and demolition rates over the scenario period

Buildings	Mean construction rate/a 2013 to 2030	Mean demolition rate/a 2013 to 2030
Single-family buildings	2.5 %	0.5 %
Terraced/semi-detached houses	2.5 %	0.5 %
Apartment blocks	2.7 %	0.67 %
Non-residential buildings*	1.7 %	0.82 %

*Excluding churches and cultural buildings

Source: Own calculation

Figure 23 shows the resulting change in new building areas from 2013 onwards. The additional gross ground area to be heated as a result of newly constructed buildings during the period from 2013 to 2030 corresponds to 33.4 million square metres. The total heated gross ground area of the building stock will be 85.1 million square metres in 2030.

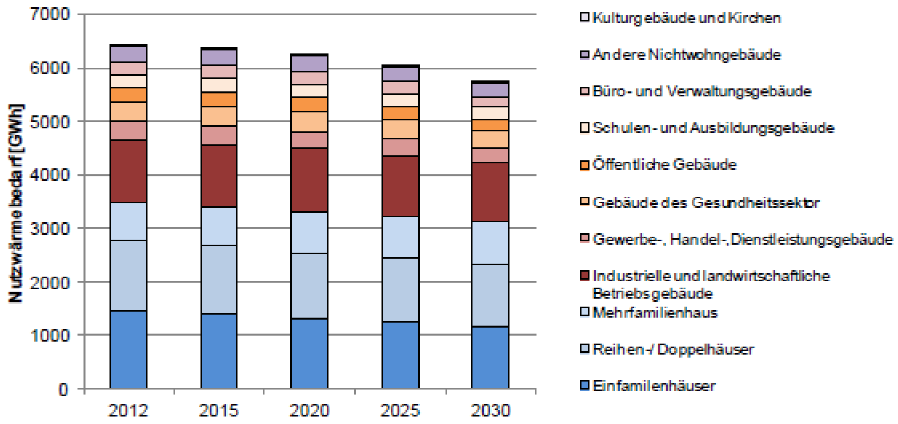


Source: Own calculation

Beheizte Bruttogrundfläche neuer Gebäude kummuliert [1 000 m^2]	Cumulative heated gross ground area of new buildings [1 000 m^2]
Nichtwohngebäude	Non-residential buildings
Mehrfamilenhäuser	Apartment blocks
Reihen-/Doppelhäuser	Terraced/semi-detached houses
Einfamilienhäuser	Single-family houses

Figure 23: Cumulative gross ground area of new buildings up to 2030

Figure 24 shows the results of the model simulation for changes in useful energy demand for space heating and hot water up to 2030 for the whole of Luxembourg. The useful heat demand falls by 10.7 % compared with the level in 2012 to 5 768 GWh in 2030. The mean energy-related renovation rate over the scenario period is 1.3 % per year.

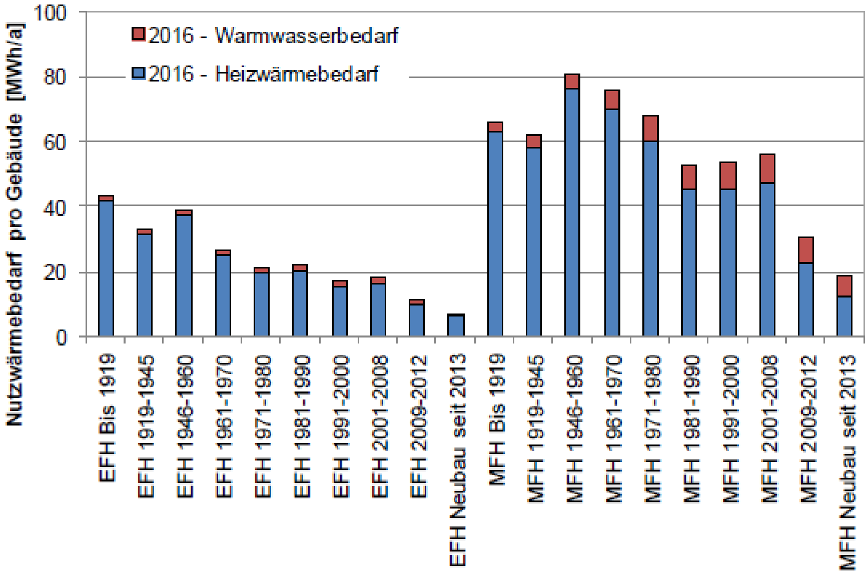


Source: Own calculation

Nutzwärmebedarf [GWh]	Useful heat demand [GWh]
Kulturgebäude und Kirchen	Cultural buildings and churches
Andere Nichtwohngebäude	Other non-residential buildings
Büro- und Verwaltungsgebäude	Offices and administration buildings
Schulen-und Ausbildungsgebäude	Schools and educational buildings
Öffentliche Gebäude	Public buildings
Gebäude des Gesundheitssektor	Buildings belonging to the healthcare sector
Gewerbe-, Handel-, Dienstleistungsgebäude	Commercial, trade and service buildings
Industrielle und landwirtschaftliche Betriebsgebäude	Industrial and agricultural buildings
Mehrfamilienhaus	Apartment blocks
Reihen-/ Doppelhäuser	Terraced/semi-detached houses
Einfamilenhäuser	Single-family houses

Figure 24: Changes in useful heat demand up to 2030

The potential for the use of high-efficiency cogeneration installations is determined on the basis of the simulation output. For cogeneration in distributed supply for individual buildings (see 5.2), the particular specific heating demand at the level of individual buildings is relevant as well as the changes in renovation activities, which reduce the potential on account of decreasing heating demands. Figure 25 shows the annual heating demand for reference single-family houses and apartment blocks for 2016.



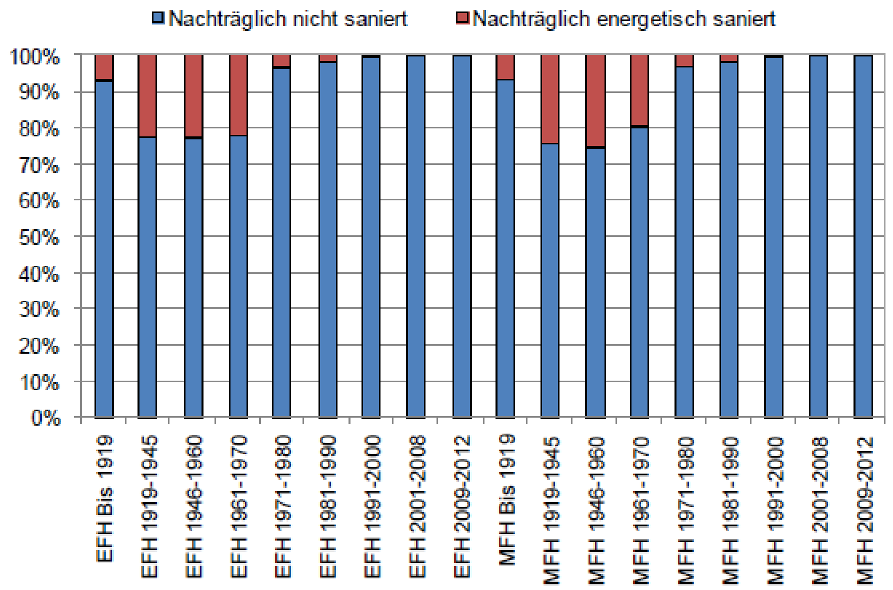
Source: Own calculation using Invert/EE-LAB

EFH Bis 1919	Single-family houses up to 1919
EFH Neubau seit 2013	Single-family house new-builds since 2013
MFH Bis 1919	Apartment blocks up to 1919
MFH Neubau seit 2013	Apartment block new-builds since 2013
Nutzwärmebedarf pro Gebäude [MWh/a]	Useful heat demand per building [MWh/a]
2016 - Warmwasserbedarf	2016 – hot water demand
2016 - Heizwärmebedarf	2016 – heating demand

Figure 25: Average useful heat demand of the reference residential building classes in 2016

Figure 26 shows the simulation output relating to the percentage of buildings in the respective building classes subsequently renovated during the simulation period up to 2030. During the period 2012 to 2030 renovations are carried out in particular in the age classes 1945 to 1970. Older buildings, on the other hand, are more likely to be demolished or subsequent renovation was already carried out before 2012 in a previous cycle.

For assessment of the economic efficiency of cogeneration in supply via the heat network, however, heat densities broken down by region are important. For this purpose, a high-resolution analysis of the simulation output was performed using a GIS model and the available GIS data for the building stock (see also Section 7).



EFH Bis 1919	Single-family houses up to 1919
MFH Bis 1919	Apartment blocks up to 1919
Nachträglich nicht saniert	Not subsequently renovated
Nachträglich energetisch saniert	Subsequently renovated for energy efficiency

Figure 26: Percentage of residential buildings subsequently renovated during the simulation period 2012 to 2030

5.2 Economic potential of distributed cogeneration installations in residential buildings

The use of distributed cogeneration technology for the supply of single residential buildings is in the lower capacity ranges below 500 kW of electrical power. The installations are subdivided according to size class and operational purpose into micro, mini and small cogeneration units (see Table 10). Distributed cogeneration installations in the residential building sector are usually designed to be heat led. From a microeconomic perspective, an effort should be made to maximise operating hours and use as much of the self-generated electricity as possible. The cogeneration installation is not therefore set up for the maximum heat load of the building in question. This makes it necessary to install a peak-load boiler. In the smaller capacity range for use in single and two-family houses, micro cogeneration units are sold as full-featured heating systems with integrated peak-load boiler. In the mid capacity range, the existing boiler often continues to be used as a peak-load boiler after installation of a cogeneration unit.

Table 10: Classification of single building cogeneration installations for distributed supply

Classification	Areas of application	Capacity range
Micro cogeneration units	Single-family houses	< 2 kW_{el}
Mini cogeneration units	Apartment blocks	2-50 kW_{el}
Small cogeneration units/CHP	Industrial sector, large building complexes	50 kW_{el} - 2 MW_{el}

Source: Own illustration (BDH, 2013)

Various technologies are used in the single building supply of residential buildings (see Table 11). Cogeneration installations based on combustion engines represent the most popular technology. In the micro cogeneration unit sector, stirling engines have been on the market for a few years and recently also fuel cell heating systems.

Table 11: Cogeneration technologies used in the distributed supply of residential buildings

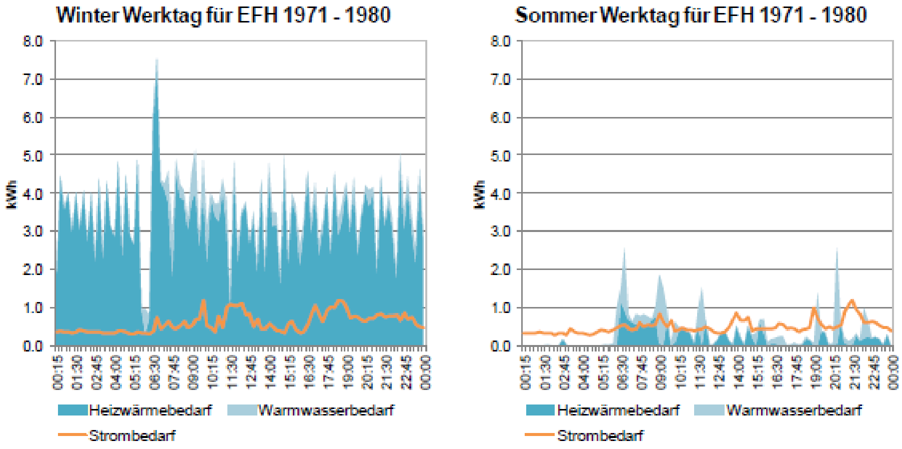
Technology	**Combustion engine**	**Stirling engine**	**Fuel cells**
Overall efficiency	< 90 %	< 85 %	< 90 %
Electrical power efficiency	28-44 %	10-30 %	30-47 %
Partial load behaviour	+	O	+++
Fuel	Natural gas, fuel oil, vegetable oil	Natural gas, biomass	Natural gas
Maturity of the market	Tried and tested	New	First commercial units available

Source: (Suttor, 2009)

5.2.1 Design of distributed cogeneration installations

The economic efficiency of distributed cogeneration installations is determined for the example reference buildings from the building typology established for Luxembourg (see Figure 25). For each reference building an optimum design for the distributed cogeneration installations is determined using hourly electricity and heat profiles. In the model calculations for single-family houses maximising the consumption of own electricity is assumed, whereas for apartment blocks the model is set to maximise the total quantity of electricity. Use of the electricity generated from cogeneration in apartment blocks is possible either by selling the generated electricity to the tenants or by the various tenants forming a common utilisation association. Due to the complexity of this, however, there are obstacles associated with the corresponding transaction costs for the building owners and users. In the economic efficiency calculation, the versions for apartment blocks with single grid feed-in as well as with proportional use of own electricity are taken into account.

