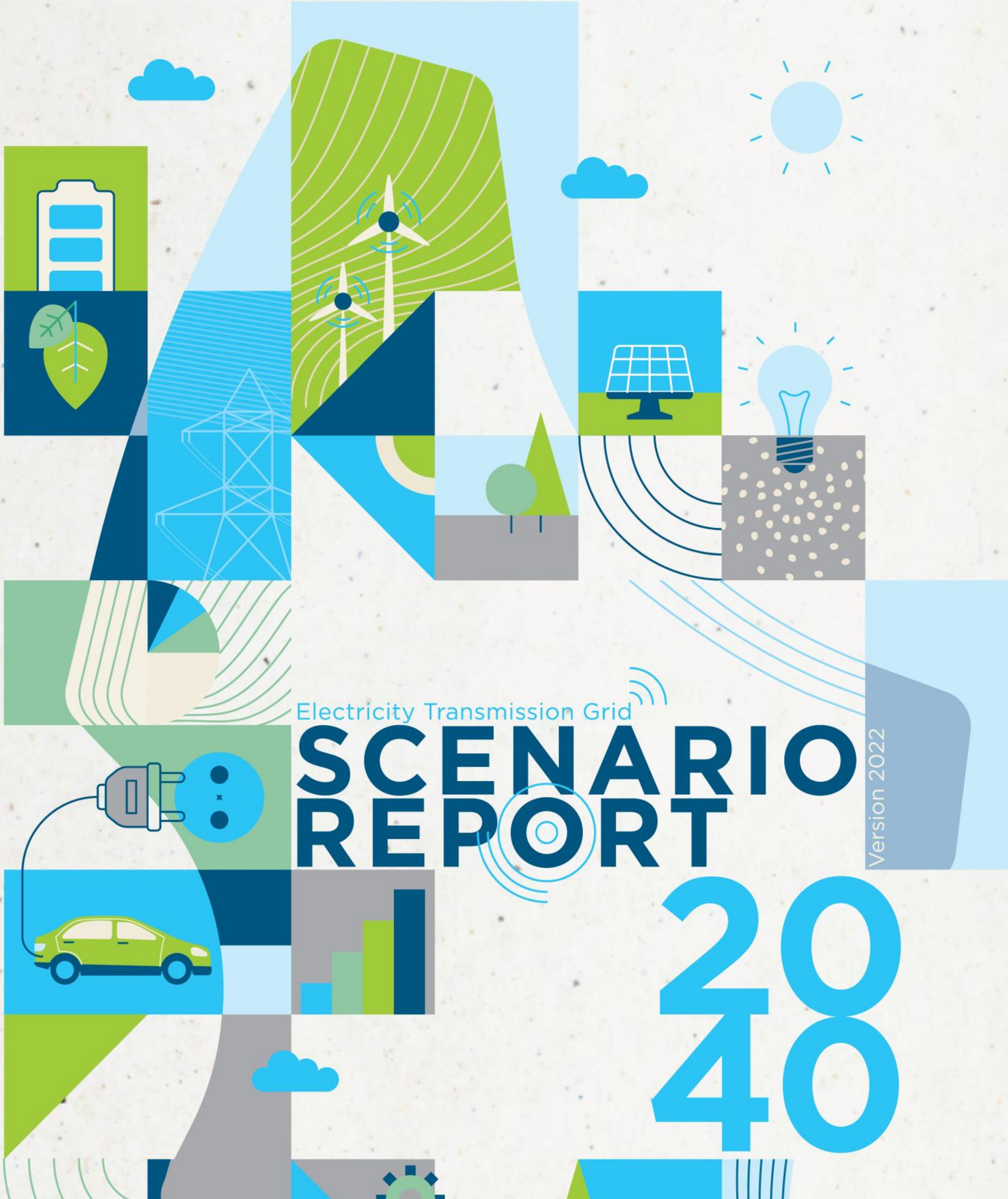

Electricity Transmission Grid

SCENARIO REPORT 2040

Version 2022

creos

Disclosure

This report represents an update of the ‘Scenario Report 2040’ from the year 2020. It is based on the current version of the national energy and climate plan - Luxembourg published in 2020.

The next edition of the ‘Scenario Report’ will be issued in two years’ time and will be based upon the updated national energy and climate plan that is being prepared over the years 2023 to 2024.

10 March 2023

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Executive summary

The energy transition in Luxembourg is in full swing and electricity is playing a major role in the decarbonisation of the country's energy system. Electricity generation from renewable energy sources is continuously growing, energy end uses such as heating and mobility are being electrified and new services are emerging due to innovative digital technologies and business opportunities. In this context, Creos Luxembourg in its position as transmission and distribution system operator is a key player for enabling the energy transition going forward.

On a political level, the European Green Deal proposed by the European Commission in December 2019 set the objective to achieve a substantial reduction of greenhouse gas emissions by 2030 and climate neutrality in Europe by 2050. The European Commission also adopted a new set of legislative proposals, the 'Fit for 55' package, in July 2021 to make the European Union's climate, energy, land use, transport and taxation policies ready for a fast implementation of the European Green Deal.

The measures from the REPowerEU Plan, presented by the European Commission in May 2022, aim to end the European Union's dependence on Russian fossil fuels, which are used as an economic and political weapon. With the REPowerEU Plan, which also aims to tackle the climate crisis by accelerating the energy transition, the objectives of the 'Fit for 55' package have been raised, completed and enhanced to save more energy, to diversify energy supplies and to accelerate the roll-out of renewable energies.

On a national level, Luxembourg has formalized its national climate and energy plan (NECP) for the first time in 2020. An assessment by the European Commission in September 2020 and by SGI (Sustainable Governance Indicators) in 2022 concluded that Luxembourg's targets were sufficiently ambitious and, in some cases, even more ambitious than the country's expected contribution. By definition, the abovementioned developments on the EU and global level are not yet included, however, an update of the NECP is currently being prepared by Luxembourg's authorities and will be published as draft version in 2023, with the objective to release the final document in 2024. For the purpose of this present report, it is therefore still appropriate to consider the data from the official current version of Luxembourg's NECP, while the next edition of the Creos Scenario Report, planned for 2024-2025, will be based on the updated NECP.

Against the above background, Creos Luxembourg contributes continuously to the energy transition by developing and operating grid infrastructures in Luxembourg, and several circumstances make this mission a challenging endeavour. In the future, electrical grids must cope with power demands that might be twice as high as today and must assimilate fast-growing renewable energy generation. The system must be ready to balance supply and demand at all times, making best possible use of all available resources. Specifically, the variability of demand and of power generation from wind and sun must be balanced using well-dimensioned grid infrastructures, dispatchable generation technologies such as biomass power plants or combustion turbines, and a flexible demand side. The increasing availability of data and digital technologies will help to orchestrate the interdependencies of these resources and facilitate infrastructure planning and operation.

The following developments will likely contribute to an increasing need for a strong electricity infrastructure:

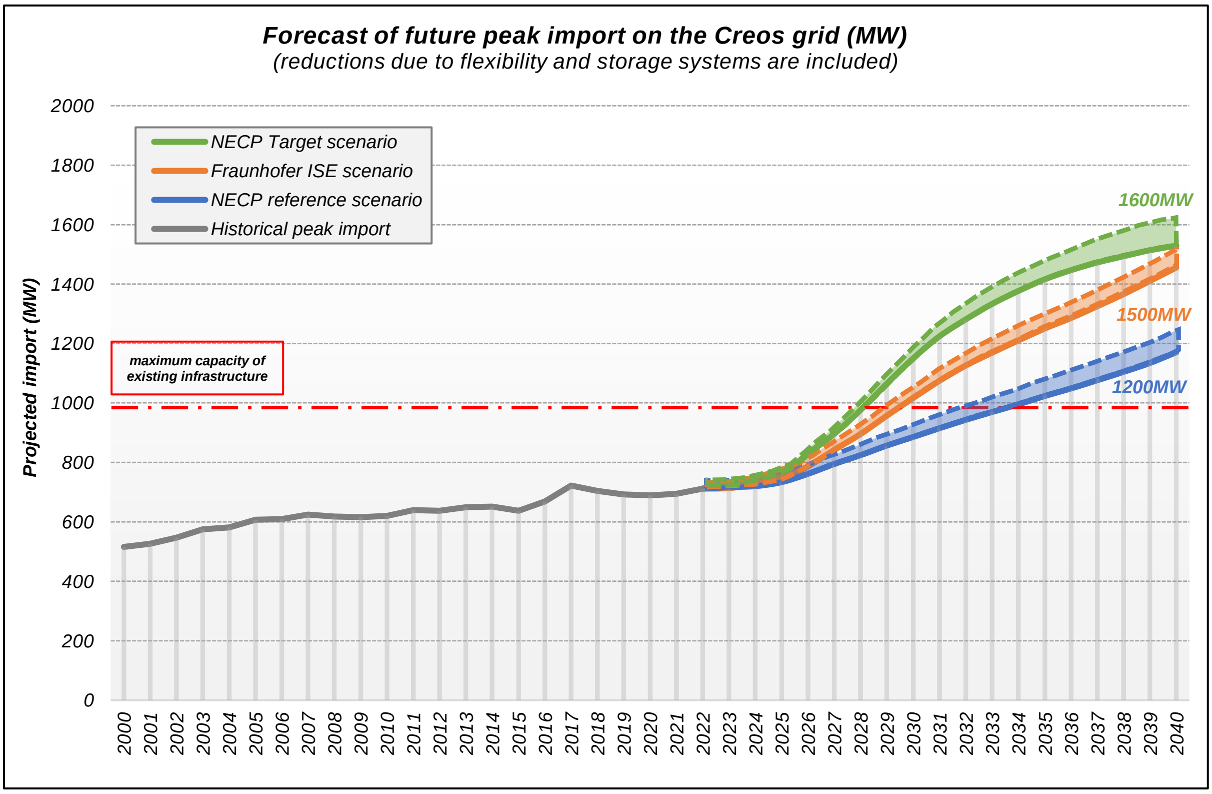
- The growing population and the diversification of the economy, including continuing digitalisation, will increase electricity consumption. Several projects for the construction of energy-intensive facilities with high power needs are already planned.
- Energy end uses are being increasingly electrified to enable energy efficiency and deep decarbonisation:
    - In the mobility sector, modal shifts are further developed and all modes are increasingly electrified. The expansion of the tramway and of the national railway infrastructures is being planned, the share of electric vehicles is rising, and the public and private charging infrastructures are growing accordingly. Luxembourg's entire bus fleet is planned to be emission-free by 2030 and battery electric trucks will also play a major role in the decarbonisation process of road freight transport. The future charging infrastructure of both light electric trucks and heavy-duty long-distance trucks driving in and across Luxembourg will certainly have a substantial impact on the country's power grid.
    - For space heating, a switch from fossil fuels to electricity for heating purposes will occur in new and renovated buildings and in all sectors. Furthermore, industries will target decarbonisation of their needs for process heat by using electricity.
- Decarbonisation with hydrogen will also occur. A certain amount of green hydrogen will be produced with electricity using electrolysers, which will have an impact on the electrical grids.

In light of the above, this report considers various data and information to derive multiple scenarios and a detailed view of future electricity needs and power demands on the electrical grids of Creos Luxembourg. It takes into account different future developments of the industrial, tertiary and residential sectors, as well as transportation and other energy end uses with high needs for electrical energy.

Besides demand, domestic electricity generation has been thoroughly analysed, broken down according to the different technologies, locations, as well as their current and future characteristics. Within the framework of this analysis, the future contribution of generation during peak demand and future peak generation during low demand have been projected with the assumption that the installed generation capacity will strongly rise.

For the forecasts of future total peak power demand, current quarter-hourly profiles were scaled up for the future, constructed profiles for e-mobility and for all new loads were added. It is assumed that future power demand will be reduced by a certain amount due to the achieved flexibilities on the demand side and due to a certain degree of electrical storage capacity. The reductions due to flexibilities have been fully accounted for in the respective loads.

The future import profiles have been established using the profiles of future power demand and by subtracting the projected generation profiles. However, to provide a clearer overview, only the peak values per year of the projected profiles for total power demand and peak import are shown.



Source: Creos Luxembourg

All scenarios developed in this report show that total peak power demand and the necessary imports on the Creos grid are steadily growing, while the secured import capacity from the neighbouring grid operator in Germany is currently limited at 980 MW. The concept and design of the existing supply lines was created over 50 years ago, at a time when the peak power demand reached only 10% to 15% of the total capacity. Today, about 75% of the total import and transmission capacity is already used during peak import, even more if energy transit occurs from Germany to Belgium.

