**ISI**

**Fraunhofer-Institut**
**System- und Innovationsforschung**
*[Fraunhofer Institute for Systems and Innovation Research]*

**Bremer Energie Institut**
*[Bremen Energy Institute]*

# Final report

## on the research into the potential of high-efficiency CHP plants in Luxembourg

Edited by:
Marian Klobasa
Fraunhofer-Institut für System- und Innovationsforschung
*[Fraunhofer Institute for Systems and Innovation Research]*

Bernd Eikmeier, Wolfgang Schulz
Bremer Energie Institut
*[Bremen Energy Institute]*

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Contact: Fraunhofer-Institut für System- und Innovationsforschung (ISI)

Breslauer Straße 48
D-76139 Karlsruhe
Competence Center: Energiepolitik und Energiesysteme
*[Energy Policy and Energy Systems]*

Dr. Marian Klobasa (M.Klobasa@isi.fraunhofer.de)

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## Glossary

| | |
|---|---|
| Others | All residential buildings which do not fall into SOH, TH or MOD categories |
| BAB | Building age bracket |
| BEI | Bremer Energie Institut *[Bremen Energy Institute]* |
| SOH | Single occupancy house |
| CTS | Commerce, trade & services sector |
| GIS | Geographic information system |
| lMOD | Large multiple occupancy dwelling |
| GST | Gas and steam turbines |
| ISI | Fraunhofer-Institut für System- und Innovationsforschung *[Fraunhofer Institute for Systems and Innovation Research]* |
| sMOD | Small multiple occupancy dwelling |
| CHP | Combined heat and power generation |
| MOD | Multiple occupancy dwelling |
| TH | Terraced house |
| DU | Dwelling unit |
| LS | Living space |
| BI | Branch of industry |

# 0 Synopsis

Article 6 of EU Directive 2004/8/EC calls for an analysis of the national potential for the use of high-efficiency cogeneration. The findings for the individual fields of application set out in the synopsis constitute a national economic analysis of the cost-effectiveness based on an average increase in the cost of fuels until 2020. In addition to this basic scenario (national economic view, cost scenario 1), a business economic analysis was also carried out and a second cost scenario identified with a greater increase in the cost of fuels.

**District heat potential**

The calculation of the viability of CHP district heat in the private household and CTS sectors is based in the first instance on a precise assessment of the district heat requirement whereby residential buildings are classified by their type and age bracket. Taking both sectors together, the heat output requirement in Luxembourg is 5,011 GWh/a.

The geographic information system (GIS) provided by the contracting body is used to identify the local circumstances and the urban development situations in the individual municipalities as well as a large number of aerial photographs taken at an angle so as to identify building heights. The degree of detail achieved in the analysis makes it possible to localise the basic district heat suitability of the municipalities which are divided into three categories on the basis of their settlement patterns. The 35 municipalities in category 1 account for some three quarters of the heat output demand of these sectors in Luxembourg and are of particular interest. They are subdivided into over 400 zones, with each zone being assessed separately with regard to cost-effectiveness.

The potential with reference to the heat output requirement is analysed firstly on the basis of these individual zones and, secondly, on the basis of combining the zones to form larger supply areas. There is in each case a potential contribution if the sum of CHP heat generation and heat distribution costs is lower than the price which is applicable on the basis of the full costs of a decentralised individual heating system.

A national economic calculation, set against a reference system for the generation of electricity in large power stations, computes the following potential for Luxembourg depending on the point of view and not to be regarded as cumulative:

- Zones supplied individually: 131 GWh/a
- Combined supply of zones: 1,051 GWh/a
  Corresponds to 21% of heat output requirement

The considerable spread is explained by the predominantly rural structure of the country with few large towns and cities. While the CHP heat generation costs are very high with small clusters of heat distribution, a pooling of zones decreases the costs considerably and thus greatly increases the potential. In both cases the cogeneration potential applies only to the two cantons of Luxembourg and Esch-Alzette and here only, or most notably, to the municipalities of the same name.

**Potential for CHP applications for buildings**

The areas of potential for property cogeneration solutions represent in many cases supply alternatives to heat supplied by pipeline and cable. The amount of heat required by the individual property decreases when connected to a heat grid therefore, as a general rule, this would yield greater potential for district heat cogeneration in cases where both options exist. Therefore property-related CHP solutions are disregarded in the areas suitable for district heating cogeneration. An analysis of large properties in category II and III municipalities based on GIS data leads to the recognition that no cogeneration potential is to be identified from a national economic viewpoint.

**Industrial potential**

Data from 59 companies are available to determine the heat requirement in industry. On this basis, and in line with Luxembourg's energy balance, the amount of fuel needed to meet the heat requirement is calculated at 8,515 GWh. This leads to a theoretical heat output of approximately 2,540 GWh which can potentially be covered by CHP plants. This potential increases to approximately 3,226 GWh by 2020 due to a rise in the final energy demand in the industrial sector.

The economic potential is identified in comparison with the full costs of separate power generation in a combined natural gas and steam turbine power station. The heat generated is evaluated in the light of the fuel cost savings with pure heat generation. The economic potential in the basic scenario thereby calculated involves a heat requirement of 1,539 GWh which can be provided by small and medium-sized CHP plants.

Table 0-1: Economic potential for CHP plants in Luxembourg in price scenario 1 until 2020 (national economic analysis)

| **Plant capacity** | **Quantity** | **Installed capacity** | | **Generation** | |
|---|---|---|---|---|---|
| | | Heat MW | Power MW | Heat GWh | Power GWh |
| Unit-type CHP (<1 MW) | 0 | 0 | 0 | 0 | 0 |
| Small CHP (1-10 MW) | 14 | 56 | 48 | 328 | 281 |
| Medium-sized CHP (10-50 MW) | 6 | 127 | 98 | 787 | 604 |
| Large CHP (>50 MW) | 1 | 60 | 60 | 423 | 417 |
| **Total** | **21** | **244** | **205** | **1,539** | **1,302** |

**Biomass potential**

In biomass CHPs the costs are currently still above the power generation costs of the separate reference technologies, thus leaving no economic potential. An analysis of the structural potential which could be exploited with appropriate subsidies reveals a heat requirement of 454 GWh/a which could be covered by CHP plants. The corresponding power generation then reaches approximately 232 GWh/a by 2020.

# 1 Starting basis and background data

## 1.1 Starting basis

The EU Directive 2004/8/EC on the promotion of cogeneration of heat and power (CHP) based on a useful heat demand in the internal energy market (Directive 2004/8/EC) entered into force on 21 February 2004. Article 6 calls for an analysis of the national potential for the application of high-efficiency cogeneration. Annex IV of the Directive defines high-efficiency cogeneration units as plants which provide primary energy savings compared with the separate production of heat and electricity, whereby these savings must be at least 10% in the case of larger plants. No minimum amount of primary energy savings is stipulated for smaller plants. The potential for the application of high-efficiency CHP plants spans four areas of application, namely combined heat and power generation for the provision of district heat, cogeneration for the supply of individual buildings, industrial applications and the exploitation of cogeneration potential through the use of biomass.

High-efficiency CHP plants constitute a building block on the way to achieving the climate protection targets set by the EU due to the primary energy savings and reductions in $CO_2$ emissions achieved in comparison with separate power and heat generation. Due regard must be had to the specific situation in Luxembourg, however, as a large proportion of the country’s power consumption is imported. Imported power is not taken into account into Luxembourg’s carbon balance, however, under the territorial system agreed in the Kyoto Protocol.

The report includes the following sections, some of which are the work of the Bremer Energie Institut under a subcontract agreement:

- Presentation of current framework and historic development (section 1, ISI)
- Deduction of areas of potential for cogeneration in the industrial sector (sections 2/ 3, ISI)
- Deduction of local/ district heating potential including areas of potential for cogeneration in the commerce, trade & services sector (sections 4/ 5/ 6/ BEI)

- Deduction of areas of potential for cogeneration in individual properties (section 7, BEI)

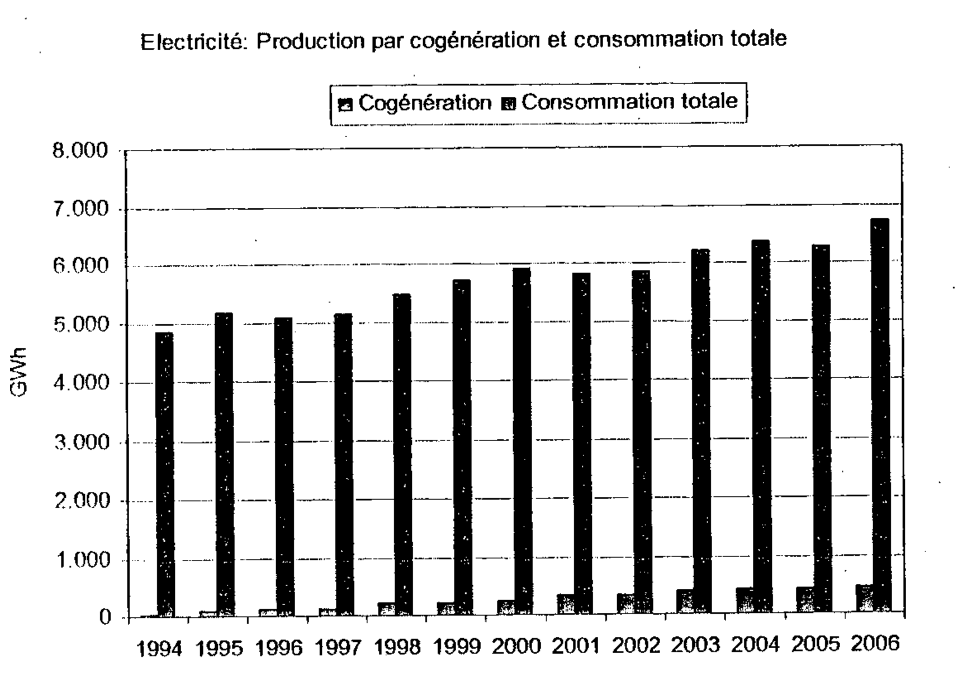
- Provision of areas of potential for cogeneration through biomass (section 8, ISI)

- Combining of areas of potential (section 9, ISI and BEI)

- Hindrances to expansion of cogeneration (section 10, ISI and BEI)

## 1.2. Current status of cogeneration

Following the introduction of the cogeneration subsidy in 1994, the proportion of power generation in CHP plants has risen from 25 GWh to 438 GWh and thus accounts for 6.5% of the total power consumption (Figure 1-1).




Source: Luxembourg Ministry of Finance

Figure 1-1: Graph showing consumption and production of cogenerated power from 1994 to 2006

The generation in CHP plants breaks down into large district heat stations (>150 kW), small district heat stations (<150 kW), customer generation, and industrial cogeneration. The installed electrical power amounts to an approximate total of 100 MW and is spread across 112 plants (as at 6.4.2007). Some of the thermal output statistics were estimated on the basis of typical data as the thermal output figures were not available for all plants (cf. Table 1-1).

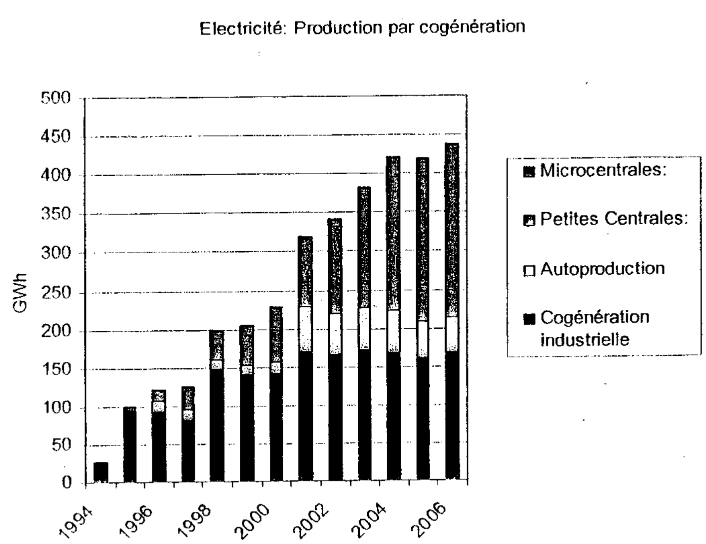
Table 1-1: Installed electrical and thermal output, quantity, capacity and generation of the existing CHP plants in 2006

| **2006** | **Electrical output** | **Thermal output** | **Qty.** | **Power capacity 2005** | **Power generation** | **Heat generation** |
|---|---|---|---|---|---|---|
| | **P(el) [kW]** | **P(th) [kW]** | | **[h]** | **GWh** | **GWh** |
| Industrial cogeneration | 21,700 | 34,000 | 2 | 7,764 | 168 | 264 |
| Customer cogeneration | 9,283 | 18,000 | 3 | 4,953 | 46 | 89 |
| Large district heat stations (Cat. II) | 71,757 | 88,400 | 71 | 3,088 | 222 | 273 |
| Small district heat stations (Cat. I) | 666 | 1,200 | 36 | 3,039 | 2 | 4 |
| **Total** | **103,406** | **141,600** | **112** | **4,237** | **438** | **630** |

Source: Luxembourg Ministry of Finance, thermal output estimated in some cases

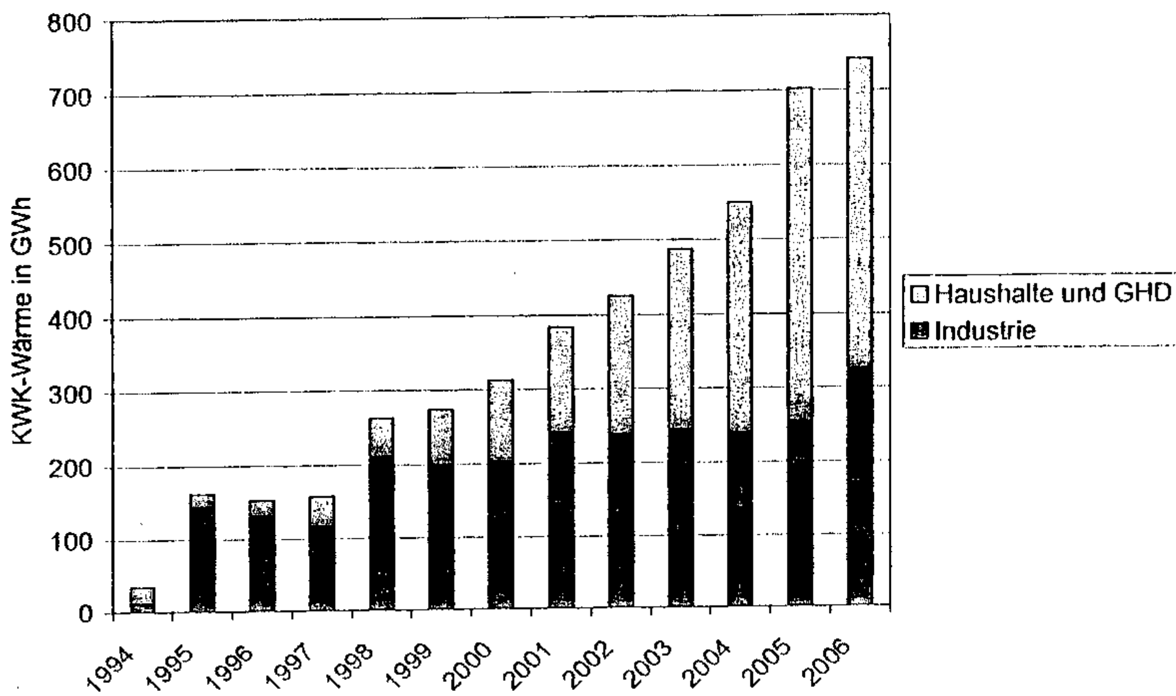
A large proportion of the power generated was provided by industrial CHP plants in the first instance (Figure 1-2), with relatively large district heat stations and customer generation making an additional contribution in recent years. Power generation in small district heat stations (<150 kW) is of less significance.

Figure 1-2: Graph showing cogenerated power production by plant type from 1994 to 2006




Source: Luxembourg Ministry of Finance

Heat generation in CHP plants was 742 GWh in 2006, some 44% of which was used in industry (cf. Figure 1-3). All the heat generated in CHP plants in 2006 accounts for approximately 1.6% of the final demand for non-electrical energy in Luxembourg.




Quelle: Energiebilanzen Luxemburg 1994 bis 2006

| DE | EN |
|---|---|
| KWK-Wärme in GWh | Cogenerated heat in GWh |
| Haushalte und GHD | Households and CTS |
| Quelle: Energiebilanzen Luxemburg 1994 bis 2006 | Source: Luxembourg's energy balance figures from 1994 to 2006 |

Figure 1-3: Graph showing the use of cogenerated heat in industry and in the commerce, trade & services sector (CTS) and the household sector from 1994 to 2006

The final energy demand in Luxembourg was approximately 52 TWh in 2005, some 12 TWh and 32 TWh of which were consumed in industry and transport respectively and some 8 TWh of which were used in all other sectors (cf. Table 1-2). The energy balance in Luxembourg does not itemise the household sector separately from the commerce, trade & services sector (CTS), therefore some of the figures have been estimated for this area. Sectors suitable for CHP plants are most particularly industry and, via a district heat supply, also the household and CTS sectors.

Table 1-2: Final energy balance for 2005 for industry, transport, others, households and CTS

<table>
<tr><th rowspan="3"></th><th colspan="5">Luxembourg final energy balance</th></tr>
<tr><th>Industry</th><th>Transport</th><th>Others</th><th>Households</th><th>CTS</th></tr>
<tr><th colspan="5">Figures in GWh</th></tr>
<tr><td>Power</td><td>3,980</td><td>94</td><td>2,084</td><td>814*</td><td>1,268*</td></tr>
<tr><td>Mineral oil</td><td>1,343</td><td>31,333</td><td>2,561</td><td rowspan="4">4,400<br>(1)</td><td rowspan="4">2,029<br>(2)</td></tr>
<tr><td>Natural gas</td><td>5,339</td><td>0</td><td>3,106</td></tr>
<tr><td>Solid + biomass fuels</td><td>953</td><td>7</td><td>190</td></tr>
<tr><td>Cogenerated heat</td><td>255</td><td>0</td><td>447</td></tr>
<tr><td>Total</td><td>11,871</td><td>31,434</td><td>8,389</td><td>5,214</td><td>3,297</td></tr>
</table>

(1) Estimate made by experts from the Luxembourg Ministry of Finance
(2) Extrapolated from heat/power ratio of 1.6
Source: Luxembourg energy balance, *data based on Eurostat statistics

## 1.3 Assumptions regarding trends in fuel prices

The cost of fuels is based on estimates of the European Commission (Primes fuel prices, Table 1-3). These import prices (excluding any taxes and duties) are converted into energy prices for specific users with the addition of differentiated charges. They also take account of costs incurred by processing, transport, apportionment, storage and distribution. Taxes and other dues ($CO_2$ certificates) also play a key role. A rate of inflation of 1.5% is applied when calculating actual prices. The base year for the data is 2005. The oil price for 2005 corresponds to approximately US $ 81 per barrel (at a rate of US $ 1.48 to the €).

Table 1-3: Price scenario 1: Trend in EU import prices for fossil fuels in € per MWh (actual 2005 prices)

| | | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| Oil | €/ barrel | 54.5 | 54.5 | 57.9 | 61.1 |
| Oil | €/ MWh | 34.5 | 34.5 | 36.6 | 38.6 |
| Gas | €/ MWh | 21.9 | 26.2 | 27.4 | 29.1 |
| Imported coal | €/ MWh | 9.4 | 8.7 | 9.0 | 9.3 |

Source: European Commission (Primes)

The additional charges for specific uses are graduated depending on the fuel and the quantity purchased and their percentages extrapolated until 2020:

- Large-scale power plant prices (surcharge of € 1.5/ MWh on price of natural gas, surcharge of € 0.54/ MWh on hard coal, according to Prognos/ EWI Energy Report and German CHP study)

- Prices for natural gas CHP plants (additional charges graduated according to size of plant, based on German CHP study)

    - From 220 MWel (power plant price + € 0.50/ MWh)
    - From 90 MWel (power plant price + € 1/ MWh)
    - From 5 MWel (power plant price + € 2/ MWh)
    - 1 MWel (power plant price + € 4/ MWh)
    - 310 kWel (power plant price + € 6/ MWh)
    - 54 kWel (power plant price + € 8/ MWh)
    - 18 kWel (power plant price + € 10/ MWh)
    - 5.5 kWel (power plant price + € 11/ MWh)

- Prices for CHP plants in natural gas households (surcharge at approx. € 13/ MWh excl. VAT)

The price of natural gas for households is therefore approx. € 36/ MWh and reflects the prices in Luxembourg at the beginning of 2007 at approx. € 38-40/ MWh (incl. taxes).

With a view to assessing the risks of rising fuel prices vis-à-vis the European Commission scenario, a second price scenario is taken for the calculation which is based on 50% higher fuel prices in 2020 (Table 1-4).

Table 1-4: Price scenario 2: Trend in EU import prices for fossil fuels in € per MWh (actual 2005 prices)

| | | **2005** | **2010** | **2015** | **2020** |
|---|---|---|---|---|---|
| Oil | €/ barrel | 54.50 | 65.40 | 78.17 | 91.65 |
| Oil | €/ MWh | 34.50 | 41.40 | 49.41 | 57.90 |
| Gas | €/ MWh | 21.90 | 31.44 | 36.99 | 43.65 |
| Imported coal | €/ MWh | 9.40 | 10.44 | 12.15 | 13.95 |

Source: Own calculation based on Primes with 50% higher prices in 2020

Further statistics for the calculation of the economic efficiency of the CHP plants are listed in Table 1-5. The expected returns are assumed at 10% instead of at 6.5% in the case of a business economic analysis. The $CO_2$ price represents the current market expectation for the next few years.

Table 1-5: Interest rate, life cycle and $CO_2$ prices used to calculate the economic efficiency of CHP plants

| **Indicator** | **Value** | **Comments** |
|---|---|---|
| Interest rate | 6.5%/ 10% | National economy/ business economy |
| Life cycle | 12-20 years | Subject to technology |
| Price of $CO_2$ certificate | € 20/ t | |

## 1.4 Current subsidy conditions for CHP plants

The rules governing the subsidy of CHP plants are set out in the following laws and ordinances:

- Law of 5 August 1993 on the rational use of energy. This law has the character of a skeleton law setting out the principles for promoting renewable energies and energy efficiency measures

- (Amended) Grand Ducal Regulation of 30 May 1994 on the production of electricity from renewable energies and on the cogeneration of heat and power

- Law of 31 May 1999 on the introduction of an environmental protection fund

- Ministerial Circular dated 20 April 2005 on the environmental protection fund

- (Amended) Grand Ducal Regulation of 22 May 2001 on the introduction of a compensation fund in the context of the organisation of the electricity market

**(Amended) Grand Ducal Regulation of 30 May 1994 on the production of electricity from renewable energies and on the cogeneration of heat and power**

This regulation sets out the subsidy rates for CHP plants. The supply of power generated from CHP plants by the grid operator CEGEDEL is guaranteed for two years and is extended for one year at a time if neither the operator of the CHP plant nor CEGEDEL cancels this agreement. The subsidy rates are defined for the two plant categories specified in the skeleton law of 5.8.1993.

**Category I plants (1 to 150 kW):**

- Basic rate: Approx. 8.2 cents/ kWh (as at 2007)

The payment is adjusted on the basis of a general consumer price index. No demand rate payments are made for these plants.

**Category II plants (151 to 1500 kW):**

- Demand rate: Approx. € 159.6/ kW per annum

- Basic rate: Approx. 8.1 cents/ kWh (daytime), approx. 4.2 cents/ kWh (night-time)

The payment is adjusted on the basis of a general consumer price index and a gas price index.

Industrial plants are not currently systematically subsidised. Nor are any payments made for avoided grid use.

### 1.5 Approval procedures for CHP plants

The granting of approval for the operation of CHP plants is subject to the authority of the Department of the Environment and the Department of Labour and Employment and is generally processed by the "Administration de l'Environnement" and the "Inspection du Travail et des Mines" under the amended law of 10 June 1999 on classified establishments ("Loi modifiée du 10 juin 1999 relative aux établissements classés").

The law distinguishes between the types of plants which need to apply for approval and sets out procedures of varying complexity for plants of different categories. Depending on their capacity, CHP plants are categorised as Class 1 (plans announced and opportunity allowed for public objection) or Class 3 (plans not announced and no opportunity allowed for public objection).

The "Administration de l'Environnement" and the "Inspection du Travail et des Mines" publish application forms and guidelines which stipulate various requirements in terms of environmental protection and safety.

In recent years these approval procedures have led to an expansion in heat-led CHP plants with a high proportion of heat recovery.

This leads the author of this report to conclude that, at the current time, there are no major legal obstacles or hindrances of similar weight to the expansion of cogeneration in Luxembourg.

The regulations are to be seen as being largely transparent and making due allowance for the specific differences between the various cogeneration technologies.

### 1.6 Basic technical and economic data relating to CHP plants

Individual reference plants are taken as models in order to calculate the cost-effectiveness of CHP plants in industry and district heating. The cost of cogeneration technologies includes capital investment (including expenditure on peripheral technical equipment and construction work), variable operating costs (fuel costs, process materials) and fixed operating costs (personnel, administration, insurance).