Included in the calculation is the high-resolution time-related information on heating and electricity demand determined using the heating and electricity profiles in standard VDI-4655, which enables energy demand to be broken down by time of day for different typical days. The daily load profiles are also differentiated according to the criteria of season: summer's day, winter's day or transitional day, working day or holiday, and meteorological cloud coverage: bright or overcast. Figure 27 compares the heating and electricity daily profiles for the winter and summer working days by way of example for the single-family reference building in the age class 1971-1980. When designing the cogeneration installation efforts should be made to achieve as long an operating period as possible so that it is designed to provide the base heat load. For economic efficiency in optimising captive electricity, the concurrence of electricity demand and heating demand is also important.



Source: Own calculation based on VDI-4655 (2008)

Winter Werktag für EFH 1971 - 1980	Winter work day for Single-family houses 1971-1980
Sommer Werktag für EFH 1971 - 1980	Summer work day for Single-family houses 1971-1980
kWh	kWh
Heizwärmebedarf	Heating demand
Warmwasserbedarf	Hot water demand
Strombedarf	Electricity demand

Figure 27: Comparison of the heating and electricity profiles on typical summer and winter work days for single-family house reference buildings in the age class 1971-1980

Table 12 shows the results for the optimum design of the individual reference buildings. The proportion of the heating demand covered by distributed cogeneration installations in the buildings is between 24 % and 58 %. The remaining heating demand and the balance of the heat load must be covered via a peak-load boiler that is taken into account in the calculation of economic efficiency.

Table 12: Design of distributed cogeneration installations for individual reference buildings

Buildings	Heat load	Cogeneration installation design		Heating demand	Cogeneration operation	Electricity generation Own consumption	
	[kW_{th}]	[kW_{th}]	[kW_{el}]	[%]	[h/a]	[kWh/a]	[%]
Single-family houses up to 1919	25	9	3	58 %	2 723	8 169	28 %
Single-family houses 1919-1945	20	2.5	1	24 %	3 237	3 237	64 %
Single-family houses 1946-1960	24	9	3	57 %	2 534	7 603	28 %
Single-family houses 1961-1970	16	2.5	1	31 %	3 237	3 237	64 %
Single-family houses 1971-1980	12	2.5	1	40 %	3 113	3 113	64 %
Single-family houses 1981-1990	13	2.5	1	38 %	3 113	3 113	64 %
Single-family houses 1991-2000	10	2.5	1	46 %	2 858	2 858	65 %
Single-family houses 2001-2008	10	2.5	1	44 %	2 858	2 858	65 %
Single-family houses 2009-2012	10	2.5	1	49 %	1 877	1 877	64 %
New single-family houses from 2013 onwards	10	2.5	0.3	51 %	1 263	1 263	66 %
Apartment blocks up to 1919	38	12.5	6	35 %	1 821	10 014	19 %*
Apartment blocks 1919-1945	37	12.5	6	36 %	1 821	10 014	23 %*
Apartment blocks 1946-1960	48	12.5	6	44 %	2 908	15 993	25 %*
Apartment blocks 1961-1970	42	12.5	6	42 %	2 497	13 735	35 %*
Apartment blocks 1971-1980	35	12.5	6	36 %	1 723	9 475	47 %*
Apartment blocks 1981-1990	27	2.5	1	37 %	6 690	6 690	100 %*
Apartment blocks 1991-2000	28	2.5	1	37 %	6 715	6 715	100 %*
Apartment blocks 2001-2008	30	9	3	44 %	2 326	6 977	78 %*
Apartment blocks 2009-2012	18	2.5	1	58 %	5 223	5 223	100 %*
New apartment blocks from 2013 onwards	14	2.5	1	57 %	2 833	2 833	100 %*

*Where use of own electricity is possible through the corresponding formation of a distribution or utilisation association

5.2.2 Economic efficiency compared with alternative heating supply options

In this section we compare the heating supply costs of various distributed heating supply options in order to assess the economic efficiency of the cogeneration installations in the different reference buildings. The following heating supply systems are compared in the analysis:

- Mini cogeneration unit with natural gas combustion engine and peak-load boiler
- Natural gas condensing boiler
- Wood pellet boiler
- Brine-water heat pump
- Air-water heat pump

For a comprehensive comparison of different heating supply options from the point of view of economic efficiency, see Lichtmeß and Viktor (2014).

The heating supply costs include capital-linked, operating and consumption-linked costs.

The calculation of heating supply costs includes the following cost components (VDI 2067-1, 2000):

- Capital-linked costs
- Consumption-linked costs
- Operating and other costs
    - Maintenance and repair
    - Chimney sweeps

Table 13 provides an overview of the economic conditions. In the calculation a uniform interest rate of 4 %[3] is applied for the capital-linked costs from the annual repayments on the investments. For the consumption-linked costs, future changes in energy costs are taken into account by means of an assumed rise in energy prices in accordance with Figure 10, also based on the annual repayments method.

Table 13: Economic conditions for the economic efficiency calculation

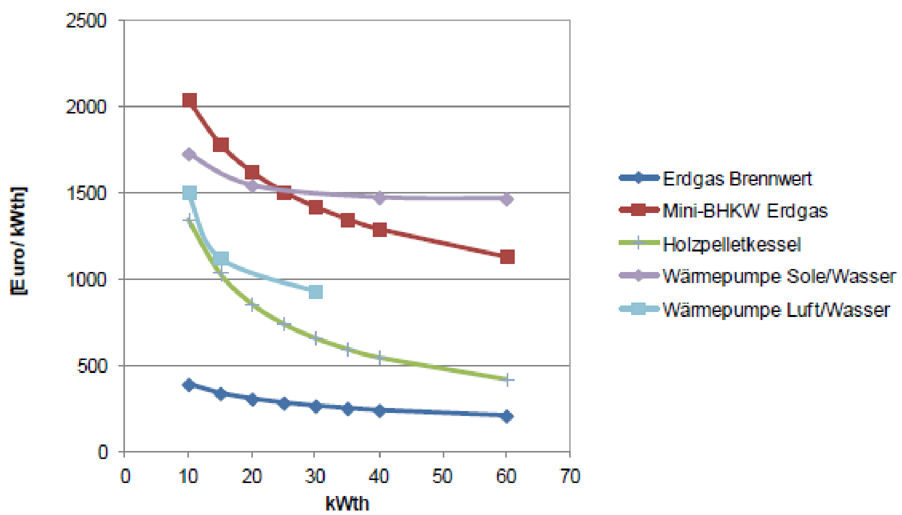
Conditions for economic efficiency calculation	
Duration of use of distributed cogeneration installation	15 years
Duration of use of other heat generators	20 years
Interest rate	4 %
Energy prices incl. price increase included in the calculation	
Natural gas	5.74 [euro cents/kWh]
Wood pellets	5.29 [euro cents/kWh]
Electricity – households	18.41 [euro cents/kWh]
Electricity – wholesale (cogeneration network feed-in)	4.42 [euro cents/kWh]
Operating costs	
Maintenance/repair of cogen. install. smaller than 9 KW_{th}	15 [euro cents/hour][4]
Maintenance and repair larger than 9 kW_{th}	41 [euro cents/hour][4]
Maintenance and repair of other heat generators	2 % investments/a

*Heat pumps, including exploitation of heat source
Source: (Dengler et al., 2011; Hofmann et al., 2011; sirAdos, 2016)

Figure 28 shows the specific investments per kilowatt of installed thermal capacity for the various heating supply systems. For the distributed cogeneration installations, investments for a natural gas condensing boiler to cover the peak load according to the design described are also taken into account. The economic efficiency of the system is determined by comparing it with the non-combined fossil fuel-based heating supply with a condensing boiler.

[3] This corresponds to the standard discount rate applied in the cost optimisation calculation for Luxembourg (see Lichtmeß and Viktor, 2014).

[4] Full maintenance contract according to manufacturer's specifications. Reference values are the operating hours.

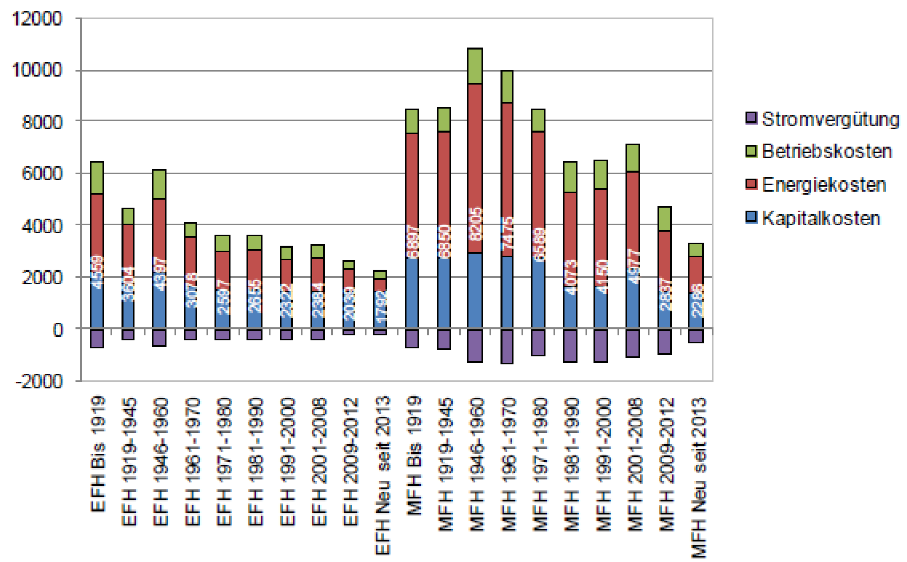


*Heat pumps, including exploitation of heat source
Source: (Dengler et al., 2011; Hofmann et al., 2011; sirAdos, 2016)

[Euro/kWth]	[Euro/kW$_{th}$]
kWth	kW$_{th}$
Erdgas Brennwert	Natural gas calorific value
Mini-BHKW Erdgas	Mini CHP natural gas
Holzpelletkessel	Wood pellet boiler
Wärmepumpe Sole/Wasser	Brine-water heat pump
Wärmepumpe Luft/Wasser	Air-water heat pump

Figure 28: Specific investment costs for common heating supply systems

The resulting annual costs for the supply of heating by distributed cogeneration systems broken down by the different cost types are shown in Figure 29 for the individual reference buildings.

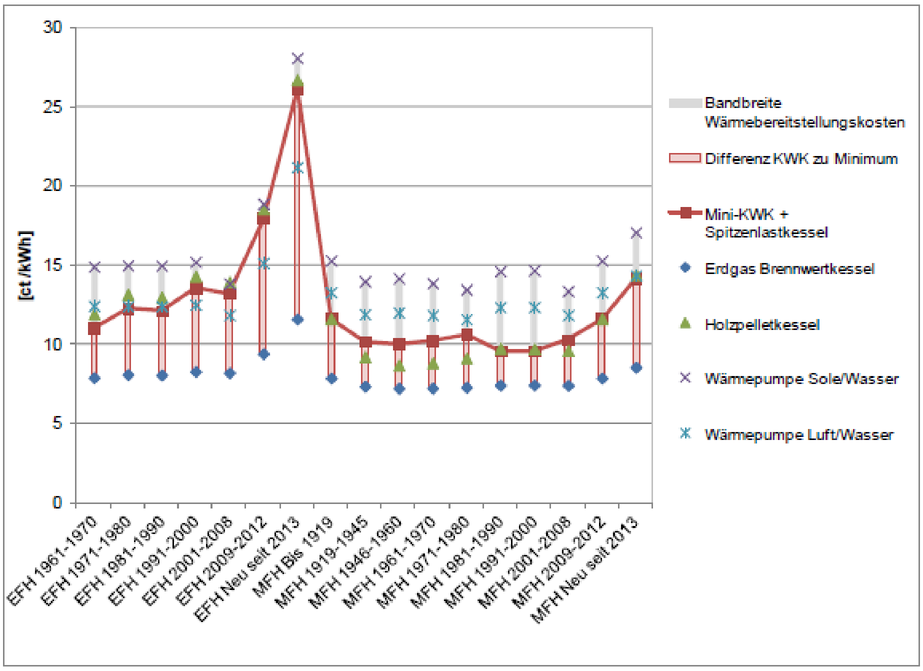


EFH Bis 1919	Single-family houses up to 1919
EFH Neu seit 2013	New single-family houses since 2013
MFH Bis 1919	Apartment blocks up to 1919
MFH Neu seit 2013	New apartment blocks since 2013
Stromvergütung	Electricity remuneration
Betriebskosten	Operating costs
Energiekosten	Energy costs
Kapitalkosten	Capital costs

Figure 29: Annual costs for the supply of heating from distributed cogeneration systems

The calculation is carried out for all comparison technologies, showing economic efficiency using the specific heating supply costs with regard to the annual useful heat demand in the individual buildings. The following figures summarise the results of the analysis, which does not take into account any financial support for renewable heating supply.