Since 2017, an interconnection between Belgium and Luxembourg via a phase-shifting transformer is in operation. But due to operational constraints and limited transmission capacities, the network capacities of the interconnector with Belgium cannot be commercialized. This interconnection with limited capacity cannot be considered as future-proof infeed for Luxembourg because the full availability of this electrical energy supply cannot be guaranteed at any time. The grid connection with Belgium is however used during daily operation as a support connection increasing the security of supply of a certain region.

Creos Luxembourg already identified the need for an increase of the electrical energy import transmission capacities of the high-voltage grid in the past and therefore launched a future-oriented replacement construction project in 2017 that will provide a better cross-border connection between Luxembourg and Germany. Studies on the environmental impact of “PROJET 380” are well underway and should lead to a swift conclusion, after a public consultation. The construction phase is planned to start in 2024 after all the administrative authorisations have been requested and duly acquired. It is Creos’ objective to commission the project by 2028.

In addition, Creos is developing various other projects to ensure a safe and efficient grid operation in the near and longer-term future. The overall planning of the grid, both on transmission and distribution level, will be outlined in the respective network development plans.

Complementary, in order to enable the potential of all flexibilities and to help optimise the operation of the electricity infrastructure, a necessary legal framework will need to be set up, and technical and economic incentives will need to be provided for electrical storage systems, smart charging systems for electric vehicles and for all kinds of demand-side and feed-in management systems.

Introduction

The mission of Creos is to ensure the security of supply of the energy transport and distribution networks and to serve the customers in a non-discriminatory way at transparent and regulated tariffs in the Grand Duchy of Luxembourg. This role is executed equally with respect to all suppliers and by respecting the company's public service and environmental protection obligations. Aware of the economic, social and environmental issues at stake, Creos has a long-standing commitment to the principles of sustainable development. The Corporate Social Responsibility policy is focused on the company's mission and values, and aims to make an effective contribution to changing the society we live in. The cornerstones of the day-to-day work of the company are respect, team spirit, commitment and excellence.

The planning of a sustainable, future-proof electrical infrastructure is becoming increasingly challenging due to the uncertainty with regard to future economic, social and environmental developments.

In addition to higher electricity consumption, the electrical grids of tomorrow will be strongly influenced by the desired decarbonisation process in the European Union. In order to stay in line with the EU targets of reduced greenhouse gas emissions, intensified use of renewable energies and improved energy efficiency, electrical grids must be adapted accordingly. The transition to a post-carbon society will bring huge changes in the industrial, tertiary, residential and transport sectors and will have a direct influence on electrical energy needs.

The transformation of Luxembourg's society has already begun and is progressing rapidly. The targeted decarbonisation in Europe and Luxembourg will certainly lead to a general shift towards electrification for heating purposes and transportation and the growing digitalisation in our society will further impact the energy grids of tomorrow.

The current trend indicates that the shift towards a much higher percentage of volatile electricity generation from renewable energy sources may happen even faster than the increase of the electricity consumption, thus intensifying the need for strong electrical transmission and distribution grids. Volatile, uncontrollable generation and high consumption will put electrical grids at all voltage levels to the test during peak times.

Although these generation and consumption peaks can be smoothed out by the enabled flexibilities on the demand and supply side, a higher rate of self-consumption of the electricity generated by renewable energies and optimised interplay between generation and load must be targeted in the future with smart grid devices and electricity storage systems. However, storage systems must function in a "grid-friendly" way to help reduce peaks on the electrical grid.

Considering recent developments and new insights, upcoming needs must be prepared for by updating the forecasts for future electricity demand and supply.

This report looks at several possible developments of Luxembourg's upcoming electricity needs, specifically those that are relevant for the high-voltage grid of Creos Luxembourg.

Political framework and other considerations

The European climate targets and the national environmental objectives are, besides economic development, the most significant factors for the projection of future electricity needs.

With the European Green Deal in December 2019, the European Commission set the objective to achieve a substantial reduction of greenhouse gas emissions by 2030 and climate neutrality in Europe by 2050. On 14 July 2021, the European Commission adopted a new set of legislative proposals, the 'Fit for 55' package, to make the European Union's climate, energy, land use, transport and taxation policies ready for the implementation of the European Green Deal. The package and its wide range of policy areas aims to make the European Green Deal a reality by achieving the following European collective goals:

- Achieve a greenhouse gas reduction of at least 55% by 2030 (compared to 1990)
- Produce 40% of energy from renewable sources by 2030
- Reach an energy efficiency target of 36% for final energy and 39% for primary energy (based on the PRIMES 2007 reference scenario) by 2030

More specifically, in context of the greenhouse gas emissions reduction target of 55%, EU emissions trading system (EU ETS) sectors will have to cut emissions by 43% (compared to 2005) and non-ETS sectors will need to reduce emissions by 30% (compared to 2005). The revised EU ETS Directive, which applies for the period 2021-2030, will enable this through a mix of interlinked measures.

The 'Fit for 55' legislative package will drive progress towards a low-carbon, and then a climate-neutral society and economy, and an affordable, secure and dependency-reduced energy system.

In May 2022, the European Commission presented the REPowerEU Plan. The measures of this plan aim to end the European Union's dependence on Russian fossil fuels, which are used as an economic and political weapon. With the REPowerEU Plan, which also aims to tackle the climate crisis by accelerating the energy transition, the objectives of the 'Fit for 55' package have been raised, completed and enhanced to save more energy, to diversify energy supplies and to accelerate the roll-out of renewable energies.

To ensure progress towards the common goals and commitments of the European Green Deal, a governance system has been put in place to monitor and to report on the performed development. Under this governance system, all the member states of the European Union had to work out and adopt the integrated national energy and climate plans (NECPs) for the period 2021-2030 and are required to develop national long-term strategies to ensure consistency between these strategies and their NECPs.

The Ministry of Energy and Spatial Planning in Luxembourg published the current version of the national energy and climate plan for Luxembourg (NECP LU) in spring 2020, with clear and explicitly specified goals for the reduction of greenhouse gas emissions, for raising the renewable energy share and for improving energy efficiency. As it dates from 2020, this version cannot include the most recent developments and political targets at EU level. However, an assessment from the European Commission in September 2020 on Luxembourg's final national energy and climate plan and an assessment study from SGI (Sustainable Governance Indicators) in 2022 concluded that the Luxembourg's targets were sufficiently ambitious and, in some cases, even more ambitious than the country's expected contribution.

Against this background, it is still appropriate to consider the values from the current version of the national energy and climate plan for Luxembourg (NECP LU) for the purpose of this report.

In detail, Luxembourg is striving to achieve the following national values in accordance with the Paris Agreement, the European climate and energy framework 2030 and the European Green Deal Roadmap in order to best contribute to the common European goals:

- A reduction of the greenhouse gas emissions of the non-ETS sectors by 55% up to the year 2030 (compared to 2005)
- An increase of the share of renewable energies from 11% (in 2020) to 25% in 2030
- A reduction of 40% to 44% of the end energy consumption compared to the EU-Primes Baseline projection (2007)

For the purpose of this report, key figures, facts and statements that are relevant for future electricity needs and future peak power on electrical grids have been identified from the national energy and climate plan (NECP LU). They are listed below in the chapter 'Selected scenarios for future electricity needs' and have been considered for the forecasts.

Concerning mobility and transport, the European Commission adopted new proposals in December 2021 that will modernise the EU's transport system by increasing connectivity and by shifting more passengers and freight to rail and inland waterways. The roll-out of electricity charging points and of an alternative refuelling infrastructure will be supported. New digital technologies and a stronger focus on sustainable urban mobility will make it easier to choose different transport options in an efficient multimodal transport system.

In fact, one of the priorities of the European Green Deal is to shift 75% of EU freight traffic from road to rail, and the relevance of some of the instrumental documents in place needs to be highlighted, such as the revised Alternative Fuels Infrastructure Regulation (AFIR), the Shift2Rail Joint Undertaking and the 2011 Transport White Paper (with its ambitious modal shift-targets to rail).

According to the EU 2011 White paper 'Roadmap to a Single European Transport Area', the transport sector must contribute to the EU climate commitments by achieving a target of a 60% emission reduction by 2050. To achieve this target, the following goals have been defined:

- 50% less 'conventionally-fuelled' cars in urban transport by 2030
- Achieve essentially CO2-free city logistics in major urban centres by 2030
- Complete phase-out of 'conventionally-fuelled' cars in cities by 2050
- Shift of 30% of road freight to rail or waterborne transport by 2030
- Shift of 50% of road freight to rail or waterborne transport by 2050

The future form of individual domestic and cross-border mobility and of public transport will therefore definitely influence the electrical energy needs of this sector.

Moreover, in the residential sector, renovation of existing buildings will certainly involve more electricity needs. Fossil fuel sources used for heating will be replaced by heat pumps and/or direct water heating. Newly constructed low-energy houses or passive buildings will have lower energy needs. Positive energy buildings could even generate their needs locally with solar systems and inject the surplus electricity into the low-voltage grid at the disposal of others. Consumers could increasingly become prosumers (producers and consumers). Communities of producers and consumers could act as local or renewable energy communities, trying to lessen their collective consumption impact on electrical grids with the help of smart systems and energy storage.

In addition, the European Council noted the fundamental importance of a fully functioning and connected internal energy market, and therefore supports all measures to ensure the achievement of electricity interconnections. The European Union has set an interconnection target of at least 15% by 2030 to encourage the member states to interconnect their installed electricity generation capacity.

The association of the European Network of Transmission System Operators for Electricity (ENTSO-E) acknowledged the Clean Energy Package as an important milestone for Europe's green energy transition and set its timely implementation as a priority.

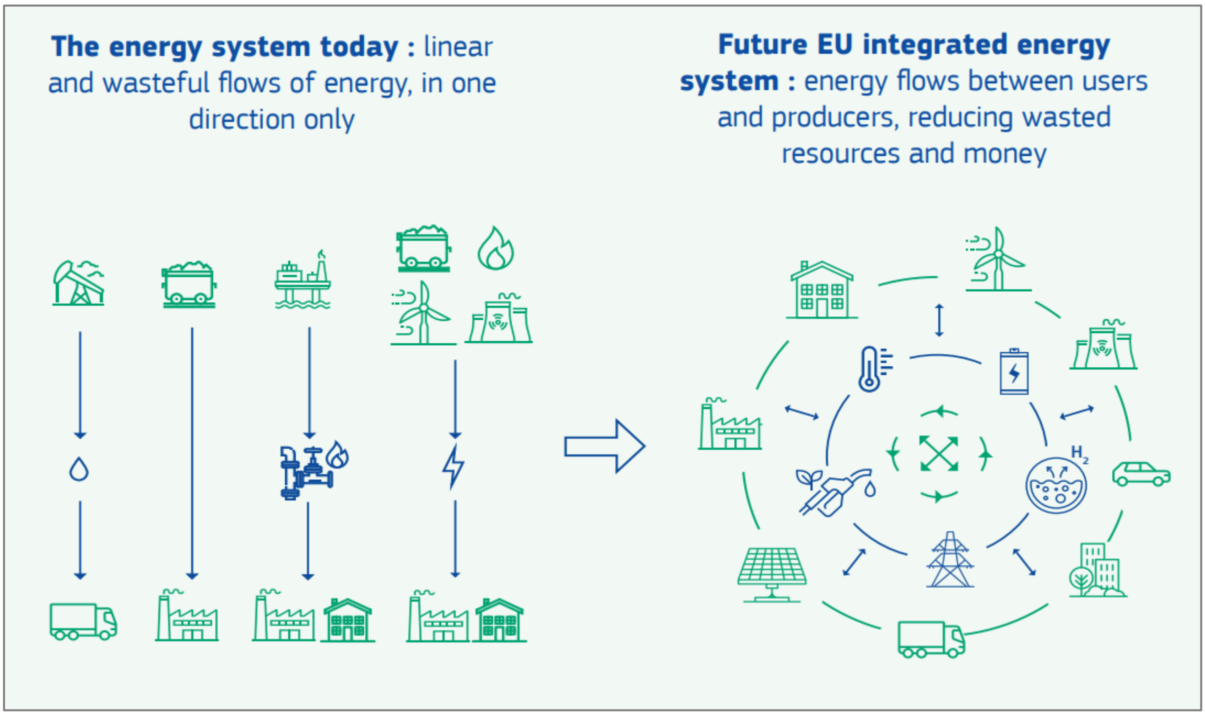
As the advent of renewable energies is central in all scenarios, electricity flows are expected to increase and become more variable. This will require network development and efficient congestion management. Future system operations will rely upon a network of systems that should work as one to ensure the seamless integration of growing shares of decentralised resources. Innovation, cooperation and sector coupling will be key enablers of future European system operations and electricity markets.