Table 1-6: Basic technical and economic data relating to 5 - 220 MW CHP plants

| **Key ratios** | **Unit** | **Gas and steam cogeneration plant (CT)** | **Gas and steam cogeneration plant (CT)** | **Gas turbine** | **Gas and steam cogeneration plant (BP)** | **Gas turbine** | **Block-type cogeneration unit** |
|---|---|---|---|---|---|---|---|
| Output [MW] | MW (el) | **220** | **100** | **90** | **20** | **10** | **5.4** |
| Electrical efficiency | % | 47.6 | 47.1 | 33.0 | 44.4 | 31.0 | 41.5 |
| Thermal efficiency | % | 40.3 | 41.0 | 52.4 | 42.3 | 49.0 | 43.2 |
| Total efficiency | % | 87.9 | 88.1 | 85.4 | 86.7 | 80.0 | 84.7 |
| Investment | €/ kW (el) | 530 | 540 | 555 | 820 | 700 | 750 |
| Fixed operating costs | €/ kW/ a % of investment | 37.1<br>7% | 37.8<br>7% | 33.3<br>6% | 57.4<br>7% | 42.0<br>6% | 15.0<br>2% |
| Other variable operating costs | €/ $MWh_{el}$ | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 8 |

Source: Eikmeier 2006, Ingenieurbüros, CT = Condensing turbine, BP = Back-pressure turbine

Table 1-7: Basic technical and economic data relating to 0.018 to 2 MW CHP plants

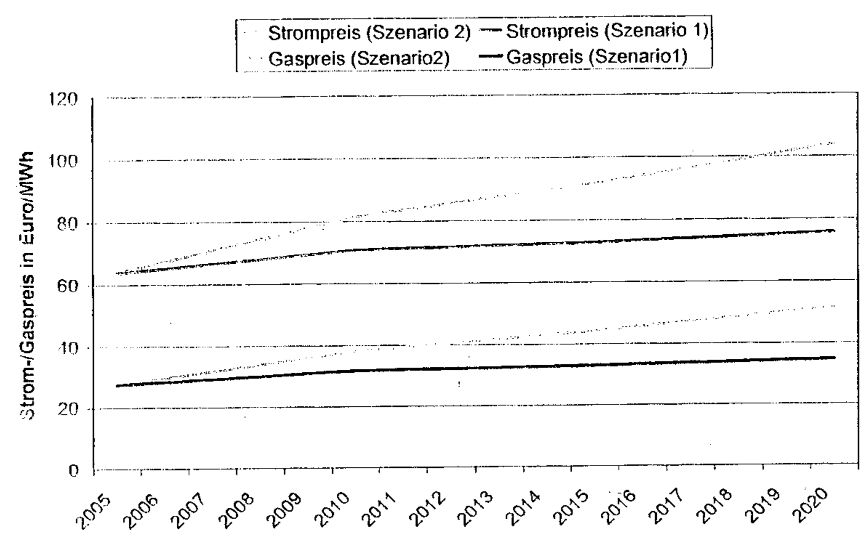
| **Key ratios** | **Unit** | **Block-type cogeneration unit** | **Block-type cogeneration unit** | **Block-type cogeneration unit** | **Block-type cogeneration unit** | **Block-type cogeneration unit** | **Block-type cogeneration unit** |
|---|---|---|---|---|---|---|---|
| Output [MW] | MW (el) | **2** | **1** | **0.5** | **0.31** | **0.05** | **0.018** |
| Electrical efficiency | % | 39.0 | 38.1 | 35.4 | 35.3 | 31.0 | 27.6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Thermal efficiency | % | 47.6 | 48.2 | 53.6 | 53.7 | 58.0 | 58.4 |
| Total efficiency | % | 86.5 | 86.3 | 89.0 | 89.0 | 89.0 | 86.0 |
| Investment | €/ kW (el) | 800 | 900 | 1200 | 1300 | 1400 | 1680 |
| Fixed operating costs | €/ kW/ a % of investment | 16.0 2% | 18.0 2% | 24.0 2% | 26.0 2% | 28.0 2% | 33.6 2% |
| Other variable operating costs | €/ $MWh_{el}$ | 8 | 12 | 15 | 16 | 20 | 28 |

Source: Eikmeier 2006, Ingenieurbüros

## 1.7 Reference power generation costs

As a reference power generation technology it is assumed that newly installed CHP plants will have to compete against separate generation provided by new gas-fired power plants with an electric efficiency rate of 58%. The full costs were identified for capacity utilisation of 4000 full load hours. The $CO_2$ emissions are valued at € 20/ t. The operating life of the power plant is assumed to be 30 years. Depending on the assumed fuel prices, the full costs of power generation in price scenario 1 increase from € 63.6/ MWh in 2006 to € 75.6/ MWh in 2020 (see Figure 1-4). In price scenario 2 the costs increase to € 103.8/ MWh. The mean electricity price which results for the period under review is therefore approximately € 71/ MWh in price scenario 1 and approximately € 86/ MWh in price scenario 2.




Quelle: Eigene Berechnungen, $CO_2$-Preis: 20 €/ t

| DE | EN |
|---|---|
| Strompreis (Szenario 2) | Electricity price (scenario 2) |
| Strompreis (Szenario 1) | Electricity price (scenario 1) |
| Gaspreis (Szenario 1) | Gas price (scenario 1) |
| Gaspreis (Szenario 2) | Gas price (scenario 2) |
| Strom-/Gaspreis in Euro/MWh | Electricity/gas price in EUR/MWh |
| Quelle: Eigene Berechnungen, $CO_2$-Preis: 20 €/t | Source: Own calculations, $CO_2$ price € 20/ t |

Figure 1-4: Graph showing trend in electricity and gas prices from 2005 to 2020 for price scenarios 1 and 2

Electricity prices in Luxembourg are currently € 90/ MWh for industrial customers and €/ MWh for domestic customers (Eurostat 2006), in each case including grid use.

The **baseline scenario** used in the study is price scenario 1 combined with a national economic cost-effectiveness analysis.

## 1.8 Assessment of primary energy savings and $CO_2$ savings

The aim of EU Directive 2004/8/EC is to save primary energy through the use of high-efficiency CHP plants and thereby minimise greenhouse gas emissions. The pronouncements of the European Commission on the greenhouse gas balance in the individual Member States mean that reductions in emissions achieved by CHP plants in Luxembourg are not factored into Luxembourg's greenhouse gas balance. Under the territorial principle the greenhouse gas account is always balanced at the place where the emissions occur. A large proportion of Luxembourg's power requirements are met by imports therefore the emissions in this case are not imputed to Luxembourg but to the countries from which the power is imported. If this imported power is replaced by national cogeneration in CHP plants then this would increase Luxembourg's greenhouse gas balance.

Primary energy savings and $CO_2$ savings are assessed in the first instance as set out in the Cogeneration Directive. The impact of an increase in national cogeneration in CHP plants on the greenhouse gas balance is discussed in section 10.

The criteria of the Cogeneration Directive of the European Union prescribe two comparable systems for the assessment of primary energy savings and $CO_2$ savings:

- Savings pursuant to the power and heat generation **actually** replaced
- Savings against the **best available** system of separate generation in plants using the same fuel

It does need to be borne in mind, however, that - as already explained - the $CO_2$ savings do not have a direct impact on Luxembourg's $CO_2$ balance as the primary effect is to avoid importing power. The first case therefore details the savings which can be achieved by taking an EU-wide view, while the second case details the savings which can be realised if there is a national expansion of the power generation capacity as compared to a new separate heat and power generation system in Luxembourg.

**Power side**

The power mix actually replaced by CHP plants is estimated at a primary energy demand of 2.5 kWh(br)/ kWh(el) and a $CO_2$ emission factor of 0.654 kg $CO_2$/ kWh(el). This corresponds to 30% nationally generated power and 70% imported power. The nationally generated power is primarily provided by Twinerg. The imported power is assessed with the specific power generation factors used by RWE. The assumed power station efficiency levels are 55% for Twinerg and 35% for the imported power. The $CO_2$ emission factors are based on the fuels used, namely natural gas (Twinerg) and hard coal (imported power).

A combined gas and steam turbine plant with a 58% efficiency rating is assumed as a benchmark reference when assessing the best available technology for separate generation using the same fuel. Natural gas is the fuel used.

**Heat side**

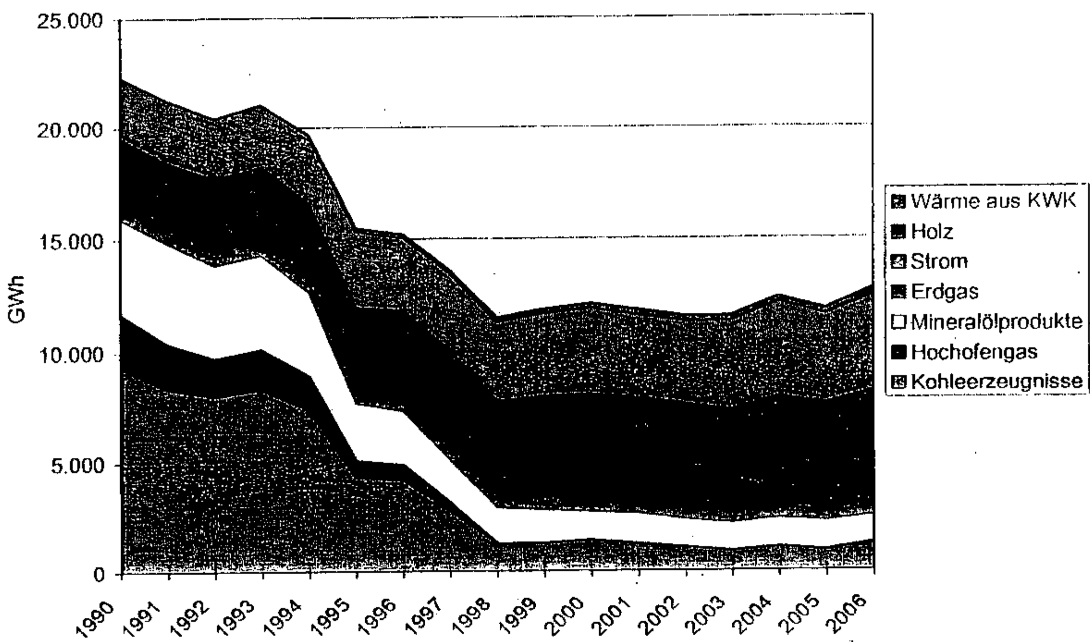
The quantity of heat replaced by cogeneration shows a primary energy demand of 1.1 kWh(br)/ kWh(th) and a $CO_2$ emission factor of 0.220 kg $CO_2$/ kWh(th) in the industrial sector, assuming the use of a natural gas-fired heating boiler with a 90% efficiency rating. In local/ district heating the calculation is based on a primary energy demand of 1.27 kWh(br)/ kWh(th) and a $CO_2$ emission factor of 0.251 kg $CO_2$/ kWh(th), assuming in this case that the generation of heat in industry is already more efficient nowadays than in private households.

On the heat side a primary energy demand of 1.1 kWh(br)/ kWh(th) and a $CO_2$ emission factor of 0.220 kg $CO_2$/ kWh(th) are the figures taken as standard for the best available technology in industry and in local/ district heating, assuming with respect to the industrial sector that improvements in efficiency in heat generators are much lower and that modernisation rates are much higher resulting in no difference between existing and new plants. A slight improvement in efficiency is assumed for local/ district heating systems.

## 2 Heat requirements in industry

### 2.1 Description of the industrial sector

The final energy consumption in industry accounts for some 25% of Luxembourg's total final energy consumption. Natural gas and electricity are the main sources of power in industry. Following a sharp decline since 1990, the proportion of coal products was down to only around 10% of the final energy consumption in 2006 (cf. Figure 2-1). This decline is mainly accounted for by the fact that the steel production industry has converted from blast furnace steel to electric steel.

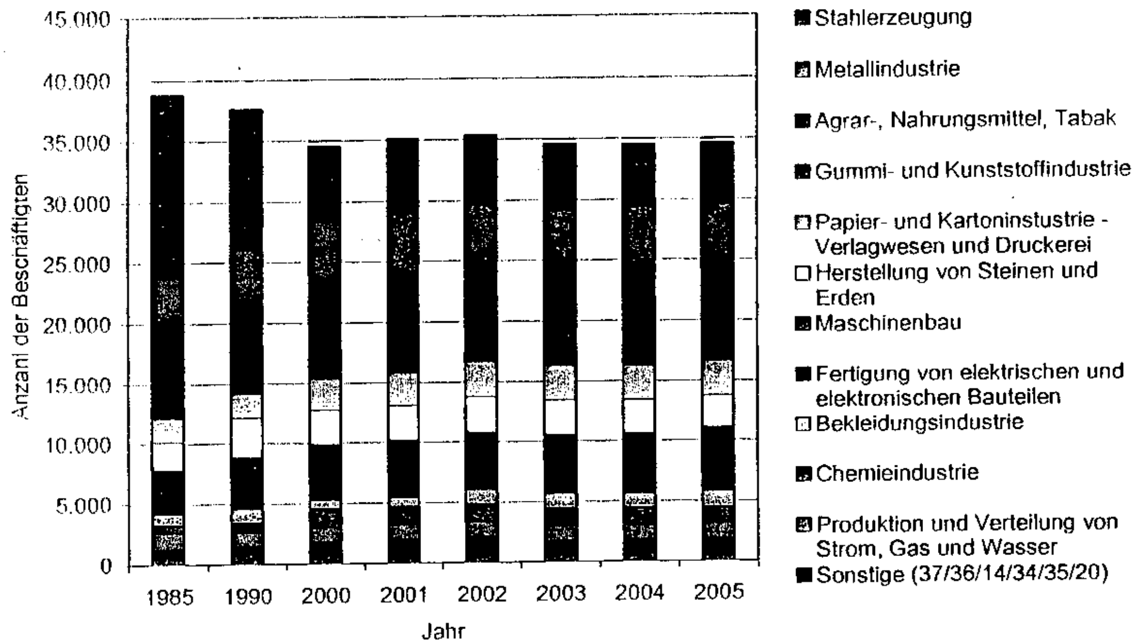



Quelle: Energiebilanz Luxemburg 1990 bis 2006

| DE | EN |
|---|---|
| GWh | GWh |
| Wärme aus KWK | Cogenerated heat |
| Holz | Timber |
| Strom | Electricity |
| Erdgas | Natural gas |
| Mineralölprodukte | Petroleum products |
| Hochofengas | Blast furnace gas |
| Kohleerzeugnisse | Coal products |
| Quelle: Energiebilanz Luxemburg 1990 bis 2006 | Source: Energy balance statistics for Luxembourg from 1990 to 2006 |

Figure 2-1: Graph showing the trend in the final energy consumption in industry from 1990 to 2006

The steel and metal industry is the biggest employer besides the construction sector (see Figure 2-2). Other major sectors of industry are food, rubber and plastics.




Quelle: Statec 2007b

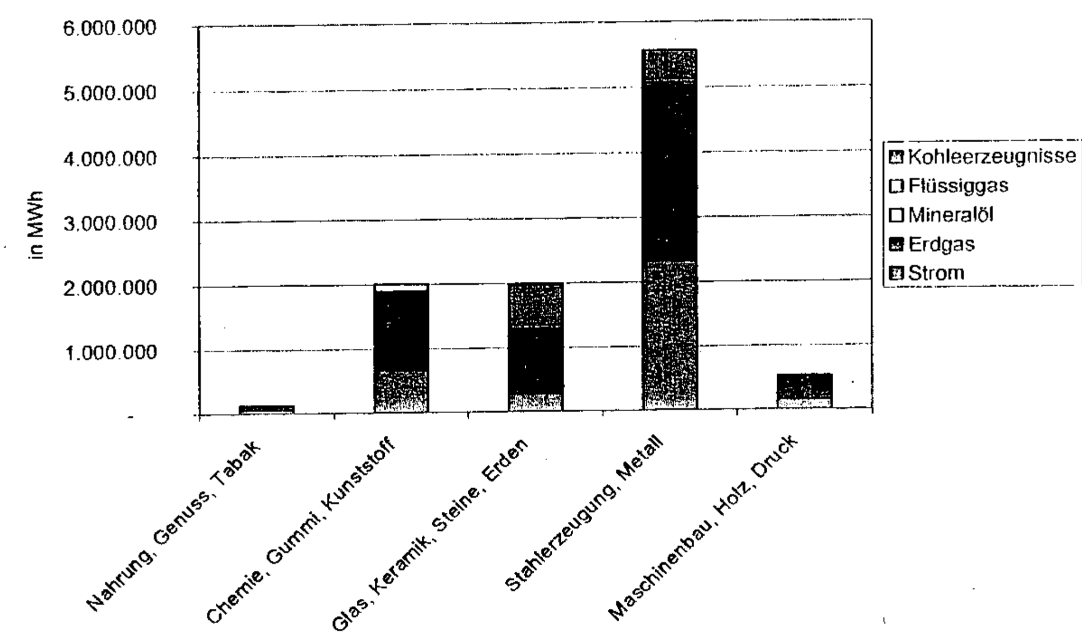
| DE | EN |
|---|---|
| Anzahl der Beschäftigten | Number of employees |
| Stahlerzeugung | Steelmaking |
| Metallindustrie | Metal industry |
| Agrar-, Nahrungsmittel, Tabak | Farming, food, tobacco |
| Gummi- und Kunststoffindustrie | Rubber and plastics industry |
| Papier- und Kartonindustrie - Verlagwesen und Druckerei | Paper and card industry, publishing and printing |
| Herstellung von Steinen und Erden | Non-metallic mineral processing |
| Maschinenbau | Mechanical engineering |
| Fertigung von elektrischen und elektronischen Bauteilen | Production of electrical and electronic components |
| Bekleidungsindustrie | Clothing industry |
| Chemieindustrie | Chemicals industry |
| Produktion und Verteilung von Strom, Gas und Wasser | Production and distribution of electricity gas and water |
| Sonstige (37/36/14/34/35/20) | Other (37/36/14/34/35/20) |

| | |
|---|---|
| Jahr | Year |
| Quelle: Statec 2007b | Source: Statec 2007b |

Figure 2-2: Trend in employment figures in industry (excluding construction sector) from 1985 to 2005

## 2.2 Heat requirements in industry in 2006

Research was conducted into the amount of power and heat required by 59 companies. A comparison with the energy balance for Luxembourg shows that the research covers some 82% of the final energy consumption of the industrial sector. The worst records are on the petroleum consumption in industry which accounts for only approximately 15% of the demand according to the energy balance. The final energy consumption is highest in the steel and metal processing industry at over 5,500 GWh, followed by the rubber and plastics industry, and then the glass industry and the non-metallic minerals industry (see Figure 2-3).



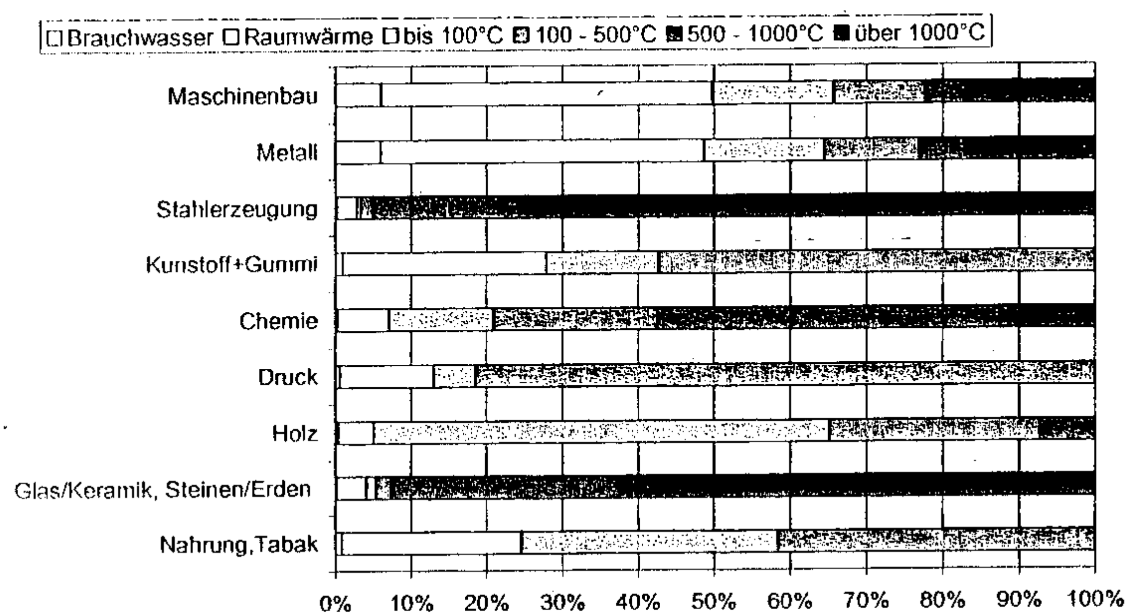

Quelle: FEDIL 2007

| DE | EN |
|---|---|
| in MWh | In MWh |
| Kohleerzeugnisse | Coal products |
| Flüssiggas | Liquefied gas |
| Mineralöl | Petroleum |
| Erdgas | Natural gas |
| Strom | Electricity |

| | |
|---|---|
| Nahrung, Genuss, Tabak | Food, luxuries, tobacco |
| Chemie, Gummi, Kunststoff | Chemicals, rubber, plastics |
| Glas, Keramik, Steine, Erde | Glass, ceramics, non-metallic minerals |
| Stahlerzeugung, Metall | Steelmaking, metal |
| Maschinenbau, Holz, Druck | Mechanical engineering, timber, printing |
| Quelle: FEDIL 2007 | Source: FEDIL 2007 |

Figure 2-3: Final energy consumption for 2006 broken down by sectors of industry and fuels

The heat consumption is calculated on the basis of the fuel requirements of the individual sectors. The first information of relevance is research conducted in Germany where the heat consumption is allocated to different temperature levels (cf. Figure 2-4). CHP plants have the technical capacity to provide heat at temperatures of up to 500ºC. Local directly-fired heat generators are required as a general rule to provide heat at temperatures in excess of 500ºC. The main sectors of industry which are suitable for CHP plants are therefore rubber and plastics, food, printing, metalworking and mechanical engineering. A large proportion of the heat required in all sectors is below 500ºC. Heat at high temperatures beyond the capability of CHP plants is required mainly in steel production, and in the glass and non-metallic mineral industries.




Quelle: KWK-Studie Deutschland (Eikmeier et al. 2006)

| DE | EN |
|---|---|
| Brauchwasser | Process water |
| Raumwärme | Space heating |
| bis 100°C | Up to 100°C |
| über 1000°C | Over 1000°C |
| Maschinenbau | Mechanical engineering |
| Metall | Metal |
| Stahlerzeugung | Steelmaking |
| Kunststoff + Gummi | Plastics + rubber |
| Chemie | Chemicals |
| Druck | Printing |
| Holz | Timber |
| Glas/Keramik, Steine/Erde | Glass/ ceramics, non-metallic minerals |
| Nahrung, Tabak | Food, tobacco |
| Quelle: KWK-Studie Deutschland (Eikmeier et al. 2006) | Source: CHP research relating to Germany (Eikmeier et al. 2006) |

Figure 2-4: Heat requirements in Germany broken down by sectors and temperature levels

On the basis of this heat distribution, the heat demand in industry suitable for CHP plants can be estimated from the total heat demand at approximately 2.8 TWh. This corresponds to the theoretical upper limits of the available potential (cf. Table 2-1). Contrary to the estimates in Germany, the heat demand of the chemicals industry was calculated on the basis of the plastics and rubber industry because, unlike Germany, Luxembourg has no established bulk chemical industry with its typical demand for heat at high temperatures. The chemicals industry found in Luxembourg primarily requires heat at temperatures up to 500ºC given the production processes involved, and this is far more accurately represented by the heat distribution in the rubber and plastics industry.

Table 2-1: Total heat consumption in industry in 2006 and demand for heat at temperatures below 500ºC

| | **Heat** | | | | **Of which cogenerated** | | |
|---|---|---|---|---|---|---|---|
| | **Total** | **Of which** | | | | | |
| | | **< 500ºC** | **< 100ºC** | **Space heating** | **Heat** | **Heat** | **Power** |
| | **GWh** | | | | **GWh** | **%** | **GWh** |
| Food & tobacco | 71 | 71 | 42 | 17 | 0 | | |
| Chemicals, rubber & plastics | 1348 | 1348 | 576 | 362 | 277 | 20.5 | 167 |
| Glass/ ceramics, non-metallic minerals | 1696 | 126 | 92 | 66 | 0 | | |
| Metal production | 3250 | 922 | 754 | 509 | 0 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| & processing | | | | | | | |
| Timber, printing, mechanical engineering | 382 | 354 | 225 | 22 | 121 | 34.2 | 39 |
| Other | 1441 | n/a | | | n/a | | |
| **Total** | **8189** | **2822** | **1688** | **711** | | | |

Detailed data are available for some companies which take part in emissions trading and make partial use of CHP plants. These companies account for some 52% of industrial fuel consumption in Luxembourg. These companies currently meet 9% of their heat requirements from CHP plants and, accordingly, approximately 9% of their power requirements. Some companies do not use CHP plants because the heat they require must be at high temperatures.

### 2.3 Forward projection of heat requirements to 2020

The heat demand is extrapolated from fuel consumption trends in the individual sectors and is based on the projections of the European Commission in Primes. The fundamental assumptions for the trend in the individual sectors are as follows:

- Development of net value-added
- Development of energy intensity

A doubling of the net value-added from € 3.1 billion to € 6.1 billion is assumed in the industrial sector in Luxembourg from 2005 to 2020. This corresponds to an annual growth rate of 4.6% for the industrial sector. At the same time the energy efficiency of the industrial sector increases year on year by some 1.6% resulting in a total increase in the final energy consumption in the industrial sector of just 54% from 2005 to 2020. As a general rule, the assumed improvements in efficiency in individual sectors cannot be continually realised in industries with just a few companies as they are mostly based on single investments in new plant technology which then lead to a sudden jump in efficiency.

Table 2-2: Development in net value-added from 2005 to 2020 broken down by sectors

| | **2005-2020** | **2005** | **2010** | **2015** | **2020** |
|---|---|---|---|---|---|
| | **Growth % p.a.** | **In € bn** | | | |
| Food & tobacco | 5.3 | 0.186 | 0.232 | 0.323 | 0.406 |
| Chemicals, rubber, plastics | 6.5 | 0.163 | 0.240 | 0.331 | 0.420 |

| | | | | | |
|---|---|---|---|---|---|
| Glass, ceramics, non-metallic minerals | 3.7 | 0.221 | 0.259 | 0.319 | 0.380 |
| Steelmaking, metal | 1.1 | 0.490 | 0.518 | 0.553 | 0.577 |
| Mechanical engineering, timber, printing, other | 5.1 | 2.038 | 2.578 | 3.504 | 4.314 |
| **Total** | **4.6** | **3.099** | **3.828** | **5.030** | **6.098** |

Source: Primes, Baseline Scenario

Table 2-3: Development in energy intensity from 2005 to 2020 broken down by sectors

| | **2005-2020** | **2005** | **2010** | **2015** | **2020** |
|---|---|---|---|---|---|
| | **Efficiency increase % p.a.** | **In tonnes of crude oil equivalent/ € million** | | | |
| Food & tobacco | 2.3 | 73.2 | 62.7 | 56.0 | 51.4 |
| Chemicals, rubber, plastics | 1.5 | 214.7 | 192.0 | 181.7 | 171.8 |
| Glass, ceramics, non-metallic minerals | 2.8 | 230.5 | 194.3 | 174.7 | 150.8 |
| Steelmaking, metal | 0.7 | 769.0 | 761.3 | 733.5 | 693.4 |
| Mechanical engineering, timber, printing, other | 0.7 | 248.1 | 240.7 | 233.6 | 222.9 |
| **Total** | **1.6** | **317.0** | **294.2** | **270.1** | **248.0** |

Source: Primes, Baseline Scenario

Table 2-4: Development in final energy consumption from 2005 to 2020 broken down by sectors of industry

| | 2005-2020 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| | **Increase %** | **In GWh** | | | |
| Food & tobacco | 53 | 159 | 170 | 210 | 242 |
| Chemicals, rubber, plastics | 107 | 406 | 536 | 700 | 840 |
| Glass, ceramics, non-metallic minerals | 12 | 593 | 584 | 649 | 666 |
| Steelmaking, metal | 6 | 4,385 | 4,589 | 4,718 | 4,654 |
| Mechanical engineering, timber, printing, other | 90 | 5,882 | 7,217 | 9,521 | 11,182 |
| **Total** | **54** | **11,425** | **13,095** | **15,798** | **17,585** |

Source: Primes, Baseline Scenario

The heat requirement suited to CHP plants is projected on the basis of the final energy consumption of the sectors. An increase in fuel consumption is expected by 2020 in the chemicals industry and in the rubber/ plastics industry in particular. By contrast, the increase in the metal production and processing industry is only very slight. A shift from heat to power applications has further impact, with the potential for cogenerated heat rising from 2,822 GWh in 2006 to approximately 3,600 GWh in 2020 (see Table 2-5).