Figure 30 assumes that the use of own electricity in apartment blocks is not possible for the reasons mentioned. It appears that the natural gas condensing boiler represents the most economically efficient option in all of the reference building variants examined[5]. For single-family houses built before the first Heat Insulation Ordinance and for apartment blocks built after 1980, the heating supply costs from distributed cogeneration installations are at approximately the same level as the most favourable renewable energy heating supply system at any one time. The specific additional costs of the cogeneration systems compared with natural gas condensing boilers are between 2.2 euro cents/kWh and 14.6 euro cents/kWh.

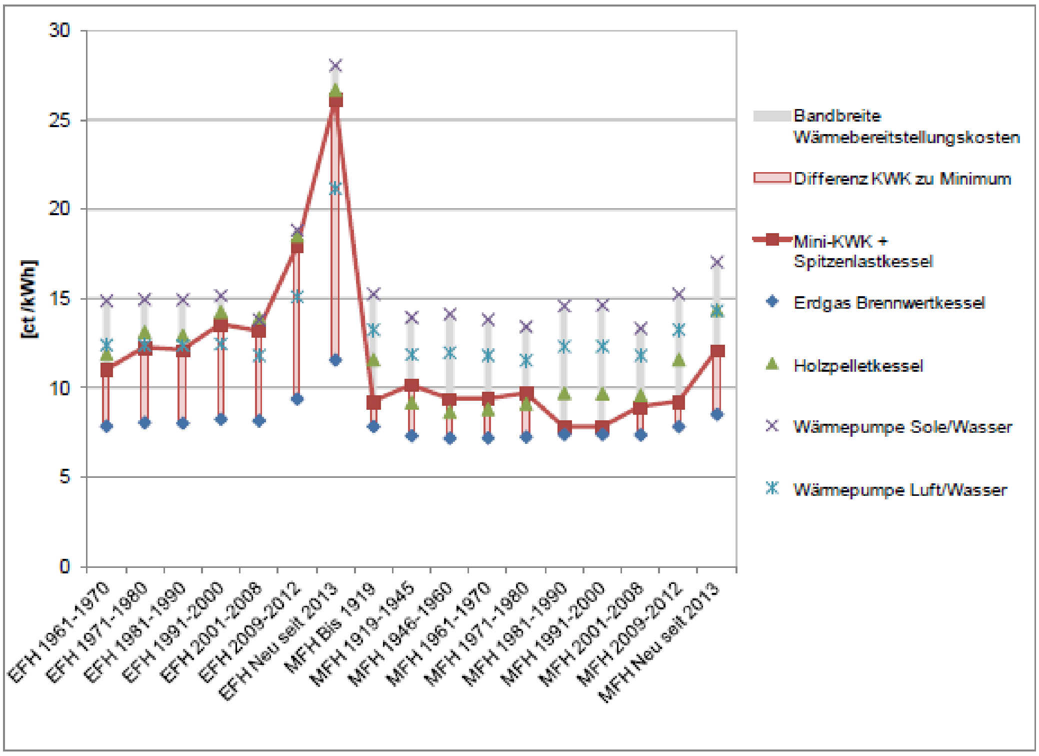


EFH Neu seit 2013	New single-family houses since 2013
MFH Bis 1919	Apartment blocks up to 1919
MFH Neu seit 2013	New apartment blocks since 2013
[ct /kWh]	**[euro cents/kWh]**
Bandbreite Wärmebereitstellungskosten	Range of heating supply costs
Differenz KWK zu Minimum	Difference between cogeneration and minimum
Mini-KWK + Spitzenlastkessel	Mini cogeneration unit + peak-load boiler
Erdgas Brennwertkessel	Natural gas condensing boiler
Holzpelletkessel	Wood pellet boiler
Wärmepumpe Sole/Wasser	Brine-water heat pump
Wärmepumpe Luft/Wasser	Air-water heat pump

Figure 30: Specific heating supply costs and economic efficiency of supply from distributed cogeneration with no use of own electricity in apartment blocks

[5] The primary energy requirements of the Energy Saving Ordinance for new buildings are not taken into account in the calculation. This means that in the new-build variants, use of the natural gas condensing boiler without the additional use of renewable energies (e.g. solar heat or PV) is either not possible on account of the requirement or cannot be represented in terms of economic efficiency due to a higher energy efficiency requirement applying to the building envelope.

If own electricity use is also possible in apartment blocks the economic efficiency increases as it avoids the purchase of electricity valued at the domestic price, which is four times higher than the wholesale electricity price, which is obtained when feeding in to the grid (Figure 31). In this context, average electricity prices over the service life of the equipment were factored in, also taking into account the expected changes in electricity prices in the future (see also section 3). Economic potential is shown by apartment blocks in the age classes from 1981 to 2000, for which the additional costs compared with the natural gas condensing boiler option are less than 1 euro cent/kWh.



EFH Neu seit 2013	New single-family houses since 2013
MFH Bis 1919	Apartment blocks up to 1919
MFH Neu seit 2013	New apartment blocks since 2013
[ct/kWh]	**[euro cents/kWh]**
Bandbreite Wärmebereitstellungskosten	Range of heating supply costs
Differenz KWK zu Minimum	Difference between cogeneration and minimum
Mini-KWK + Spitzenlastkessel	Mini cogeneration unit + peak-load boiler
Erdgas Brennwertkessel	Natural gas condensing boiler
Holzpelletkessel	Wood pellet boiler
Wärmepumpe Sole/Wasser	Brine-water heat pump
Wärmepumpe Luft/Wasser	Air-water heat pump

Figure 31: Specific heating supply costs and economic efficiency of supply from distributed cogeneration with use of own electricity in apartment blocks

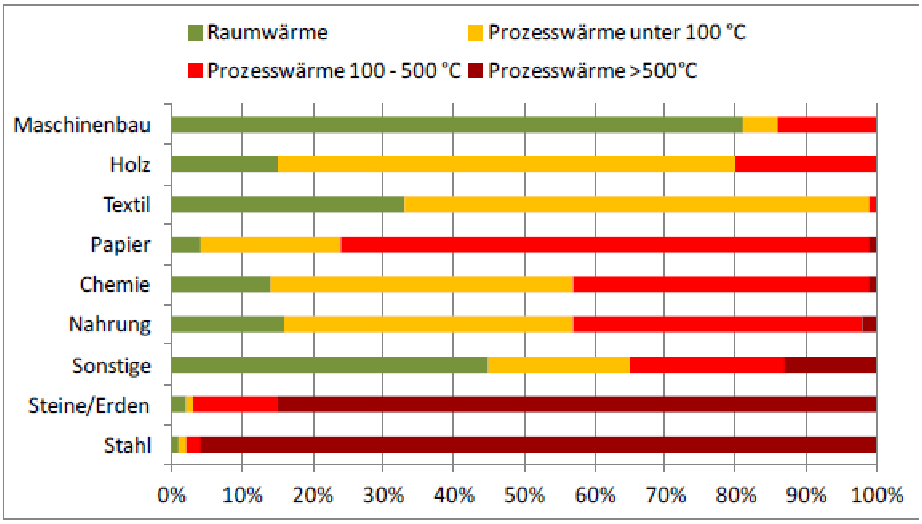
6 Assessment of the potential for cogeneration in industry

6.1 Changes in heating demand in industry up to 2030

The forecast of the final energy demand in industry is based on the estimations in the Third National Energy Efficiency Action Plan for Luxembourg (Ministry of the Economy, 2014), in which changes in added value as well as energy efficiency are derived for the individual industrial sectors. Added value in the industrial sectors and in industrial production is shown as displaying an increase of 0.5 %/a. Exceptions are the steel sector and the glass industry, for which no increase in added value (steel industry) or decrease (glass industry) is assumed. During the economic crisis in 2009, added value in the industrial sector fell dramatically and has remained at this lower level ever since. Some sectors, such as the chemical and pharmaceuticals industries, have increased again since then, however, but in other sectors, such as the steel or glass industry, added value has continued to decrease.

Energy demand is forecast on the basis of energy intensity in relation to the added value of the sectors, although this energy demand will be reduced by an increase in energy efficiency in the individual sectors. For the energy-intensive sectors, the baseline forecast includes autonomous improvement in annual energy efficiency of 0.5 %/a and for the other sectors an improvement of 0.2 %/a. With more ambitious energy efficiency requirements, a higher increase in efficiency of 1.7 %/a is expected by 2020, which could be implemented by means of a voluntary agreement with industry.

As already shown in Section 4, the fuel input in industry is used almost exclusively for the supply of heat. Cogeneration installations can provide heat up to a temperature level of approximately 500 °C. Therefore, the heating demand for high-temperature applications should not be taken into account in the assessment of the potential for cogeneration in industry. This high-temperature heating demand is found in the steel and glass industries in particular (see Figure 32).



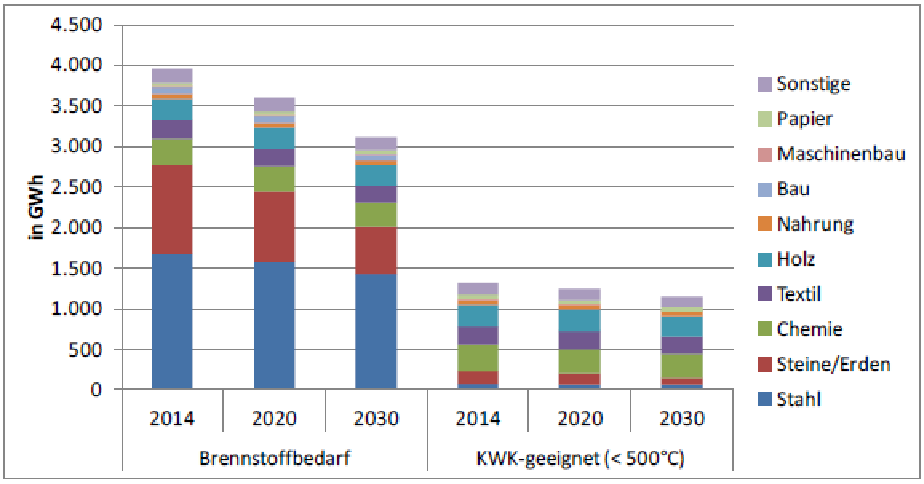
Source: own illustration based on Fleiter 2012, Temming 2005

Figure 32: Heating demand by temperature level and industrial sector

Stahl	Steel
Steine/Erden	Pit and quarry
Sonstige	Other
Nahrung	Food
Chemie	Chemical
Papier	Paper
Textil	Textiles
Holz	Wood
Maschinenbau	Mechanical engineering
Raumwärme	Space heating
Prozesswärme unter 100 °C	Process heat below 100 °C
Prozesswärme 100 - 500 °C	Process heat 100-500 °C
Prozesswärme >500°C	Process heat > 500 °C

Based on the assumptions made, the final energy demand in the industrial sector is decreasing overall, despite a slight increase in added value due to improvements in efficiency (see Figure 33). It falls from just under 4 000 GWh in 2014 to approximately 3 100 GWh in 2030. Therefore, compared with the last 10 years, the decrease in final energy demand in industry will continue but at a slower pace.

The majority of the final energy demand occurs in the steel and pit and quarry sectors (glass/cement), which require high-temperature heat. Therefore, the fuel demand for heat below 500 °C, which could be covered by cogeneration installations, makes up only around a third of the heating demand.



Source: own illustration

Brennstoffbedarf	Fuel demand
KWK-geeignet (< 500°C)	Suitable for cogeneration (< 500 °C)
in GWh	in GWh
Sonstige	Other
Papier	Paper
Maschinenbau	Mechanical engineering
Bau	Construction
Nahrung	Food
Holz	Wood
Textil	Textiles
Chemie	Chemical
Steine/Erden	Pit and quarry
Stahl	Steel

Figure 33: Changes in fuel demand and in fuel demand that is suitable for cogeneration in industry in 2014, 2020 and 2030 by sector

Of the heating demand suitable for cogeneration installations of 1 146 GWh in 2030, 264 GWh goes on space heating (see Table 14). This equates to only around 8 % of the final energy consumption in industry. If we also consider the heating demand below 100 °C, the proportion increases to 777 GWh or just under 22 % of the final energy consumption.

Table 14: Fuel demand in industry overall and according to temperature level for 2014, 2020 and 2030

in GWh	2014	2020	2030
Fuel demand	3 952	3 592	3 107
Suitable for cogeneration (< 500 °C)	1 315	1 245	1 146
Space heating	297	283	264
below 100 °C (excluding space heating)	561	542	513
100-500 °C	458	420	369
> 500 °C	2 637	2 347	1 961

Source: own illustration

6.2 Economic efficiency of industrial cogeneration installations

The economic assessment and profitability of cogeneration installations are obtained by comparing the generating costs of a cogeneration installation with those of the separate generation of heat and electricity, taking into account all cost elements as well as various revenue options (see Table 15). On the electricity side, the reference used for own consumption of the electricity from cogeneration is the relevant electricity price for final customers for electricity procured externally. Any charges and taxes that are incurred when purchasing electricity externally must also be taken into account here. If the electricity from cogeneration is fed into the grid and sold, the average electricity price on the electricity market is used as reference.

On the heat side, alternative heat generation based on natural gas represents the reference technology. The price of natural gas is an important factor in this regard. Taxes and other price elements, such as network charges, are important here, too.