Accordingly, ENTSO-E calls for stronger cross-border cooperation to distribute and resorb the highly variable electricity flows from renewables and to avoid congestion.

Integrated energy system

To support decarbonisation and to build a climate neutral society, an integrated system that links all energy sources, consumption sites, storage systems and transport/distribution infrastructures is needed. This integrated energy system based upon renewable energies will also require flexibilities from all involved parties to be as effective as possible.

The European Union envisions that the future integrated energy system will be a circular and interconnected energy system, which will be more efficient and will waste less resources.



Source: European Commission Factsheet: EU Energy System Integration Strategy

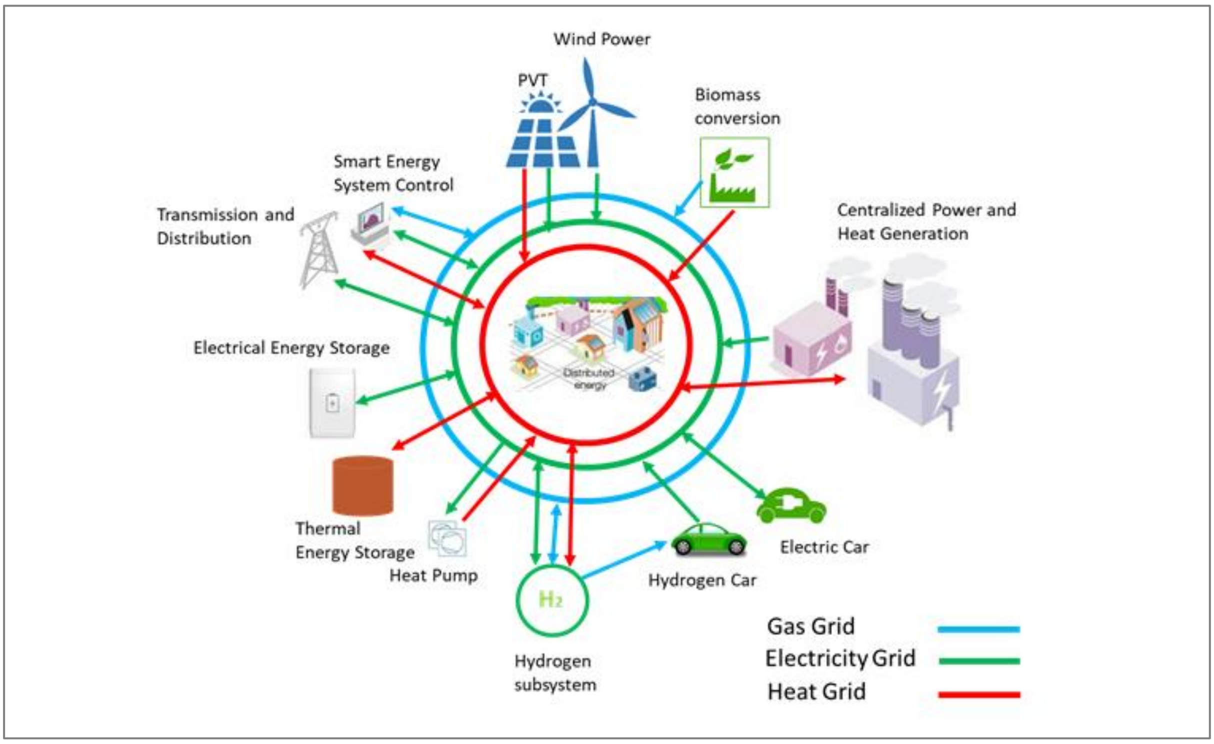
A possible pathway to decarbonisation is the large-scale use of electricity as dominant energy carrier for buildings, transport, heating and for process applications in industry, provided that most of the required electricity is generated by renewable energy sources. Although this method to reach decarbonisation is easily feasible for some end-use applications, other specific end-uses will have technical difficulties and high costs related to a full electrification.

A more probable, practical and cost-effective way to decarbonise energy demand would be the increased use of renewable energies in all end-use sectors. Electricity generated by renewable energy sources could be complemented by other energy carriers, for example biogas, biofuel and hydrogen for applications which are hard to electrify or for which a hybrid solution would offer benefits.

To implement the envisioned integrated energy system, it is primordial to achieve an encompassing sector coupling on demand and supply side and for energy storage. The combination of end-use sector coupling and cross-vector integration will increase the flexibility of the energy system and optimise the use of renewable energy when it is abundantly available.

Innovative strategies to combine energy carriers such as electricity, heat, gas and fuels for energy consumptions in buildings, industries and for transportation must be developed. By using different energy storage technologies, optimal combination of these energy carriers can be achieved and the use of renewable energies maximised.

In an integrated energy system as depicted here below, renewables energies together with flexible resources will significantly contribute to the security of supply.



Source: University of Twente (Enschede – NL)

Besides the transport and distribution infrastructures, energy demand, energy supply, energy storage and flexibility in all its forms are the major components of an integrated energy system.

In this context, the chapters here following should be seen as part of it:

- Electrical energy demand
- Electrical energy generation and renewable energies
- Electrical energy storage
- Flexibility

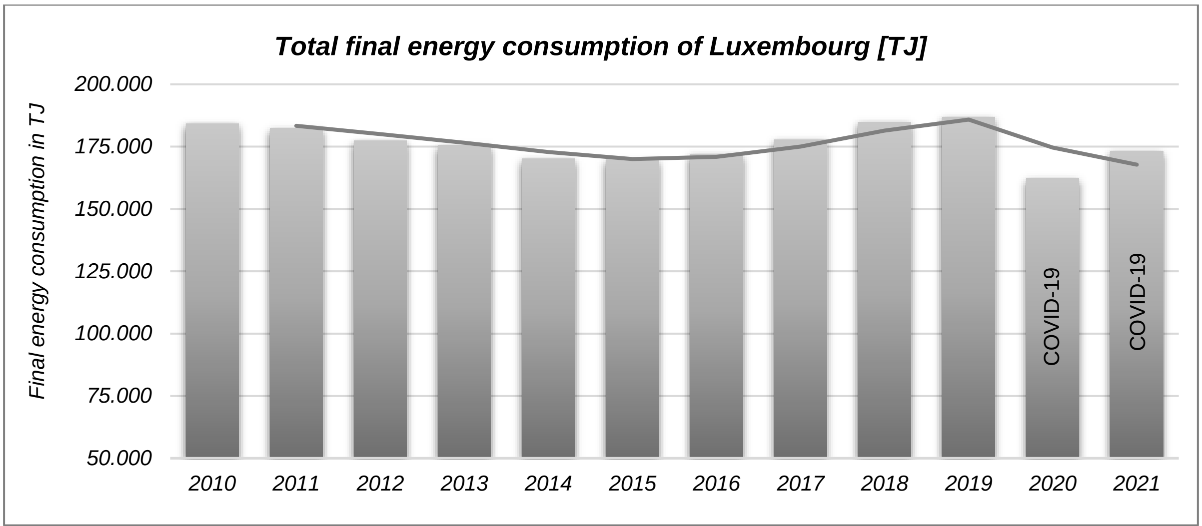
Electrical energy demand

Retrospective

Retrospective of final energy consumption

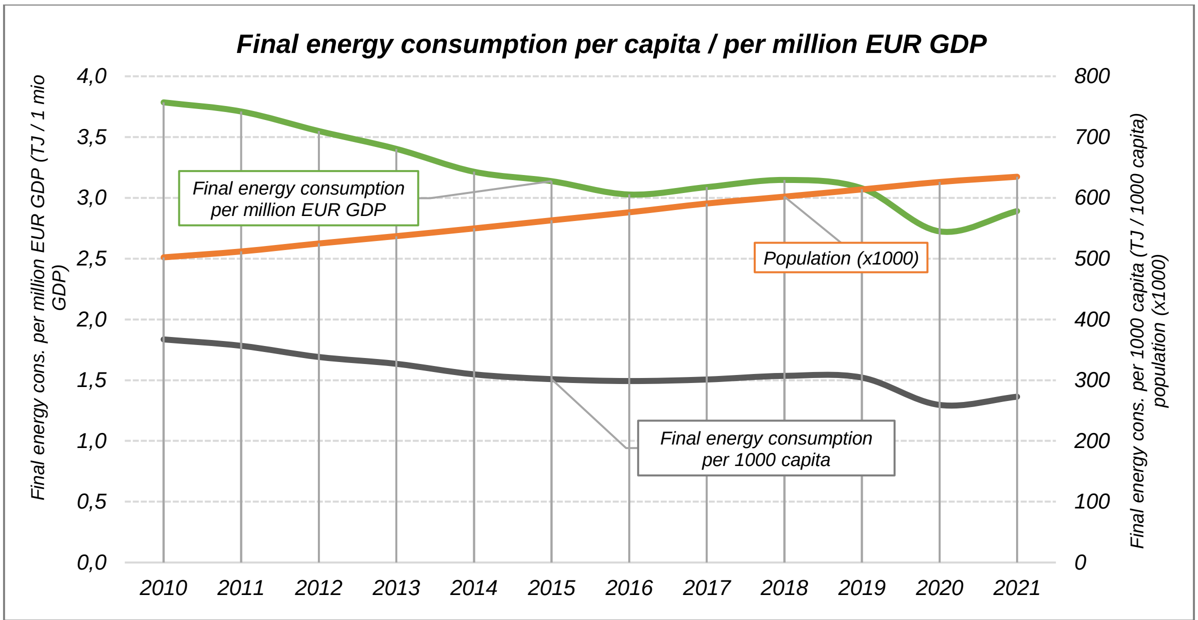
The total final energy consumption of Luxembourg decreased in the first half of the last decade, from 2010 to 2015, but has reincreased since then. However, from 2010 to 2019, the total final energy consumption of Luxembourg only marginally increased by 1,34%.

The years 2020 and 2021 must be viewed as exceptional due to the COVID-19 health crisis.



Source: STATEC & Creos Luxembourg

To assess more accurately recent energy and efficiency trends, final energy consumption must be considered in relation to population growth and economic performance.

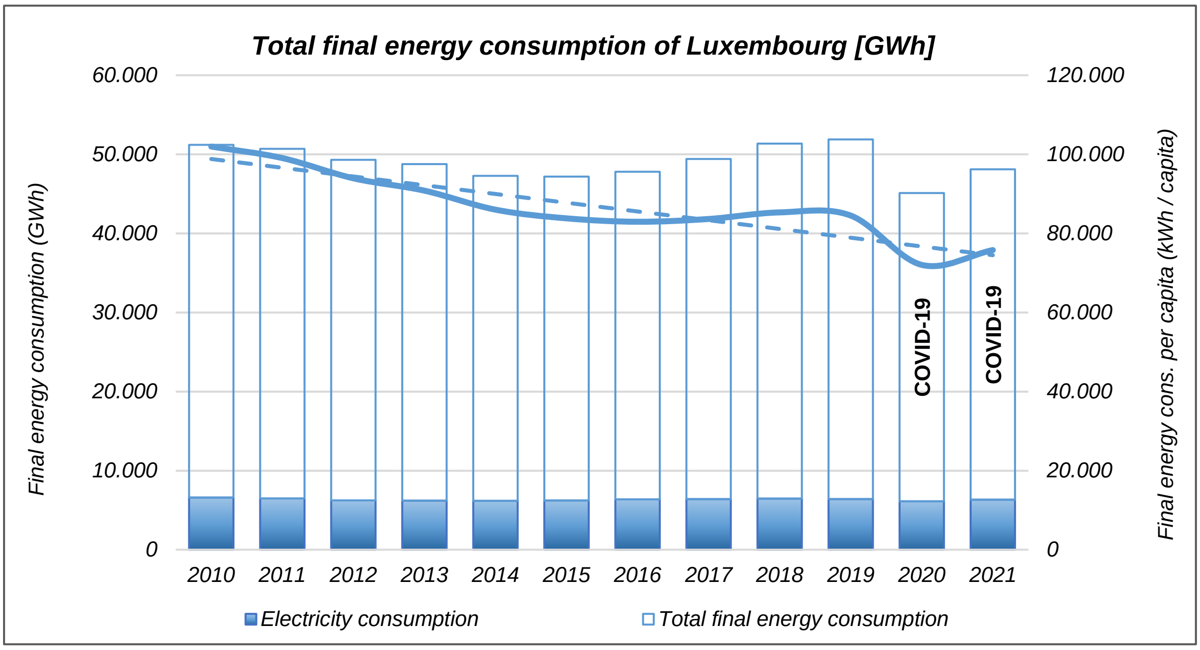


Source: STATEC & Creos Luxembourg

Although the population and the economy in Luxembourg have grown considerably over the last 10 years, final energy demand has only slightly increased. The decrease of the energy consumption per capita is not due to a stagnating economy or an economic downturn, but the result of better energy perfomance and more energy efficiency.