Table 2-5: Trend in total heat consumption and demand for heat at temperatures below 500ºC in industry from 2006 to 2020

| | Fuel requirement | | | | Of which suited to CHP | | |
|---|---|---|---|---|---|---|---|
| | **2006** | **2010** | **2015** | **2020** | **2010** | **2015** | **2020** |
| | **GWh** | | | | **GWh** | **GWh** | **GWh** |
| Food & tobacco | 71 | 73 | 83 | 91 | 73 | 83 | 91 |
| Chemicals, rubber & plastics | 1348 | 1566 | 1923 | 2181 | 1566 | 1923 | 2180 |
| Glass/ ceramics, non-metallic | 1696 | 1647 | 1636 | 1583 | 122 | 121 | 117 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| minerals | | | | | | | |
| Metal production & processing | 3250 | 3039 | 2827 | 2546 | 862 | 802 | 722 |
| Timber, printing, mechanical engineering | 382 | 417 | 485 | 510 | 387 | 450 | 473 |
| Other | 1441 | 1608 | 1939 | 2159 | n/a | n/a | n/a |
| **Total** | **8189** | **8349** | **8894** | **9070** | **3010** | **3380** | **3584** |

# 3 Analysis of cost-effectiveness of industrial CHP plants

## 3.1 Procedure

**National economic analysis:**

The potential of industrial CHP plants in terms of the national economy can be calculated by way of a comparison with an alternative separate power and heat generating system. It is necessary in the process to identify reference technologies for the generation of both the power and the heat. In this study the following approach is adopted with regard to determining the industrial potential:

- Comparison of cogenerated electricity with the full costs of a new separate generating technology using the same fuel
  - Power side: Evaluation of power generation including costs of a new combined natural gas and steam turbine plant (cf. also section 1.7)
  - Heat side: Evaluation of heat generation including savings on fuel for separate heat generation, heat generator with 90% efficiency

Given these conditions, the cost-effectiveness of industrial CHP plants depends on the achievable number of full load hours. Therefore the first step is to calculate what length of utilisation of the CHP plants described in section 1.6 is needed in order to arrive at the same power generation costs as with the reference technology.

In order to calculate the economic potential of cogeneration it is then necessary to proceed to the second step which is to identify those companies which have sufficient annual heat demands and the necessary production times to reach the required number of full load hours.

**Business economic analysis:**

In terms of business economics, the starting point is to calculate the power generation costs of the plants and to compare these with achievable revenues for the generated power. Government subsidies are not currently available for cogenerated power from industrial plants therefore the marketing of the power to an energy supply company constitutes the reference case. The wholesale prices or the EEX cogeneration reference price (CHP index) are taken as guide prices.

### 3.2 Potential from a national economic viewpoint

In order to calculate the potential in terms of the national economy, it is necessary in the first instance to work out how many full load hours of the individual CHP technologies would be needed to arrive at the same generation costs as with the separate reference power generation system. On account of the tapering scale of costs, the large plants reach the same price as the reference power at lower numbers of full load hours. One factor which emerges most strongly is that the small plants up to 310 kW(el) are always more expensive than the separate reference power generation (see Table 3-1).

Table 3-1: Minimum number of full load hours to be achieved at industrial CHP plants

| | Block-type cogeneration unit | | | | Gas turbine | Gas and steam turbine | Gas turbine | Gas and steam turbine | |
|---|---|---|---|---|---|---|---|---|---|
| Electrical output [MW] | 0.5 | 1 | 2 | 5.4 | 10 | 20 | 90 | 100 | 220 |
| Price scenario 1 € 20/ t $CO_2$ | >8760 | 6500 | 4500 | 3900 | 5000 | 4400 | 2900 | 2500 | 2400 |
| Price scenario 2 € 20/ t $CO_2$ | >8760 | 6300 | 4200 | 3600 | 5000 | 4000 | 2600 | 2200 | 2100 |

The second step is to identify those companies which have sufficient heat demands as well as the necessary production times to operate the CHP plants for the required number of full load hours.

It is evident that a large number of those enterprises with high energy requirements typically operate a triple shift system. For the other companies, the method of production was estimated on the basis of employee numbers and typical production times, as are known to apply to German companies.

The analysis of the production times of the companies shows that some of the companies which operate dual and triple shift production systems do achieve the necessary number of full load hours. Operating times of approximately 4660 hours and 7000 hours on dual and triple shifts respectively were assumed to identify the thermal output and the amounts of cogenerated heat. The heating provided by the CHP plants was set at 75% of the total heat demand (related to the amount of heat generated). It was assumed that a peak-load boiler was used for the remaining heat.

On this basis, approximately 21 plants would be possible in Luxembourg altogether which, given a thermal output of some 244 MW, could provide approximately 1539 GWh of heat (see Table 3-2). The plants would mainly be block-type cogeneration units and smaller cogeneration plants.

Table 3-2: Economic potential for CHP plants in Luxembourg until 2020 adopting price scenario 1

| Plant output | Qty. | Installed capacity | | Generation | |
|---|---|---|---|---|---|
| | | Heat | Power | Heat | Power |
| | | MW | MW | GWh | GWh |
| Block-type cogeneration unit (<1 MW) | 0 | 0 | 0 | 0 | 0 |
| Small CHP (1-10 MW) | 14 | 56 | 48 | 328 | 281 |
| Medium-sized CHP (10-50 MW) | 6 | 127 | 98 | 787 | 604 |
| Large CHP (>50 MW) | 1 | 60 | 60 | 423 | 417 |
| **Total** | **21** | **244** | **205** | **1,539** | **1,302** |

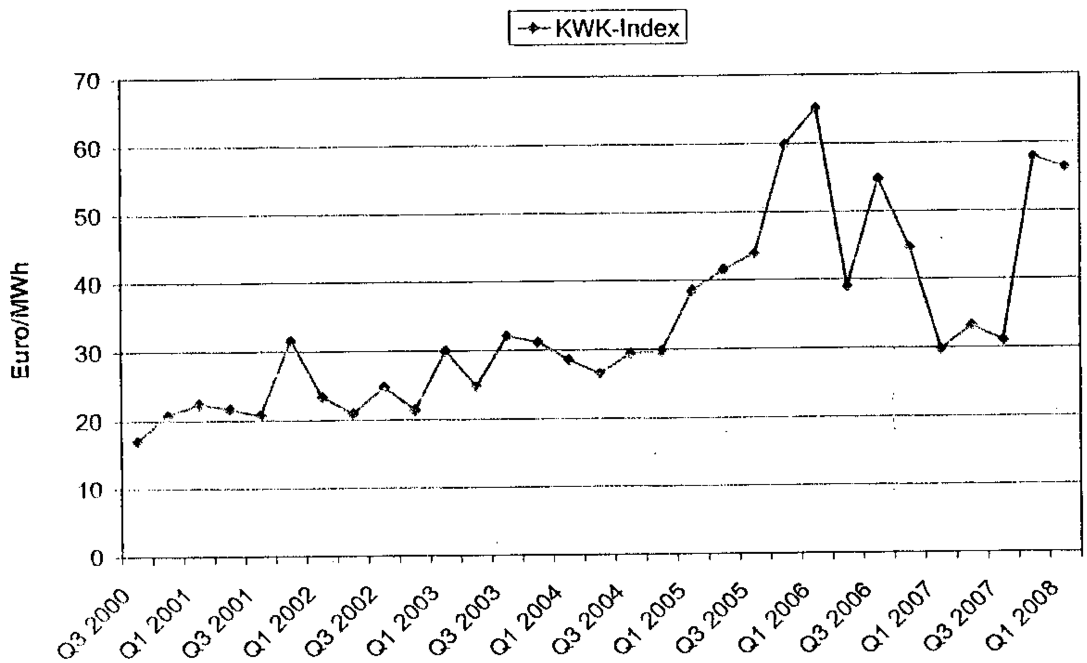
The number of full load hours needed for cost-effective operation in price scenario 2 is only slightly lower therefore there are only two more plants in this case with an installed thermal capacity of 4.3 MW. As such, the increase in potential is likewise very small.

Table 3-3: Economic potential for CHP plants in Luxembourg until 2020 adopting price scenario 2

| Plant output | Qty. | Installed capacity | | Generation | |
|---|---|---|---|---|---|
| | | Heat | Power | Heat | Power |
| | | MW | MW | GWh | GWh |
| Block-type cogeneration unit (<1 MW) | 0 | 0 | 0 | 0 | 0 |
| Small CHP (1-10 MW) | 16 | 60 | 51 | 348 | 298 |
| Medium-sized CHP (10-50 MW) | 6 | 127 | 98 | 787 | 604 |
| Large CHP (>50 MW) | 1 | 60 | 60 | 423 | 417 |
| **Total** | **23** | **248** | **209** | **1,559** | **1,319** |

## 3.3 Potential from a business economic viewpoint

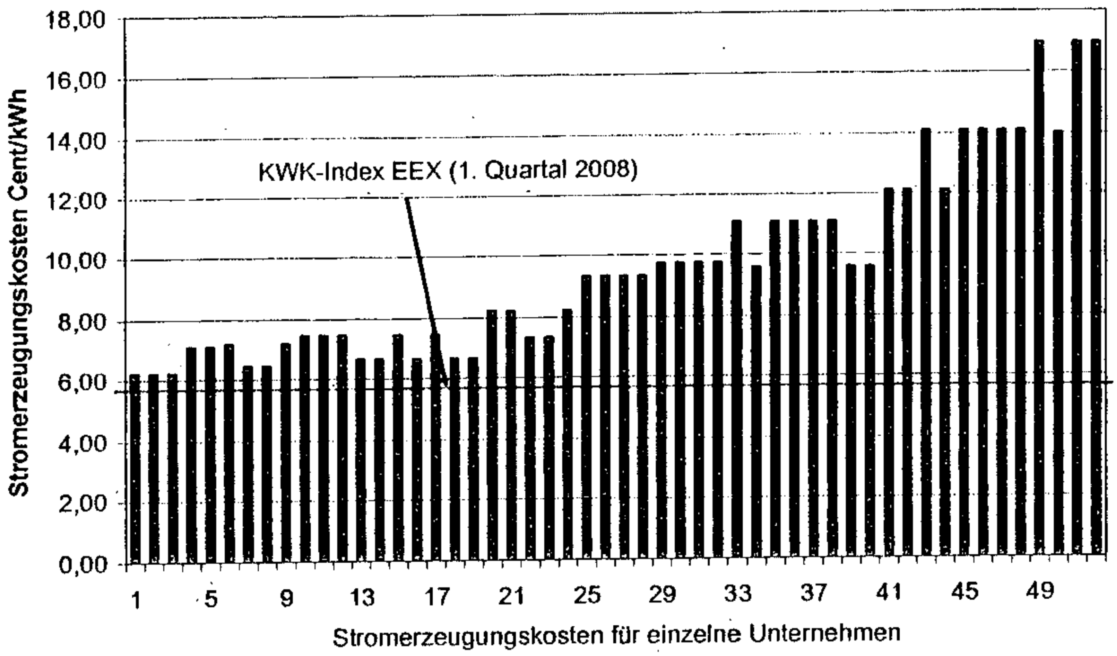
One point of relevance is that, when calculating the potential of cogeneration from a business economic viewpoint, the demands on the plants in terms of profitability are higher than when taking a national economic view. Another point of relevance is the basis of comparison for separate power generation. The expected rate of return on capital is therefore 10%. The cost-effectiveness of the CHP plants is then compared with the costs for a CHP plant arising from a comparison of costs for separate generation. On the heat side the savings on fuel are taken into consideration as in the national economic assessment. On the power side the valuation is based on achievable revenues for the sale of electricity on the wholesale market. The EEX CHP index is taken as the reference variable in this case.




| DE | EN |
|---|---|
| KWK-Index | CHP index |
| Euro/MWh | EUR/MWh |
| Q3 | Q3 |
| Q1 | Q1 |

Figure 3-1: Graph showing the trend in the EEX CHP index from the third quarter of 2000 to the first quarter of 2008

Given expected potential revenues of approximately € 58/ MWh for the cogenerated power, it would appear in general that the CHP plants have precious little chance of achieving their full costs. This would be the preserve of very large plants.




| DE | EN |
|---|---|
| KWK-Index EEX (1. Quartal 2008) | EEX CHP index (1st quarter of 2008) |
| Stromerzeugungskosten Cent/kWh | Power generation costs in cent/kWh |
| Stromerzeugungskosten für einzelne Unternehmen | Power generation costs for individual companies |

Figure 3-2: Power generation costs of individual companies allowing for a heat generation credit and comparison with the EEX CHP index

## 3.4 Primary energy and $CO_2$ savings

The calculation of the primary energy savings and $CO_2$ savings is seen once against the actual power mix in Luxembourg (including imported power) and once against a new separate generation system using the same fuel, duly bearing in mind the specific situation of Luxembourg, however, where the $CO_2$ savings would not impact on the national greenhouse gas balance on account of the fact that it would be primarily imported power which would be replaced (cf. also section 10). With the additional fuel required to generate power the net result may even be more emissions.

**Total potential in comparison with the actual power mix**

Given the reference system defined in section 1.7, the cogeneration potential identified would entail savings of both primary energy and $CO_2$. There is evidently very little difference between the two price scenarios as there is hardly any change in the economic potential of the industrial CHP plants. The primary energy savings add up to 1,680 GWh and 1,703 GWh (price scenarios 1 and 2 respectively). The $CO_2$ savings amount to 528,000 t $CO_2$ and 535,000 t $CO_2$ (price scenarios 1 and 2 respectively).

Table 3-4: Primary energy savings and $CO_2$ savings by CHP plants in comparison with current situation

| | **Primary energy savings in GWh** | | **$CO_2$ savings in 1000 t $CO_2$** | |
|---|---|---|---|---|
| | **Price scenario 1** | **Price scenario 2** | **Price scenario 1** | **Price scenario 2** |
| Unit-type CHP (<1 MW) | 0 | 0 | 0 | 0 |
| Small CHP (1-10 MW) | 370 | 392 | 115 | 122 |
| Medium-sized CHP (10-50 MW) | 743 | 743 | 238 | 238 |
| Large CHP (>50 MW) | 567 | 567 | 175 | 175 |
| **Total** | **1680** | **1703** | **528** | **535** |

Source: Own calculations; national economic analysis; on account of the territorial principle, the $CO_2$ savings do not impact on Luxembourg's greenhouse gas balance

**Additional potential in comparison with actual power mix**

A proportion of the existing cogeneration potential is already being exploited in the industrial sector. In order to calculate the additional savings of primary energy and $CO_2$ which can be attained, the existing proportion of cogeneration must be deducted from the savings. In 2006 the generation accounted for some 214 GWh of power and for some 326 GWh of heat. If these amounts are deducted from the total potential, the primary energy savings are reduced to 1421 GWh and 1423 GWh (price scenarios 1 and 2 respectively). The achievable $CO_2$ savings thus amount to 445,000 t $CO_2$ and 452,000 t $CO_2$ (price scenarios 1 and 2 respectively).

**Total potential in comparison with best available system of separate generation**

The reductions are smaller when the savings are seen against a separate system of generation with the same fuel. The primary energy savings add up to 611 GWh and 619 GWh (price scenarios 1 and 2 respectively). The $CO_2$ savings amount to 121,000 t $CO_2$ and 123,000 t $CO_2$ (price scenarios 1 and 2 respectively).

Table 3-5: Primary energy savings and $CO_2$ savings by CHP plants in comparison with new separate generation systems

| | **Primary energy savings in GWh** | **$CO_2$ savings in 1000 t $CO_2$** |
|---|---|---|

| | Price scenario 1 | Price scenario 2 | Price scenario 1 | Price scenario 2 |
|---|---|---|---|---|
| Unit-type CHP (<1 MW) | 0 | 0 | 0 | 0 |
| Small CHP (1-10 MW) | 139 | 148 | 28 | 29 |
| Medium-sized CHP efficiency (10-50 MW) | 247 | 247 | 49 | 49 |
| Large CHP (>50 MW) | 225 | 225 | 45 | 45 |
| **Total** | **611** | **619** | **121** | **123** |

**Additional potential in comparison with actual power mix**

If the approximate 214 GWh of power and the approximate 326 GWh of heat generated in 2006 are deducted, then the primary energy savings are reduced to 528 GWh and 536 GWh (price scenarios 1 and 2 respectively). The achievable $CO_2$ savings thus amount to 104,000 t $CO_2$ and 106,000 t $CO_2$ (price scenarios 1 and 2 respectively).

### 3.5 Capital expenditure required for full exploitation of potential

The investment required to unleash the additional potential can be estimated on the basis of the specific capital costs for CHP plants set out in section 1.5, according to which the specific outlay is € 550-900/ kW(el) for plants of the 1-90 MW(el) range. Taking account of the industrial plants already installed, the resulting capital expenditure is in the order of some € 117 million and € 120 million (price scenarios 1 and 2 respectively).

Table 3-6: Capital expenditure required to utilise the cogeneration potential in industry

| | Capital expenditure in € million | | Installed electrical power in MW | |
|---|---|---|---|---|
| | Price scenario 1 | Price scenario 2 | Price scenario 1 | Price scenario 2 |
| Unit-type CHP (<1 MW) | 0 | 0 | 0 | 0 |
| Small CHP (1-10 MW) | 38 | 41 | 48 | 51 |
| Medium-sized CHP (10-50 MW) | 43 | 43 | 62 | 62 |
| Large CHP (>50 MW) | 35 | 35 | 60 | 60 |
| **Total** | **117** | **120** | **170** | **173** |

The total potential can only be realised over a relatively long period of time. Assuming that two to three plants can be installed each year, it would take seven to 11 years to reach the approximate total of 21 plants. The plants are generally added to existing installations where the existing heat generation system remains in operation, therefore reinvestment cycles only play a key role in the case of a complete redevelopment of the power and heat supply system.

Table 3-7: Possible roadmap for realisation of total cogeneration potential in industry

| | 2006 | 2008 | 2010 | 2012 | 2014 |
|---|---|---|---|---|---|
| Rate of realisation [%] | 21.2 | 41 | 61 | 80 | 100 |
| CHP potential [GWh/a] | 326 | 629 | 932 | 1,236 | 1,539 |
| Capital costs [€ million] | 0 | 29 | 58 | 88 | 117 |

# 4 Heat requirements in residential buildings

A buildings register is the first thing required in order to keep detailed records of the space heating requirements in residential buildings, and the second thing required is a quantity listing containing the number of dwelling units (DU) as defined in the register. This section deals first with the buildings register before outlining the various steps needed in order to take a methodical approach to devising the quantity listing and the expected result. The section concludes with the projections for this sector until the year 2020.

## 4.1. Keeping a real estate register

The buildings register has the task of classifying the total stock of residential buildings into their different types and age brackets (BAB) so as to allow the necessary calculation of potential. The register is therefore required to differentiate between building types and to state representative values for these types, firstly in respect of the amount of living space heated, and secondly in respect of the specific heat consumption figures. In order to ensure that the calculated or applied mean values result in the correct total heat quantity, the figure should be checked against the target value which emerges from the official statistics.

Earlier studies (ISI, 2007) have provided buildings register data (ISI, 2006) although these data cannot be applied directly for various reasons. For example, only one type of multiple occupancy dwelling is included, some living space data seem implausible, and two building age brackets do not correspond to the listings in the statistics. In response to further inquiries the Vienna University of Technology provided additional information (Kranzl, 2007) but, for similar reasons, these data do not satisfy the specific requirements of this project either because they are different and higher than in the previous projects in respect of the buildings register.

Therefore all the information which has already been provided will be scrutinised and also compared with the buildings register data from Germany, as used in the analysis of the potential of cogeneration in Germany (Eikmeier et al., 2006). This should not be difficult because the construction methods are not fundamentally different, especially with regard to buildings constructed before the introduction of minimum insulation standards. The statistics for 2001 will also be consulted in order to check or recalculate individual figures.

If the building numbers stated in the statistics at commune level are to be of any use at a later date without further adjustment, the building age groups in the buildings register must be in line with the brackets chosen in the statistics. The building types which are too finely subdivided in the statistics have been merged. The categories of farm, detached single occupancy house (DSOH) and non-detached single occupancy houses have all been merged to form the type SOH; the type terraced house (TH) can be transferred directly; the multiple occupancy dwellings (MOD) are subdivided into two types in line with the statistics, namely sMOD for small buildings with up to four dwelling units (DU) and lMOD for large buildings with more than four dwelling units. All other types are included under “Others”. The resulting table features the total number of dwelling units in Luxembourg according to the register listings.

Now the figures from 2001 still need to be adjusted to the base year. The total number for 2005 is taken from STATEC, 2007a. The fine subdivision can be derived from STATEC, 2006 as this provides the numbers of buildings added in the last few years broken down by building types. The total number of buildings added in the last few years corresponds almost exactly to the figures for 2001 to 2005, with a (subsequently revised) difference of just 3%. The number of additional DUs built is entered in the “post-1996” building age bracket which is rendered more precisely as “1996 - 2005”. The replacement of buildings and therewith the reduction of the specific heat demand need not be taken into account in view of the short period of time as this aspect is covered by the later alignment with the final energy balance for 2005.

Table 4-1 shows the result. This table is used later for the balance of the specific useful heat demand. According to the contracting body, the vacancy rate is so low that it need not be taken into account, i.e. all the DUs listed in this project are presumed to be heated.

Table 4-1: Number of dwelling units in Luxembourg in 2005 as itemised in the buildings register

| **No. of DUs** | **Pre-1919** | **1919-1945** | **1946-1960** | **1961-1970** | **1971-1980** | **1981-1990** | **1991-1995** | **1996-2005** | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| **SOH** | 9,586 | 6,850 | 8,897 | 8,231 | 12,511 | 11,411 | 7,304 | 8,611 | **73,403** |
| **TH** | 8,100 | 13,623 | 10,545 | 5,155 | 4,276 | 2,659 | 1,718 | 2,224 | **48,300** |
| **sMOD** | 2,106 | 4,091 | 5,450 | 4,686 | 4,197 | 3,081 | 3,494 | 5,765 | **32,870** |
| **lMOD** | 444 | 897 | 1,219 | 2,346 | 4,884 | 2,851 | 3,847 | 5,066 | **21,553** |
| **Others** | 755 | 795 | 770 | 394 | 455 | 479 | 224 | 519 | **4,391** |
| **Total** | **20,991** | **26,256** | **26,881** | **20,812** | **26,324** | **20,481** | **16,587** | **22,186** | **180,517** |

The calculation of the mean living space (LS) follows on from this. The dwelling areas can be calculated from the statistics as weighted averages. The figures appear to tally well with the data in the registers of the ISI and the Vienna University of Technology. Table 4-2 gives the individual figures.

Table 4-2: Average amount of living space per dwelling unit in Luxembourg in 2005 as itemised in the real estate register

| LS/ DU [m²] | Pre-1919 | 1919-1945 | 1946-1960 | 1961-1970 | 1971-1980 | 1981-1990 | 1991-1995 | 1996-2005 |
|---|---|---|---|---|---|---|---|---|
| **SOH** | 153 | 138 | 138 | 146 | 159 | 174 | 173 | 182 |
| **TH** | 122 | 119 | 122 | 125 | 129 | 136 | 131 | 130 |
| **sMOD** | 79 | 78 | 81 | 86 | 88 | 88 | 85 | 89 |
| **lMOD** | 46 | 57 | 66 | 78 | 79 | 76 | 76 | 81 |
| **Others** | 88 | 80 | 82 | 89 | 92 | 105 | 96 | 103 |

The statistics cannot be used to calculate the specific amounts of useful heat. A comparison of the data from the ISI, the Vienna University of Technology and for Germany would suggest, after establishing a comparability structure, that most of the data tally well and that the majority of the ISI data can therefore be used directly. The few differences are confined to the first three building age brackets, i.e. buildings constructed before 1955, where some of the figures from the ISI and the Vienna University of Technology are much higher. An initial alignment with the target value of the final energy required by this sector supports the fact that these figures would generate an excessively high total therefore the relevant individual figures are limited to 1.2 times the respective value for Germany.

The final adjustment of the specific useful heat demand and therewith of the real estate register is made via the final energy balance for Luxembourg for 2005 (ISI, 2007b) where the figure for the building sector is 4,277 GWh/a. Added to this is the percentage from the district heating sector (584 GWh/a) which applies to residential buildings. It is estimated by the ISI at 60% (350 GWh/a), thus giving a final energy consumption in the residential building sector of 4,627 GWh/a.

Several preparatory steps are required in order to be able to make the adjustment. Firstly, the proportion of dwelling units with electric heating systems is to be taken out of the reckoning as this subset is not included in the building sector but in the power consumption in the final energy statistics. To this end the statistics for 2001 can be charted as they itemise these data in the necessary detail. The resulting percentages lie between 0.7% and 10%.

The mean annual utilisation coefficient must then be determined for all other types of heating. This can be done by consulting the prepared quantity listing. This is combined with typical values for heating systems which are taken from Prognos/ EWI, 2005. Factoring in the quantities, the resulting mean annual utilisation coefficient for all the existing heating systems is 0.79, which corresponds exactly to the value stated for Germany in 2005 (Tzscheutschler et al., 2006).

The hot water generation is analysed on the basis of the data from ISI, 2006. It transpires that the distribution of the systems is virtually identical in the different building types, thus allowing the results to be easily transferred to per capita statistics. The resulting percentage of electric water heating is 4.6%. Mean values are applied from Prognos/ EWI, 2005 for all other systems in turn which then results in a weighted annual utilisation coefficient of 0.60. This computes to an annual final energy consumption of 500 GWh/a for non-electric applications for domestic water heating in residential buildings.

After deducting the electric applications and adding the final energy consumption for domestic water heating, the figures can now be balanced with the final energy target based on the mean annual utilisation coefficient for the heating systems. The result is a slight overestimation of just 6.6%. All the values for the specific useful heat demand are finally reduced by this factor thus arriving exactly at the target value. Table 4-3 shows the results.

Table 4-3: Specific useful heat demand for space heating in Luxembourg in 2005 as itemised in the real estate register

| kWh/ m² p.a. | Pre-1919 | 1919-1945 | 1946-1960 | 1961-1970 | 1971-1980 | 1981-1990 | 1991-1995 | 1996-2005 |
|---|---|---|---|---|---|---|---|---|
| **SOH** | 225 | 225 | 250 | 202 | 153 | 139 | 121 | 80 |
| **TH** | 162 | 176 | 166 | 142 | 113 | 107 | 102 | 80 |
| **sMOD** | 204 | 164 | 169 | 145 | 115 | 102 | 83 | 60 |
| **lMOD** | 136 | 182 | 155 | 159 | 117 | 102 | 83 | 60 |
| **Others** | 214 | 194 | 209 | 174 | 134 | 121 | 102 | 70 |

## 4.2 Preparing the quantity listings

### 4.2.1 Preparing the statistics for 2001

The survey dated 15 February 2001 and the individual statistics forming part of this survey can be used as a central resource for this task. They provide a very good basis because they are detailed and incorporate relevant classifications and they are also quite up to date. Particular use was made of the following tables:

- Number of buildings, broken down by building type, available for every town
- Number of buildings, broken down by building type and age bracket, available for every commune
- Number of DUs, broken down by building type, available for every commune

- Number of DUs, broken down by building age bracket, available for every commune.