To estimate industry electricity prices, the current price situation in Luxembourg is extrapolated based on future changes in the wholesale electricity prices. Based on the current situation, an annual price rise of 2.4 % is assumed, so that the current industry electricity prices of approximately EUR 100/MWh (including charges and taxes) rise to approximately EUR 115/MWh in 2030. For the electricity from cogeneration fed into the grid, a remuneration of approximately EUR 35/MWh (wholesale price in 2015) is assumed, rising to EUR 53/MWh by 2030. These price changes are based on estimates at EU level (WEO 2015, Primes 2014) and have been specifically adjusted for the situation in Luxembourg (see also Section 3).

Heat credits are derived from the savings in fuel costs for pure heat generation with 85 % efficiency. Thus, for industrial customers a gas price of approximately EUR 39/MWh (2015) in Luxembourg results in a heat credit of approximately EUR 46/MWh_{th}. In order to ascertain economic efficiency, a mean electricity and fuel price over the expected period is factored in. The certificate price increases during the period under consideration following the European Commission's reference scenario (Primes 2014) from the current EUR 5/t to EUR 10/t in 2020 and EUR 31/t in 2030. Here a mean certificate price of EUR 12/t over the duration of the period is used in the calculation. In the context of the economic efficiency assessment, only installations with a combustion capacity of more than 20 MW are affected by the certificate prices. For smaller installations these costs are not relevant for the economic efficiency calculation.

Table 15: Costs and revenues considered in the assessment of the economic efficiency of industrial cogeneration installations

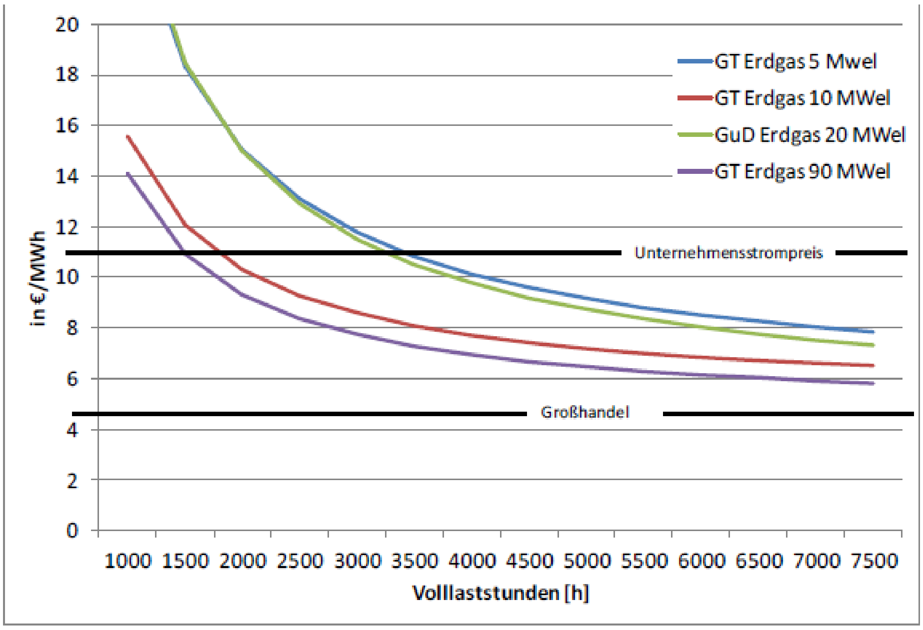
Expenses		
Investments	Installation-specific	All investments and planning costs (12-20 years' service life, 6.5 % real interest rate)
Operating costs	Installation-specific	Fixed costs (including staffing and maintenance costs) Variable costs (including consumption-dependent repair costs)
Fuel costs, natural gas	Final customer-specific	Free-at-frontier prices plus charges and taxes, application-specific surcharges according to purchase volume
CO_2 certificates	EUR 12/t	Wholesale price for EEA (European Emission Allowance) for installations > 20 MW_{th}
Revenues		
Electricity remuneration (feed-in to grid)	EUR 44.2/MWh	Remuneration for electricity from cogeneration (based on wholesale electricity price)
Electricity remuneration (own consumption)	Final customer-specific	Electricity procurement avoided (based on final customer electricity price including charges, fees)
Heat remuneration	Final customer-specific	Costs of alternative heat generation, fuel costs in particular
Cogeneration subsidies		Payments for feeding in electricity or heat from cogeneration, other funding opportunities (including investment grants)

Source: own illustration

For the majority of industry in Luxembourg the final energy demand is less than 20 GWh. There are barely 40 undertakings in Luxembourg that have a final energy demand higher than 20 GWh/a. In view of this, it is the cogeneration installations smaller than 20 MW electrical capacity in particular that are interesting for Luxembourg. If steam is used as process heat, gas turbines with waste heat boilers or combined cycle installations are particularly suitable. In sectors that primarily require hot water, such as the food industry, block-type thermal power plants are also suitable for use as cogeneration installations.

For the economic efficiency analysis, mean electricity and fuel prices over the service life of the installations are used in the calculations.

Larger GT installations above 10 MW_{el} based on natural gas with a capacity utilisation of 5 000 hours a year attain electricity generation costs of approximately EUR 65 to 71/MWh (see Figure 34). For enterprises with a correspondingly high energy demand that could install such an installation, the electricity procurement costs are closer to the wholesale price and therefore this would only be economically efficient if there is high capacity utilisation of the installation.

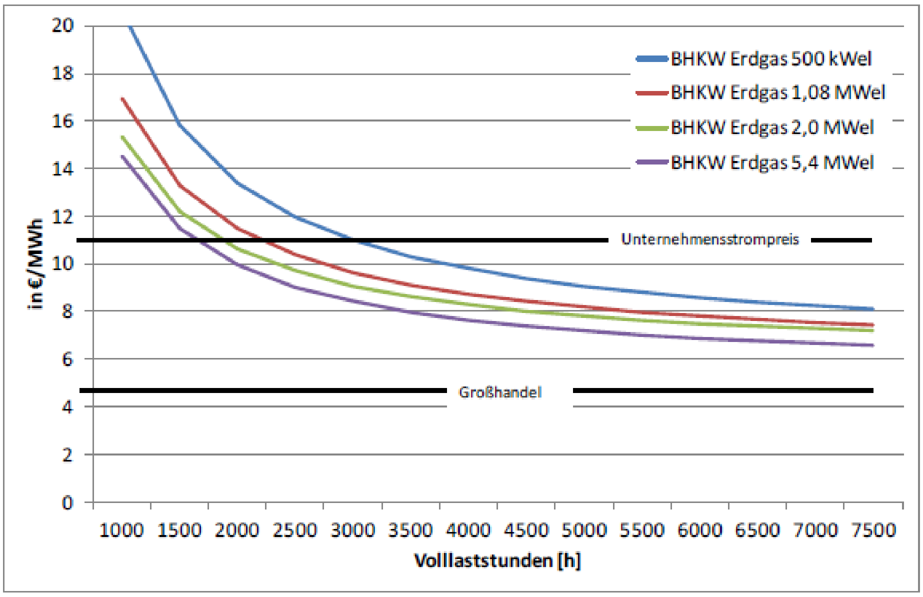


Source: own calculations

in €/MWh	in EUR/MWh
Volllaststunden [h]	Full load hours [h]
GT Erdgas 5 Mwel	GT natural gas 5 MW_{el}
GT Erdgas 10 MWel	GT natural gas 10 MW_{el}
GuD Erdgas 20 MWel	CC natural gas 20 MW_{el}
GT Erdgas 90 MWel	GT natural gas 90 MW_{el}
Großhandel	Wholesale
Unternehmensstrompreis	Business electricity rate

Figure 34: Electricity-generating costs for GT with heat utilisation or CC installations as a function of capacity utilisation

For block-type thermal power plants, the electricity-generating costs are slightly higher at between EUR 71 and 91/MWh at 5 000 full load hours (see Figure 35). Here, too, economic efficiency is only achieved at comparatively high-capacity utilisation. For smaller enterprises, which have higher electricity procurement costs, cogeneration installations are only likely to be economical if they would mean that the comparatively expensive procurement of electricity could be avoided.



Source: Own calculation

in €/MWh	in EUR/MWh
Volllaststunden [h]	Full load hours [h]
BHKW Erdgas 500 kWel	Block-type TPP natural gas 500 kW_{el}
BHKW Erdgas 1,08 MWel	Block-type TPP natural gas 1.08 MW_{el}
BHKW Erdgas 2,0 MWel	Block-type TPP natural gas 2.0 MW_{el}
BHKW Erdgas 5,4 MWel	Block-type TPP natural gas 5.4 MW_{el}
Großhandel	Wholesale
Unternehmensstrompreis	Business electricity rate

Figure 35: Electricity-generating costs for block-type thermal power plants as a function of capacity utilisation

In assessing the economic efficiency of cogeneration installations in industry, it appears that these installations usually have higher electricity-generating costs compared with electricity wholesale, even if very high-capacity utilisation can be achieved. Compared with external procurement, however, the cogeneration installations considered may achieve economic efficiency.

6.3 Changes in the potential for additional cogeneration as a result of refurbishment and the construction of new industrial cogeneration installations

Based on the current and future useful energy demand in industry and the considerations with regard to economic efficiency it is possible to estimate the potential for additional cogeneration installations compared with the status quo. Luxembourg's cogeneration installations were characterised by large plants that were included in the European emissions trading system (CEGYCO, CEDUCO). The cogeneration installation CEDUCO, a cooperation between Enovos and Dupont, was no longer in operation in 2013 (Enovos 2014). In 2015 the CEGYCO plant was also no longer in use. No newer installations have been built in industry in recent years due to the lack of economic efficiency. Publications relating to individual installations also show that capacity utilisation of cogeneration installations on the electricity side has, if anything, decreased (Enovos 2014).

Based on the economic efficiency calculations, the minimum heating demand can be derived from the required full load hours and the size of the installation. The energy demand of 10 GWh stated in the Directive in this regard is a lower estimate. A useful heat demand of 10 GWh can, for example, be achieved by a block-type thermal power plant with a 2 MW thermal capacity and 5 000 full load hours. Currently it can be assumed that in total around 36 enterprises have a final energy demand greater than 20 GWh, making up more than 700 GWh of the final energy demand. For these enterprises, economic efficiency can be achieved by avoiding external procurement if longer payback periods are accepted. For larger enterprises, however, the electricity procurement conditions are often closer to the wholesale prices. Economic efficiency is therefore lower, and thus, combined with the short payback periods required in industry, the potential is not expected to be realised.

Overall, an economic potential of approximately 500 GWh of final energy or 425 GWh of useful energy is expected in industry that could be covered by heat from cogeneration (see Table 16). Compared to 2014 when just under 190 GWh of heat was generated from cogeneration, this represents more than a doubling of the heat supplied from cogeneration. These installations have now been decommissioned, however. Therefore, it would only be possible to realise the potential that has been identified if the economic conditions were considerably improved.

Relevant sectors include the chemicals industry and the wood and food industries in particular. No detailed potentials have been estimated for the other sectors, as the necessary installation size is not achieved here, due to the size of the enterprises and the associated heating demand. For individual sites, however, heat supplied using cogeneration installations (in particular block-type thermal power plants) may be economically viable if the limiting conditions (high electricity procurement costs, continuous heating demand, long payback periods possible) are particularly favourable. It was not possible to look at individual cases in this way during this study.