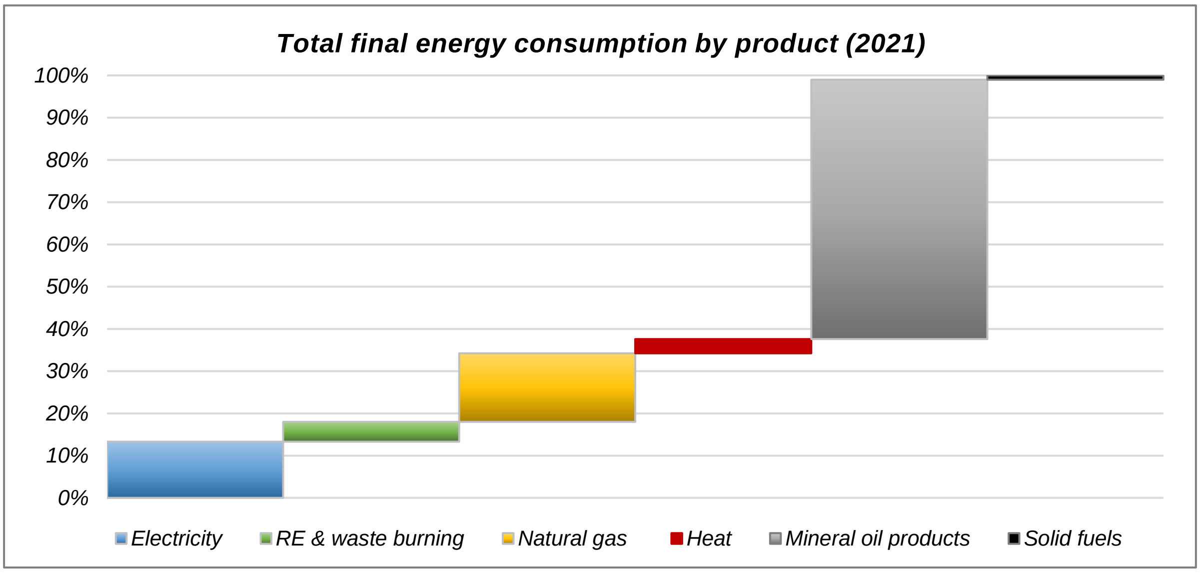
The final energy consumption of Luxembourg reached about 173.169 TJ in 2021 (162.400 TJ in 2020) and expressed in GWh about 48.102 GWh (45.101 GWh in 2020).

Currently, the consumption of electricity, with about 6.300 GWh, represents a mere fraction of the total energy consumption. But decarbonisation and the energy transition will have fundamental effects on the detailed composition of the consumed energy in the future.



Source: STATEC & Creos Luxembourg

In 2021, electricity consumption made up about 13% of final energy consumption. Mineral oil products and natural gas are still the most consumed products today.

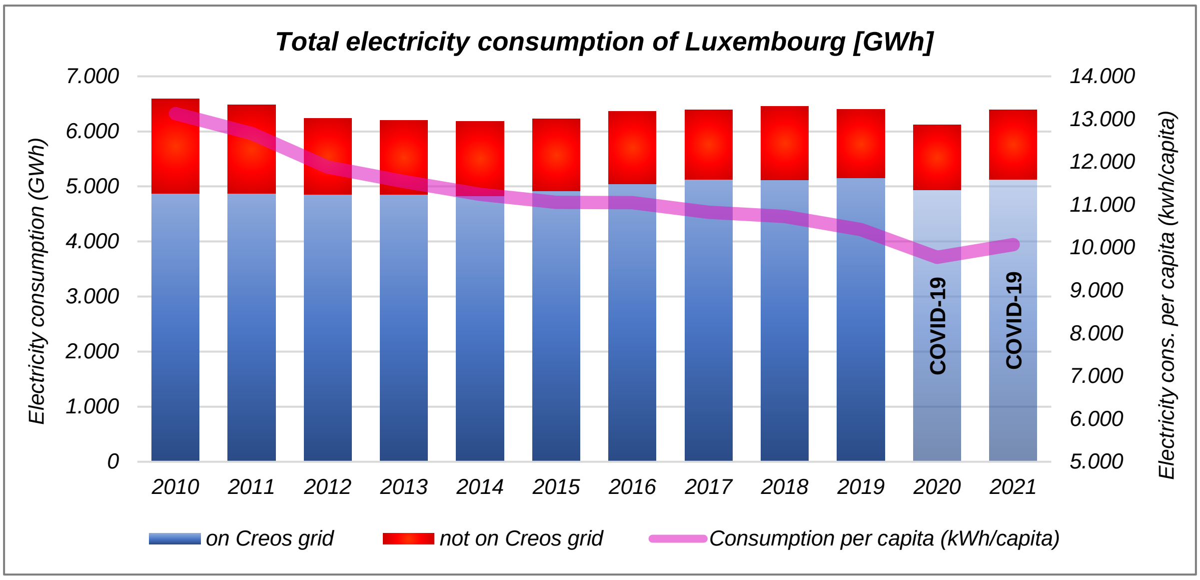


Source: STATEC & Creos Luxembourg

Retrospective of electricity consumption and sectorial breakdown

For this retrospective, the most recent available data from the National Institute for Statistics and Economic Studies – STATEC has been used. The data has been processed and completed by Creos Luxembourg, if necessary and when data was available.

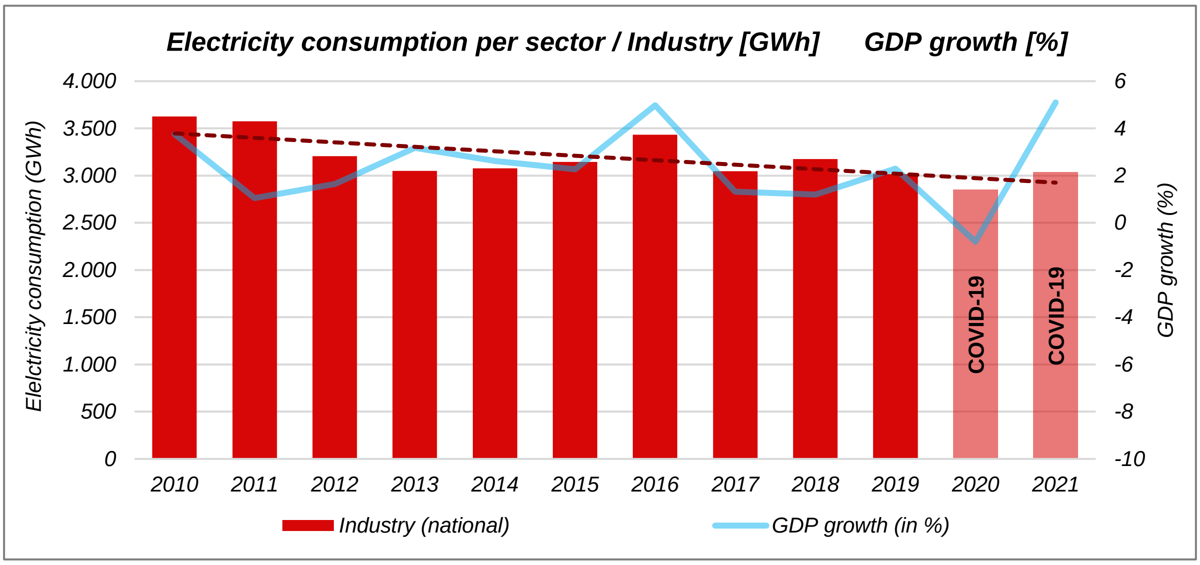
The total electricity consumption of Luxembourg decreased from 2010 to 2014 but increased again steadily from 2014 to 2019.



Source: STATEC & Creos Luxembourg

The decreasing electricity consumption figures per capita show an overall increase in energy efficiency. In fact, electricity consumption per capita decreased by more than 20% in the last 10 years. Despite the clear growth of the population, total electricity consumption slightly decreased by 3% between 2010 and 2021.

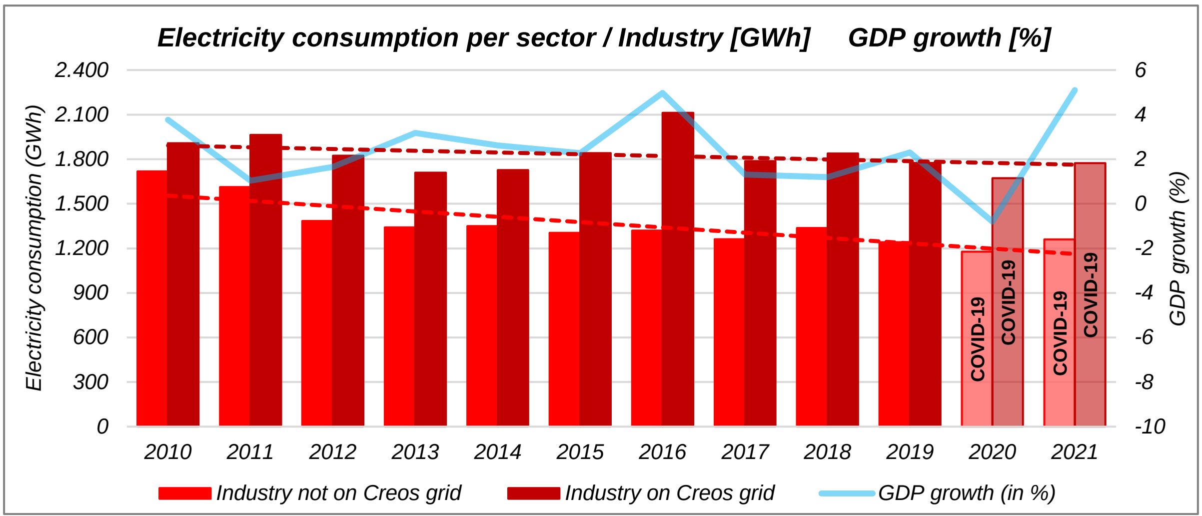
The reduced consumption from 2010 to 2014 was the result of energy saving measures throughout industry, a decline of this sector and weaker economic activity, although there was a slight recovery in 2016, as seen here below.