It is necessary in the first instance to trace the changes in the commune structures which have occurred since the statistics were compiled in order to be able to carry out all the calculations within the commune structure of the base year of 2005. This means merging Bastendorf and Fouhren with the commune of Tandel in the canton of Vianden and merging Kautenbach and Wilwerwiltz with the commune of Kiischpelt in the canton of Wiltz.

The second step is to bring the building type classification in all the tables into line with the subdivisions in the buildings register. Those buildings and DUs which are not allocated to any age bracket are then split over all the building age brackets in due proportions. This is done separately on an individual basis for each building type and for each commune.

The building type and building age bracket are only linked at commune level and must be transferred to the towns (villages)[1] in this commune. The respective age bracket proportions for all building types will be calculated for each commune. These detailed calculations will be applied to every town in the individual communes. Once this labour-intensive process has been completed, the resulting table will feature the building type and age bracket at town level.

The next step is to convert the building numbers into the number of DUs while still retaining the same level of detail. The ratio of DUs to buildings is available at commune level therefore these data can again be used for each town in a commune. There are bound to be inaccuracies but these can be gauged by checking the target value. The concurrence levels for single occupancy houses (SOH) and terraced houses (TH) are excellent, and the match levels for Others are also good although this category is negligible in terms of quantities. Multiple occupancy dwellings (MOD) is the only category where there are major discrepancies. This was also inevitable in view of the greater spread in MODs in the ratio of DUs to buildings. Due to the trend towards building larger MODs from 1970 onwards, there is a tendency when applying mean ratios, to underestimate the actual number of DUs in the later building age brackets and to overestimate them in the older building age brackets. This inaccuracy can be levelled out by applying a correction factor after the alignment of each building age bracket.

The final necessary adjustment is to subdivide the MODs into two types to bring them into line with the register structure, namely small and large multiple occupancy dwellings (sMOD, lMOD), as this subdivision is not present in the detailed statistics. By compiling the register, the total numbers for the two types and the respective shares of each type in each building age bracket will be available as target values for a balance at national level. This subdivision will be applied to each town, albeit including the application of a

[1] The term 'town' is used hereinafter irrespective of the size of the settlement, the main point being to differentiate from the next highest level of classification, namely the communes.

correction factor which will be calculated for each town on the basis of the ratio of DUs to buildings in that town. The greater this number, the higher the number of lMODs must be. The mean ratios of DUs to buildings for sMODs and lMODs can be used to calculate backwards to arrive at the respective proportions of these two types. Another factor to bear in mind when applying this mathematical breakdown process, especially in the case of very small towns, is that lMODs are only possible from at least four DUs in one building age bracket in a town. The deviations from the target totals for the building age brackets are surprisingly small and average out at 3.7%. Only in the subset which is clearly the smallest in terms of quantity, the pre-1919 building age bracket and lMOD (0.9% of all DUs in MODs), the difference is much greater - precisely because the low indefinite numbers give rise to larger relative errors. This step in turn concludes with a further correction where the respective deviations serve as correction factors for each building age bracket.

Once all these steps have been completed, the resulting quantity listing specifies the number of DUs in the five building types of the building register for each town with the respective building age bracket. All the subtotals tally with the totals for Luxembourg. The allocation of towns to communes and cantons is also shown therefore it is also very simple to calculate the totals on these levels.

### 4.2.3 Updating of the quantity listings from the 2001 structure to the base year of 2005

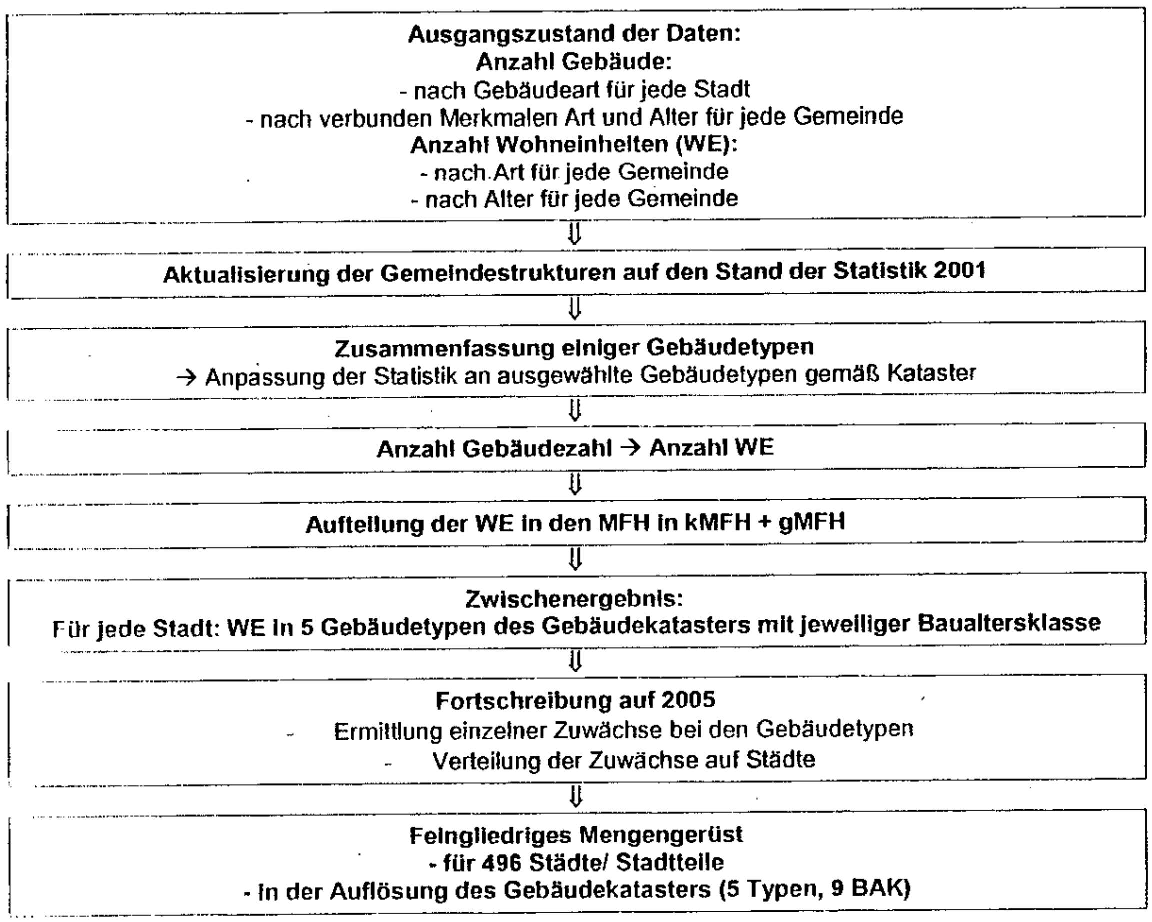
In parallel to the buildings register, the detailed quantity listings also need to be updated from the 2001 structure to the base year of 2005, i.e. a “1996-2005” age bracket needs to be added to the “post-1996” BAB. The total balance for Luxembourg yields the target values for the individual building types (see Table 3-1). These increases have to be spread over the individual towns, with MODs and the other building types being treated separately because there are major structural differences in the distribution of building types in that the proportion of MODs is much higher in larger towns than in small towns or rural communities.

The building completion figures at commune level are available for 2003 and 2004 (STATEC, 2006a), (STATEC, 2005). The distribution tallies very well with the planning permission applications for the last few years at commune level (STATEC, 2007b). A comparison with the commune percentages in the last two building age brackets also shows a very good level of concurrence and indicates that additional building figures for the individual communes are very stable and therefore lend themselves well to being applied for this short period. The additional buildings can be distributed by their types according to the respective town proportion in the building age bracket from 1996 onwards.

Once this last step has been completed the resulting quantity listing of residential buildings is available as a 496 * 45 matrix which disperses the number of DUs for the base year of 2005 as follows:

- 496 towns or urban districts (the city of Luxembourg is broken down into 24 urban districts in the statistics)
- 5 building types in
- 9 building age brackets.

It allows a simple summation due to the allocation to communes and cantons. The most important steps are illustrated again in Figure 4-1.




| DE | EN |
|---|---|
| Ausgangszustand der Daten:<br>Anzahl Gebäude:<br>- nach Gebäudeart für jede Stadt<br>- nach verbunden Merkmalen Art und Alter für jede Gemeinde<br>Anzahl Wohneinheiten (WE):<br>- nach Art für jede Gemeinde<br>- nach Alter für jede Gemeinde | Initial data:<br>Count buildings:<br>- by building type for each town<br>- by type and age for each commune<br>Count dwelling units (DUs):<br>- by type for each commune<br>- by age for each commune |
| ▼ | ▼ |

| | |
|---|---|
| Aktualisierung der Gemeindestrukturen auf den Stand der Statistik 2001 | Update commune structures to statistics for 2001 |
| ▼ | ▼ |
| Zusammenfassung einiger Gebäudetypen<br>-> Anpassung der Statistik an ausgewählte Gebäudetypen gemäß Kataster | Merge some building types<br>-> Adjust statistics to building types selected for use in register |
| ▼ | ▼ |
| Anzahl Gebäudezahl -> Anzahl WE | Count buildings -> Count DUs |
| ▼ | ▼ |
| Aufteilung der WE in den MFH in kMFH + gMFH | Break down DUs in the MODs into sMODs + lMODs |
| ▼ | ▼ |
| Zwischenergebnis:<br>Für jede Stadt: WE in 5 Gebäudetypen des Gebäudekatasters mit jeweiliger Baualtersklasse | Intermediate data:<br>For each town: Classify DUs in 5 building types on buildings register with respective building age bracket |
| ▼ | ▼ |
| Fortschreibung auf 2005<br>- Ermittlung einzelner Zuwächse bei den Gebäudetypen<br>- Verteilung der Zuwächse auf Städte | Project forward to 2005<br>- Calculate increases in individual building types<br>- Distribute increases across towns |
| ▼ | ▼ |
| Feingliedriges Mengengerüst<br>- für 496 Städte/ Stadtteile<br>- In der Auflösung des Gebäudekatasters (5 Typen, 9 BAK) | Detailed quantity listing<br>- For 496 towns/ urban districts<br>- As broken down in buildings register (5 types, 9 building age brackets) |

Figure 4-1: Steps involved in drawing up a quantity listing of residential buildings

Classification by the number of DUs in one place yields the result shown in Table 4-4. More than half of all places in Luxembourg have 100 DUs at the most, while three quarters have 250 DUs at the most. Only eight towns have 2,500 DUs or more. This underlines the generally very rural character of the country of Luxembourg.

Table 4-4: Classification of number of dwelling units in the towns in Luxembourg in 2005

| Number of DUs | Number of towns | Percentage |
|---|---|---|
| Up to 100 DUs | 240 | 50.7% |
| 101 - 250 DUs | 115 | 24.3% |
| 251 - 500 DUs | 54 | 11.4% |
| 501 - 1,000 DUs | 32 | 6.8% |
| 1,001 - 2,500 DUs | 24 | 5.1% |
| 2,501 - 5,000 DUs | 5 | 1.1% |

| | | |
|---|---|---|
| 5,001 - 10,000 DUs | 1 | 0.2% |
| Over 10,000 DUs | 2 | 0.4% |
| **Total** | **473** | **100%** |

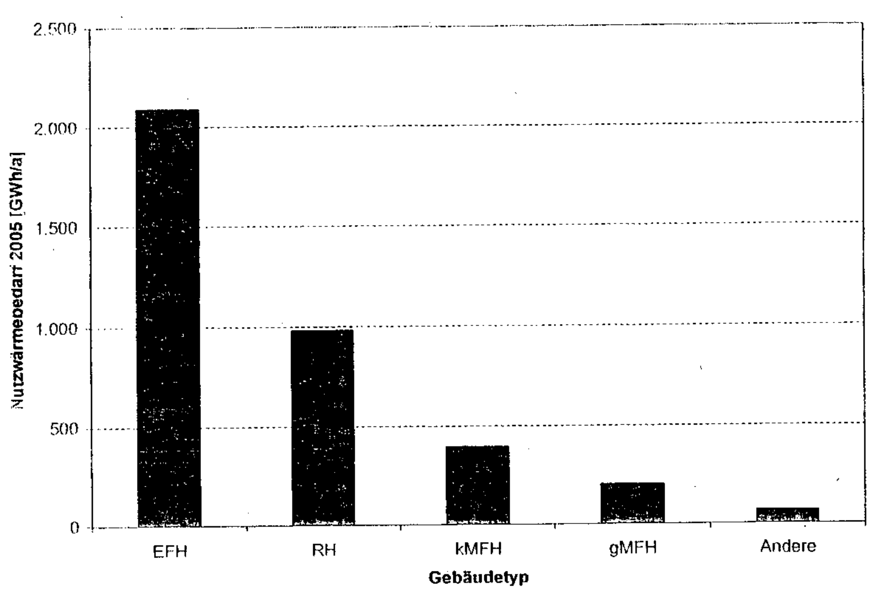
## 4.3 Domestic water heating requirements

The useful heat demand for domestic water heating in the residential buildings is indicated in the first instance by the number of inhabitants and then apportioned to the DUs. In STATEC, 2007a the number of inhabitants in Luxembourg for 2005 is stated to be 446,999. The figure allowed for each individual is 700 kWh/ pers.*a, which results in a total useful heat demand of 313 MWh/a. This corresponds to 9.1% of the space heating demand, related to the net energy (at final energy level the figure is 12.1%).

Given a total of 180,517 dwelling units and a mean occupancy rate of 2.48 pers./ DU, this corresponds to a mean demand of 1,733 kWh/ DU*a. It should be borne in mind, however, that the household size also depends on the building type and the mean size of a DU. Statistical data can provide information in this regard. This information can be used to specify an occupancy factor for each building type which is between 2.20 pers./ DU in MODs and 2.70 pers./ DU in SOHs (corresponds to between 1,540 and 1,890 kWh/ DU*a). The values are aligned so as to arrive at the total useful heat demand.

## 4.4 Structure of useful heat demand in 2005

A total of 3,740 GWh is calculated for the useful heat demand in the residential buildings sector for 2005. The following graphs and arguments relate to the sum of space heating and domestic water, but the structural breakdown for the space heating alone looks the same in principle because this is the dominant factor at 90.9%. Figure 4-2 shows how this amount breaks down across the individual building types.

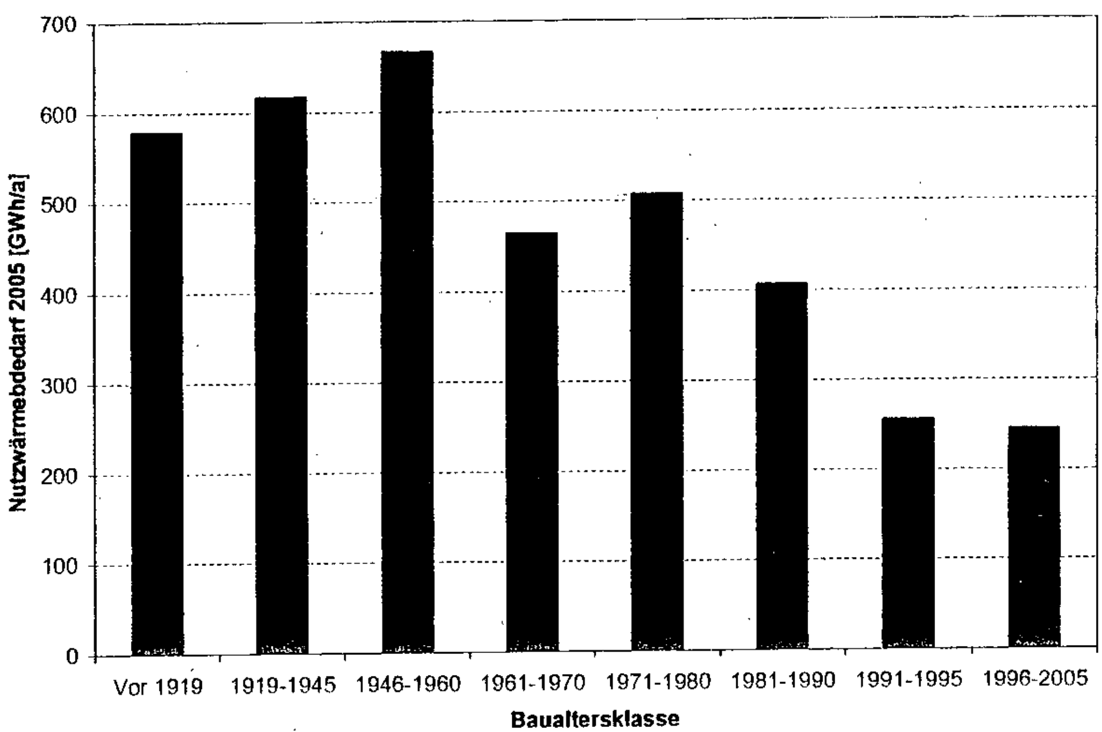


| DE | EN |
|---|---|
| Nutzwärmebedarf 2005 [GWh/a] | Useful heat demand in 2005 [GWh/a] |
| EFH | SOH |
| RH | TH |
| kMFH | sMOD |
| gMFH | lMOD |
| Andere | Others |
| Gebäudetyp | Building type |

Figure 4-2: Useful heat demand as allocated to building types in the residential buildings sector in 2005

More than half of the demand (56%) applies to the SOHs and a good quarter to the THs (26%). This reflects the fact that there are not many relatively large towns in Luxembourg and therefore comparatively few MODs overall (sMODs + lMODs together total 16%). The number of "Others" is negligible (2%).

Figure 4-3 illustrates the distribution across building age brackets, although it should be noted that the time spans for the age brackets are different.




| DE | EN |
|---|---|
| Nutzwärmebedarf 2005 [GWh/a] | Useful heat demand in 2005 [GWh/a] |

| | |
|---|---|
| Vor 1919 | Pre-1919 |
| Baualtersklasse | Building age bracket |

Figure 4-3: Useful heat demand as allocated to building age brackets in the residential buildings sector in 2005

The distribution is as expected. The first three building age brackets account for the highest quantities of heat because these age brackets span longer periods of time and are indicative of an era when insulation was of an inferior standard. Together they represent exactly 50% of the total heat demand in this sector. The downward trend in the other age brackets is indicative of the fact that the buildings gradually need less heat (cf. specific useful heat demand in Table 4-3).

Table 4-5 shows how the heat demand in the sector is spread over the 12 cantons.

Table 4-5: Specific useful heat demand of residential buildings in Luxembourg in 2005 listed by cantons

| **Canton** | **Useful heat demand in 2005 (GWh/a)** | **Percentage** |
|---|---|---|
| Esch-Alzette | 1,108 | 29.6% |
| Luxembourg | 1,019 | 27.3% |
| Capellen | 336 | 9.0% |
| Diekirch | 215 | 5.8% |
| Mersch | 206 | 5.5% |
| Grevenmacher | 194 | 5.2% |
| Remich | 138 | 3.7% |
| Redange | 130 | 3.5% |
| Echtemach | 125 | 3.3% |
| Clervaux | 118 | 3.2% |
| Wiltz | 115 | 3.1% |
| Vianden | 34 | 0.9% |
| **Total** | **3,740** | **100%** |

Esch-Alzette and Luxembourg clearly top the table with the highest heat demand because the larger towns of the country are concentrated in these cantons which together account for more than half of the total with some 57%.

## 4.5 Forward projection to 2020 in baseline scenario

Some definitions are required to determine a baseline scenario for the years until 2020. These relate to the following factors at the level of net energy:

- Trend in population figures (relevant to domestic water)

- Building renovation rates
- Useful heat demand of renovated buildings
- Change in DUs overall
- Replacement of demolished buildings
- Construction of new DUs
- Specific useful heat demand of newly constructed DUs
- Regional distribution of individual changes in building stock.

All the assumptions made in this regard are unpacked in more detail in the following sections.

### 4.5.1 Trend in population figures

In order to ensure that the figures tally well with those from earlier studies it was agreed with the contracting body to use the "Central" scenario from STATEC 2007a as a baseline case. It contains the following data on the change in population and the number of DUs (see Table 4-6):

Table 4-6: Assumptions in "Central" scenario

| Year | Population | Ratio to 2005 | No. of DUs | Ratio to 2005 | Pers./ DU | Ratio to 2005 |
|---|---|---|---|---|---|---|
| 2005 | 446,999 | 1.000 | 180,517 | 1.000 | 2.48 | 1.000 |
| 2010 | 466,453 | 1.044 | 193,060 | 1.070 | 2.42 | 0.976 |
| 2015 | 485,496 | 1.086 | 205,953 | 1.141 | 2.36 | 0.953 |
| 2020 | 505,447 | 1.131 | 220,063 | 1.219 | 2.30 | 0.930 |

According to these assumptions, the number of inhabitants will rise by 13.1% by the year 2020. On account of the fact that the domestic water consumption per person remains constant, the increase in the demand for useful heat for the domestic water heating corresponds exactly to this percentage increase. Owing to the fact that this increase is lower than the increase in dwelling units in the same period (21.9%), the mean number of persons per DU drops slightly which is in line with the trends in other European countries and corresponds to an increase in living space per capita.

The domestic water consumption in 2005 constitutes only 8.4% of the total useful heat demand in this sector, therefore the population growth of 13.1% by 2020 corresponds to a rise in the total useful heat quantity of just 1.1% (related to the base year). This shows clearly that a regional subdivision of demographic trends is not necessary. Analyses of statistics of recent years (STATEC, 2007b) also show moderate differences in the cantons in this regard.

### 4.5.2 Renovation of residential buildings

The data used in this regard are also based on earlier studies (ISI, 2007c). A comparison with the figures used in the study of cogeneration potential for Germany (Eikmeier et al., 2006) shows a good degree of concurrence.

Depending on the building type and age bracket, i.e. the initial state in any given case, a rounded factor of “renovated building/ non-renovated building” is set for the specific useful heat demand of a DU. In the best case scenario it is 0.50 and in the worst case 0.85. This ratio comes to 0.66 as the weighted average of the 2005 stock.

The proportion of renovated buildings is also specified pursuant to the classifications in the buildings register. They are much lower for newer buildings with acceptable insulation standards than for very old and poorly insulated buildings. A rate of 1.5% is taken as a maximum, resulting in a weighted average renovation rate of 0.72%. A new BAB with a specific useful heat demand of 55-75 kWh/ $m^2$*a is being introduced for all buildings constructed between 2006 and 2020; the renovation rate for these new buildings is negligible.
A comparison of the specific useful heat demand of the individual building types in the various building age brackets in 2020 with the initial situation in 2005 shows that there is a saving of around 9 - 10% at best in the case of the oldest SOHs on account of the low renovation rates, while for all buildings constructed after 1970 the rate is no higher than 3%. With regard to the building figures for 2005, the weighted average comes to 4.1%. Demolition causes a further drop but these figures nevertheless prove how long it takes at “normal” renovation rates to achieve a significant reduction in the demand for heat - with an increase in consumption being brought about at the same time by the addition of buildings. More exact results for 2020 are detailed in section 4.6.

### 4.5.3 Building demolition and construction

The prognosis until 2020 in STATEC, 2007a provides more accurate figures for a “Haut” scenario for the replacement of outgoing DUs (demolition quantity) for the three five-year periods under review (base years 2010, 2015, 2020). The differences between this scenario and the “Central” scenario used as the baseline for this analysis of potential are only minor (increase in population of 16.0% instead of 13.1% and increase in DUs by 24.7% instead of 21.9 % by 2020), therefore the proportion of the growth accounted for by replacements for demolished buildings (which is very constant over the relevant periods) can be easily transferred. The proportion amounts to some 58% in the entire period under review, i.e. more than half of new buildings are replacements (related to the number of DUs) for old existing buildings. Related to the existing building stock, the replacement rate amounts to around 0.8% which is much higher than in Germany (0.45%, albeit related to living area). This is due to the different dynamics of the housing market, brought about by the high influx rates and the growth in population. The individual data are brought together in Table 4-7.

Table 4-7: Demolition and construction of dwelling units

| Period | Demolition & replacement | Growth | New build total |
|---|---|---|---|
| 2006-2010 | 7,669 | 12,543 | 20,212 |
| 2011-2015 | 7,536 | 12,893 | 20,429 |
| 2016-2020 | 7,684 | 14,110 | 21,794 |
| **Total** | **22,889** | **39,546** | **62,435** |

There are no data on regional distribution therefore estimates are required. Data from different sources concur well when projecting forward from 2001 to 2005 (cf. section 4.2.2), thus demonstrating a very stable trend at national level. This is therefore carried forward and the distribution of growth to 2020 plotted as before.

Detailed studies in earlier research conducted by the BEI (AGFW, 2004) showed that the demolition of old buildings in the old West German states (the newly-formed German states are a special case due to their historic development) is largely in proportion with the building types, i.e. there is not a disproportionately high number of one type of buildings being demolished. Therefore this approach will also be applied to Luxembourg. A distribution among building age brackets is still needed. This cannot be proportional, however, as the frequency of demolition rises as the age of the buildings increases. Therefore estimates will also be transferred from Germany for this distribution.

## 4.6 Useful heat demand in 2020

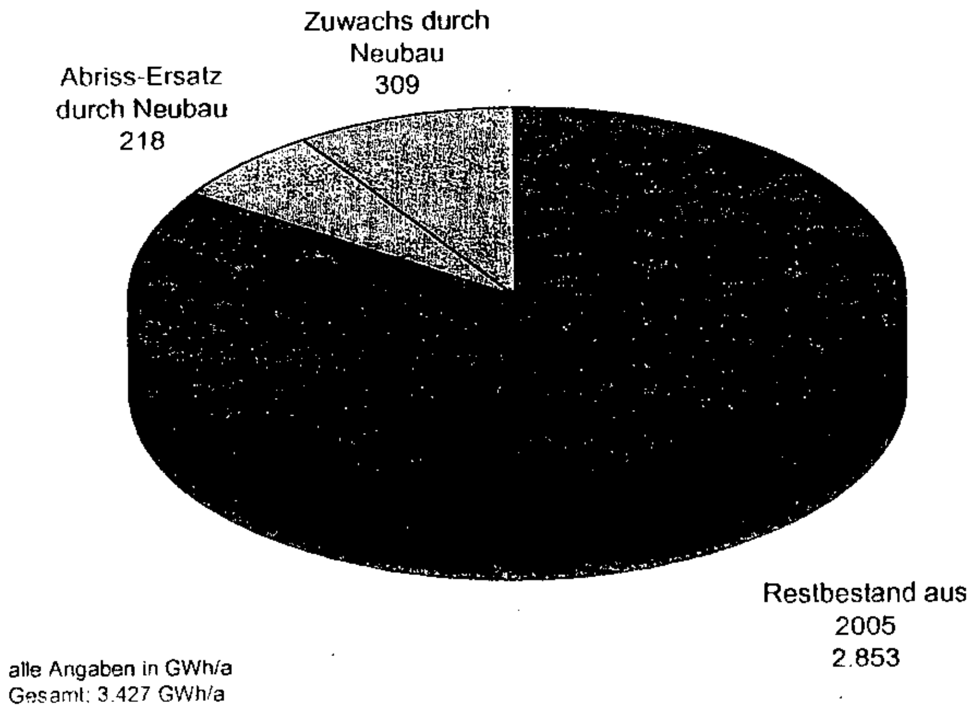
The quantity listings for the baseline years of 2010, 2015 and 2020 will be drawn up in a labour-intensive process whereby the distribution functions described are applied to the detailed matrix of residential buildings. The most significant results for the year 2020 are given here. As the following figures make clear, the years from 2010 to 2015 can be omitted as the changes are minor in comparison with the initial position in 2005. Table 4-8 shows the changes in totals in the period under review.