Table 16: Assessment of the potential for additional heat from cogeneration in industry up to 2030 based on final energy consumption in industry

	Fuel demand in GWh		Suitable for cogeneration (< 500 °C) in GWh		Existing cogeneration installations in GWh	Potential for expansion in GWh
In GWh	**2014**	**2030**	**2014**	**2030**	**2014**	**2030**
Steel	1 670	1 422	67	57		
Pit and quarry	1 094	589	164	88		
Chemical	319	295	316	292		210
Textiles	226	208	226	208		
Wood	274	253	274	253	65	150
Food	61	57	60	56		25
Construction	77	71	0	0		
Mechanical engineering	13	12	13	12		
Paper	51	47	50	46		
Other	167	154	145	134	122	115
Total	**3 952**	**3 107**	**1 315**	**1 146**	**187**	**500**
	*Heat from cogeneration**					*425*
	*Electricity from cogeneration***					*255*

Source: own assessment, * Conversion of final energy to useful heat from cogeneration using a factor of 0.85, ** Electricity from cogeneration calculated using a power to heat ratio of 0.6

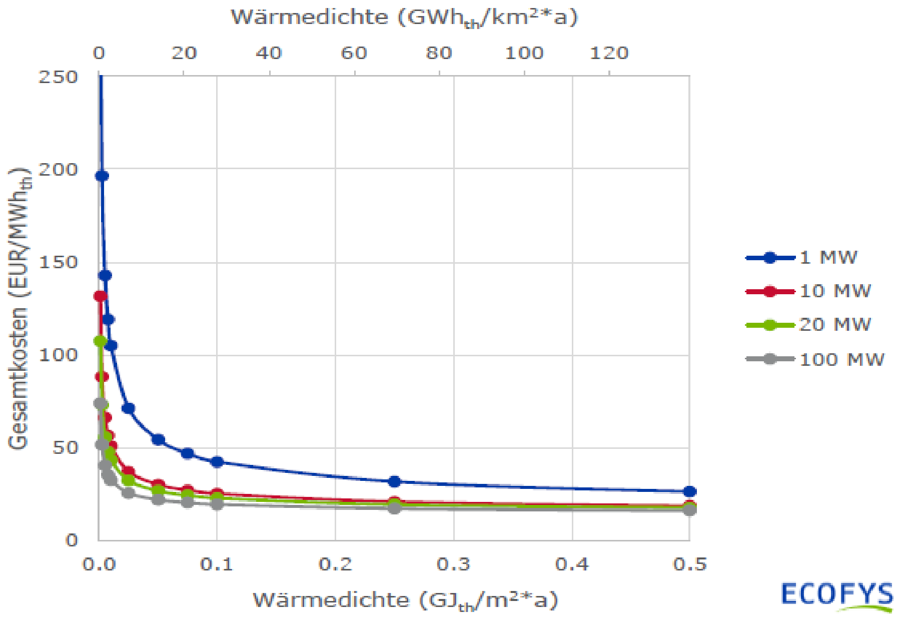
7 Assessment of the potential for heat network supply and centralised cogeneration installations

The Energy Efficiency Directive defines a plot ratio of at least 0.3 for regions with the potential for heat network supply. From the analysis of the building stock it is evident that this criterion is not met in any municipality in Luxembourg (see 4.4). Using the plot ratio as the only criterion for assessing the potential is problematic, however. Although it provides an indicator for the heating demand, heat density and heating demand are also dependent on the distribution of the building structure. Moreover, higher-resolution geographical differentiation can yield high plot ratios within the municipality. Therefore, a detailed heating demand analysis for all municipalities in Luxembourg is being carried out to investigate the heating demand in a 250 x 250 m grid square for 2012 and 2030.

This will assess the potential using not only the plot ratio, but also the additional criteria of specific heat density and the annual heating demand using limits values for technical realisation according to Büchle et al. (2015). In addition, the limit value for the plot ratio is reduced to 0.1:

- Useful heat density > 10 GWh/(km^2a)
- Useful heat demand > 10 GWh/a
- Plot ratio > 0.1

The minimum heat density stems from the fact that, with heat densities below 10 GWh, the heat distribution costs rise dramatically due to higher losses (Büchle et al., 2015; Klobasa et al., 2008). Conversely, the size of the network has a significant effect on distribution costs in the case of very small installations of 1 MW only (Figure 36).



Source: (Büchle et al., 2015)

Wärmedichte (GWhth/km2*a)	Heat density (GWh$_{th}$/km^2*a)
Gesamtkosten (EUR/MWhth)	Total costs (EUR/MWh$_{th}$)
Wärmedichte (GJth/m2*a)	Heat density (GJ$_{th}$/m^2*a)

Figure 36: Heat distribution costs as a function of heat density

7.1 Determining local heating demands and heat densities

The basis for determining local heating demands and heat densities is the results of the simulation of the changes in heating demand in Luxembourg. The results are firstly broken down to municipal level and then to individual buildings. At municipal level, the distribution of different building types and uses of residential and non-residential buildings are taken into account as well as the distribution in terms of age for residential buildings in order to determine the specific useful heat demand for each square metre of ground area. Using land registry data, the exact default locations for the buildings can be entered into the model. The heating demand for the new-builds within the simulation period up to 2030 is distributed among the municipalities according to the population trend over the last 10 years.

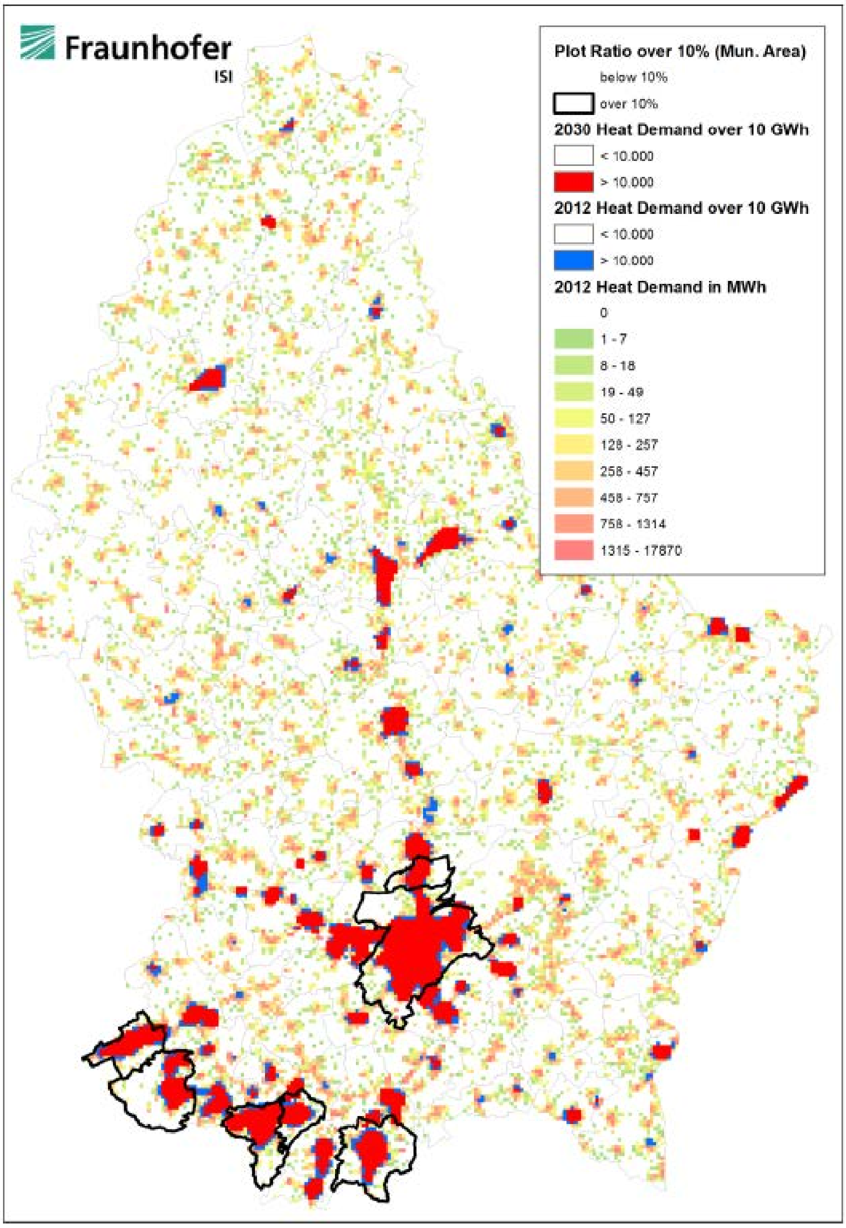
The distribution is carried out within a GIS environment on the basis of the available building plans, distinguishing between residential and non-residential buildings.

A 250 x 250 m vector grid is then laid out over the whole area of the country and the demands of the individual buildings are aggregated. For 2030, the new-builds have also been allocated to these squares. In another step in the process, within the perimeter of each square the heating demands within a square kilometre are added up and examined to see whether the critical annual heating demand of 10 GWh/a is attained. This method was applied for 2012 and for 2030. If the criterion is met, the grids concerned are coded and then the total heating demand within these areas is added up.

7.2 Results of the heating demand maps for 2012 and 2030 for Luxembourg

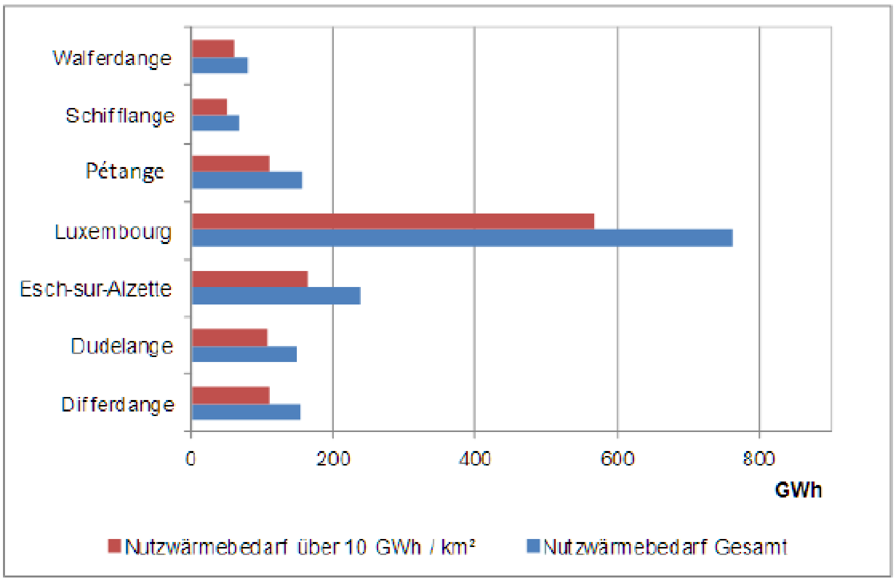
In the seven municipalities that achieve a plot ratio above 0.1 there are large areas that attain a heat density and heat sales above 10 GWh per year. In addition, there are other municipalities which, although they have a low plot ratio, nevertheless show relevant areas in the heating demand analysis. Figure 37 shows the results relating to the distribution of the heating demand and identifies the areas that meet the pre-defined conditions. The map also shows the areas in the individual municipalities that are no longer relevant for economic development in terms of heating networks due to the decrease in heating demand (marked in blue).

The largest heating demand of above 700 GWh is shown by the municipality of Luxembourg City, followed by Esch-sur-Alzette (see Figure 38). In total, the heating demand that is able to be exploited by heating networks in the seven municipalities that meet the limit values for displaying potential is around 1 606 GWh in 2012, falling to 1 170 GWh by 2030. In 2030 this equates to 5 % of the heating demand in the building sector.



Source: Own illustration

Figure 37: Distribution of the useful heat demand and areas of economic potential for heating supply



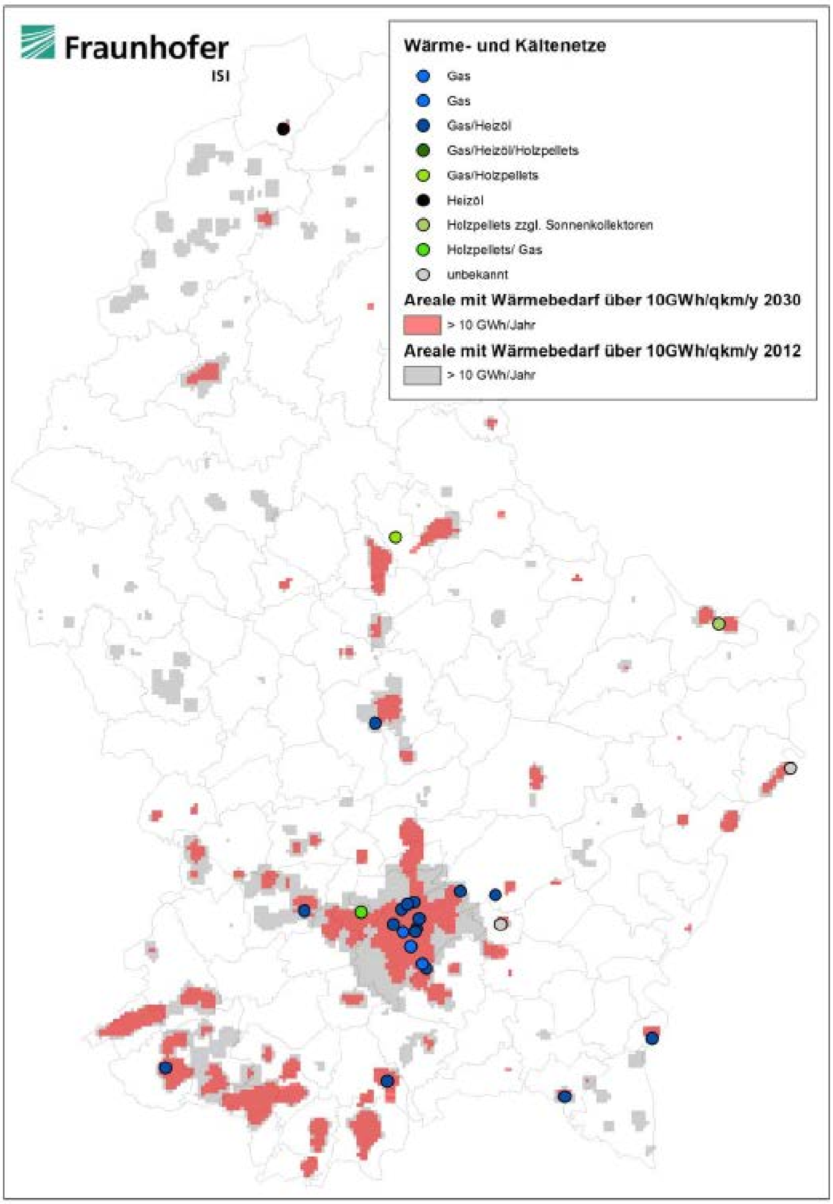
Source: own calculations

Walferdange	Walferdange
Schifflange	Schifflange
Pétange	Pétange
Luxembourg	Luxembourg
Esch-sur-Alzette	Esch-sur-Alzette
Dudelange	Dudelange
Differdange	Differdange
Nutzwärmebedarf über 10 GWh/km^2	Useful heat demand over 10 GWh/km^2
Nutzwärmebedarf Gesamt	Useful heat demand total

Figure 38: Potentially exploitable heating demand in the heating network regions

Analysis of the current heating networks[6] reveals that the vast majority of networks are in the municipalities with economic potential for heating networks. Most of the networks are in the greater Luxembourg City area and adjacent municipalities (Figure 39). It also appears, however, that smaller heating networks exist in municipalities which do not meet the plot ratio criterion but nevertheless have heat densities of over 10 GWh/km^2 per year with corresponding minimum heat sales even in 2030 according to the heating demand analysis that was carried out.