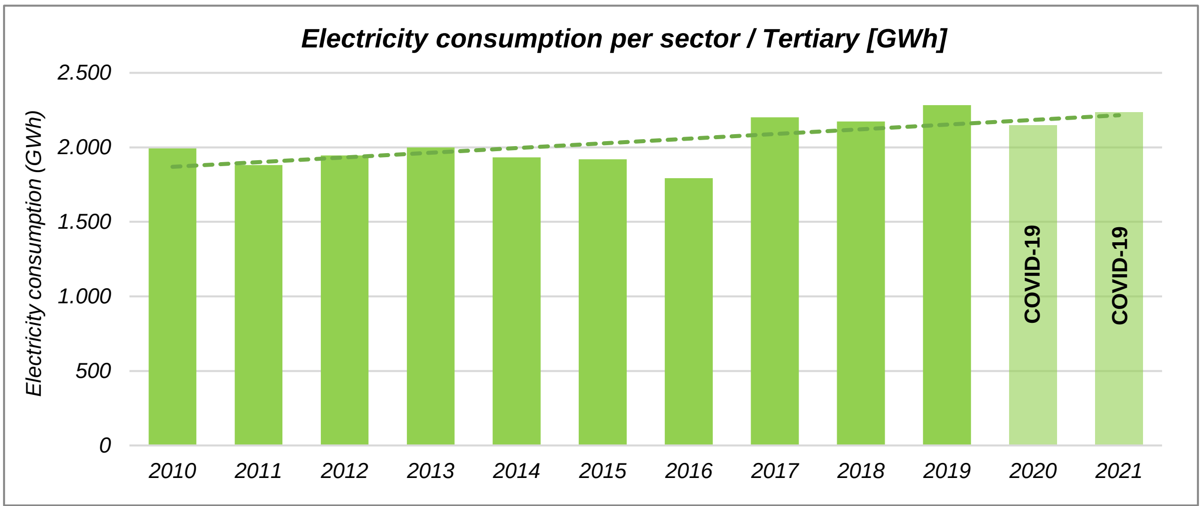


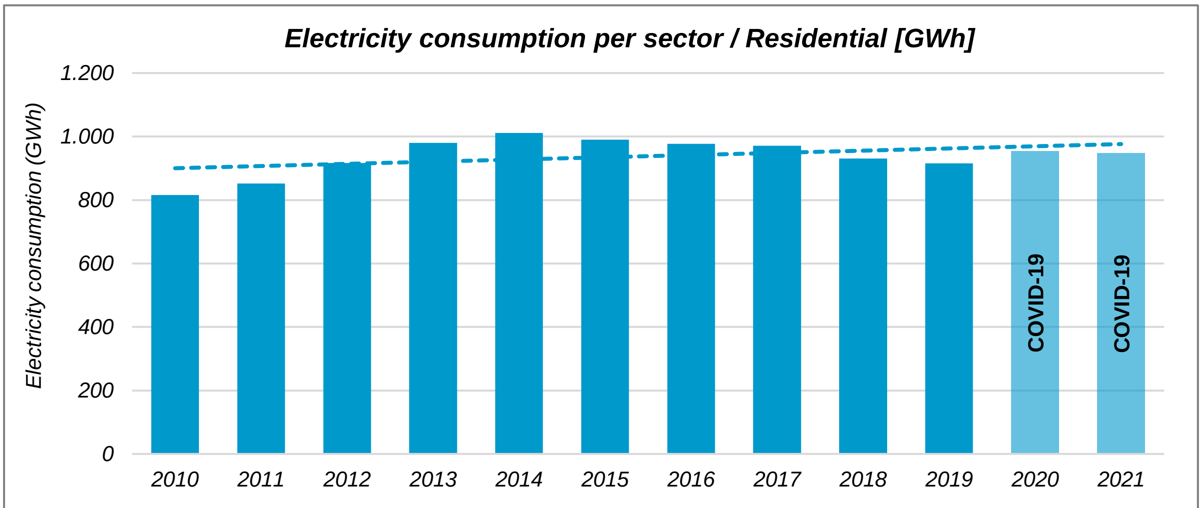
Source: STATEC & Creos Luxembourg

The decrease of the electricity consumption of the steel industry, which is not connected to the Creos grid, was more pronounced than that of the lighter, mixed industries connected to the Creos grid.

The consumption of the tertiary sector was slightly less during the last 2 years because of the COVID-19 health crisis and that of households decreased slightly from 2014 on. However, both sectors still had a positive trend for electricity consumption over the last decade.

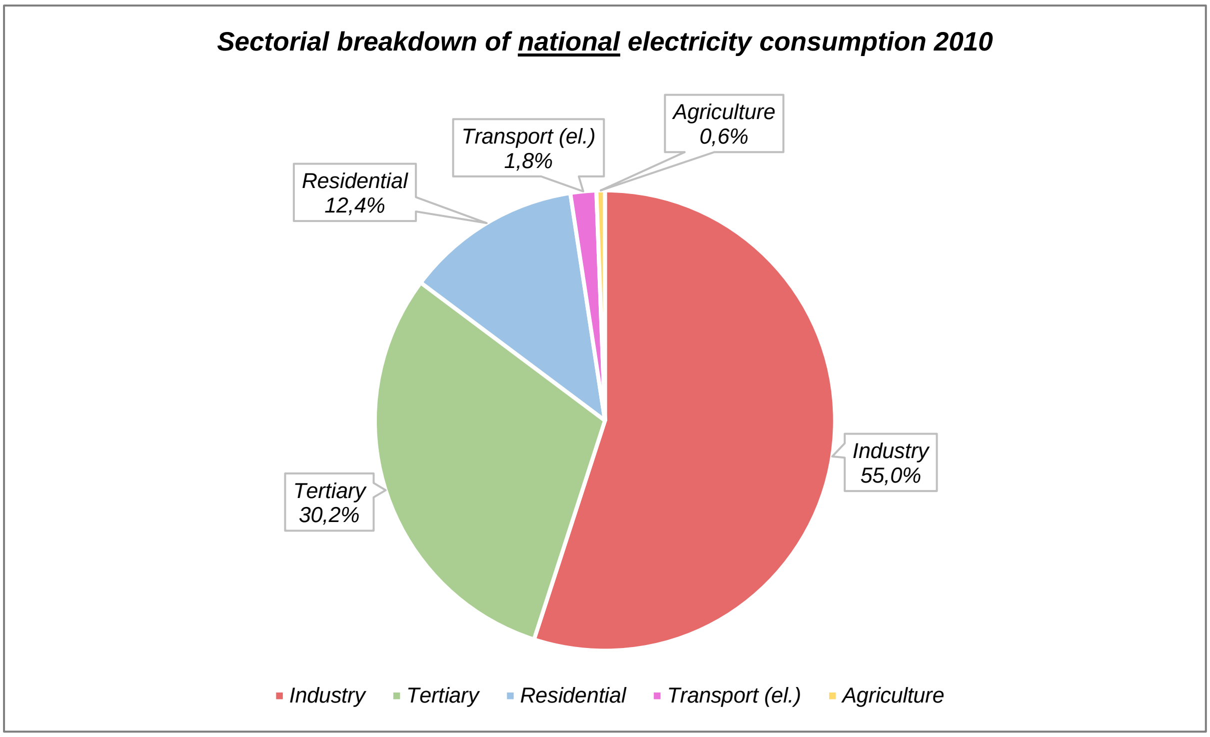


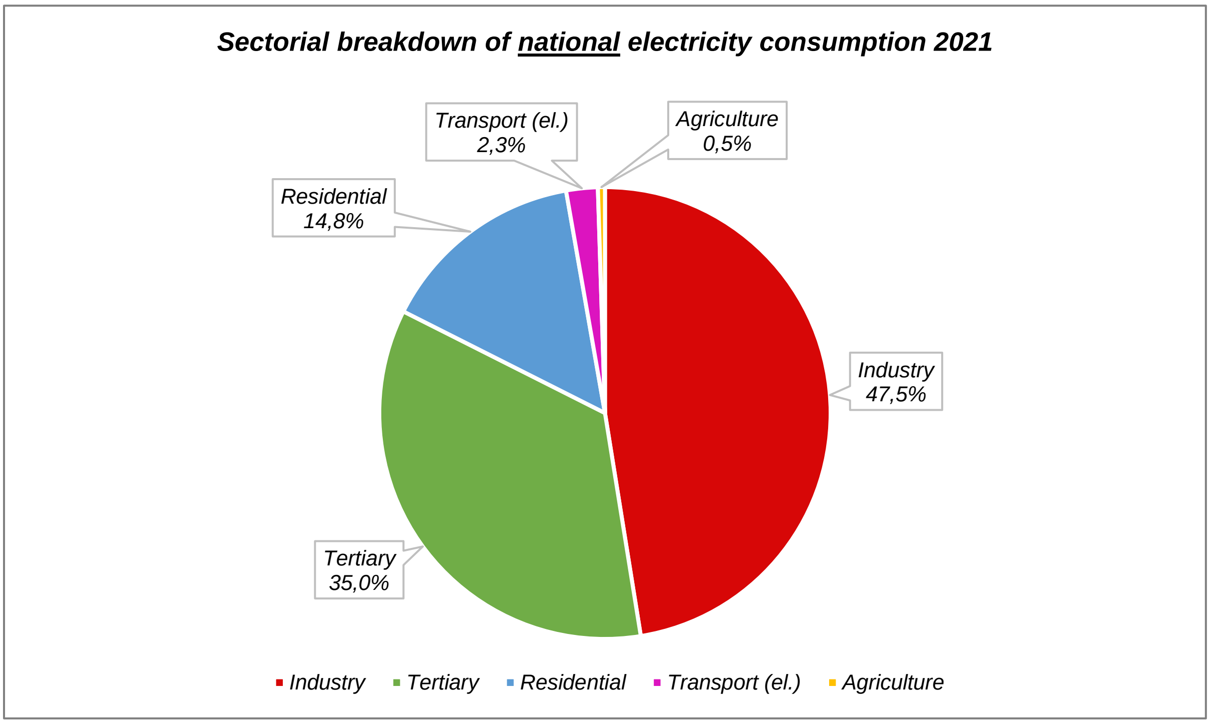




Source: STATEC & Creos Luxembourg

* not included: el. transport, agriculture & losses





Source: STATEC & Creos Luxembourg

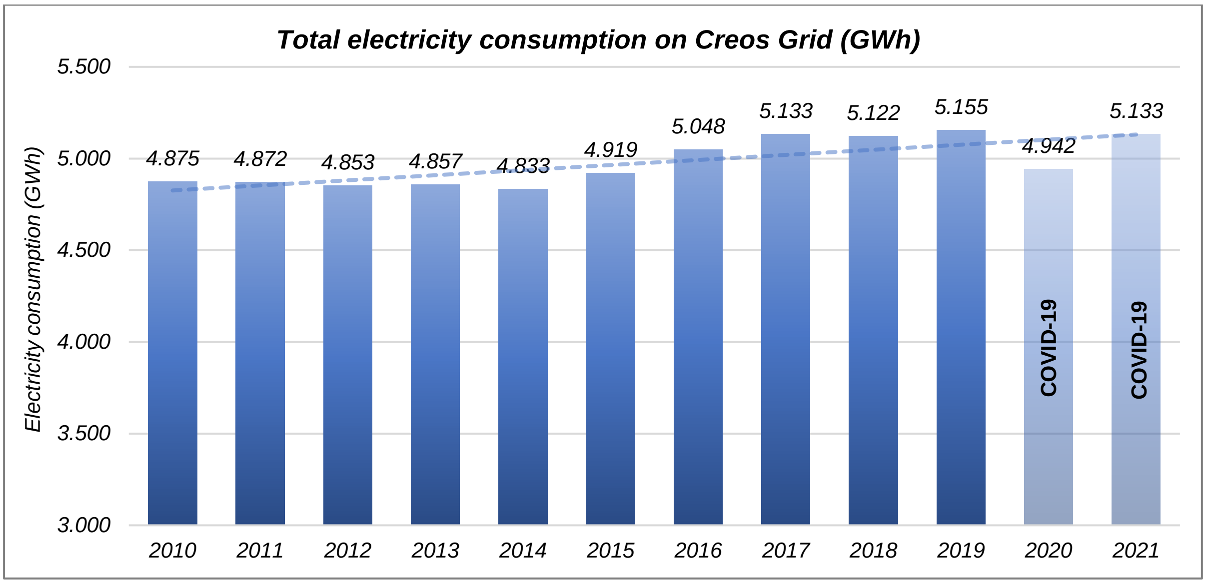
The general trend towards growth of the residential and the tertiary sector can be identified by looking at the relative numbers in the sectoral breakdown. The industry share has decreased accordingly, but is still the biggest component of the total electricity consumption of Luxembourg.

During the last 10 years, the slight decrease of consumption of the industry sector has been mostly compensated by the growth of consumption of the tertiary and the residential sectors.

Despite a slight decline (-3%) of the national electricity consumption during the past decade (2010–2021), there has been a slight increase (5,3%) of the consumption on the Creos grid during that period.

This shows that assumptions made on a national level must be analysed in detail and adapted accordingly to the slightly different situation on the Creos grid.

The decrease of consumption in 2020 and the moderate consumption in 2021 were due to the COVID-19 health crisis and its continuing repercussions.

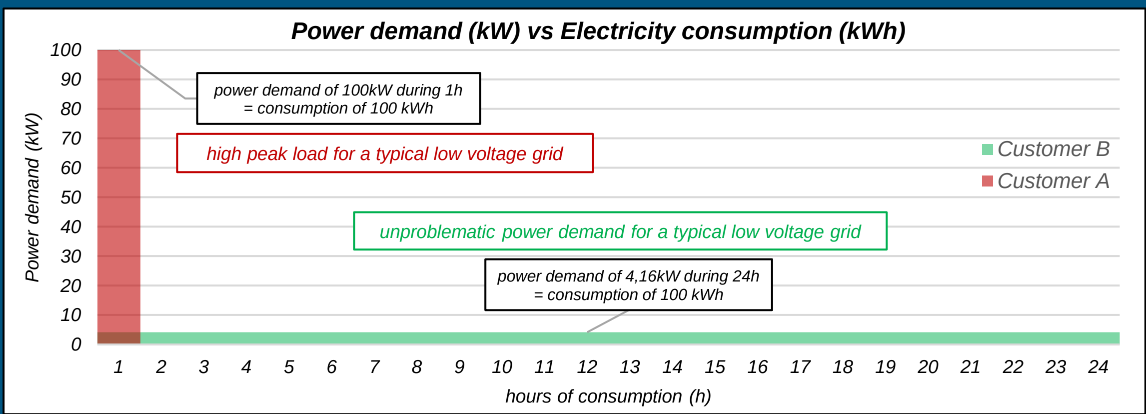


Source: Creos Luxembourg

Info box: Electricity consumption and power demand

It is essential to understand the difference between electricity consumption and power demand, both should not be confused. Indeed, identical consumption can have quite different power needs and grid necessities.