Table 4-8: Trend in useful heat demand in residential buildings between 2005 and 2020

| Useful heat [GWh/a] | 2005 | 2020 | Change |
|---|---|---|---|
| Space heating | 3,427 | 3,379 | -1.4% |
| Domestic water | 313 | 354 | +13.1% |
| **Total** | **3,740** | **3,733** | **-0.2%** |

The space heating demand drops by only 1.4% by 2020. This reduction is virtually entirely offset by the increase in domestic water heating which corresponds to the growth in population in this period. Overall the useful heat demand in the residential buildings sector remains virtually constant (-0.2%).

A more detailed analysis of the space heating demand is worthwhile. Figure 4-4 illustrates the proportions in 2020 in comparison to the building supply.



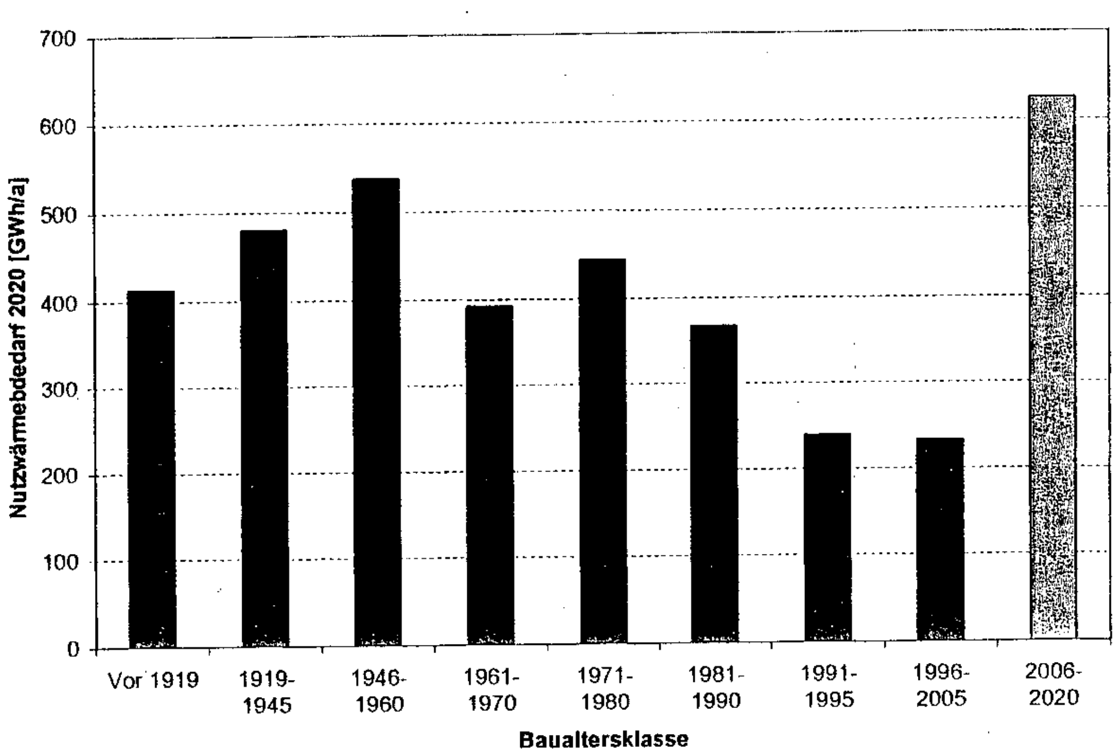

| DE | EN |
|---|---|
| Abriss Ersatz durch Neubau<br>218 | Demolished properties replaced by new buildings<br>218 |
| Zuwachs durch Neubau<br>309 | New buildings added<br>309 |
| Restbestand aus 2005<br>2.853 | Building supply remaining from 2005<br>2,853 |
| alle Angaben in GWh/a<br>Gesamt: 3.427 GWh/a | All figures in GWh/a<br>Total: 3,427 GWh/a |

Figure 4-4: Segmentation of net energy required for space heating in the residential buildings sector in 2020

The supply remaining from 2005 which will still be used in 2020 (“Building supply remaining from 2005”) still represents a good 84% of the space heating demand. The replacement of demolished buildings with new buildings accounts for a further 6.4% while 9% is the percentage increase in dwelling units.

A comparison of the heat required in 2020 by the remaining stock plus the buildings constructed to replace those demolished with the figures from 2005 yields a reduction of just 10.4% in the useful heat demand for this subset. This reduction is brought about partly by the renovation of existing buildings but predominantly by the much lower specific useful heat consumption of new buildings in comparison to the ones which they replace.

Finally, Figure 4-5 shows the changed distribution of the total useful heat demand (space heating and domestic water) for the year 2020 (cp. Figure 4-3 for the year 2005).




| DE | EN |
|---|---|
| Nutzwärmebedarf 2020 [GWh/a] | Useful heat demand in 2020 [GWh/a] |
| Vor 1919 | Pre-1919 |
| Baualtersklasse | Building age bracket |

Figure 4-5: Proportion of useful heat demand by building age brackets in the residential building sector in 2020

It is clear that buildings constructed after 2005 already make the highest demands on useful heat of all the building age brackets. This is due to the decreases in the other BABs, the high new-build rate in Luxemburg, and not least to the fact that this graph uses a 15-year span for new buildings. In contrast to Figure 4-3 there are major changes, the most noticeable being the significant decrease in older buildings and the large proportion of new buildings. The reason for this is the movement in the housing market shown in

Table 4-7 in line with the prognosis: these figures are appreciably higher than those of the recent past.

# 5 Useful heat demand in the CTS sector

As a rule, the commerce, trade & services sector (CTS) is harder to pin down than other sectors because its scope is not normally adequately defined in statistics. Luxembourg is no exception in that this sector poses a particular challenge. An analysis of Eurostat statistics on final energy balance for 2004/ 05 (Eurostat 2007) shows a ratio of heat consumption (233 GWh/a) to electricity consumption (1,268 GWh/a) of 0.18. This seems implausible in comparison with ratios in other countries, such as France (1.77 in 2002) or Germany (1.92 in 2002) where heat consumption is much higher.

A factor of 1.6 was used for calculations in the study on energy efficiency. This ratio is also to be used in this study in the interests of consistency. This gives heat consumption figures of 2,029 GWh/a and 1,359 GWh/a for final energy and net energy respectively in the CTS sector.

The BEI has also estimated the breakdown of the heat consumption in the CTS sector more accurately, drawing on employment figures ("number of people in work") in the individual branches of industry (BI) in 2005 from STATEC, 2006b. The distribution across these BIs matches surprisingly well with the spread in Germany, in that (as expected) only the figures for the "banking sector and insurance industry" are higher in Luxembourg than in Germany. Data for specific useful heat consumption per employee for the individual branches of industry are available from Eikmeier et al. 2006. These figures take account of the fact that in some BIs only a certain proportion of the employees are deployed at a fixed location. It is only this section which is relevant for alternative heat supply by cogeneration; energy consumption figures at building sites at varying locations, etc. are not suitable in the same way for stationary heat supply. The intrinsic values can be transferred to Luxembourg, not just on account of the structural correlation, but because the demand for space heating in this sector applies to service buildings which are comparable to those found in Germany. After the figures have been aligned with the above target value it is possible to estimate the heat consumption of the individual branches of industry.

# 6 Local and district heating potential

## 6.1 Methodology and approach

The cost-effectiveness of a pipeline-based heat supply system depends not only on the amount of heat purchased but also on the specific heat density and the pipeline lengths required (and therefore also the pipeline costs). Settlement typologies were therefore defined as far back as the end of the nineteen-seventies and consulted when appraising the suitability of housing estates for a district heat system or natural gas supply. Settlement typologies would, for example, contain information on the following factors:

- Building density and heat density
- Typical pipeline lengths for sub-distribution and house connections
- Specific pipeline costs
- Particular operating parameters, such as grid losses.

Areas can be evaluated by the representative principle on this basis without having to carry out individual analyses.

The contracting body did, however, provide nationwide data for a geographic information system (GIS) for the country of Luxembourg. This database enables a very detailed analysis of the local conditions and initially avoids standardisation as encountered when defining urban settlement types. There are also numerous aerial photographs for almost every locality taken at an angle so as to facilitate the evaluation of building types and building heights. Time does not allow for individual analysis of the large number of very small towns and villages which are not suitable for pipeline heat supply therefore a representative approach is adopted in this regard. The course of action is set out in detail below.

### 6.1.1 Use of the geographic information system

The buildings in the GIS are subdivided into various subsets (layers). For example, there are layers of buildings, public buildings, industry, farm buildings, etc. Taking account of the location and most particularly the aerial photographs, it is only the first two layers mentioned above which lend themselves to individual analysis. Farm buildings are almost always uninhabited utility buildings, for example, therefore there are no layers which adequately represent the entire CTS sector. Branch of industry 6 (Other services: public administration, education and tuition, health service, public services) mainly constitutes services which are rendered in public buildings and thus relates very well to the public buildings layer. The other branches of industry of the CTS sector (e.g. hospitality industry, commerce, banking sector, insurance industry) are in the buildings layer.

The useful heat consumption for the CTS sector thus needs to be distributed across these two areas/ layers. The useful heat consumption for the individual CTS subsets can be calculated on the basis of the employment figures in the individual branches of industry from STATEC, 2006b and the figures for the specific useful heat consumption per employee (subdivided into 12 branches of industry) from Eikmeier et al., 2006. The total is then balanced with the useful heat consumption target for the entire CTS sector (1,359 GWh/a, cf. section 5) resulting in a correction factor which is applied as standard to all branches of industry. The resulting amount is the volume of useful heat which relates to the above areas and thus to the public buildings layer. It amounts to 466 GWh/a; the remaining CTS amount in the buildings layer therefore comes to 894 GWh/a. The public buildings layer thus accounts for a good third of the useful heat consumption in the CTS sector, which is slightly more than the proportion of employees (just under a quarter).

The reason for this is the slightly higher specific demand in comparison with the volume allotted to the buildings layer.

There is no adequate breakdown of employment figures at commune level for the CTS sector therefore the heat consumption represented by public buildings must be balanced nationwide.

The geographical breakdown and target alignment also comes into question in respect of the CTS section subsumed within the buildings layer. Seen against the backdrop of the ratios in Germany, the ratio of this useful heat consumption in the CTS to the useful heat consumption of residential buildings is constant to a great extent and largely independent of town size. This is not surprising as this sector represents products and services which are usually aimed at the end customer and thus shows direct proportion to the number of inhabitants and therefore also to the number of dwelling units. It is therefore possible, with sufficient accuracy, to allocate the CTS consumption to the individual towns and communes proportionally to the respective heat consumption of the residential buildings, thereby effecting an increase of 23.9%. The fact that there are CTS zones within the residential building zones is not of sufficient significance to warrant separate consideration due to the proportionality, as this is factored in when converting the floor space figures in residential areas and useful heat quantities identified by the GIS.

The comparison of the residential buildings in the GIS (87,889) with the number of buildings in the statistics (119,911) gives a substantial minority of 27%. A comparison of the CTS buildings with the aerial photographs offers an explanation for this discrepancy. This shows that neighbouring buildings and terraced houses which are recorded separately in the statistics are classed as one single building in the GIS in any given case. However, the GIS totals the surface area of all the building parts therefore there is no problem in terms of the further process.

The GIS allocates all buildings to communes and states the ground area but does not state the number of storeys or building age brackets. Therefore the aerial photographs are consulted. This is a very time-consuming process whereby the respective parts of a town are identified in the pictures and a mean number of storeys assigned for each visible section of built-up areas. Where applicable, a distinction is drawn between residential buildings and public buildings. By proceeding in this fashion almost nationwide assignment is possible for all the buildings in the areas of Luxemburg relevant to district heat systems. The few areas which are not visible on aerial photographs can be approximated with sufficient accuracy using normal photographs and settlement patterns. In a bid to cut the amount of work, the very small places which are very similar in urban development terms are evaluated by taking a sufficiently large random sample and typical numbers of storeys. Once this work has been completed, the resulting database contains the volumes and floor space requiring heating for all the buildings in the country.

### 6.1.2 Recording the communes and towns in the GIS

The 116 communes of Luxembourg are ranked on the basis of the number of buildings in the statistics or the calculation of useful heat consumption and are then subdivided into three categories:

- I: 35 communes with relatively large towns.
  These communes account for 72.2% of the useful heat consumption of the two sectors under review here, namely private households and CTS.

- II: 22 communes with at least one town with at least 250 buildings.
  These communes account for 10.6% of the useful heat consumption.

- III: 59 communes which have no town with at least 250 buildings.
  These communes account for 17.2% of the useful heat consumption.

The bigger a town, the higher the housing density and the mean number of storeys, i.e. the heat density and therefore the suitability for pipeline heat supply. Therefore all the communes are studied to the degree which is commensurate with their suitability. The communes in category I, which account for some three quarters of the useful heat consumption, are each subject to very detailed analysis.

**Category I**

This category contains all the communes in Luxembourg with the largest towns and thus also holds the most significant potential in terms of district heat. These communes and towns will therefore be covered individually in full depth. The principal approach is to be explained using the example of the town of Esch (see Figure 6-1).


Die Gemeindegrenze ist blau-gestrichelt dargestellt.

| DE | EN |
|---|---|
| Die Gemeindegrenze ist blau-gestrichelt dargestellt. | The commune boundary is shown by the blue dotted line. |

Figure 6-1: Method of recording the development structures taking the town of Esch as an example

Firstly, each town is subdivided into a larger number of zones (nomenclature: [abbreviation for commune]-[abbreviation for town]-[zone number]). These zones are concentrations of similar areas in terms of development, and they are also determined by the geographical boundaries of standard settlement structures. For example, zones 9, 8 and 5 in the town centre have uniform structures which are characterised by decreasing housing density from zone 9 to zone 5. This goes hand in hand with decreasing numbers of storeys in virtually all towns. Zone 1 is an example of an intrinsically uniform built-up area which is not connected with other zones and is therefore recorded as a separate entity. Large (blocks of) public buildings are also recorded individually in many cases because they are often very different from the buildings around them. Moreover, these data can be used later to determine the potential of individual building solutions.

The number of zones depends on the homogeneity of the settlement patterns and the size of the town in any given case. For example, the city of Luxembourg is divided into 60 zones while smaller towns are normally subdivided into around 15 zones. Any individual buildings which are isolated and widely dispersed are then combined together in each commune in order to complete the records for each commune and allow the useful heat figures to be balanced with the register target. The 35 communes in category I are thus subdivided into 408 zones altogether which are dealt with as separate entities.

The zone areas and the building numbers and ground areas in each of these settlement areas can be calculated from the GIS. If there are relatively large, undeveloped vacant spaces in individual zones then these are deducted when the figures are adjusted before further calculations.

As previously explained, the storey numbers are then calculated from the aerial photographs, with the assembling of the many sections ultimately generating average values for each individual zone divided into buildings and public buildings. The ground areas from the GIS can be added up to provide useful area totals for each zone and a total for each commune.

**Category II**

All the places in these communes with more than 250 buildings are recorded as separate zones. All isolated and dispersed buildings and those not suitable for district heat supply are again totalled together to complete the records for the commune and to allow the useful heat figures to be balanced at commune level. The analysis of example towns shows a very high degree of similarity between the average storey numbers. Therefore a mean value can be used for the calculations. The same goes for heat density figures.

**Category III**

These communes can be generally classified as not relevant to district heating on account of their dispersed settlements. No differentiation is therefore made within the commune. An analysis of example communes again yields the average storey numbers and heat density figures applicable to this category.

### 6.1.3. Balance with buildings register and calculation of heat density figures

The figures are balanced with the useful heat consumption targets separately for each individual commune by taking this value and the total useful area of a commune and calculating an area-related specific useful heat consumption which is applied to all further calculations within this commune. By an alignment at commune level which, in most cases, is almost identical with the largest town in this commune, the specific composition of this town is taken into account (frequency of building types and building sizes, building age brackets).

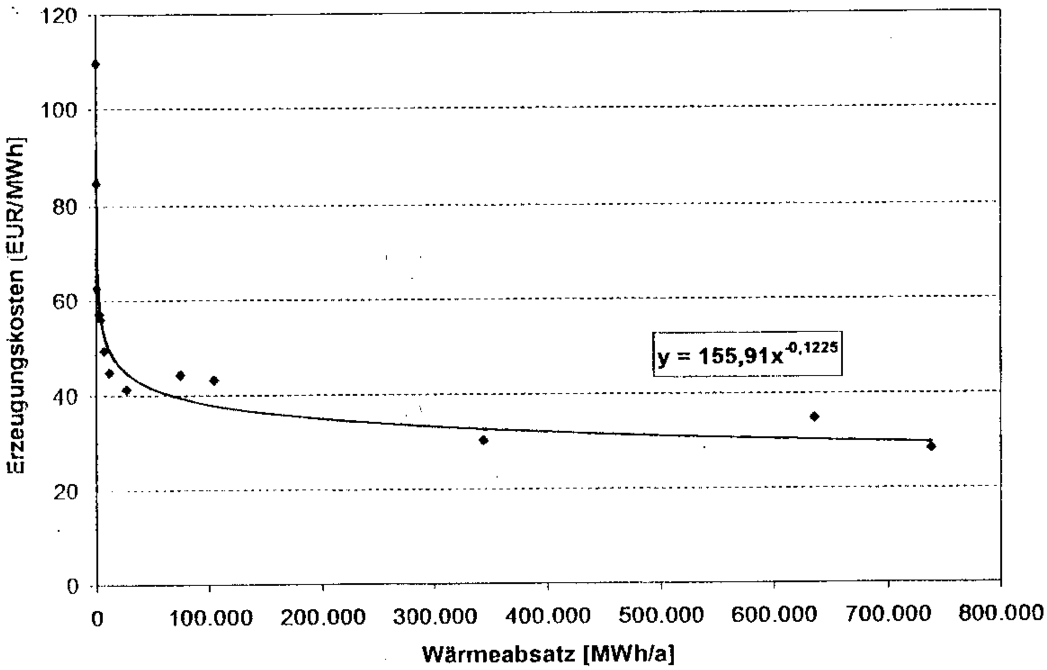
The specific useful heat consumption provides the useful heat quantity of a zone and the relevant local heat density in conjunction with the zone area. The only areas for which average values are used are the remainders in category II and the irrelevant small towns in category III.

### 6.1.4. Calculating the heat cogeneration costs

The heat costs are identified on the premise of the baseline data of 13 CHP plants and peak-load boilers cited in section 1.6. Applying a mean number of operating hours of 4,000 h/a, they represent a potential heat market of between 69 MWh/a and 738 GWh/a (including the peak-load boilers).

**National economic viewpoint**

The first calculation is on the power side, where the sum of the annual capital costs, operating costs and fuel costs leads to specific power generation costs. These are set off for each year under review against the costs avoided in respect of the reference generation system in large power stations (these rise in price scenario 1 from € 63.6/ $MWh_{el}$ in 2006 to € 75.6/ $MWh_{el}$ in 2020, cf. section 1.7) and, on conversion of the alternative costs, yield the specific generation costs of (pure) cogeneration on the heat side. Avoided grid costs are not taken into account. These intermediate results are then consolidated with the specific cogenerated heat costs together with the costs of generation incurred by the peak-load boiler as a weighted average of the respective quantities of heat generated. In order to take account of the development of these costs in the period under review there is a final calculation of the mathematical mean for each plant. Figure 6-2 shows the results related to the heat sales as well as the approximation function. This drops very sharply down to a heat output of around 50 GWh/a, at which point the decrease in unit costs slows down as the heat sales volume rises.




| DE | EN |
|---|---|
| Erzeugungskosten [EUR/MWh] | Generation costs [EUR/MWh] |
| Wärmeabsatz [MWh/a] | Heat sales [MWh/a] |

Figure 6-2: Specific cogenerated heat costs plotted against heat sales (national economic analysis, price scenario 1)

In comparison with the analysis of cogeneration potential in Germany, the cost level in Luxembourg in this study is higher because of the increase in fuel prices, etc. and because there are no credits for avoided grid costs; in Germany the amount applied depending on the voltage level was between € 2.00/ MWh (high voltage) and € 27.60/ MWh (low voltage) (Eikmeier et al., 2006). As such, the advantage of decentralised generation and supply is not taken into consideration. The result is a corresponding reduction in the economic potential of cogeneration, as illustrated by the sensitivity observations in section 6.2.3.

**Business economic viewpoint**

Adopting the business economic viewpoint, the current feed-in tariff is applied for the plants up to 1.5 MW for the entire period under review (cp. section 1.4). The resulting amount requires a specific approach. The larger plants which fall into subsidy category II can be largely financed on the power side, i.e. from this feed-in tariff. This leads to very low heat costs. Larger plants which no longer qualify for this subsidy cannot reach these values despite the decline in unit costs with increasing plant size, resulting in a sharp increase in cost function. The question as to which plant types and sizes are required to exhaust the potential is irrelevant for the analysis of the potential, therefore the observations need to be limited to the plant sizes which are eligible for the subsidy as these have the lowest heat generation costs and thus the greatest possible potential. The costs function therefore needs to have a cap on the input variable for the heat output. The implications of the high impact of the subsidy on the evaluation of the cogeneration potential are discussed in the presentation of the results (see section 6.3.2).

All the cost functions are summarised in Table 6-1.

Table 6-1: Cost functions of heat cogeneration

| Observation model | Cost function of heat cogeneration [€/ MWh] |
|---|---|
| National economy, price scenario 1 | $155.91 * x^{-0.1225}$ |
| National economy, price scenario 2 | $184.55 * x^{-0.1208}$ |
| Business economy, price scenario 1 | $499.45 * x^{-0.3713}$ (up to 1.5 $MW_{el}$ only) |
| Business economy, price scenario 2 | $628.96 * x^{-0.379}$ (up to 1.5 $MW_{el}$ only) |

x = Heat sales [MWh/a]

### 6.1.5 Calculating the heat distribution costs

The heat distribution costs are calculated with the aid of some 40 zones in several towns which represent the entire range of typological settlement structures in Luxembourg which are suitable in principal for district heating. Furthermore, results from the study of cogeneration potential for Germany are available for 11 types of settlement and these are also consulted by way of comparison. The interest rates applied are identical to those for the CHP plants, and 30 years is taken for the physical lifespan of the distribution.

There are no data about all the existing local and district heating systems. Therefore calculations are always made for a grid expansion or for a new grid which means a conservative estimate as against the lower costs in individual areas due to grid densification.

One central specification is the maximum building connection rate in an area. It is set at 100% for the purposes of this study in order to be consistent in pursuing the target idea of a potential calculation. This assumption means that each building can be integrated in a district heating system regardless of how it is heated - the replacement of gas heating systems or storage heaters is most definitely not ruled out. Lower connection rates would lead both directly and indirectly to lower cogeneration potential due to higher specific heat distribution costs. The magnitude of this effect is presented in the sensitivity observations in section 6.2.3.

Table 6-2 shows the range of pipeline lengths and pipeline costs applied. The specific value used is the product of the building density analysis and of the heat density analysis. The values are based on various studies in Germany and are also in line with empirical values from Luxembourg projects, showing pipeline costs of between some € 260/m and

€ 570/m; on average they are around € 400/m. The calculated mean of the zones studied is also at this level.

Table 6-2: Pipeline lengths and pipeline costs

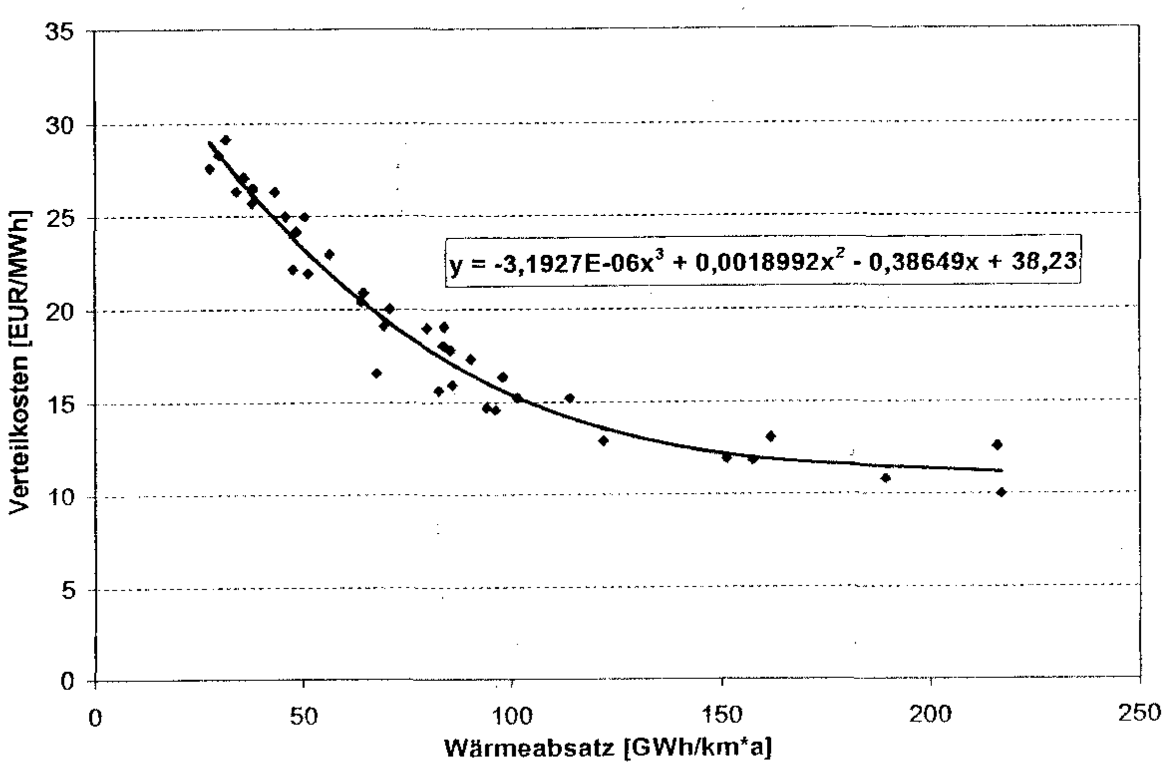
| | **Length [m]** | **Cost [€/m]** |
|---|---|---|
| Sub-distribution | 8 - 14 | 290 - 500 |
| House connection | 6 - 10 | 290 - 400 |

When expanding the grid, different expansion rates are applied when installing the pipelines and the house connections in order to take account of the lead time required in practice for the pipeline installation and the associated starting losses. The costings also factor in the impact of the possible replacement of natural gas supply, costs for upstream distribution, substations, pumping electricity and expenditure on administration and sales.