[6] The analysis includes the heating and cooling networks operated by LuxEnergie (LuxEnergie, 2016).



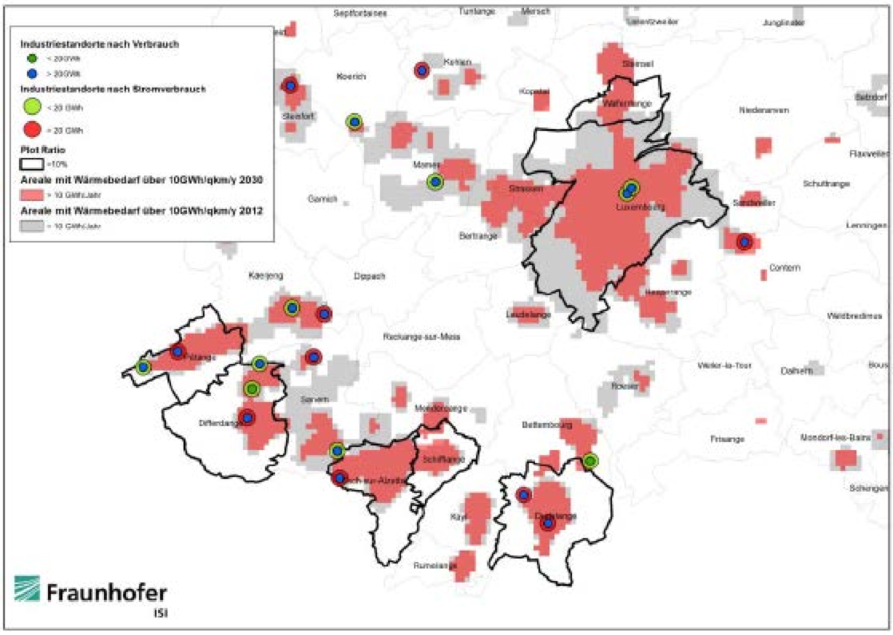
Source: Own illustration

Wärme- und Kältenetze	Heating and cooling networks
Gas	Gas
Gas/Heizöl	Gas/fuel oil
Gas/Heizöl/Holzpellets	Gas/fuel oil/wood pellets
Gas/Holzpellets	Gas/wood pellets
Holzpellets	Wood pellets
Heizöl	Fuel oil
Holzpellets zzgl. Sonnenkollektoren	Wood pellets plus solar panels
Holzpellets/Gas	Wood pellets/gas
unbekannt	Unknown
Areale mit Wärmebedarf über 10GWh/qkm/y 2030	Areas with a heating demand over 10 GWh/km^2/yr 2030
> 10GWh/Jahr	> 10 GWh/year

Figure 39: Economic potential for heating networks and current heating networks

7.3 Detailed heating demand maps for municipalities with economic potential for heating networks

Detailed analysis of the heating network regions identified makes it clear which areas will fall below the minimum heat density threshold by 2030. However, it is also clear that there are opportunities for a linked heating network supply outside the boundaries of the municipalities, too. For example, the municipality of Sanem is not identified as a heating network region, as it does not achieve the minimum plot ratio. However, the heating demand map shows that, together with the adjacent municipalities, it makes up a continuous area of sufficient heat density. Figure 40 also shows the industrial sites in the municipalities which, depending on the required temperature level, could be integrated into a heating network supply system as additional heat consumers or suppliers of waste heat.



Source: Own illustration

Industriestandorte nach Verbrauch	Industrial sites according to consumption
20 GWh	20 GWh
Industriestandorte nach Stromverbrauch	Industrial sites according to electricity consumption
Plot Ratio	Plot ratio
Areale mit Wärmebedarf über 10GWh/qkm/y 2030	Areas with a heating demand over 10 GWh/km²/yr 2030
> 10GWh/Jahr	> 10 GWh/year

Figure 40: Detailed illustration of heating demand and the industrial sites in the heating network regions

7.4 Conclusion with regard to the potential for high-efficiency cogeneration installations

Overall, it appears that a considerable proportion of the available cogeneration potential in the building sector is already exploited by existing local heating systems. According to the analyses carried out in this study, however, the potential exists for expanding the current provision in the future. According to the 2014 energy balance, in the household and commercial sectors a total of 908 GWh of heat (final energy) is currently consumed. In comparison, in the seven municipalities identified there is potential for 1 606 GWh of useful heat in the building sector. If we assume an efficiency of 85 %, this gives a final energy demand for this useful heat of 1 889 GWh. Therefore, around 50 % of the economic potential in the building sector is being exploited. In the medium term, the useful heat demand will decrease as a result of improved energy efficiency in the building sector to 1 170 GWh (useful heat) in 2030 or 1 376 GWh (final energy). A further increase by 50 % is therefore possible in the medium term, based on the current situation. Further potentials over and above the 1 170 GWh of useful heat exist as a result of the development of municipalities adjacent to the seven that have been identified, which alone do not achieve the necessary heat density (including the municipality of Sanem).

In the industrial sector, the final energy demand that is suitable for cogeneration was approximately 1 315 GWh in 2014, of which approximately 187 GWh [7] is estimated to be currently covered by heat from cogeneration. This equates to approximately 14 % of the technical potential. Further exploitation is not economically viable at present, as evidenced by the decommissioning of the existing industrial cogeneration installations CEDUCO, CEGYCO and TwinERG. Likewise, in the medium term, only a limited expansion of industrial cogeneration is expected to be economically efficient, enabling approximately 500 GWh of heat from cogeneration (final energy) to be generated. Good site conditions are necessary for this, however – in other words, long service lives for the installations. Longer payback periods must also be accepted.

[7] The 2014 energy balance accounts for 157 GWh of network-connected heat, but this also includes own consumption of heat.

8 Recommendations for action and strategies to cover the heating demand in the future

To develop future strategies relating to the role of cogeneration technologies and district heating and to cover the heating demand a distinction must be made between areas with a high heat density that to a certain extent already have local or district heating systems and areas with a low heat density. Other key points are the questions relating to the energy sources used (renewables or fossil fuels), the type of building stock (new-builds or old buildings) and the building renovation options.

8.1 Recommendations for action for areas with a high heat density

Areas with a high heat density have been identified in the study and usually encompass the areas in which local or district heating networks have already been constructed. This applies in particular to the seven municipalities with a plot ratio > 0.1. Due to the high heat densities in these areas the possibility of centralised cogeneration installations with network-based heat distribution achieving economic efficiency is considerably better than in areas with a lower heat density.

In areas with a high heat density, a centralised heating supply using cogeneration may therefore be a cost-effective option compared with other heating supply options. Due to the existing heating demand, this will be the case in particular if large centralised heat generators are used as affordable heat generation options and are utilised to capacity. As a result of economies of scale, the specific investments for heat generators decrease as the installations get larger. With the same utilisation time, the costs for the MWh of heat generated are lower for large heat generators than for small installations.

Heating networks using cogeneration systems may also be an interesting option in the medium term for situations where renovation is difficult (old building stock) and at the same time the use of distributed renewable energies (e.g. heat pumps, pellet boilers) is almost impossible.

Conversely, this also means, however, that in areas where renovation of the building stock is quite possible and at the same time the installation of distributed renewable energies can also be carried out, expansion or construction of new heating networks is not recommended. Therefore, a decision concerning the further expansion or new installation of heating networks should always be preceded by examination of the possibility of renovation and the distributed generation of renewable heat. Only an integrated approach like this will enable efficient heating supply.

As a technology option for supplying a heating network it should always be checked whether the use of renewable energies is possible. Pellet or woodchip boilers combined with steam turbines are options here, although they only enable the generation of small quantities of electricity. Other technologies, such as wood gasification and subsequent generation of electricity in a block-type thermal power plant, have established themselves to a limited extent only, but would enable the generation of larger quantities of electricity. If supply based on renewable energies is not possible, e.g. because no biomass is available locally, the use of natural gas-based cogeneration installations is also possible.

For practical implementation in specific projects, more detailed analyses should be carried out in order to assess the advantages. This requires an analysis of the local conditions, which includes the topology, but also other measures that are already planned that will influence the long-term local heating demand. However, economic efficiency cannot usually be achieved without financial support for the production of heat and/or the local or district heating network, irrespective of whether fossil or renewable energies are used.

Good opportunities for a cost-effective solution may present themselves in particular if it is possible to utilise waste heat from existing industrial installations, which is the intention, for example, in a large project that is planned in a new part of Luxembourg City (*Cloche d'Or*) through the use of waste heat from a waste incineration plant.

In view of the switching of the electricity and heating system to a supply based predominantly on renewable energies, a strategy for centralised heating supply should not put the emphasis on expanding centralised cogeneration capacities, but rather on the expansion of heating networks that will serve as a flexible electricity and heating system. Centralised cogeneration installations are only one of several different options in this system. In the areas of high heat density that have been identified, centralised cogeneration installations usually represent the more cost-effective option compared with distributed cogeneration installations for single buildings due to economies of scale.

The role of heating networks in the energy system of the future

Heating networks can play a key role in the decarbonising of the energy system. In urban and densely populated areas with multi-storey residential buildings in particular, the potential for the use of distributed renewable energies for the supply of heat, such as heat pumps, solar installations and biomass boilers, is extremely limited. At the same time, ambitious measures to reduce energy demand are feasible to a limited extent only due to various insulation constraints, such as preservation orders or distance regulations. Heating networks offer a cost-effective supply of heat, immediately and in the future, that can be predominantly or fully covered by renewable energies. It would also enable the exploitation of waste heat potentials from industry, as discussed in the previous section.

In areas with a high heat density which have unfavourable conditions for renovation or for the use of distributed renewable energies, heating networks also represent the central infrastructure for linking the electricity and heating sector. The use of heat storage units can enable the generation of electricity by cogeneration installations based on demand. Excess electricity from wind and PV installations can also be stored or utilised efficiently with the use of power-to-heat options such as large heat pumps. It is therefore recommended that the possibility of expanding the heating networks be examined in the seven municipalities identified and in individual cases in other regions with a high heat density. In combination with an ambitious renovation strategy, this may be an efficient option for decarbonising the heating sector, for existing buildings in particular. Heating networks therefore represent an additional decarbonisation measure alongside the renovation of buildings. These networks should be closely coordinated with renovation measures. Building renovation is an important pillar in the climate protection strategy, as significant long-term improvements in efficiency need to be achieved in this regard in particular. Therefore, in the continued development of heating networks and cogeneration technologies, what the medium-term decrease in heating demand will be as a result of renovation measures in the area of building efficiency in the regions under consideration should always be examined first. If it emerges that there will still be a high heating demand in the medium term which cannot, or can only with difficulty, be covered by distributed renewable energies, it should be examined whether a heating network-based supply would be cost-effective compared with other heating options. The overarching aim here should be to identify the most cost-effective route possible to reducing emissions in the heating sector.

If, in the future, own supply systems using PV and storage systems prove to be cost-effective as a result of significantly reduced storage costs, this will pose no competition to the recommended expansion of the heating networks in areas with a high heat density and a difficult renovation situation. Expansion of the heating networks would principally affect existing buildings in densely populated areas where own supply systems using PV and storage systems would be difficult to implement. These types of systems can be implemented more readily in new buildings and single-family houses and therefore complement the potential expansion of the heating networks well.

Requirements for a modern power and heat system

Centralised cogeneration installations are just one possible component of a modern power and heating system. Other generating options are non-combined renewable energy heat generators, such as large solar arrays or large heat pumps. In view of the increasingly volatile generation of electricity by wind and PV, the most important requirement for a modern power and heat system is the provision of flexibility and coverage of the residual load in the electricity system while at the same time covering the heating demand with low primary energy consumption. This can be achieved by multivalent systems combining different forms of energy that can be used by the system, for example by integrating an electricity-generating heat supply (cogeneration installation) with an electricity-consuming heat supply (heat pump, electrode boiler).