To illustrate the difference and its implications, the following figure should help:



Source: Creos Luxembourg

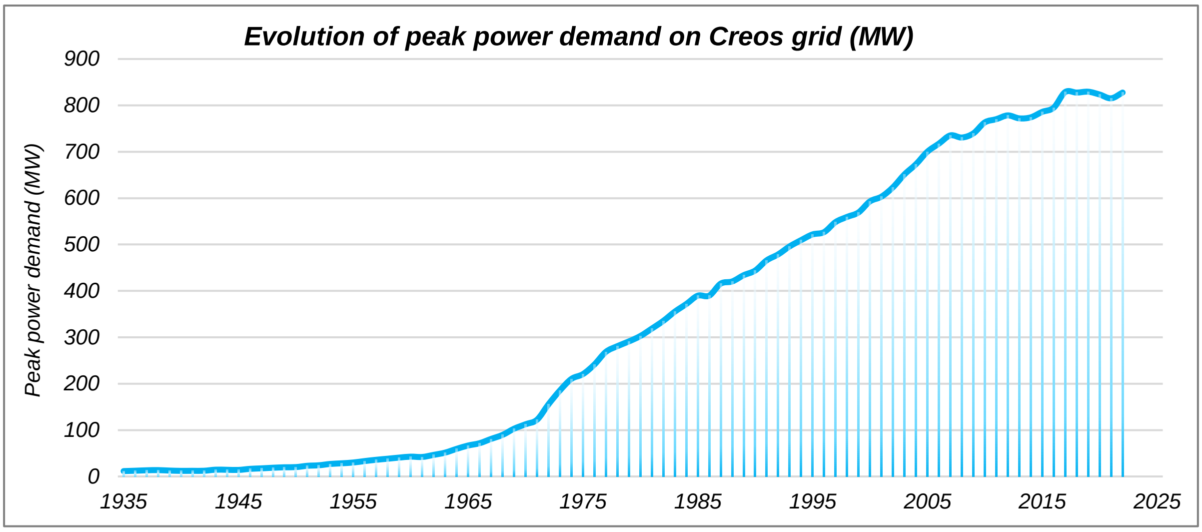
A customer 'A' can have a high specific peak power demand with a specially adapted grid infrastructure for this need, even if this infrastructure is only used during certain times. A customer 'B' has a low power demand, which could be connected and supplied by standard means. His power need is constant over time.

Both customers have the same consumption, but very different grid requirements.

This should help explain and accentuate the necessity of establishing different forecasts for electricity consumption and peak power demand.

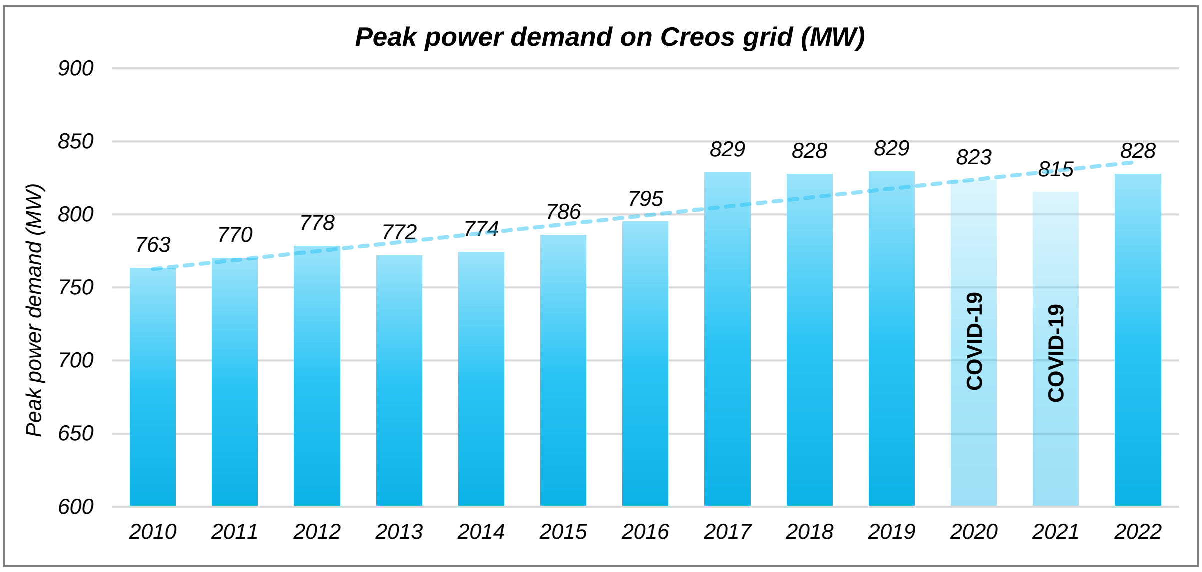
Retrospective of peak power demand

For grid dimensioning, peak power demand is more relevant than yearly electricity consumption. In the past, there has always been variable but persistent growth of power demand on the Creos grid.



Source: Creos Luxembourg

Indeed, due to various past developments, peak power increased by 6,3% over the last 10 years, by 32,8% over the last 20 years and by 73% over the last 30 years.



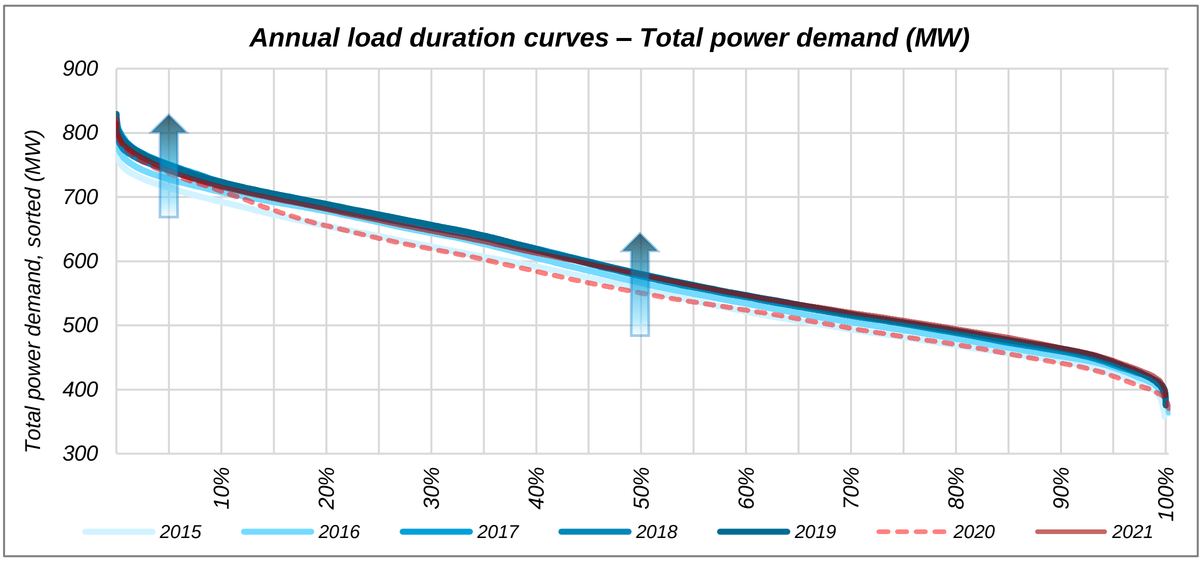
Source: Creos Luxembourg

The extraordinary leap in peak power demand in 2017 was mostly caused by the temporary and partial switch of the industries connected to the industrial grid of the system operator 'Sotel' on the Creos grid.

For the year 2020, the real effects of the COVID-19 health crisis on the peak power demand remain unclear. The peak value of 823 MW was measured in January, but the first major effects of the COVID-19 health crisis on electricity consumption and power demand only started being noticeable from March 2020 on. It is, however, reasonable to assume that the health crisis somewhat inhibited peak demand during autumn and winter of the year 2020.

The health crisis certainly influenced peak power demand during the year 2021.

The exceptionality of the years 2020 and 2021 can also be identified in the following chart, showing the annual power duration curves from 2015 to 2021.



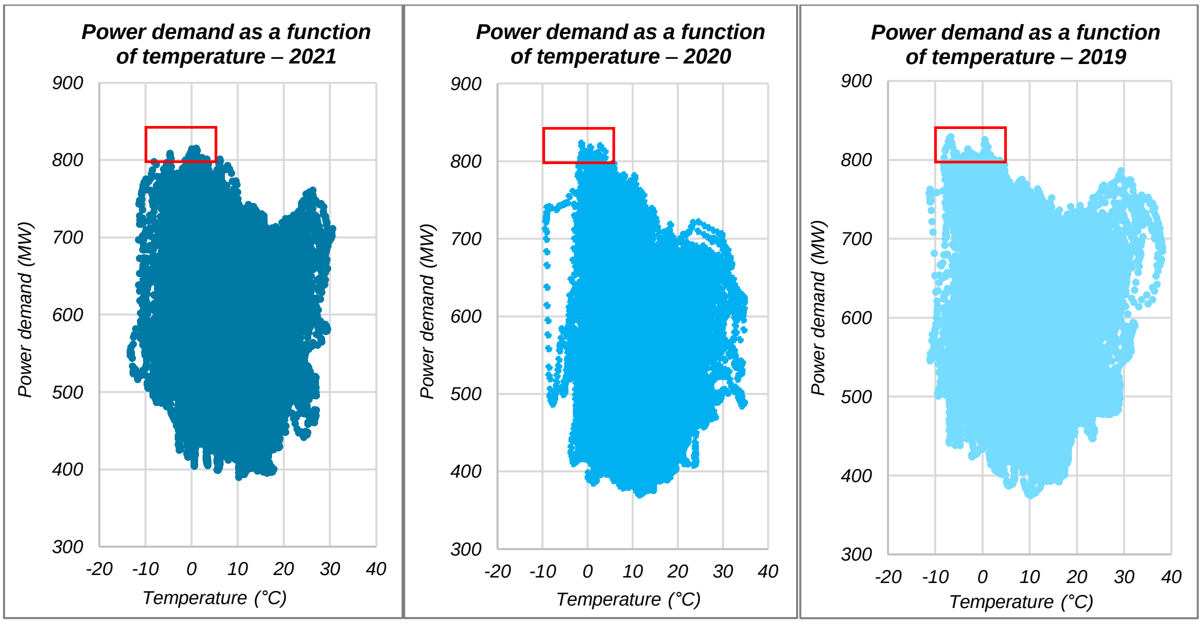
Source: Creos Luxembourg

Before the health crisis, the total power demand curve kept rising year after year.

For 5% of the time for the year, this means for more than 430 hours, electric power between 750 MW and 829 MW was needed in 2019, and between 742 MW and 815 MW in 2021. That range was notably lower in 2015, with values between 711 MW and 786 MW.

Various factors influence electricity consumption and power demand, such as the economic and demographic situation, the daily habits of the population, the specific circumstances of the analysed region, and the external temperature and heating needs.

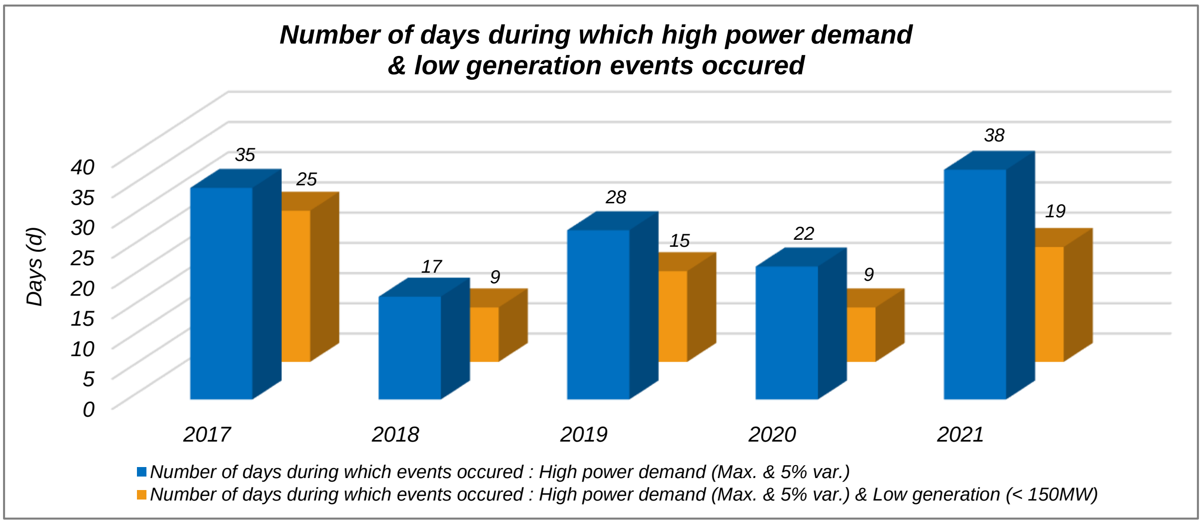
The charts below show the measured power demand values (15 min average values) for a whole year as a function of temperature. In recent years, the highest power demand always occurred in a temperature range between -10°C and a few degrees Celsius.