The specific distribution costs decrease slowly in the period under review as the heat throughput and the costs apportioned to installation and distribution increase steadily. In order to factor in this effect, the results are stated as mathematical means (national economic approach with a capital market interest rate of 6.5%). Having regard to different levels of heat loss, the distribution costs in this case come to between € 11.2/ MWh and € 29.0/MWh (and naturally continue to rise in areas ill-suited to district heating and irrelevant in this regard).

An examination of the individual areas shows that it is possible to derive a good correlation between the specific heat distribution costs [€/ MWh] and the heat density [GWh/ km*a]. Figure 6-3 shows the values for the national economic analysis and the approximation function used for the calculations. The business economic analysis is conducted at the same time and need not be presented here as the results are only marginally different.

A corresponding approach is chosen in connection with the heat losses in the distribution network although its breadth is of lesser importance. These correlations can be used in order to be able to allocate individual distribution costs and distribution losses to all individually recorded zones when calculating the cogeneration potential without necessitating hundreds of individual analyses and calculations: these would have been well beyond the scope of the analyses.




| DE | EN |
|---|---|
| Verteilkosten [EUR/MWh] | Distribution costs [EUR/MWh] |
| Wärmeabsatz [GWh/km*a] | Heat sales [GWh/km*a] |

Figure 6-3: Specific heat distribution costs plotted against heat sales

The business economic analysis basically runs along similar lines, except for the higher interest on capital, and the resulting graph for the distribution costs is similar. It is necessary, however, to factor in the restriction to CHP plants of up to max. 1.5 $MW_{el}$ resulting from the calculation of the heat cogeneration costs. Such plants lead to much smaller (local) heating networks in comparison to an approach which is aimed at larger district heating areas. This is where a settlement typology approach reaches its limits as with increasingly smaller networks the dependence on the specific local conditions rises sharply and will manifest itself in practice in major ranges of fluctuation in the heat distribution costs which are in the order of € 30/ MWh.

This dependence on the underlying conditions in any given case is of importance, first and foremost because, due to the very generous subsidies with these plants, the specific distribution costs exceed the specific heat generation costs and thus have a significant impact on the applicable total costs. The potential is therefore highly sensitive in that it is subject to fluctuating distribution costs.

### 6.1.6 Calculating and identifying the cogeneration potential

The first step is to assess whether pipeline-based cogeneration is cost-effective **for the supply of individual zones**, having due regard for distribution losses. The equation in 6-1 must be satisfied to verify cost-effectiveness.

Wärmeerzeugungskosten [€/ MWh]
+ Wärmeverteilkosten [€/ MWh]
<= anlegbarer Wärmepreis [€/ MWh]

| DE | EN |
|---|---|
| Wärmeerzeugungskosten [€/ MWh] | Heat generation costs [€/ MWh] |
| + Wärmeverteilkosten [€/ MWh] | + Heat distribution costs [€/ MWh] |
| <= anlegbarer Wärmepreis [€/ MWh] | <= Applicable cost of heat [€/ MWh] |

If it is satisfied, then this zone is included in the calculation of the potential. This verification of potential is provided as additional information; it does not establish any proof of the (maximum) potential.

The second step involves a similar assessment in respect of the **merging of zones**. Little by little the zones are grouped according to their ranking in terms of cost-effectiveness, naturally taking account of the geographical situation of the zones. As a general rule, the town centre where the heat density is at its highest forms the nucleus of the growing supply zone. If (smaller) zones are too far apart for a grid expansion to be economically viable then this is also factored into the calculations, as is the direct geographical proximity of two places beyond commune borders. This grouping process is not relevant to towns of categories II and III, or it does not alter the outcome, as these categories represent scattered and discontiguous development structures in small towns.

This assessment method is very important, especially for a country like Luxembourg which has very few large towns and cities and therefore fewer areas with metropolitan development structures and high levels of heat consumption. The graph of the cogeneration costs shows a steep drop as heat consumption increases (cf. Figure 6-2), therefore an increase in heat sales soon causes a significant decline in values and therewith a noticeable improvement in the cost-effectiveness of cogeneration - more than making up for the rise in heat distribution costs which goes along with the decrease in heat density and housing density. It is therefore clear that this assessment will lead to much higher cogeneration potential and is duly typical of the scenarios studied.

A third assessment method is to identify the quantities of heat which just satisfy or fail to satisfy the criteria for cost-effectiveness, i.e. there is a high level of sensitivity to changed input parameters. It makes sense to specify this **range of potential** in view of the need to make approximations and calculate with arithmetic means because a result just over or just under parity with the applicable heat cost should not be included in the calculation of the potential on a purely mathematical basis only or should not be included at all. With this approach just slight changes in the input data would very quickly "tip" these zones from being non-cost-effective to being cost-effective or vice versa. Instead such cases are tantamount to a fundamental ability to compete therefore the specific local conditions would decide whether there is potential for cost-effective cogeneration.

The applicable heat price is the reference of a separate generation system, consisting of natural gas heating and the supply of electricity. Taking a national economic view and a starting price of € 46.5/ MWh in 2006 (derived from a full cost comparison with decentralised solutions, cp. Eikmeier et al., 2006) for price scenario 1, the resulting mathematical mean is € 50.7/ MWh. The prices of the individual years are arrived at by factoring in the increase in the cost of gas whereby the applicable district heating price only contributes to the rise in the price of gas by a factor of 0.75, which corresponds to the mean share of the annual total costs accounted for by the fuel costs. A similar approach is taken in the other scenarios; the mathematical means are summarised in Table 6-3.

Table 6-3: Applicable heat prices

| Observation model | Mathematical mean [€/ MWh] |
|---|---|
| National economy, price scenario 1 | 50.7 |
| National economy, price scenario 2 | 51.4 |
| Business economy, price scenario 1 | 59.0 |
| Business economy, price scenario 2 | 59.2 |

Source: Own calculations based on Eikmeier et al., 2006

When calculating the potential viability of cogeneration there is always a potential demand for useful heat. This is met in any given case by a CHP plant and the associated peak-load boiler which is an integral part of the feasibility calculations. However, the examples below are to be restricted to the quantities of useful heat supplied by the CHP plant. It is therefore necessary to work out the peak-load boiler portion which depends on the size of the plant. The heat demand can be met by a large number of combinations of individual CHP plants, therefore a mean percentage of 25% is taken as standard. The percentage might currently be slightly higher in many projects but there is still room for improvement with new installations.

## 6.2 Areas of potential seen in the national economic analysis in price scenario 1

### 6.2.1 Potential in the case of supply of individual zones

The results of this approach are summarised in Table 6-4 for price scenario 1.

Table 6-4: Potential for the supply of cogenerated heat to individual zones (national economic analysis, price scenario 1)

| Commune | Heat potential [GWh/a] | Proportion of demand [%] |
|---|---|---|
| Category I | 131 | 3.6% |
| Category II | 0 | 0.0% |
| Category III | 0 | 0.0% |
| **Total** | **131** | **2.6%** |

The first thing to put on record is that, as expected, towns in categories II and III, i.e. the sparsely populated areas, do not account for any cogeneration potential. The reason for this is the insufficiently high quantity of heat purchased which, as already mentioned, leads to very high specific generation costs. The criteria for cost-effectiveness are clearly not satisfied, i.e. fall short of the target by at least € 20/ MWh. It is only in category I towns that there are zones which offer potential for viable cogeneration. This amounts to 3.6% of the useful heat consumption in this category; in relation to Luxembourg as a whole the percentage is 2.6%.

This potential is spread over just two cantons and the communes/ towns of the same name in these cantons:

- Luxembourg 71 GWh/a
- Esch-Alzette 60 GWh/a.

It is only in these towns - the two biggest cities in the country of Luxembourg - that there are large urban districts with multi-storey buildings which have a sufficiently high heat density and adequate quantities of purchased heat. In Esch, for example, these are in the central area Esc-Esch-9 (cf. Figure 6-1). As regards the cantons, the potential percentages of useful heat demand are in the order of some 8% and 21% respectively.

The targets for cost-effectiveness are, however, very narrowly missed in a few zones in the towns of Luxembourg and Esch-Alzette.

### 6.2.2 Areas of potential gained through the combination of zones

As already explained, this analysis relates only to the zones in category I towns because these are the only ones with the geographical proximity required for the expansion of grids. The results are presented in Table 6-5.

Table 6-5: Potential for cogenerated heat gained by combining zones (national economic analysis, price scenario 1)

| Commune | Potential [GWh/a] | Proportion of demand [%] |
|---|---|---|
| Category I | 1,051 | 29.1% |
| Category II | 0 | 0.0% |

| | | |
|---|---|---|
| Category III | 0 | 0.0% |
| **Total** | **1,051** | **29.1%** |

The potential rises significantly in comparison to the supply of individual zones. Nevertheless, it is still confined to just two cantons:

- Luxembourg 701 GWh/a
- Esch-Alzette 350 GWh/a.

However, there is now also potential in the commune of Differdange (in the canton of Esch-Alzette). These three communes can be entirely supplied with cogenerated district heat under these basic conditions from a national economic viewpoint with the exception of a negligible minority of widely scattered isolated buildings.

The main reason for the significant increase in potential is the drastic reduction in generation costs which comes with the enlargement of the area; changes in grid losses and distribution costs play a less significant role.

Applying a mean CHP coefficient of 1.05 from new CHP plants, the resulting power generation amounts to 1,104 GWh/a.

As the breakdown in Table 1-1 shows, 277 GWh/a is the heat output calculated (as at 2006) for those CHP plants which are allocated to the private household and CTS sectors. It therefore follows that 26.4% of the cogeneration potential in Luxembourg is already exhausted or, to put it another way, the potential for cogeneration amounts to 774 GWh/a.

In this scenario a cumulative heat output in the order of some 130 GWh/a and an identical amount of heat density are required in order to be competitive. Whether these conditions are met depends on local circumstances, i.e. on the respective development structure. For example, there are communes like Sanem in the canton of Esch-Alzette which have the required heat consumption levels but much lower heat density. The consequence of this is higher heat distribution costs which render cogeneration uneconomic. Conversely there are communes which have a high heat density but are too small to achieve sufficiently high volumes of heat sales. One example of this case is Rumelange in the canton of Esch. However, the two conditions are not met in the majority of the communes.

Table 6-6 lists the 35 communes in category I in rank order. The relative cost-effectiveness is stated in each case, i.e. it is equal to the heat generation costs plus the heat distribution costs minus the applicable district heating price (cf. equation 6-1).

A value above zero indicates that cogeneration/ district heating would be a viable solution while a negative score indicates the opposite. The individual scores thus show how wide the margin of viability is and to what specific extent each commune falls short of the benchmark. Dudelange and Petange are borderline cases.

Overall the analysis of the contiguous zones in comparison to the areas divided into small sections shows the central requirement of a pipeline-based cogenerated heat supply targeted at the area. This supply option can only capitalise on its strengths if there is a large enough grid and therewith a sufficiently high level of heat sales. A clear long-term strategy is required, however, in order to supply the vast majority of any given town. Examples in various countries show that this is possible in principle - hence the expediency of identifying potential in this way - it is comparatively rare, however, which also indicates that the norm in most cases is a short-term approach to planning and a lack of any clear district heating expansion strategy. The comparison of the two areas of potential cited here shows what "price" will be paid for failing to adopt a long-term strategy with a view to the cogeneration option and district heating solutions.

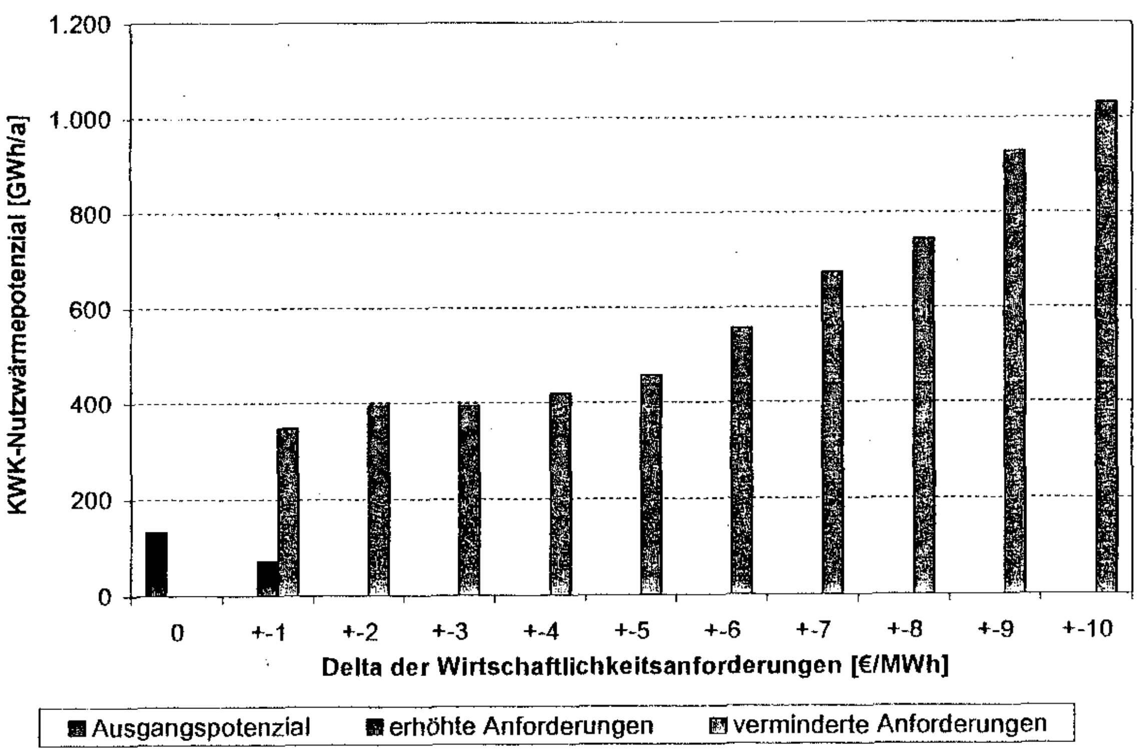
Table 6-6: Ranking of communes with district heating viability (national economic analysis, price scenario 1)

| Rank | Commune | Relative cost-effectiveness [€/ MWh] |
|---|---|---|
| 1 | LUXEMBOURG City | 6.5 |
| 2 | ESCH-ALZETTE | 2.8 |
| 3 | DIFFERDANGE | 1.4 |
| 4 | DUDELANGE | -0.3 |
| 5 | PETANGE | -1.5 |
| 6 | SANEM | -4.5 |
| 7 | SCHIFFLANGE | -5.9 |
| 8 | HESPERANGE | -6.1 |
| 9 | DIEKIRCH | -7.3 |
| 10 | ETTELBRUCK | -7.5 |
| 11 | RUMELANGE | -7.5 |
| 12 | KAYL | -7.5 |
| 13 | BETTEMBOURG | -7.6 |
| 14 | MERSCH | -8.7 |
| 15 | STRASSEN | -8.8 |
| 16 | WILTZ | -9.2 |
| 17 | ECHTERNACH | -9.7 |
| 18 | WALFERDANGE | -10.1 |
| 19 | GREVENMACHER | -10.2 |
| 20 | MERTERT | -12.0 |
| 21 | BERTRANGE | -12.3 |
| 22 | MONDERCANGE | -12.8 |
| 23 | BASCHARAGE (CAPELLEN) | -12.9 |
| 24 | MONDORF | -13.1 |
| 25 | REMICH | -13.3 |
| 26 | MAMER | -14.0 |
| 27 | STEINSEL | -14.4 |

| | | |
|---|---|---|
| 28 | STEINFORT | -14.5 |
| 29 | SANDWEILER | -16.0 |
| 30 | NIEDERANVEN | -16.2 |
| 31 | ROESER | -16.5 |
| 32 | KOPSTAL | -17.4 |
| 33 | BISSEN | -17.5 |
| 34 | JUNGLINSTER | -18.8 |
| 35 | KEHLEN | -19.6 |

### 6.2.3 Potential range and sensitivity analyses

The following analysis shows the impact of a difference in parity in equation 6-1. The respective delta for the reference case varies between - € 10/ MWh (reduced demands on the cost-effectiveness of cogeneration) and +€ 10/ MWh (heightened demands). With regard to the methods applied, it is tantamount to a price for heat which is increased or reduced by this amount; alternatively it can also be interpreted as low or higher heat generation or heat distribution costs in comparison to the reference case. Therefore it can be seen how sensitively the amounts of potential react to changed input parameters. Figure 6-4 shows the results when the zones are regarded individually while Figure 6-5 shows the outcome when the zones are combined together.




| DE | EN |
|---|---|

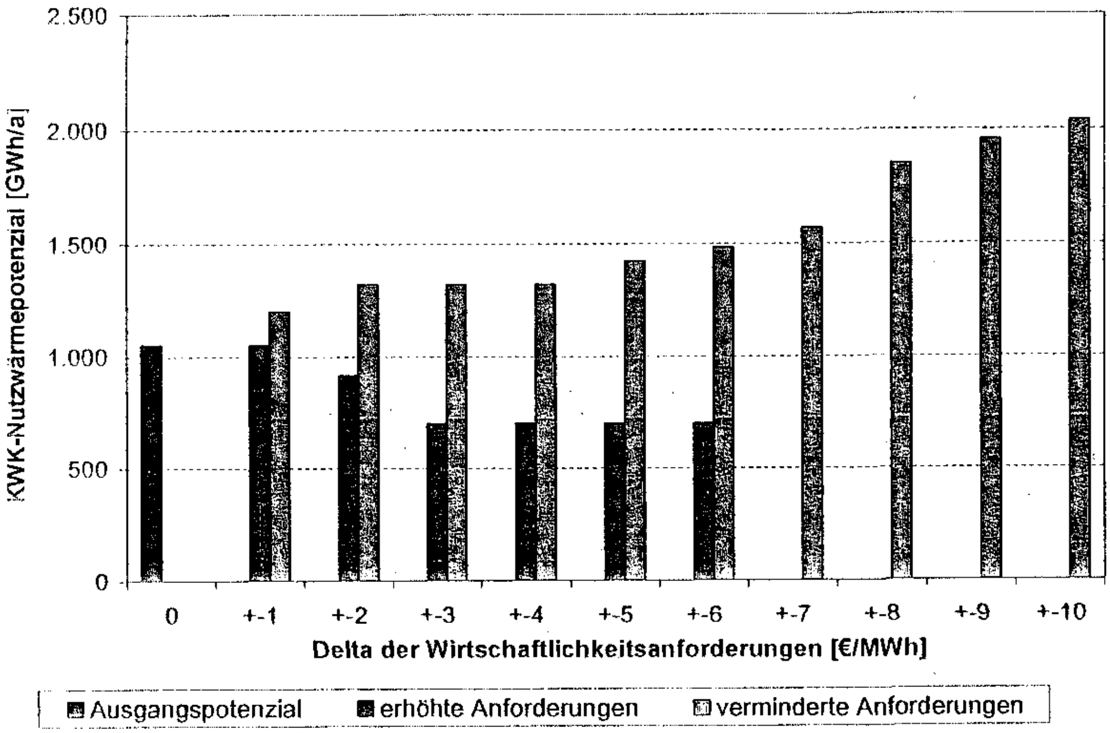
| | |
|---|---|
| KWK-Nutzwärmepotential [GWh/a] | Cogenerated useful heat potential [GWh/a] |
| Delta der Wirtschaftlichkeitsanforderungen [€/MWh] | Delta of cost-effectiveness demands [€/MWh] |
| Ausgangspotential | Initial potential |
| erhöhte Anforderungen | Increased demands |
| verminderte Anforderungen | Reduced demands |

Figure 6-4: Fluctuation of potential in the analysis of individual zones subject to cost-effectiveness demands (national economic analysis, price scenario 1)

In the first case it can be seen that with a delta of +€ 2.0/ MWh the potential is already zero. In other words the relative cost-effectiveness in each zone is under this value and is therefore just above the decentralised supply option.

If lesser demands are made on the cost-effectiveness, however, then the potential increases rapidly, which demonstrates that several zones only just miss the target parity through equation 6-1. At a delta of just € 1/ MWh the potential is 348 TWh/a and therefore almost 2.7 times as high as in the baseline case.

When the zones are grouped together, the potential is similar in principle but with gentler gradients. The potential identified - most particularly in the city of Luxembourg - proves to be much more robust when faced with heightened cost-effectiveness demands, as shown by the individual values in Table 6-6. Conversely, lesser demands on cost-effectiveness cause the potential to rise slowly which, at a delta of € 5/ MWh, is some 40% higher than in the reference case.




| DE | EN |
|---|---|
| KWK-Nutzwärmepotential [GWh/a] | Cogenerated useful heat potential [GWh/a] |
| Delta der Wirtschaftlichkeitsanforderungen [€/MWh] | Delta of cost-effectiveness demands [€/MWh] |
| Ausgangspotential | Initial potential |
| erhöhte Anforderungen | Increased demands |
| verminderte Anforderungen | Reduced demands |

Figure 6-5: Fluctuation of potential in the grouping of zones subject to cost-effectiveness demands (national economic analysis, price scenario 1)

## 6.3 Potential of the other scenarios

### 6.3.1 National economic analysis, price scenario 2

The variant with sharper rises in energy prices brings a slight improvement in the cost-effectiveness of the CHP plants. The results are summarised in Table 6-7 and contrasted with those from price scenario 1.

The cogeneration potential rises by around 14% to 1,199 GWh/a and is still restricted to category I communes. Looking at the individual areas in isolation, the potential is 244 GWh which is almost double the figure in price scenario 1. This major change was to be expected in view of the high sensitivity of the results in the variant previously examined in that a minor improvement in cost-effectiveness brings about a jump in potential (cf. Figure 6-4).

Table 6-7: Cogeneration potential (national economic analysis, price scenario 2)

| Commune | Potential with supply of individual zones [GWh/a] | Potential with grouping of zones [GWh/a] |
|---|---|---|
| Category I | 244 | 1,199 |
| Category II | 0 | 0 |
| Category III | 0 | 0 |
| **Total** | **244** | **1,199** |
| Ratio in relation to national economic analysis, price scenario 1 | 1.87 | 1.14 |

### 6.3.2 Business economic analysis

Reference has already been made to the specific implications of the current subsidy situation in the discussion about cogeneration costs in section 6.1.4. They are clearly dominant over the alternative of energy price scenarios, as illustrated by the figures in Table 6-8 and Table 6-9.

Table 6-8: Cogeneration potential (business economic analysis, price scenario 1)

| Commune | Potential with supply of individual zones [GWh/a] | Potential with grouping of zones [GWh/a] |
|---|---|---|
| Category I | 2,471 | 2,659 |
| Category II | 281 | 281 |
| Category III | 0 | 0 |
| **Total** | **2,752** | **2,940** |

Table 6-9: Cogeneration potential (business economic analysis, price scenario 2)

| Commune | Potential with supply of individual zones [GWh/a] | Potential with grouping of zones [GWh/a] |
|---|---|---|
| Category I | 2,595 | 2,659 |
| Category II | 281 | 281 |
| Category III | 0 | 0 |
| **Total** | **2,876** | **2,940** |

| | | |
|---|---|---|
| Ratio in relation to national economic analysis, price scenario 1 | 1.05 | 1.00 |

The first thing to notice is that there is very little difference, as expected, between the supply of individual zones and the cumulative approach. This is because the analysis is confined to plants with a maximum output of 1.5 $MW_{el}$. Many zones have a much higher demand even before being grouped with neighbouring areas which would mean they would need to be supplied by several plants. In this case, therefore, the zones are not expanded to all intents and purposes with a view to achieving much greater output classes but the approach is to retain a large number of smaller individual plants. In contrast to the national economic analysis there is now also potential in category II, albeit of far less consequence in terms of quantity.

The potential is very great and corresponds to a share of some 59% in the useful heat demand in this segment in price scenario 1. The reason for this is evident in the pyramid formed by the zone sizes required for viability: as the heat demand decreases and as the size of CHP plant which borders on viability decreases, there is a huge rise in the number of areas which can thereby be supplied. This is particularly true for a country like Luxembourg with a large number of relatively small towns. In other words, there are few remaining cases which are too small for cost-effective supply. These are mainly solitary houses / groups of houses.

The levels of potential are only high when the current subsidy terms and conditions are taken into account, however. If there is a significant reduction in subsidy rates it would no longer be viable to supply the many small areas and the potential would drop sharply.

Against this backdrop the potential identified in this scenario is to be interpreted as a ceiling in terms of the viability which can be argued.

### 6.4 Primary energy savings and $CO_2$ savings

The primary energy savings are always seen in reference to a standard of comparison. In this case there are two alternatives:

- Savings as compared to existing fuel mix
- Savings as compared to new generation systems (with the same fuel = natural gas).

The data on which the reference systems are based were presented in section 1.5. The annual utilisation coefficient for the existing heating boilers is 0.79, the value calculated when the register was drawn up (cf. section 4.1).

The results depend marginally on which CHP plants supply the potential identified. In order to minimise this influence further and avoid the necessity of making concrete plant assessments, an approximation function is again used as the method of calculation. The savings for each CHP plant (including peak-load boiler) are calculated separately and then related to the corresponding heat sales. Mean factors of specific savings can thus be calculated across the entire range of plants and then applied to the respective levels of potential.

The calculation only takes account of the cogeneration expansion potential, i.e. the possible construction of new CHP plants above and beyond the existing ones.

The results for the reference case are presented in Table 6-10, i.e. the national economic analysis in price scenario 1. The results are on a substantial scale. The differences between the standards of comparison, especially in the case of the $CO_2$ savings, are due to the significant proportion of other fuels in the power mix.

Table 6-10: Possible savings (national economic analysis, price scenario 1)

| **Standard of comparison** | **$CO_2$ savings [thousand t $CO_2$/a]** | **Primary energy savings [$GWh_{BR}$/a]** |
|---|---|---|
| Existing plants | 490 | 1,655 |
| New plants | 120 | 608 |

The savings in the other scenarios need not be presented here as the results are in the same proportion to each other as the respective amounts of potential.

The resulting $CO_2$ quantities with regard to Luxembourg's $CO_2$ balance are presented in section 10.

### 6.5 Capital expenditure requirements

The required capital investment is split over the CHP plants including the associated peak-load boilers and the heat distribution system. The calculated heat demand can be covered by a number of combinations of individual CHP plants, therefore it makes sense to do the calculation with mean capital costs for every heat unit supplied per annum in the relevant range of plants. If the gas turbines which are mainly used in the industrial sector are not factored into the calculation then there are only very slight differences between the individual plants.

In order to calculate the investment required for the heat grids, a separate cost estimate is carried out for each area of potential in a commune which takes account of the different heat densities and total quantities of heat. This is based on the analysis of the investment costs in the zones, of which there are about 40, which was used to identify the specific heat distribution costs. As regards the specific investment costs subject to the heat density, the resulting function takes a comparable course to the distribution costs (cf.

Figure 6-3) in that the specific capital expenditure requirement related to the supply volume decreases as the heat density increases. The individual values vary only slightly when the approximation function is applied.