Conclusions

The heating demand analysis showed that in areas with a high heat density, primarily in seven municipalities with a plot ratio higher than 0.1, there is a certain amount of potential for a heating network-based supply in Luxembourg, estimated to be around 5 % of the heating demand in the building sector in 2030. The realisable economic potential depends on other local conditions and the extent to which high connection rates can be achieved. Municipal heating and cooling supply plans that include not only the supply side but also municipal renovation strategies represent an important measure for defining the economic potential more closely and for realising this potential. Funding instruments aimed at expanding heating networks should take account of the generating side requirements mentioned for a modern power and heating system.

8.2 Recommendation for action for areas with a low heat density and for distributed cogeneration installations

Analysis of the heating demand has shown where there are areas with a high heat density in which there may be opportunities to operate heating networks with centralised heat production cost-effectively. This is the case in particular in seven municipalities in Luxembourg. There are also areas outside these municipalities which may have sufficient heating demand for individual installations, enabling cogeneration installations to operate cost-effectively here, too. In the medium term, however, these areas will decrease considerably due to building renovation measures. Expansion of the heating networks and installation of centralised cogeneration plants is therefore not recommended for these areas. In individual cases and for existing cogeneration installations, the extent to which the local expansion of existing networks could be economically viable should be examined, however. Small networks could also be viable on account of local conditions, for example high local availability of renewable energies such as biomass (wood).

These small heating networks are also an option for making greater use of biomass based on wood or pellets and open up the possibility of using pellet imports, for example, if this option would make a greater contribution to the amount of electricity produced from renewable energy sources.

This study has not investigated whether, from the point of view of the national economy, the use of distributed cogeneration installations is a viable and important technology for the transformation of the entire system, or whether, in the area of distributed supply, efforts should be made to instigate a switch to non-combined renewable heating technologies. This would require a comprehensive analysis of the non-combined generation options, too, as well as the medium-term developments in the electricity system, including the renewable energies in the European electricity market.

In so far as distributed cogeneration installations are seen as the key component of the future energy system, however, the following recommendations for action can be made with regard to energy sector conditions and the structuring of a subsidy system.

In the residential building sector, the economic potential for the use of distributed cogeneration installations is regarded as low in Luxembourg under current conditions. If cogeneration installations are to be used in the energy system as far as possible to cover the consumption of own electricity, economic potentials in apartment blocks can be exploited. This can be achieved in particular by subsidising contracting and removing legal and information-related barriers to the sale of tenants' electricity and by the creation of user associations. No economic potential can be seen for system-relevant grid feed-in with low consumption of own electricity due to the large difference between the wholesale electricity price and the final customer price in the residential building sector.

In the industrial sector, the economic potential is also very limited due to the low wholesale prices expected. Here, too, to a limited extent there is additional potential for the expansion of the industrial production of electricity from cogeneration, in particular by avoiding the external procurement of electricity and the consumption of own electricity. Longer payback periods are necessary for this, but these are not usually possible in industry due to the uncertainty with regard to future developments. Therefore, the following recommendations for action can be made for distributed cogeneration installations in commercial and industrial applications.

The economic viability of existing fossil fuel-based installations in industry has deteriorated significantly in recent years, which has led to the closure of most of the existing industrial cogeneration installations. The expected changes in natural gas and electricity prices will not improve the economic viability substantially in the medium term, either. Overall, the capacity utilisation of fossil fuel-based cogeneration installations as well as of other electricity-generating installations is decreasing. The analyses have shown, however, that for sites with a continuous heating demand and thus high-capacity utilisation, the generating costs are close to the wholesale electricity prices and lower than the electricity procurement costs for enterprises. In order to exploit this high-efficiency potential, clear conditions for own use should be established which allow continued own use within acceptable capabilities but in the process promote flexible operation. In this context, examination of the effect of investment grants could be an interesting option.

The focus for this should be on sites at which integration into district heating networks is also possible or where there is a high heat density in the surrounding area. With integration into a district heating network, industrial sites can increase the heat density or heat consumption and thereby improve the economic efficiency of district heating networks. Moreover, in the medium term it will also be easier to supply renewable heating in the industrial sector via a district heating network. On the other hand, industrial sites with the potential for utilising waste heat or with their own heat-generating installations can improve their economic efficiency by feeding heat into a district heating network.

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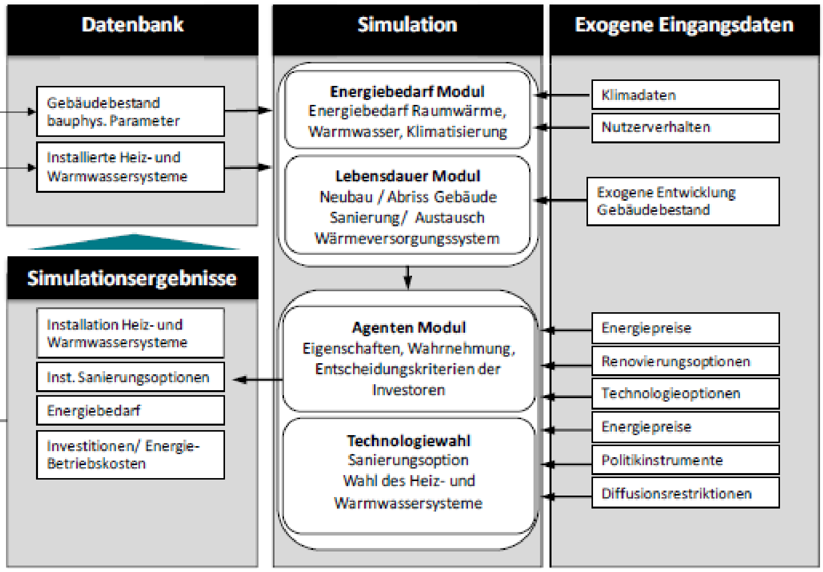
9 Annex

9.1 Description of the Invert/EE-Lab model

The simulation model Invert/EE-Lab was used to determine the changes in energy demand. This model was developed by the Energy Economics Group of the Technische Universität Wien and with the help of the Frauenhofer Institute for Systems and Innovation Research ISI it has been used and further developed in the context of many national and European projects.

In terms of method, Invert/EE-Lab is a bottom-up, techno-economic simulation tool which allows determination of the energy demand options and their coverage for heating (space heating and hot water) and air conditioning of residential and non-residential buildings and the modelling of the effects of different promotional instruments in annual steps (Figure 41).



Source: (Steinbach, 2015) based on Kranzl et al. (2013)

Datenbank	Database
Gebäudebestand bauphys. Parameter	Building stock physical construction parameters
Installierte Heiz- und Warmwassersysteme	Installed heating and hot water systems
Simulationsergebnisse	Simulation results
Installation Heiz- und Warmwassersysteme	Installation of heating and hot water systems
Inst. Sanierungsoptionen	Inst. renovation options
Energiebedarf	Energy demand
Investitionen/ Energie-Betriebskosten	Investments/energy operating costs
Simulation	Simulation
Energiebedarf Modul	Energy demand module
Energiebedarf Raumwärme, Warmwasser, Klimatisierung	Energy demand for space heating, hot water, air conditioning
Lebensdauer Modul	Service life module
Neubau / Abriss Gebäude	New-build/demolition of buildings
Sanierung/ Austausch	Renovation/replacement
Wärmeversorgungssystem	Heating supply system
Agenten Modul	Agents module
Eigenschaften, Wahrnehmung, Entscheidungskriterien der Investoren	Characteristics, perception, investors' decision-making criteria
Technologiewahl	Choice of technology
Sanierungsoption	Renovation option
Wahl des Heiz- und Warmwassersysteme	Choice of heating and hot water systems
Exogene Eingangsdaten	Exogenous input data
Klimadaten	Climate data
Nutzerverhalten	User behaviour
Exogene Entwicklung Gebäudebestand	Exogenous changes in building stock
Energiepreise	Energy prices
Renovierungsoptionen	Renovation options
Technologieoptionen	Technology options
Energiepreise	Energy prices
Politikinstrumente	Policy instruments
Diffusionsrestriktionen	Diffusion restrictions

Figure 41: Structure of the Invert/EE-Lab simulation model

The basis for the model is a detailed representation of the building stock according to building type, age class and state of renovation, with relevant physical construction and economic parameters, including the technologies used to provide space heating, hot water and air conditioning. Based on this, the heating and cooling energy demand is determined, taking into account user behaviour and climate data. The technology investment decision and efficiency measures are determined, taking into account investor-specific decision-making processes and barriers as well as energy source potentials.

With Invert/EE-Lab it is possible to use different scenarios to analyse the effect of different policy instruments and design options on the development of renewable energies in the building sector.

To produce a simulation of the use of renewable energies in the building sector that closely matches the actual situation, the following relevant circumstances, among others, are represented in the model:

Consideration of investor-specific barriers and processes involved in investment decision-making relating to heating supply systems and efficiency measures.

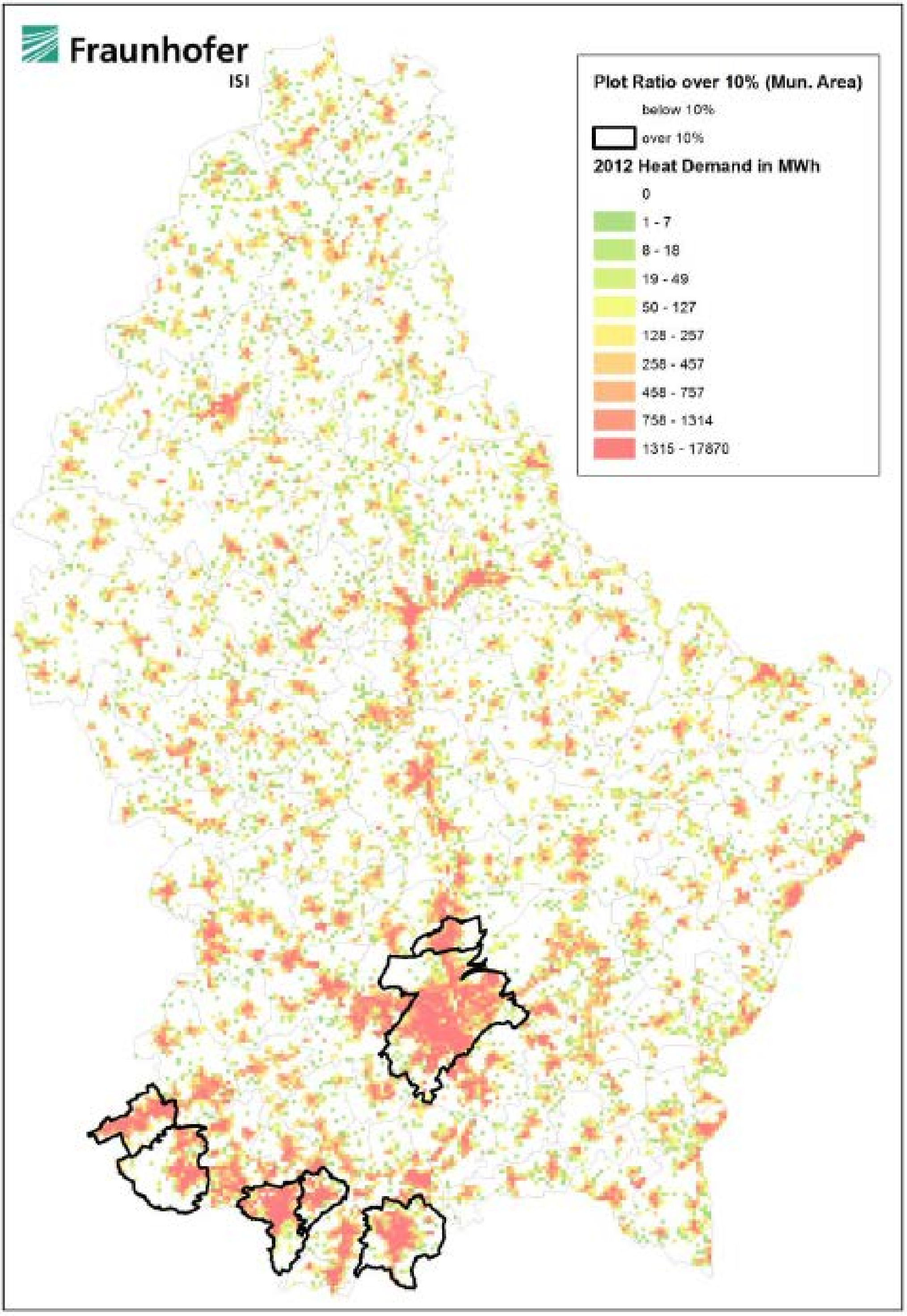
The temperature level of the heating distribution system is taken into account in the simulation, in particular the interaction between this and the efficiency levels or performance coefficients of the energy delivery technologies. This is particularly significant for a simulation of the use of heat pumps in older buildings that closely reflects the actual situation.