Source: Creos Luxembourg

To better identify the frequency, the specific moments and the duration of the events during which high power demands occur, a more detailed and aggregated view of the measurements is necessary.

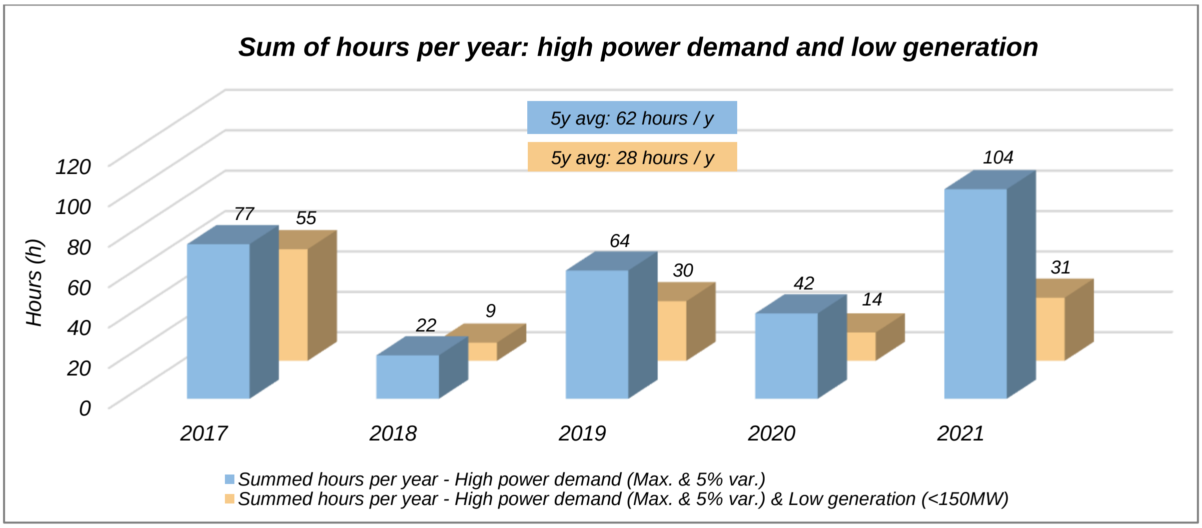
The events when there is generally high power demand and the events when there is high power demand and low generation at the same time, happen during several and different days of the year. The chart below indicates **the number of days** throughout a year during which those events occurred in the past five years.



Source: Creos Luxembourg

The range of high power values has been chosen between 95% and 100% of the peak value. For example, for 2021, high power values between 775 MW and 815 MW were selected (app. range 40 MW).

The following chart shows the summed up **length of time** of the measured events (15 min values) during which high power demand situations (and high power/low generation situations) happened over the last five years.

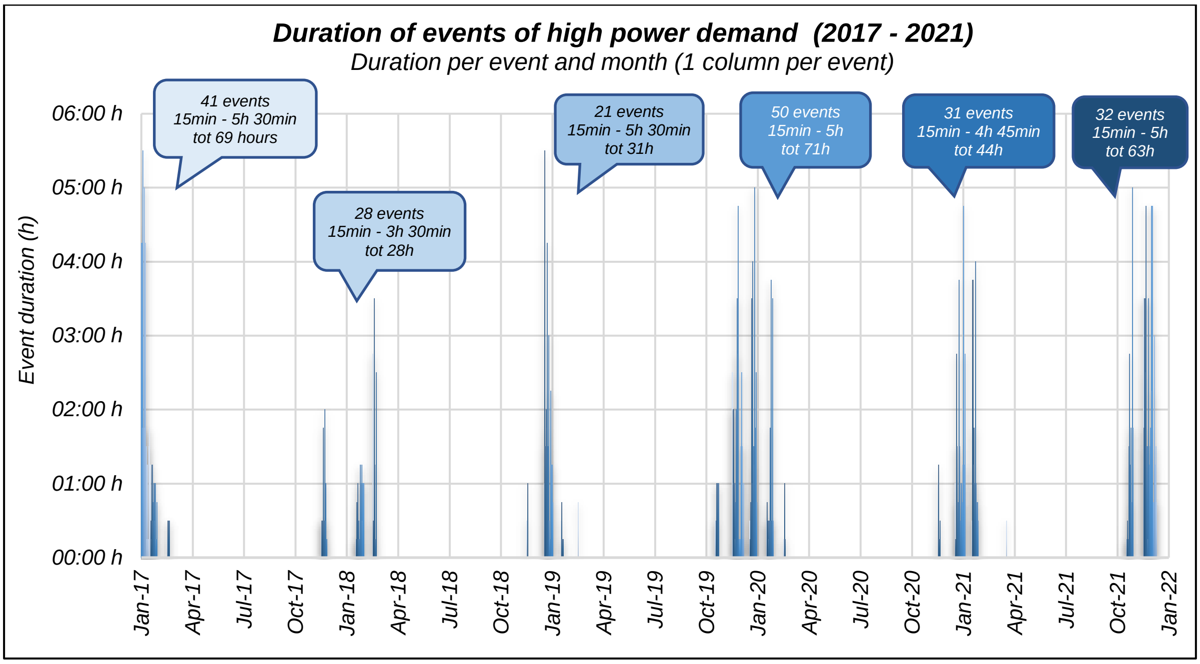


Source: Creos Luxembourg

In 2021, high power demand events with a total duration of 104 hours arose, and during 31 hours throughout that year, high power demand and low generation occurred at the same time. The 5-year average duration of high power demand events was 62 hours per year, the average duration of high power demand/low generation events was 28 hours per year.

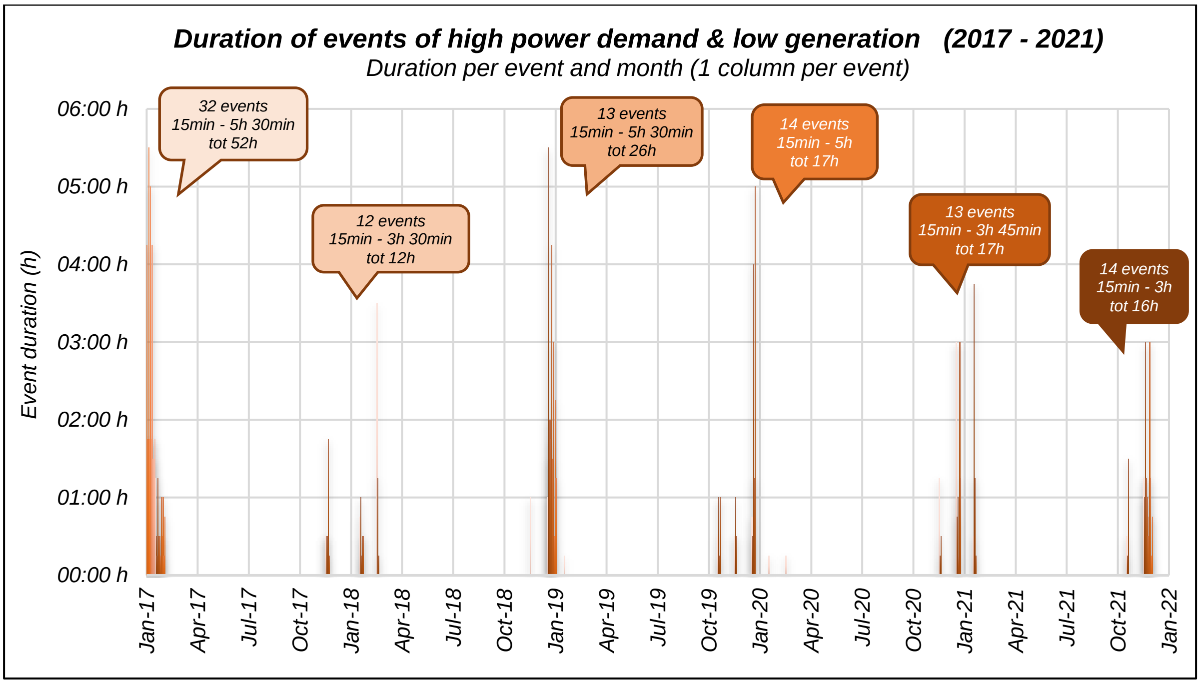
Between January 2017 and December 2021, the high power demands at the highest voltage level happened during working days, daytime hours and during the cold season.

As shown below, those events often lasted several continuous hours.



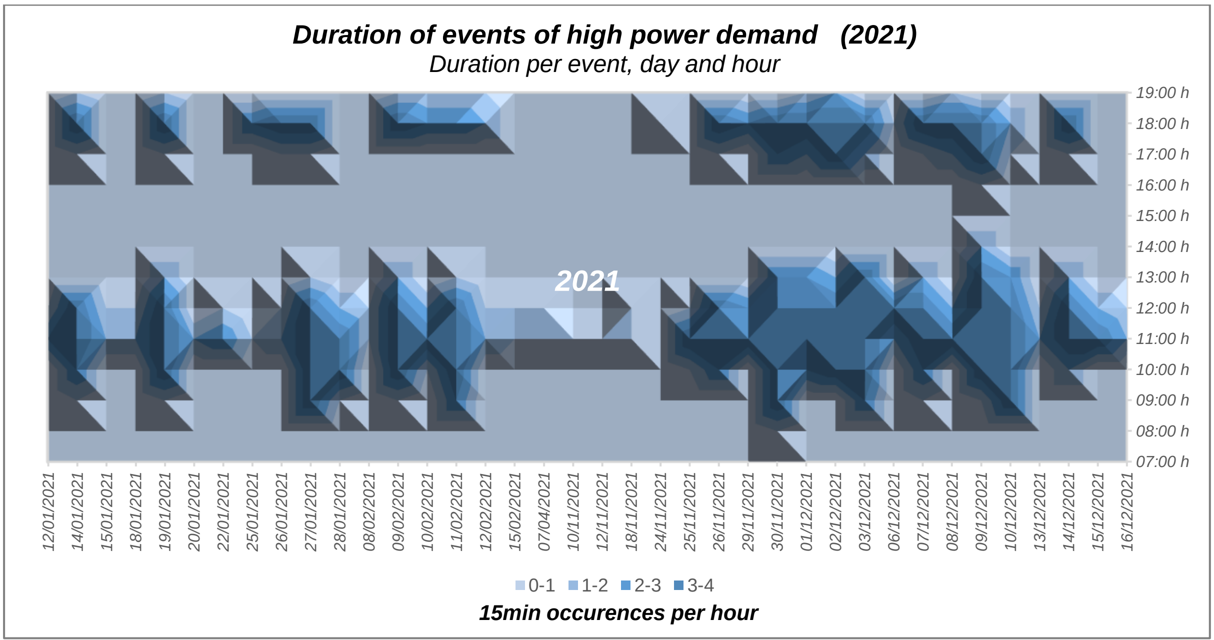
Source: Creos Luxembourg

The events when high electric power was needed and simultaneously electricity generation was low, were less frequent but they still always occured during working days, daytime hours and during winter months. Those events too lasted several hours.