No (new) capital costs are incurred for the existing cogeneration (26.4% of the total potential). Therefore the capital costs listed in Table 6-11 relate only to the potential of additional buildings (73.6% of the total potential). As such, the CHP plants account for around two thirds of the total capital expenditure and the heat grids for around one third.

Table 6-11: Capital investment costs (national economic analysis, price scenario 1)

| **Capital investment costs for:** | **Capital costs [€ million]** | **Percentage [%]** |
|---|---|---|
| CHP plant incl. peak-load boiler | 176 | 67.7 |
| Heat distribution network | 84 | 32.3 |
| **Total** | **260** | **100** |

One possible expansion route towards realising the total cogeneration potential is shown in Table 6-12. It is based on the cycle of modernisation of decentralised generator technology in the heating market extending on average over some 20 years, bearing in mind that the change in heating provision is not relevant in practice until an existing plant is in line for modernisation after its physical life has been spent, i.e. there is a need for action on the part of the user.

Table 6-12: Possible route to exploitation of total cogeneration potential

| | **2006** | **2010** | **2015** | **2020** | **2025** |
|---|---|---|---|---|---|
| Percentage of exploitation [%] | 26.4 | 50 | 70 | 85 | 100 |
| Cogeneration potential [GWh/a] | 277 | 553 | 736 | 893 | 1,051 |
| Capital costs [€ million] | 0 | 93 | 154 | 207 | 260 |

## 7 Potential for CHP applications for buildings

In addition to the cogeneration potential arising from pipeline-based heat supplies, the areas of potential in the residential buildings and CTS sectors were studied, as identifiable in the supply of individual properties. There is immediately a need to establish boundaries to avoid counting properties twice because they can be supplied both individually and as part of a larger area. As a general rule, a pipeline-based area-wide supply is always more cost-effective than supplying individual buildings, therefore the observations are confined to those communes of little relevance for local and district heating systems, namely categories II and III. Nor should it be overlooked that particularly large buildings were recorded separately in the detailed analysis of the settlement structures of the communes in category I (cf. e.g. Esc-Esch-2 in Figure 6-1).

## 7.1 Procedural method

First of all, the GIS data are used to identify all the buildings and public buildings which have a ground area of at least 200 m$^2$ [2]. This can be regarded as the minimum size from which a building is deserving of individual analysis. Table 7-1 lists the number and sizes identified.

Table 7-1: Large individual buildings in the communes of categories II and III

| **Ground area [m$^2$]** | **Residential buildings** | **Public buildings** |
|---|---|---|
| 200-400 | 9,774 | 363 |
| 400-600 | 1,716 | 138 |
| 600-800 | 609 | 52 |
| 800-1000 | 279 | 26 |
| 1000-1200 | 119 | 30 |
| 1200-1400 | 75 | 14 |
| 1400-1600 | 41 | 11 |
| 1600-2000 | 41 | 10 |
| 2000-3000 | 30 | 9 |
| 3000 and above | 8 | 7 |
| **Total** | **12,692** | **660** |

The very high number of buildings shows clearly that it is not possible to conduct specific individual analyses, e.g. of the local proximity of several buildings with the option of a combined heat supply. A general estimate makes little sense in rural regions therefore the following identification of potential is restricted to the supply of individual buildings.

The ground area of each building is first converted into usable area and then into the useful heat demand using the numbers of storeys and specific heat demand figures assigned to the communes. Naturally there are major variations in respect of each individual building when applying mean conversion factors. This method is therefore not a suitable way of making reliable statements in terms of a planning basis relating to a specific building. It does, however, duly serve the purpose pursued here of enabling the potential to be estimated for the individual buildings as a whole.

The figures calculated for the useful heat demand range between 18 MWh/a and the peak value of 1,408 MWh/a. In total these buildings represent a useful heat demand of 700 GWh/a, although it does need to be borne in mind that the minimum level for recording was deliberately set very low. If the study is restricted to buildings with a consumption of 100 MWh/a and above, then the total consumption is immediately reduced to 164 GWh/a.

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[2] Adjoining houses (e.g. terraced houses) are often recorded in the GIS as one single building and its ground area as the sum of all individual ground areas. In principle, however, such buildings can be supplied by a generating plant irrespective of the actual situation.

The potential viability is calculated using the methodology previously applied, albeit with two differences:

- Heat distribution costs are no longer incurred
- Applicable heat costs must be adapted to the size of the building supplied.

Once again an approximation function is used which takes account of the economies of scale of alternative heat generation using a heating boiler. The CHP plants in question are small therefore 25% is the mean percentage of heat output applied to the peak-load boilers.

## 7.2 Results

Naturally the results are less reliable than those of the district heating potential. The spread of the individual buildings around the mean values applied is very much higher than with the integrated analysis of several hundred or thousands of buildings. As the very low levels of potential (see Table 7-2) and detailed analyses show, however, this imprecision is of lower-ranking importance.

Table 7-2: Potential of CHP applications for buildings

| **Price scenario** | **National economic analysis [GWh/a]** | **Business economic analysis [GWh/a]** |
|---|---|---|
| Price scenario 1 | 0.0 | 5.4 |
| Price scenario 2 | 0.0 | 4.3 |

Cogeneration alternatives cannot be shown to be cost-effective in any case when taking a national economic view. The criteria for viability are plainly not met, i.e. by at least € 25/ MWh. As sensitivity calculations show, this statement is very robust in the face of changed input data. The reason for this is insufficiently high credits on the power side leading to non-competitive heat prices. The smaller block-type cogeneration units which are of relevance in this segment do not pay without such cross-subsidies on account of their unfavourable cost structures. However, the comparatively bad balance on the power side is due to not including the avoidance of grid costs in the national economic approach. If this was factored in on a scale like in Germany, for example, then the CHP solutions could by all means be competitive, at least for the largest buildings with separate heat and power generation.

In terms of the business economy there is little potential in the largest buildings, all of which fall into category II communes. The somewhat lower figure in price scenario 1 is explained by the fact that the subsidy rates are equal in both price scenarios for the relevant plants of subsidy category 1 (up to 150 $kW_{el}$). Hence the cost-effectiveness of cogeneration declines relative to the rise in energy prices and this decline cannot be counterbalanced by the economies of scale as plant sizes increase - the heat consumption of individual buildings is too low.

The business economy variants also produced potential of 319 GWh/a for district heating supply in the category II communes and did so in those areas which have at least 250 buildings in a densely built-up area. A comparison shows that the largest buildings are located in these regions, i.e. the potential in individual buildings is already included in the district heat potential. As such, the potential of CHP applications for buildings constitutes only one supply alternative and may not be added to the total potential.

# 8 Use of biomass in CHP plants

## 8.1 Available biomass fuel potential in Luxembourg

The potential for high-efficiency cogeneration with biomass comprises three areas of potential, namely from biomass in solid, liquid and gas form. The potential in the individual states has been calculated in renewable energy research for Luxembourg (ISI 2007).

Table 8-1: Realisable, technical and theoretical potential for biomass fuels in solid, liquid and gas form

| **Biomass fractions** | **Status quo 2005** | **Realisable by 2010** | **Realisable by 2020** | **Technical potential** | **Theoretical potential** |
|---|---|---|---|---|---|
| | **Calorific value in GWh** | | | | |
| **Solid biomass** | **379** | **610** | **1,713** | **4,872** | **7,027** |
| Wood fuel | 64 | 117 | 517 | 2,137 | 2,536 |
| Old/scrap forest crop | 200 | 270 | 481 | 481 | 604 |
| Energy crops | 0 | 71 | 284 | 1,422 | 2,891 |
| Organic waste | 115 | 138 | 151 | 174 | 174 |
| Solid farming waste | 0 | 14 | 280 | 658 | 822 |
| **Liquid biomass** | **15** | **41** | **88** | **326** | **660** |
| Energy crops | 12 | 27 | 60 | 298 | 628 |
| Used cooking oils/fats | 3 | 14 | 28 | 28 | 32 |
| **Gaseous biomass** | **79** | **176** | **369** | **1,281** | **2,351** |
| Liquid manure | 26 | 52 | 117 | 152 | 168 |
| Garden/landscape waste | 18 | 36 | 81 | 120 | 133 |
| Biological waste | 1 | 16 | 36 | 36 | 40 |
| Offal | 0 | 0 | 2 | 2 | 2 |
| Energy crops | 21 | 42 | 95 | 930 | 1,963 |
| Sewage gas | 13 | 29 | 37 | 39 | 43 |
| Landfill gas | 0 | 1 | 1 | 2 | 2 |
| **Total biomass** | **473** | **827** | **2,170** | **6,479** | **10,038** |

Source: RES research Luxembourg (ISI 2007)

When calculating the amounts of potential, competing types of energy use play a major role. Biomass can be used for the generation of heat only, for example, or for combined heat and power generation as well as for the preparation of fuel. Energy crops can also be grown on the same areas for solid as well as for liquid and gaseous forms of biomass. For this reason this assessment will be brief and restricted to the most significant assumptions made in order to calculate the potential.

The total area of Luxembourg is 2,586 km², 86.6% of which is farmland and forest (as at 2004). The agricultural land is purported to be 1,281 km², approximately 615 km² of which is farmland and 650 km² of which is grassland and pasture. The woodland area is 897 km². The following general conditions were factored in when studying the potential for renewable energies.

**Wood fuel**

Approximately 15% of woodland is classified as unsuitable for sustainable forestry (e.g. steep hillside locations) when calculating renewable timber resources. A further 5% is discounted due to protected landscape status.

**Energy crops**

The agricultural land is used as the basis for energy crops. The areas suitable for energy crops were divided into three equal parts for solid, liquid and gaseous forms of biomass. The breakdown of the plants was as follows:

- Solid biomass: grain (33%), energy grasses (33%), short-rotation forests (33%)
- Liquid biomass: rape (50%), wheat (50%)
- Gaseous biomass: wheat (33%), maize (33%), energy grasses (33%)

The theoretical potential figures are based on the assumption that the total area of agricultural land is used to grow energy crops. The calculation of suitable areas for the technical potential excludes grassland and 2,300 ha set aside for nature conservation. It is believed to be a viable estimate that 20% of the technically suitable areas will be developed by 2020 (solid and liquid biomass) and 10% for gaseous biomass. This corresponds to the use of approximately 10,000 ha of farmland to grow energy crops or approximately 16% of the existing arable land.

**Other relevant factors**

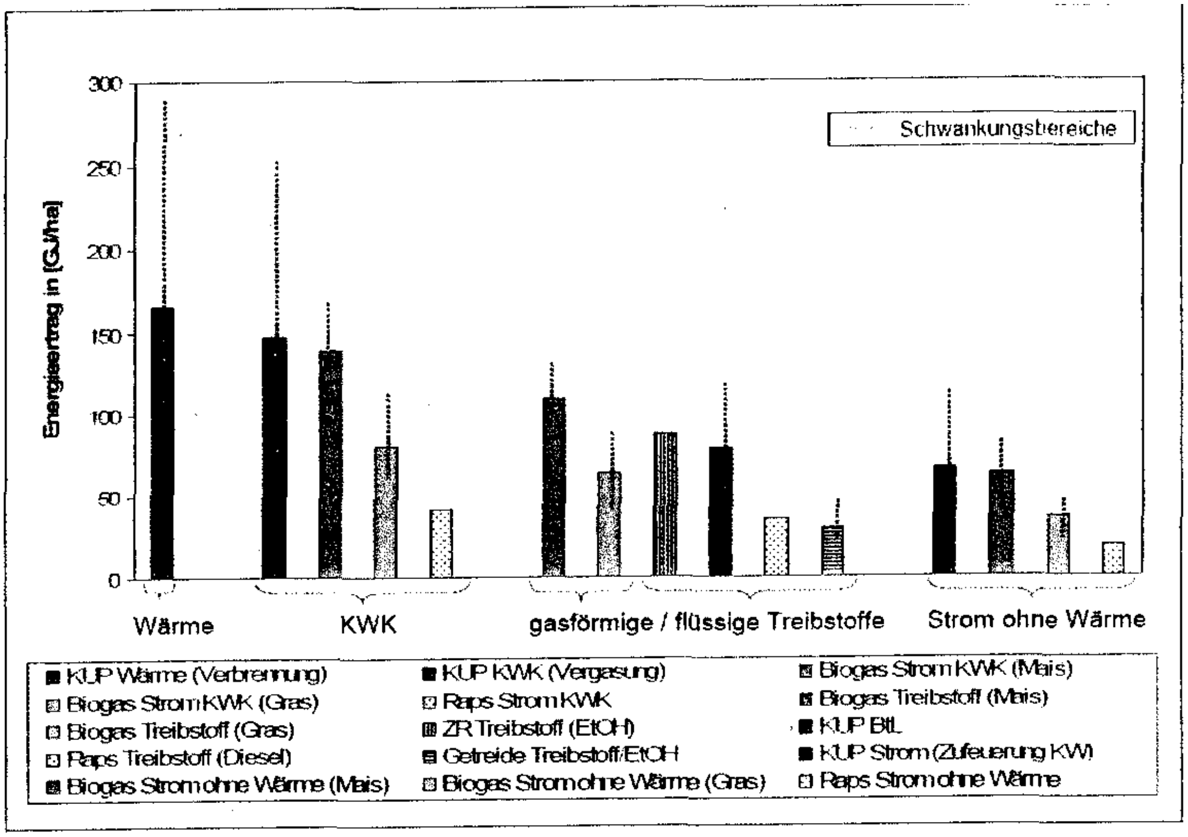
These areas of agricultural land and woodland can be used for biomass production although there would be numerous restrictions to taken into account. Moreover, the following would also be relevant in terms of the environment:

- Nitrate pollution, phosphate pollution, pesticides
- Soil erosion and soil compaction
- Water consumption, biodiversity
- Extensification of farming practices (e.g. 30% in EEA study)
- Exemption of areas for nature conservation (e.g. 3% in EEA study)

Other factors of influence for estimating the potential of the agricultural land are as follows:

- Increases in production
- Degree of self-sufficiency
- Additional environmental conditions (proportion of natural woodland, percentage of nature conservation area in relation to the total area, proportion of wildlife corridors)
- Permission to plough up grassland (conversion of meadows/ pasture into farmland)

The question thus arises as to what part biomass should play in the various areas of energy use and how big a role is played by nature conservation factors. The use of biomass in heating and in cogeneration tops the graph in energy yield (see Figure 8-1), as studies in Germany have shown.




Quelle: SRU 2007

| DE | EN |
|---|---|
| Schwankungsbereiche | Fluctuations |
| Energieertrag in [GJ/ha] | Energy yield in GJ/ha |
| Wärme | Heat |
| KWK | Cogeneration |
| gasförmige / flüssige Treibstoffe | Gaseous / liquid fuels |
| Strom ohne Wärme | Power excl. heat |
| KUP Wärme (Verbrennung) | Short-rotation plantation heat (combustion) |
| Biogas Strom KWK (Gras) | Biogas cogenerated power (grass) |
| Biogas Treibstoff (Gras) | Biogas fuel (grass) |
| Raps Treibstoff (Diesel) | Rapeseed fuel (diesel) |
| Biogas Strom ohne Wärme (Mais) | Biogas power excl. heat (maize) |
| KUP KWK (Vergasung) | Short-rotation plantation cogeneration (gasification) |
| Raps Strom KWK (Gras) | Rape cogenerated power (grass) |
| ZR Treibstoff (EtOH) | ZR fuel (EtOH) |
| Getreide Treibstoff/ EtOH | Grain motor fuel/ EtOH |
| Biogas Strom ohne Wärme (Gras) | Biogas power excl. heat (grass) |
| Biogas Strom KWK (Mais) | Biogas cogenerated power (maize) |

| | |
|---|---|
| Biogas Treibstoff (Mais) | Biogas motor fuel (maize) |
| KUP BtL | Short-rotation plantation fuel (BtL) |
| KUP Strom (Zufeuerung KW) | Short-rotation plantation power (HC co-firing) |
| Raps Strom ohne Wärme | Rapeseed power excl. heat |
| Quelle: SRU 2007 | Source: SRU 2007 |

Figure 8-1: Graph summarising current energy yields in GJ/ ha (net) from renewable resources applying a range of usage strategies

A comparison of the technical potential for solid, liquid and gaseous biomass through energy crops in Luxembourg already indicates that the yield of liquid fuels is much lower than solid or gaseous biomass on the same area.

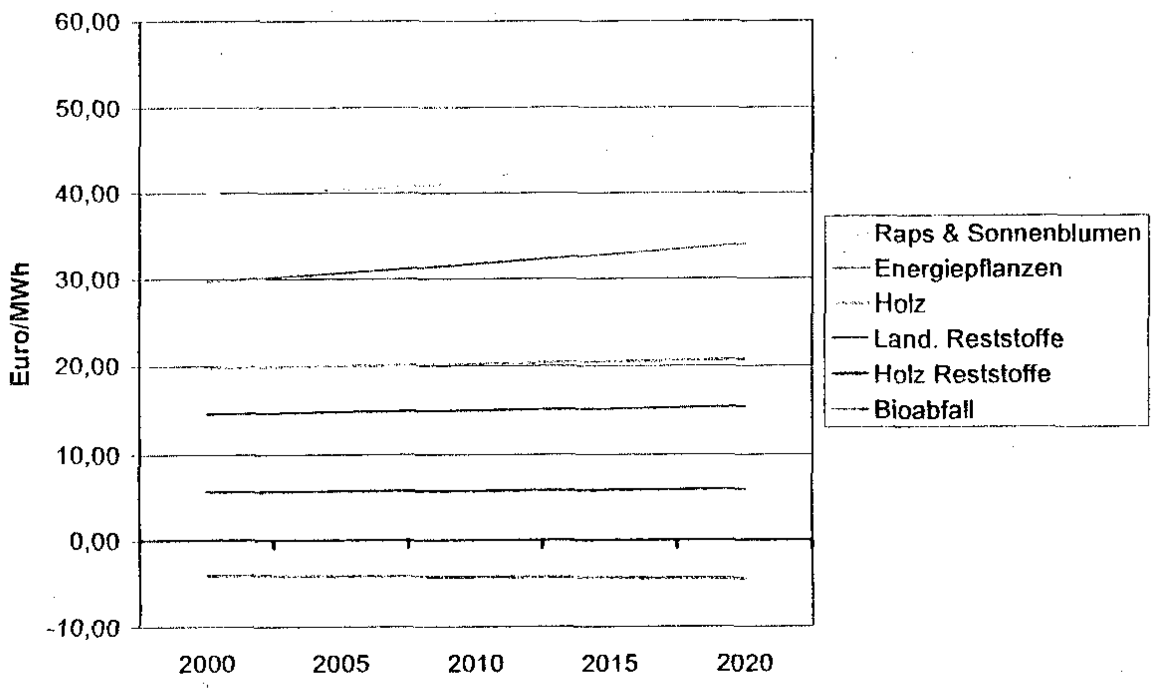
Table 8-2: Levels of technical potential for energy crops

| | | **Solid biomass** | **Liquid biomass** | **Gaseous biomass** | **Total** |
|---|---|---|---|---|---|
| **Technical potential** | **Calorific value in GWh** | 1,422 | 298 | 930 | 2,650 |
| **Arable land used** | **ha** | 20,235 | 20,235 | 20,235 | 60,705 |

Source: RES research Luxembourg (ISI 2007)

## 8.2 Biomass fuel costs

The fuel costs incurred for the individual biomass fractions are set out in the following diagram. The cheapest fractions are biological waste as well as waste generated by farming and the lumber industry. Fuels from wood become more expensive if they are not made from waste materials. Energy crops produce fuel costs of approximately € 30/ MWh. Energy crops which are used to produce liquid fuels work out at approximately € 40/ MWh.




Quelle: GreenX-Database

| DE | EN |
|---|---|
| Raps & Sonnenblumen | Rape & sunflowers |
| Energiepflanzen | Energy crops |
| Holz | Wood |
| Land. Reststoffe | Farming waste |
| Holz Reststoffe | Waste wood |
| Bioabfall | Biological waste |
| Quelle: GreenX-Database | Source: Green-X database |

Figure 8-2: Trend in fuel prices related to the calorific value for various biomass fractions until 2020

### 8.3 Cogeneration technologies conducive to the exploitation of biomass potential

As a general principle, the following cogeneration technologies are available for the use of biomass:

- Small biogas plants (liquid manure only)
  These plants are used to generate power and heat from liquid manure. The utilisation of the heat generated by the plants is frequently problematic as they are generally in rural areas and the neighbouring farms have relatively low levels of heat consumption.

- Large biogas plants (including use of renewable resources)
  These plants are used to generate power and heat from renewable primary products (energy crops, garden/landscape waste). The heat generated by the plants must by utilised through local heating systems.

- Wood-fired power stations
  Wood-fired power stations are used for the consumption of solid biomass. Steam is generated in a boiler and expanded via a steam turbine. Heat extraction is possible.

- Woodgas-powered CHP unit
  Suitable for small plants in the 100 to 500 kW(el) range, woodgas-powered CHP units are still at the pre-production stage. In contrast to the use of steam turbines, the small-scale cogeneration units boast much higher efficiency levels and lower costs.

- Stirling machines
  Stirling machines can be fired with wood (e.g. wood pellets) and are on the verge of commercial viability for household use of solid biomass.

The cost parameters for individual plants are presented in Table 8-3. The capital costs and the costs involved with operation and consumption are relevant to the power generation costs.

Table 8-3: Basic technical and economic data relating to CHP plants for the utilisation of biomass

| Parameters | Unit | Small biogas plant (slurry) | Large biogas plant (NaWaRo)* | Wood-fired power station | Woodgas-powered CHP unit | Stirling |
|---|---|---|---|---|---|---|
| **Output** | **kW (el)** | **30** | **350** | **5000** | **155** | **9** |
| **Electrical efficiency** | **%** | 25.5% | 31.3% | 13.5% | 30.2% | 24.2% |
| **Thermal efficiency** | **%** | 59.5% | 56.3% | 71.5% | 49.8% | 69.8% |
| **Total efficiency** | **%** | 85.0% | 87.5% | 85.0% | 80.0% | 94.0% |
| **Investment** | **€/ kW** | 4,500 | 3,170 | 3,850 | 5,540 | 5,989 |
| **Fixed operating costs** | **€/ kW/ a % of investment** | 445.5<br>9.9% | 243.6<br>8.7% | 246.4<br>6.4% | 360.1<br>6.5% | 269.5<br>4.5% |

Source: Eikmeier 2006
* NaWaRo = renewable resources

## 8.4 Assessment of biomass-based cogeneration potential

Credits are awarded for heat according to the fossil fuel savings (see Table 8-4), having due regard for the fact that some of the heat is used for own consumption and that the total amount of heat generated cannot actually be used. The plants are generally power-controlled therefore they reach high full load hours. For the cost-effectiveness calculations, therefore, 7000 full load hours are assumed on the power side.

This brings the power generation costs (with heat credits) for biogas plants to approximately € 129 to € 142/ MWh. In solid biomass the power generation costs differ depending on the fuels used (old forest crop / wood fuel). In this case the costs are between € 44 and € 188/ MWh. If the plants are used for local heat supply, the heat consumption occurs mainly in the winter. For this reason only some of the generated heat is taken into account with the heat credits.

Table 8-4: Power generation costs allowing for heat credits

| **Parameters** | **Unit** | **Small biogas plant (slurry)** | **Large biogas plant (NaWaRo)*** | **Wood-fired power station** | **Woodgas-powered CHP unit** | **Stirling** |
|---|---|---|---|---|---|---|
| **Output** | **kW (el)** | **30** | **350** | **5000** | **155** | **9** |
| **Power generation costs** | **€/ MWh (el)** | 178 | 180 | 143/ 251** | 164/ 212 | 188/ 248 |
| **Heat credit** | **€/ MWh (th)** | 42 | 42 | 37 | 42 | 42 |
| **Heat use** | **%** | 50 | 50 | 50 | 50 | 50 |
| **Power generation costs (incl. heat credit)** | **€/ MWh (el)** | 129 | 142 | 44/ 152** | 129/ 177 | 128/ 188 |

Source: Own calculations, * NaWaRo = renewable resources, ** old forest crop/ wood fuel

This shows that the resulting power generation costs do not reach the reference power generation costs even with relatively high heat purchase rates and the payments associated therewith. The only exception is the wood-fired power station if it is remunerated for the heat and can use old forest crop as fuel. Almost half of the available potential in terms of scrap wood until 2020 was already exhausted by 2005 hence the assumption that it would be impossible to operate a wood-fired power station exclusively with scrap wood. As such, no technology will achieve the cost-effectiveness by 2020 without additional subsidy.

To estimate the potential savings of primary energy and $CO_2$, the possible power and heat generation in CHP plants is estimated on the basis of the fuel potential which can be realised. Table 8-5 shows the allocation of the realisable fuel potential to CHP technologies. The solid biomass is used in district heating plants and the gaseous biomass in biogas plants. The figures also take account of the fact that some of the wood fuel is used for direct heat generation.

Table 8-5: Allocation of realisable fuel potential to CHP use

| Biomass fractions | 2005 | 2010 | | 2020 | |
|---|---|---|---|---|---|
| | Status quo | Realisable | Of which cogenerated | Realisable | Of which cogenerated |
| | Calorific value in GWh | | | | |
| **Solid biomass** | **379** | **610** | **155** | **1,713** | **1,040** |
| Wood fuel | 64 | 117 | 0 | 517 | 195 |
| Old/scrap forest crop | 200 | 270 | 70 | 481 | 281 |
| Energy crops | 0 | 71 | 71 | 284 | 284 |
| Organic waste | 115 | 138 | | 151 | |
| Solid farming waste | 0 | 14 | 14 | 180 | 280 |
| **Liquid biomass** | **15** | **41** | **0** | **88** | **0** |
| Energy crops | 12 | 27 | 0 | 60 | 0 |
| Used cooking oils/fats | 3 | 14 | 0 | 28 | 0 |
| **Gaseous biomass** | **79** | **176** | **130** | **369** | **293** |
| Liquid manure | 26 | 52 | 52 | 117 | 117 |
| Garden/landscape waste | 18 | 36 | 36 | 81 | 81 |
| Biological waste | 1 | 16 | | 36 | |
| Offal | 0 | 0 | | 2 | |
| Energy crops | 21 | 42 | 42 | 95 | 95 |
| Sewage gas | 13 | 29 | 0 | 37 | 0 |
| Landfill gas | 0 | 1 | 0 | 1 | 0 |
| **Total biomass** | **473** | **827** | **285** | **2,170** | **1,333** |

Source: ISI 2007, own estimates

The power and heat generated from the biomass used is then worked out from the technical data of the wood-fired power stations and the biogas plants, assuming a heat recovery of 50% for the biogas plants and for the wood-fired power stations. In actual operation a heat recovery of this magnitude will be difficult to achieve as heat customers are frequently in short supply at the plant locations. By way of comparison, Table 8-6 also includes the quantities of power and heat which can be achieved with various policies on subsidies and which have been calculated in research into renewables for Luxembourg (ISI 2007). The BAU scenario pictures the development on the basis of the incentive schemes currently in place. The renewables and Kyoto scenarios picture the development with maximum exploitation of the realisable potential.