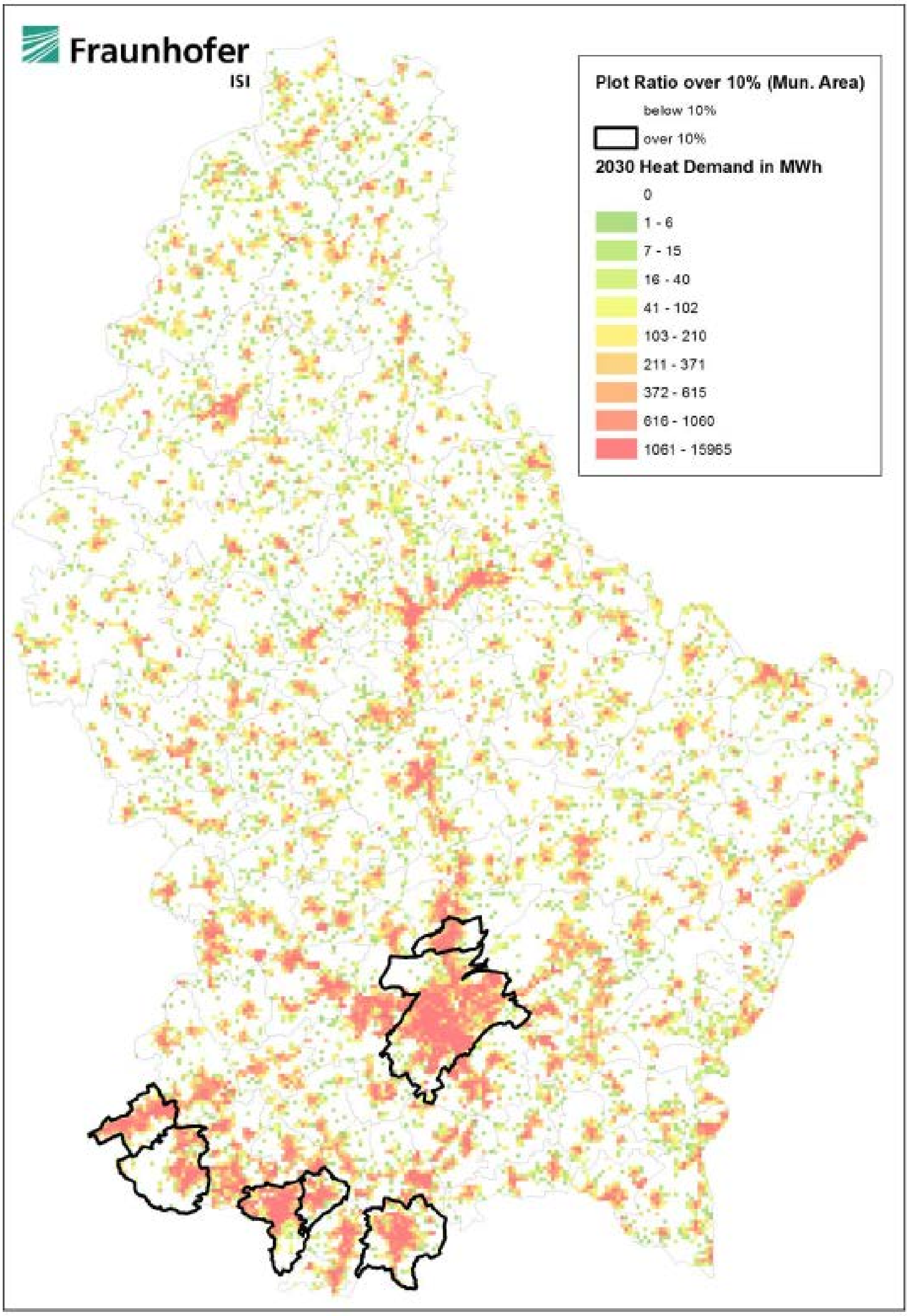
The supply of energy from solar thermal installations is modelled on a monthly basis, taking into account the corresponding solar radiation. The roof area available to solar thermal installations according to the geometry of the reference buildings is also taken into account in the model.

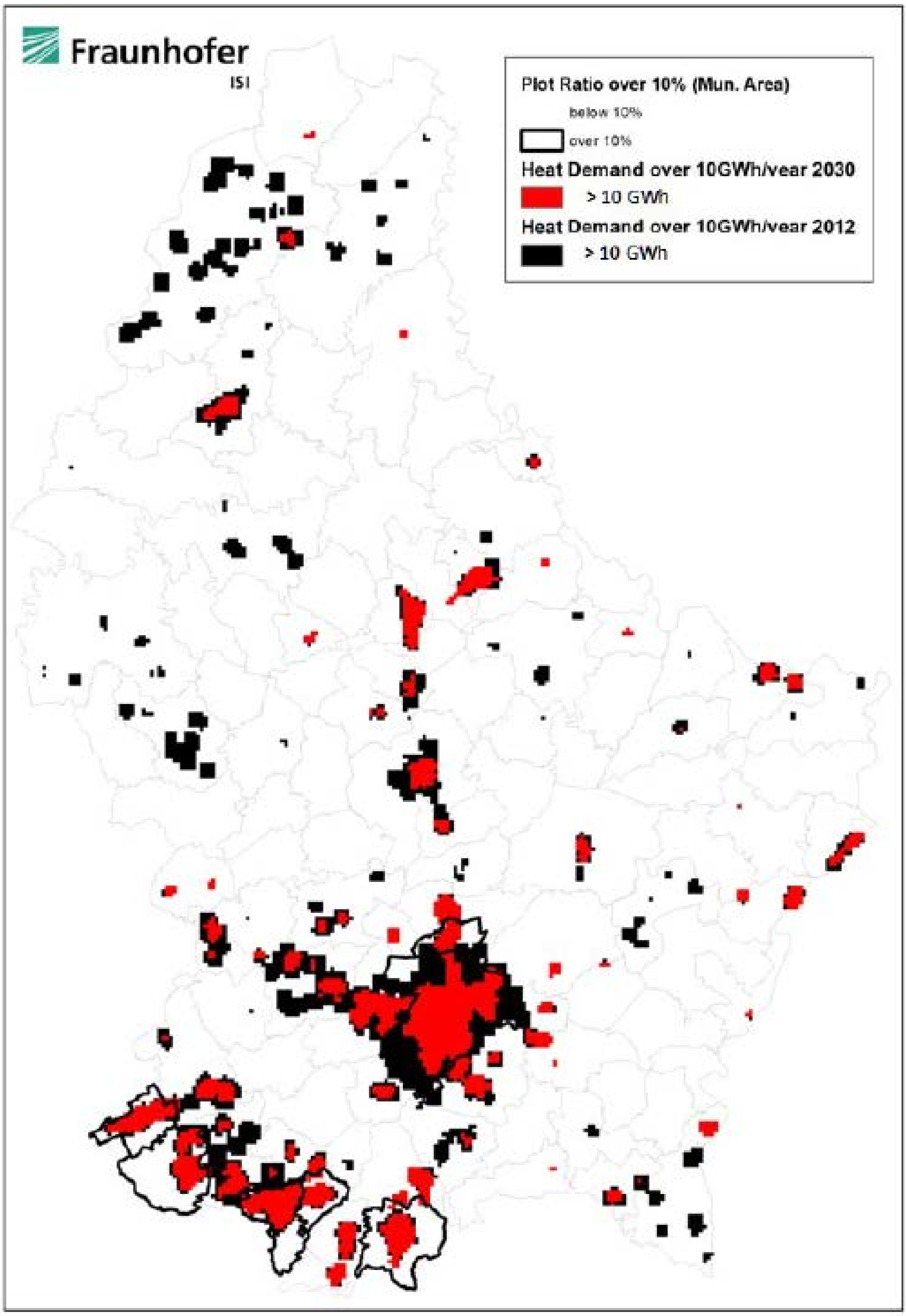
Policy instruments for promoting heating from renewable energies and efficiency measures, such as investment grants (market incentive schemes), obligations to use renewable energies (Act promoting renewable energies in the heating sector [EEWärmeG]) or extra-budgetary allocation systems are defined for specific technologies and buildings (new-builds, existing buildings, public buildings).

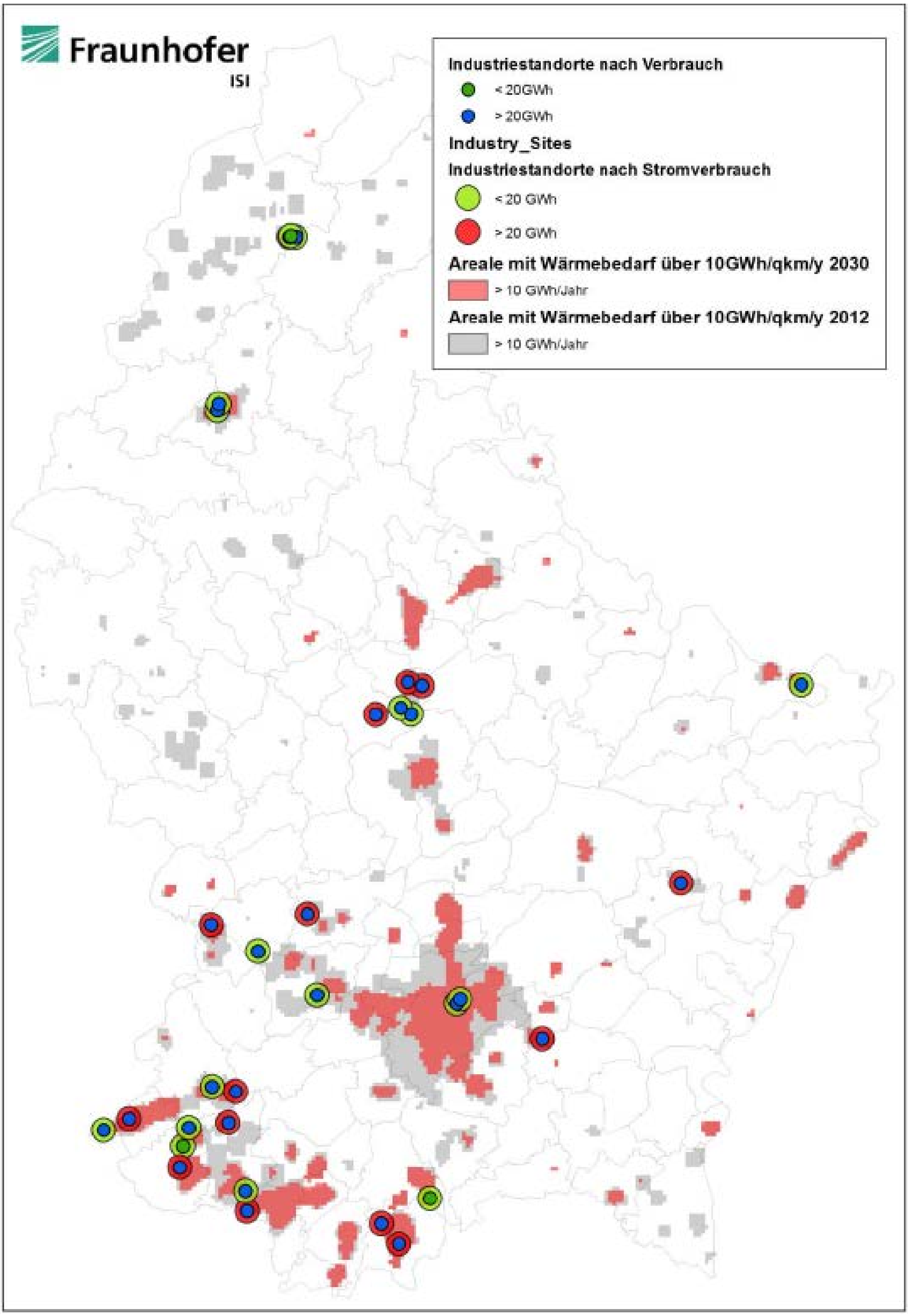
In addition, the limitations of renewable energy sources are taken into account via defined cost potentials, including changes in these potentials over the simulation period.

9.2 Additional heating demand maps




Fraunhofer
ISI
Plot Ratio over 10% (Mun. Area)
below 10%
over 10%
2030 Heat Demand in MWh
0
1 - 6
7 - 15
16 - 40
41 - 102
103 - 210
211 - 371
372 - 615
616 - 1060
1061 - 15965


Fraunhofer
ISI
Plot Ratio over 10% (Mun. Area)
below 10%
over 10%
Heat Demand over 10GWh/year 2030
> 10 GWh
Heat Demand over 10GWh/year 2012
> 10 GWh



Industriestandorte nach Verbrauch	Industrial sites according to consumption
20 GWh	20 GWh
Industriestandorte nach Stromverbrauch	Industrial sites according to electricity consumption
Areale mit Wärmebedarf über 10GWh/qkm/y 2030	Areas with a heating demand over 10 GWh/km^2/yr 2030
> 10GWh/Jahr	> 10 GWh/year