Table 8-6: Potential power and heat generation by biomass cogeneration and comparison with expansion scenarios according to RES Luxembourg research

| **Technology** | **Year** | **Cogenerated power** | **Cogenerated heat** |
|---|---|---|---|
| | | **GWh/a** | **GWh/a** |
| Wood-fired power station | 2010 | 21 | 56 |
| | 2020 | 140 | 372 |
| Biogas with local heating | 2010 | 40 | 37 |
| | 2020 | 92 | 82 |
| **Total** | **2010** | **62** | **92** |
| | **2020** | **232** | **454** |
| **Expansion scenarios according to RES Luxembourg research (ISI 2007)** | | | |
| BAU | 2010 | 35 | 13 |
| | 2020 | 76 | 36 |
| Renewables | 2010 | 35 | 27 |
| | 2020 | 220 | 228 |
| Kyoto | 2010 | 44 | 34 |
| | 2020 | 203 | 210 |

## 9 Summary of the various areas of potential for Luxembourg

The preceding analysis of the individual zones is summarised in the following section (see Table 9-1). Given the very different subsidy models for cogeneration in local/ district heating and in industry, the national economic analysis is taken as the basis for the evaluation of cost-effectiveness in comparison with a new reference plant for power generation. The main potential for expansion of cogeneration is in industry. There is also substantial potential in pipeline-based district heat supplies.

Table 9-1: Summary of areas of potential under price scenario 1 (national economic analysis)

| **Total areas of potential** | **Useful energy** | | **Proportion of total potential** | |
|---|---|---|---|---|
| | **Heat** | **Power** | **Heat** | **Power** |
| | **GWh** | **GWh** | **%** | **%** |
| Pipeline-based local/ district heating | 1,051 | 1,037 | 41 | 44 |
| Property-related CHP plants | 0 | 0 | 0 | 0 |
| Industrial CHP plants | 1,539 | 1,302 | 59 | 56 |
| Biomass CHP | 0 | 0 | 0 | 0 |
| **Total** | **2,590** | **2,339** | **100** | **100** |

Source: Own calculations

The current stock of CHP plants splits into district heating and industry (see Table 9-2). Some 13% of the potential calculated in relation to industrial CHP plants on the heat side has already been exhausted. The proportion of local/ district heating as it stands today is approximately 26% of the existing potential on the heat side.

Table 9-2: Summary of existing CHP plants (as at 2006)

| **Existing potential** | **Useful energy** | | **Proportion of available potential** | |
|---|---|---|---|---|
| | **Heat** | **Power** | **Heat** | **Power** |
| | **GWh** | **GWh** | **%** | **%** |
| Pipeline-based local/ district heating | 277 | 224 | 26 | 22 |
| Property-related CHP plants | | | | |
| Industrial CHP plants | 326 | 215 | 13 | 17 |
| Biomass CHP | n/a | 33 | n/a | 14 |
| **Total** | **630** | **472** | **n/a** | **n/a** |

Source: Own calculations

If the existing potential is deducted from the total potential, the remaining useful heat expansion potential is in the order of 1,213 GWh in industry and 774 GWh/a in pipeline-based local/ district heating (see Table 9-3).

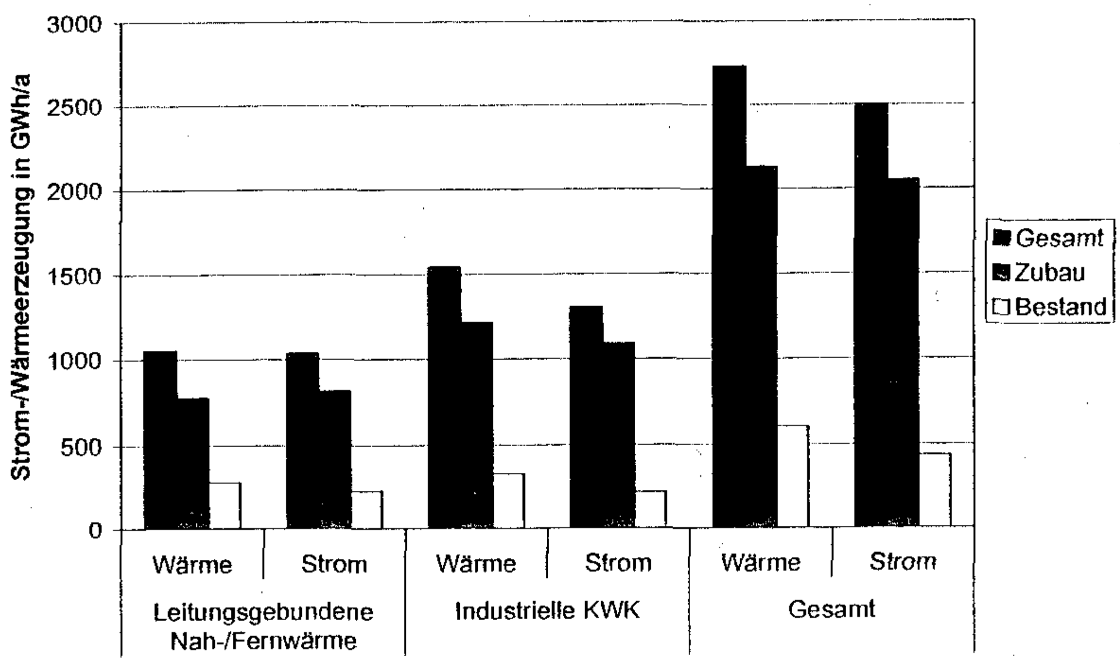
Table 9-3: Summary of expansion potential under price scenario 1 (national economic analysis)

| **Expansion potential** | **Useful energy** | | **Proportion of available potential** | |
|---|---|---|---|---|
| | **Heat** | **Power** | **Heat** | **Power** |
| | **GWh** | **GWh** | **%** | **%** |
| Pipeline-based local/ district heating | 774 | 813 | 74 | 78 |
| Property-related CHP plants | 0 | 0 | 0 | 0 |
| Industrial CHP plants | 1,213 | 1,087 | 87 | 83 |
| Biomass CHP | 0 | 0 | 0 | 0 |
| **Total** | **1,987** | **1,900** | " | " |

Source: Own calculations

Overall it is clear that there is considerable expansion potential in combined heat and power generation in Luxembourg (cf. Figure 9-1). This involves new CHP plants in industry where, according to the analyses in this study, there is still great potential for useful heat which could be covered by combined generation. This potential is not currently being realised because it is not viable from a business economic viewpoint in the majority of cases.

There is slightly less potential in local/ district heating where the existing potential can be tapped through the gradual expansion of suitable areas (especially in the cantons of Luxembourg and Esch-Alzette).




Quelle: Eigene Berechnung

| DE | EN |
|---|---|
| Strom-/Wärmeerzeugung in GWh/a | Power/ heat generation in GWh/a |
| Gesamt | Total |
| Zubau | Expansion |
| Bestand | Existing stock |
| Wärme | Heat |
| Strom | Power |
| Leitungsgebundene Nah-/Fernwärme | Pipeline-based local/ district heat |
| Industrielle KWK | Industrial CHP |
| Gesamt | Total |
| Quelle: Eigene Berechnungen | Source: Own calculations |

Figure 9-1: Existing, expansion and total potential of CHP plants in local/ district heating, in industry and in Luxembourg as a whole (price scenario 1, national economic analysis)

**Primary energy savings and $CO_2$ savings**

The primary energy savings and $CO_2$ savings depend very much on the systems chosen as reference models (cf. Table 9-4). The savings are therefore calculated once in comparison with the actual existing stock and once in comparison with new plants which use the same fuel as the CHP plants. The calculation in comparison with the existing stock reveals the short-term increases in efficiency which can be achieved by CHP plants. The comparison with new plants using the same fuel reflects the advantage of CHP plants over separate generation in terms of the investment required in new plants and is more indicative of the long-term perspective. It is clear that CHP plants bring about big savings as opposed to existing power and heat generation systems. Even if compared with new separate generation systems, there are still savings to be made, albeit significantly lower.

The level of investment required for the development of expansion potential is approximately € 384 million. In the case of district heating systems this includes the capital expenditure on the required peak-load boilers and the grids.

Table 9-4: Primary energy savings, $CO_2$ savings and capital expenditure required for expansion (excluding existing stock)

| **Expansion potential by 2020** | **Savings compared to status quo** | | **Savings compared to new plants** | | **Investment needs** |
|---|---|---|---|---|---|
| | **Primary energy** | **$CO_2$** | **Primary energy** | **$CO_2$** | **€ million** |
| | **GWh/a** | **1000 t $CO_2$/a** | **GWh/a** | **1000 t $CO_2$/a** | |
| Pipeline-based local/ district heating | 1,655 | 490 | 608 | 120 | 260 |
| Property-related CHP plants | 0 | 0 | 0 | 0 | 0 |
| Industrial CHP plants | 1,421 | 445 | 528 | 104 | 117 |
| Biomass CHP | 0 | 0 | 0 | 0 | 0 |
| **Total** | **3,076** | **935** | **1,136** | **224** | **377** |

Source: Own calculations based on national economic analysis, price scenario 1

The higher savings of primary energy and $CO_2$ in local/ district heating in comparison to industry are explained by the use of gas turbines in industry which have greater heat generation capacities. Moreover, in the comparison with existing stock, heating boilers with poorer efficiency rates than in industry are being superseded in district heating networks. One factor of relevance in this regard is that the $CO_2$ savings which have been identified cannot be factored into Luxembourg's greenhouse gas balance on account of the territorial principle (cf. also section 10).

## 10 Obstacles hindering the realisation of cogeneration potential

The (possible) obstacles to greater use of cogeneration arise at various levels and are therefore discussed separately below.

### 10.1 Availability of fuels and trends in fuel prices

**Natural gas** is low in emissions and is of particular significance in respect of the use of cogeneration in Luxembourg with an emphasis on relatively small generation units. Despite rising worldwide energy consumption levels, experts are not anticipating any shortage in the availability of natural gas by 2030. Energy supplies will increasingly depend on politically and economically unstable producing countries and transit countries, however, and the supply risks will increase. This is particularly true of Europe's rising dependency on imports as a whole.

Regarding the trend in prices there are admittedly major uncertainties. Firstly, the recent substantial price increases have created an air of insecurity while the price fluctuations are as much of a hindrance to capital investment planning. The high volatility in the price of natural gas has less effect on power cogeneration than on separate power generation, however, because the cogenerated heat is not competing for sales with the heat generated directly from natural gas in individual heating plants, the price of which is subject to the same fluctuations. In this respect the fluctuating natural gas prices can even serve as an argument in favour of the spread of cogeneration technology.

One key factor which has a major influence on the cost-effectiveness of CHP plants is the **ratio of the price of gas to the price of electricity**. If the price of gas rises more in future than the price of electricity then the relative amount of credit which the CHP plants could achieve on the power side as compared to pure heat generation will tend to decrease. The reverse will be true if the increase in the price of electricity is higher than the reference index on the heat side - a trend which favours the CHP plants.

The future price of electricity will also be largely influenced by the trend in coal prices which have also risen sharply in the past. The question as to which fuel will have the greater influence on the electricity prices in the future, whether coal or gas, depends very much on the trade in $CO_2$ emissions and the certificate prices. This may compensate in terms of fuel prices in favour of coal if certificate prices are high. The increased use of renewable energies in electricity will bring wholesale electricity prices down in future as greater influence is exerted on the electricity markets, most notably by wind energy with its lower marginal costs. The ratio between the price of electricity and the price of natural gas is therefore unlikely to change to any great degree in future in favour of cogeneration.

**Availability of biomass and trends in biomass prices**

The availability of biomass is mainly limited by the acreage of cultivable land. There is more competition surrounding the use of biomass therefore its future availability is dependent on several developments. The key considerations in this respect are the use of biomass for heating, for biofuel production and for power and heat supply. The subsidy conditions for the various types of use may result in limited availability of fuel for combined power and heat generation.

Nature conservation issues also play a key role in the future availability of biomass. The trend in nature conservation towards more extensive cultivation of the available areas and towards designating areas for nature conservation can impose further limits on future potential.

The availability of biomass waste which is suitable for energy recovery is also limited, as shown in section 8.

One other option is to import biomass from other countries. The availability in this case depends very much on the Europe-wide demand for biomass and, in the case of certain biomass fractions, on the worldwide demand. Particular attention is to be devoted to the sustainable production of the imported biomass fractions, an issue which has been subjected to highly critical analysis, most particularly in the area of liquid biomass (biofuels).

The increasing use of biomass in many European countries has already put up biomass prices in the past, indicating that prices will increase if demand begins to outstrip supply.

## 10.2 Political and legal framework

One factor of particular importance in respect of the further expansion of cogeneration in Luxembourg is its contribution to the various international and EU-wide commitments which Luxembourg has entered into, the most notable of these being the following targets.

- Kyoto target for reduction in $CO_2$ emissions
- Compulsory aim to increase the proportion of renewable energy in line with the EU Renewable Energy Directive
- Reduction in final energy demand in line with EU Directive on Energy Efficiency

**Emissions trading**

The proposals of the European Commission with a view to improving the EU system for the trade in greenhouse gas emissions do not lift all of the constraints currently restricting the expansion of cogeneration in Luxembourg. Emissions which are reduced by avoiding the importation of power from abroad are not factored into Luxembourg's greenhouse gas balance in respect of plants outside the scope of emissions trading on account of the territorial principle.

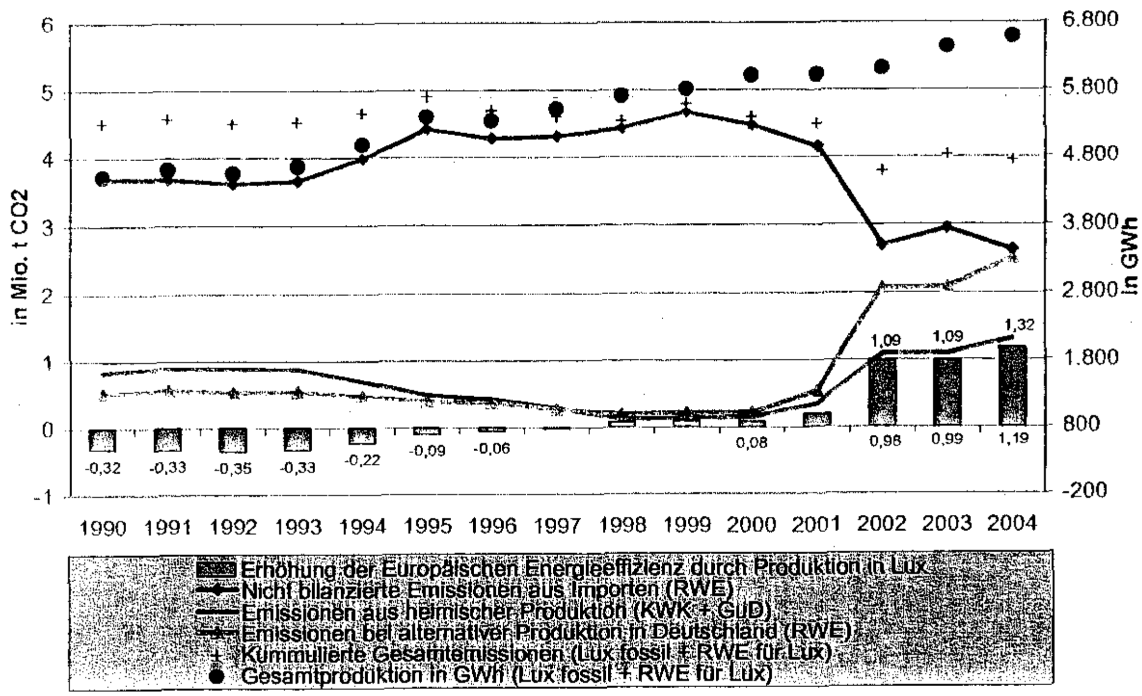
Plants which do fall under the emissions trading scheme, however, will no longer be affected in future by national emission limits. The climate protection targets of the EU are to be met firstly in the context of the emissions trading system and, secondly, through measures in the sectors beyond the scope of the emissions trading system. The Europe-wide target in emissions trading is a reduction of 21% between 2005 and 2020. The emission certificates will therefore also be auctioned all over Europe. For CHP plants within the emissions trading system it will therefore be of great significance in future how many emission certificates they will need for heat supply and how pure heat generators will be treated at the same time.

CHP plants which are operated outside the emissions trading scheme do make a contribution to the efforts to reduce emissions in Europe. On account of the above-mentioned territorial principle, however, they do not help to reduce emissions in Luxembourg. The convention established by the European Commission, according to which emissions are allocated to the state in which they are emitted, may be justified for all other EU states where the domestic electricity production roughly covers the demand but would give rise to absurd conclusions about Luxembourg. As such, it makes sense to favour an analysis here which puts the focus on the global $CO_2$ reduction effected by cogeneration as opposed to separate generation.

The emission reduction target beyond the scope of the emissions trading system will be approximately 21% for the period from 2005 to 2020. Small CHP plants which do not fall under the EU's emissions trading system will not be able to make any contribution to this target. On account of the fact that more fuel is required for combined power and heat generation as compared to pure heat generation, CHP plants actually push up Luxembourg's greenhouse gas emissions. On the power side they mainly supplant imported power which is not counted in Luxembourg's $CO_2$ balance. On the heat side they mainly replace local oil and gas heating systems, the emission levels of which are only slightly worse than those of small CHP plants.

Primarily, however, the real saving through CHP plants is much greater on the power side. The national cogenerated power production replaces imported power with emission factors of 0.78 g $CO_2$/ kWh on average. The national power mix has a mean emission factor of 0.41 g $CO_2$/ kWh. As Figure 10-1 shows, Luxembourg has thus relieved the European balance of more than 1 million t $CO_2$ per annum while the national Kyoto balance has been encumbered with all the emissions from the additional domestic generation, i.e. by more than 1 million t $CO_2$.

The dark blue line shows the $CO_2$ emissions incurred by the amount of power imported from Germany (emissions of power mix of RWE) and which are consequently not attributed to Luxembourg's balance but to Germany's. Luxembourg's domestic production on the basis of fossil fuels has risen significantly since 2001 (see light blue line). If the amount of power produced in Luxembourg had been produced in Germany by RWE, the resulting emissions would be much higher (red line). This alternative production in Germany is well above the Luxembourg levels, especially since 2002, as the German power generation at RWE has a worse record in energy efficiency and $CO_2$ efficiency overall. The green bars show the $CO_2$ emissions which have been saved by national power generation as opposed to the RWE mix. These savings are similar in height to the increase in Luxembourg's $CO_2$ balance. Although the total power consumption has increased in Luxembourg (black dots), the total emissions (black crosses) have actually been on a downward trend since 2001. The expansion of the Luxembourg production has thus had a positive effect overall on the efficiency of power generation in Europe.




Quelle: (NAP Luxemburg)

| DE | EN |
|---|---|
| in Mio. t $CO_2$ | In million t $CO_2$ |
| in GWh | In GWh |
| Erhöhung der Europäischen Energieeffizienz durch Produktion in Lux | Increase in European energy efficiency due to production in Lux |
| Nicht bilanzierte Emissionen aus Importen | Emissions from import not ascribed to |

| | |
|---|---|
| (RWE) | balance (RWE) |
| Emissionen aus heimischer Produktion (KWK + GuD) | Emissions from domestic production (CHP + GST) |
| Emissionen bei alternativer Produktion in Deutschland (RWE) | Emissions from alternative production in Germany (RWE) |
| Kumulierte Gesamtemissionen (Lux fossil + RWE für Lux) | Cumulative total emissions (Lux fossil + RWE for Lux) |
| Gesamtproduktion in GWh (Lux fossil + RWE für Lux) | Total production in GWh (Lux fossil + RWE for Lux) |
| Quelle: (NAP Luxemburg) | Source: (NAP Luxembourg) |

Figure 10-1: Impact of Luxembourg's power generation (based on fossil fuels) on the efficiency of European power generation

Given the potential expansion of power cogeneration of 2,047 GWh/a by 2020 (national economic analysis, price scenario 1), full utilisation of the potential would result in additional emissions on Luxembourg's balance in the order of 123,000 t/a in district heating and 149,000 t/a in industry. The reason for this is the replacement of imported power which is not counted towards Luxembourg's greenhouse gas balance. The calculation largely corresponds to the comparison with the status quo (cf. section 1.7). The emissions from imported power, when factored in, do not effect a reduction in emissions in contrast to the comparison with the status quo. Hence the additional emissions cited above.

**Proportion of renewable energies**

The proposal of the European Commission for a new directive on renewable energies envisages an increase in the proportion of renewable energies from 0.9% to 11% of Luxembourg's total consumption of end-use energy from 2005 to 2020. The use of biomass may play a key role in achieving this target. The greatest benefit is derived from the use of biomass in combined power and heat generation, as explored in this study. If conventional oil-based or natural gas-fired heating systems are replaced by the installation of biomass-based CHP plants, this will also have a positive effect on the emissions balance of the plants which are not involved in emissions trading. In this way biomass cogeneration can make a twofold contribution, firstly in increasing the proportion of renewable energies and, secondly, in reducing Luxembourg's emissions balance.

**Directive on Energy Efficiency**

The country of Luxembourg has further obligations to fulfil in connection with the EU Directive on Energy Efficiency, according to which the Member States of the EU are committed to reducing the consumption of end-use energy by 9% by 2016. CHP plants can only make a contribution towards meeting this target if their primary energy saving is recognised as a way of increasing final energy efficiency.

**Cogeneration subsidies**

Measures designed to promote CHP plants always appear to have a positive impact on their cost-effectiveness and therefore on their further expansion. However, there are also obstacles. Limiting subsidies to certain output classes can present an obstacle for those plants which are not subsidised. It can lead to plant dimensions which are suboptimal in terms of the supply volume and the available potential, with insufficiently large CHP plants being deliberately installed because they achieve better cost-effectiveness figures on account of the subsidies. A similar problem can arise when the individual allowance rates vary too dramatically in relation to output classes.

Another point of relevance is the duration of the subsidy and its vulnerability in terms of changes to subsidy rates. If an investor is uncertain whether the subsidy conditions in force at the time of the investment decision will remain valid for a sufficiently long term then this is a major hindrance because, in many cases, a plant will only be viable at a given amount of subsidy.

**Avoided network charges**

In contrast to central power generation or the purchase of power from abroad, which is of particular relevance for Luxembourg, decentralised power generation near consumer sites makes far fewer demands on the grid. This leads to lower grid access costs which are also referred to as avoided network charges. If this benefit is not duly credited in the case of cogenerated power supplies then this will constitute a drastic deterioration in the cost-effectiveness of CHP plants and therefore a major obstacle.

## 10.3 Obstacles relating to specific applications

**(Excessively) high profitability requirements**

The potential identified is based on the general conditions and assumptions documented in the report. The sensitivity analyses make clear the substantial extent to which changed input parameters can affect the level of potential. One very distinct obstacle, especially in industry and in utility companies, is the need for (excessively) high profitability. If investors expect payback periods less than halfway through the life of the plants, for example, or if they want double-digit percentage returns on capital, then CHP plants will be difficult to present as a viable option - but then again the same often applies to possible alternative investments.

**High fixed costs**

Capital investment in CHP plants and, most notably, in heat grids requires security of demand over as long a period as possible, but the general willingness of consumers to enter into long-term contractual commitments has declined with the liberalisation of the energy market. Many consumers are too enamoured with the prospect of being able to change supplier or to force their existing suppliers to reduce prices by informing them of their intention to change supplier.

**Extension of gas supply**

Every extension of gas supply curbs the extension of cogeneration for two reasons. Firstly, there is competition within the utility companies between gas and district heating. Secondly, high levels of capital spending and advance investment in the distribution system structure are required for the extension or development of gas supply areas therefore, as a general rule, no concurrent investment is made in such areas in heat grids (which are vying for the same customers). From a consumer viewpoint, the option of being able to operate a separate gas heating system with natural gas also constitutes an alternative to being connected to a district heating network supplied by CHP plants.

**Decrease in heat consumption**

The decrease in demand for low-temperature heat in industry and the improvement of buildings are causing heat consumption to fall which leads to a gradual deterioration in cost-effectiveness, especially in the case of the CHP plants which feed into a local or district heating grid. Regardless of whether it actually comes to fruition, the mere expectation of this trend is sufficient to inhibit willingness to invest in a cost-intensive supply structure.

**Industrial cogeneration**

The limited availability of corporate capital is proving to be a central obstacle to the development of cogeneration potential in industry. On account of the relatively low expected rates of return in connection with CHP plants, many companies prefer to invest in their core business where they are better able to assess both the market and the risks. Many companies are not interested in taking a relatively large share in the electricity market. They frequently lack the necessary know-how in this regard, and acquiring this know-how is again tied up with high transaction costs.

## 10.4 Conclusions with regard to the implementation of EU Directive 2004/08/EC

The aims of the EU Directive 2004/08/EC are to economise on primary energy and to reduce $CO_2$ emissions. The analyses have shown that, in national economic terms, there are areas of potential both in district heating and in industry but that these areas of potential cannot help to reduce Luxembourg's national greenhouse gas balance on account of the country's specific situation. This is because the power imports which are replaced are not counted towards the national greenhouse gas balance.

It is highly likely that industrial plants which are participating in the emissions trading scheme will no longer be subject to national limits in future but that EU-wide limits will be put in place with regard to greenhouse gas emissions. An expansion of cogeneration through plants which are then participating in emissions trading will no longer have any direct effect on the national greenhouse gas balance. The development of cogeneration in industry is therefore no longer an obstacle to the attainment of Luxembourg's greenhouse gas reduction targets.

The situation is different for CHP plants which are not participating in the emissions trading scheme. In the past the subsidy conditions for small and medium-sized district heating plants in Luxembourg have helped to increase the proportion of high-efficiency CHP plants. Under the existing conditions they are actually counterproductive; they are not helping to reduce greenhouse gases and nor will they do so in future on account of the territorial balance principle. This is a major obstacle to their further development and to the perpetuation of the current subsidy rates and therefore also to the implementation of the Cogeneration Directive. Further clarification is needed as to how the commitment to reduce greenhouse gases can be reconciled with the expansion of cogeneration beyond the trade in emissions in respect of Luxembourg. Nobody disputes the positive impact on European energy supplies which can be brought about by an expansion of Luxembourg's cogeneration, including in terms of reducing greenhouse gases. The reductions in $CO_2$ emissions which are a factual reality have been analysed in detail in this study.

To sum up, there has been some expansion of cogeneration in the past. The expansion is currently proceeding at a slower pace. Some areas, such as industry, have already seen a decline in power generation to some extent in the past year. This indicates that the cost-effective operation of CHP plants is at best difficult for industrial operators to achieve under the current conditions. In order to ensure further expansion in future, it is necessary to explore all the avenues whereby the potential $CO_2$ savings made by CHP plants can be taken into account in Luxembourg's greenhouse gas balance.

The justification for continued subsidisation otherwise rests primarily on the increase in the security of energy supplies and on the greater efficiency in heat supplies which can be achieved with decentralised district heating plants. Moreover, when making further increases in national power generation levels, high-efficiency CHP plants constitute the more cost-effective option as compared to new combined gas and steam turbine plants without heat recovery.

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