Source: Creos Luxembourg

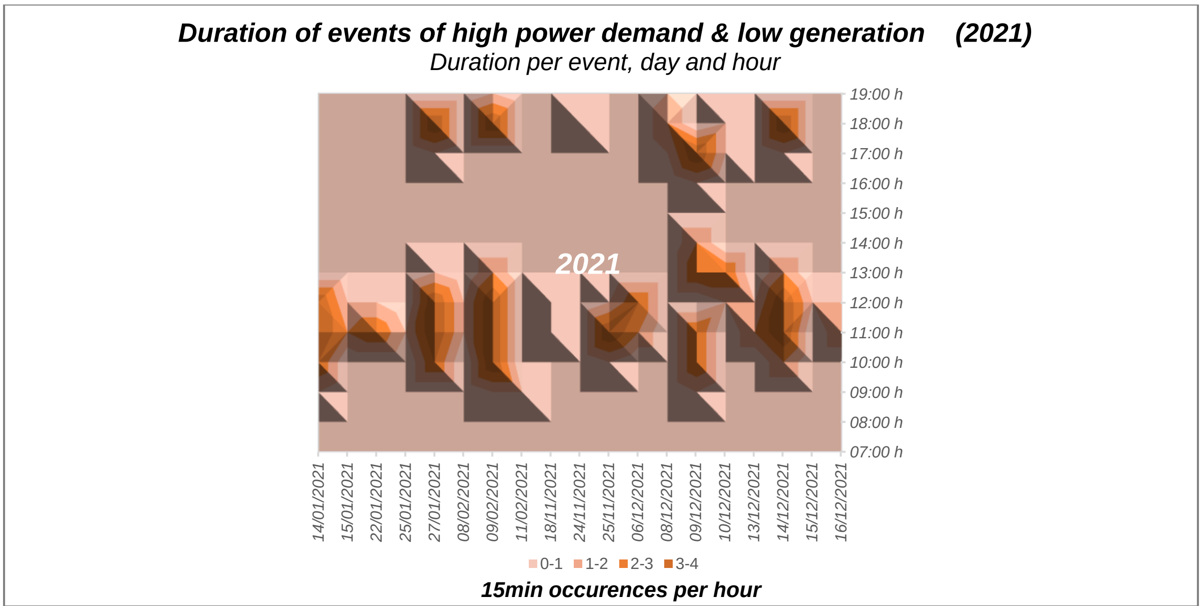
The high power demand events during the identified days of the year were distributed as follows over the daytime hours:



Source: Creos Luxembourg

During the identified days, high power demand occured in the morning between 8:00 am and 1:00 pm, and in the afternoon between 4:00 pm and 7:00 pm. Often those events had a duration of several continous hours.

It can also be noted that high power demand often occured on several consecutive days. (e.g. on the 29 Nov, 30 Nov, 1 Dec, 2 Dec, 3 Dec 2021)



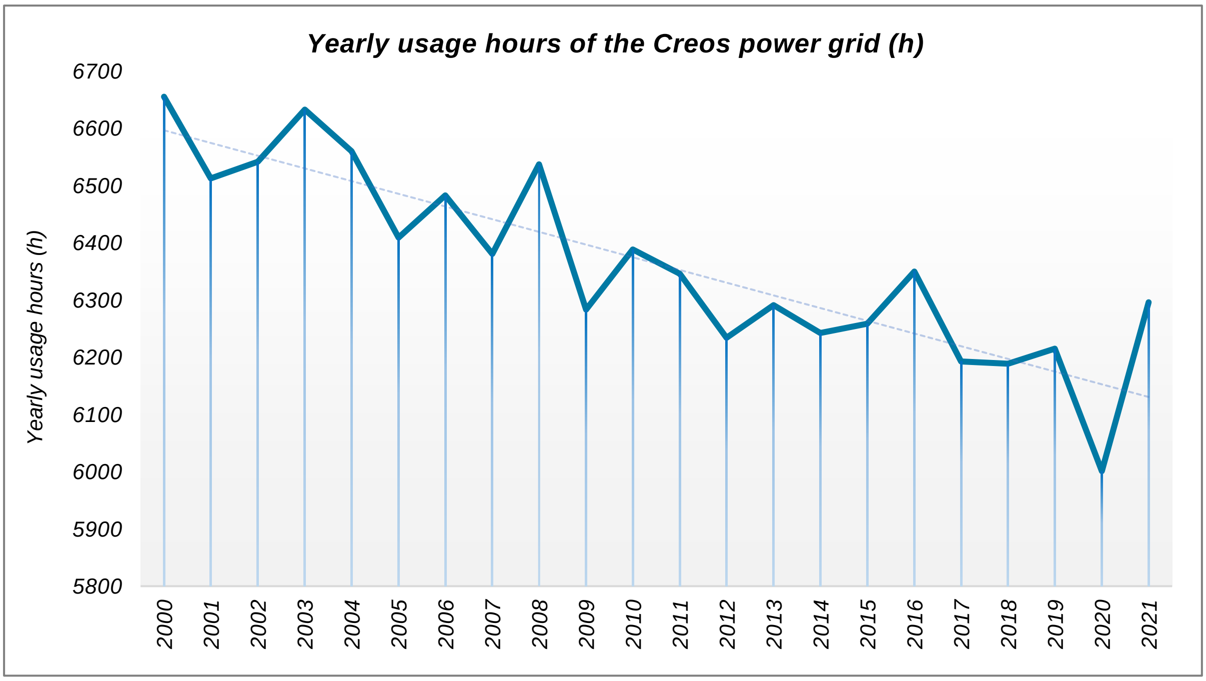
Source: Creos Luxembourg

There were fewer events when high electric power was needed and simultaneously electricity generation was low, but those events still occured in the morning between 9:00 am and 1:00 pm, and in the afternoon between 4:00 pm and 7:00 pm. The events also had a duration of several continous hours on several consecutive days.

Yearly usage hours

The yearly usage hours or annual utilisation of the Creos power grid is the ratio of annual total electricity consumption and peak power demand.

The yearly usage hours on the Creos grid have decreased over the last 20 years:



Source: Creos Luxembourg

This steady decrease is probably due to the fact that peak power demand has grown faster than electricity consumption. The yearly usage hours would have been constant if consumption and power demand had grown at the same pace.

Greater power demand over shorter periods of time and more erratic consumption behaviour will very probably lead to a further decrease of the usage hours in the future. This growing decoupling of electricity consumption and power demand could even lead to an increasing peak power demand while electricity consumption decreases.

Even with better control on the demand side, a higher degree of control of electricity generation and a certain degree of electricity storage capacity, the future grid must be built to satisfy these erratic and growing peak power demands.

Selected scenarios for future electricity needs

National Energy and Climate Plan for Luxembourg (NECP)

In the context of the National Energy and Climate Plan for Luxembourg (NECP), a forecast of future national electricity consumption, up to the year 2040, has been made with the following main assumptions.

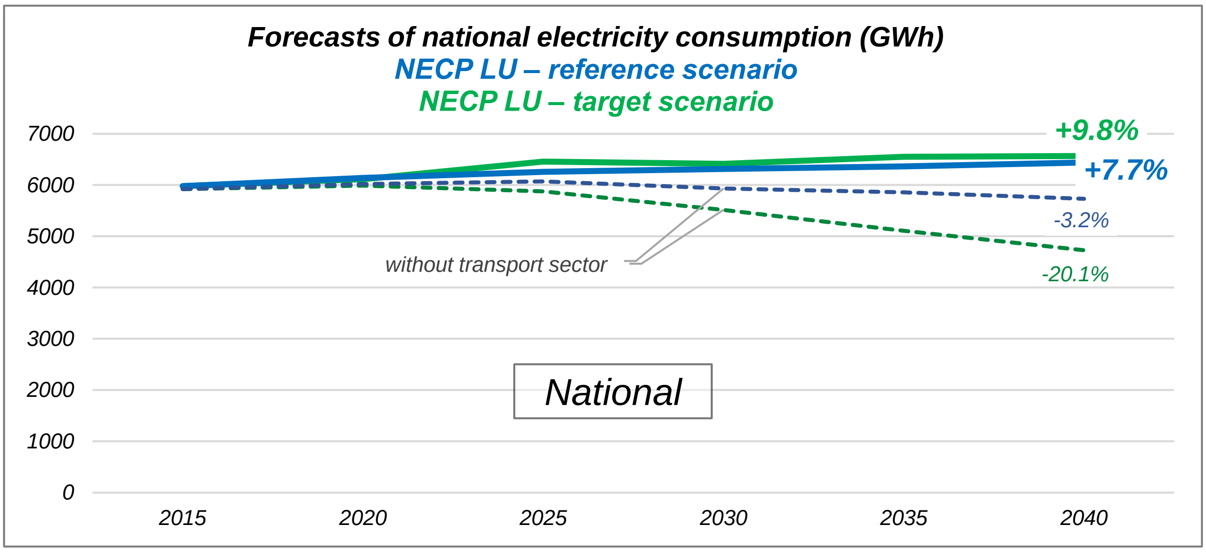
According to STATEC, the population could increase to 752.000 inhabitants in the year 2030, and up to 870.000 inhabitants in 2040. Furthermore, long-term economic growth has been presumed with steady yearly growth of GDP of 3% from the year 2025 on.

From a simplified point of view, it can be assumed that energy demand and electricity needs will rise proportionally with population increase and with economic growth but will also decrease proportionally with energy efficiency improvements.

It seems quite certain that fossil fuels must be replaced to cover future final energy demand. A shift towards the use of more electricity is certain to take place. For instance, future electrical transportation means will be more energy-efficient than 'conventionally-fuelled' vehicles, but greater amounts of electricity must be provided. For new houses, energy-efficient heat pumps, which are more effective than conventional heating solutions using fossil fuels, will certainly be used for heating needs.

The National Energy and Climate Plan for Luxembourg takes up two forecast scenarios for the future, the 'reference scenario' with a slight increase of 5,2% of total final energy demand and the 'target scenario – Paris Art. 2.1a' with a decrease of 40% of final energy demand. For both scenarios, the relative growth of national electricity consumption has been calculated (NECP Luxembourg/pages 156 and 186: Comparison of the evolution of heating requirements and electricity consumption):

1) In the reference scenario, national electricity consumption is expected to rise about **8%** between 2015 and 2040.
2) In the target scenario – Paris Art. 2.1a, national electricity demand rises slightly more, about **10%** between 2015 and 2040.



Source: NECP Luxembourg & Creos Luxembourg

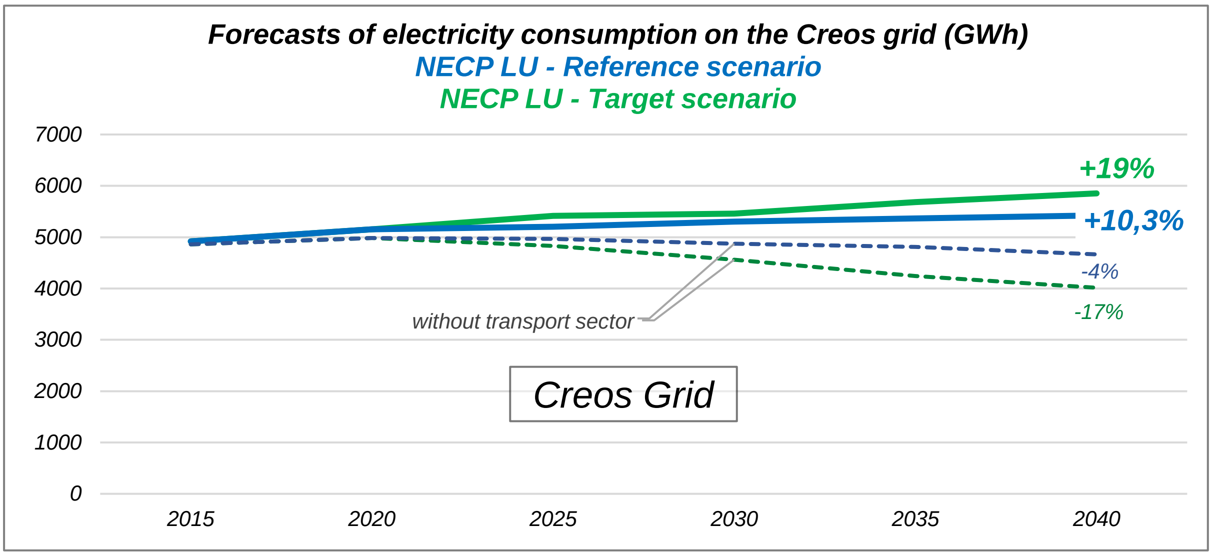
It should be noted here that the figures of both forecast scenarios represent future national electricity consumption, a slight rectification of the values for the consumption on the Creos grid must be made.

The bottom-up model used for the calculations in the NECP LU considered the sectors: Industry, Tertiary (Commerce and Services), Residential and Transport, whereby a distinction has been made between the sectors under the emission trading system (ETS) and those not under emission trading (non-ETS). Heavy industries and aerial transport are under the emission trading system (ETS), while the residential, the tertiary sector and the smaller industries are not under emission trading (non-ETS).

For the reference scenario, this resulted in a growth of the future electricity consumption of 17% for the non-ETS industry and a decrease of 6% for the ETS industry. For the target scenario, the consumption of the non-ETS industry and the ETS industry ought to decrease about 17% respectively 33%.

But a good part of the 'ETS industry' is not supplied by the Creos grid, so that an adjustment of the consumption growth of the industry sector and of the total electricity need is therefore necessary to reflect more correctly the future electricity consumption on the Creos grid. All the non-ETS industry and about 30 to 40% of the ETS industry is supplied by the Creos grid.

After the adaptation, the following numbers were re-calculated for future electricity consumption on the Creos grid:

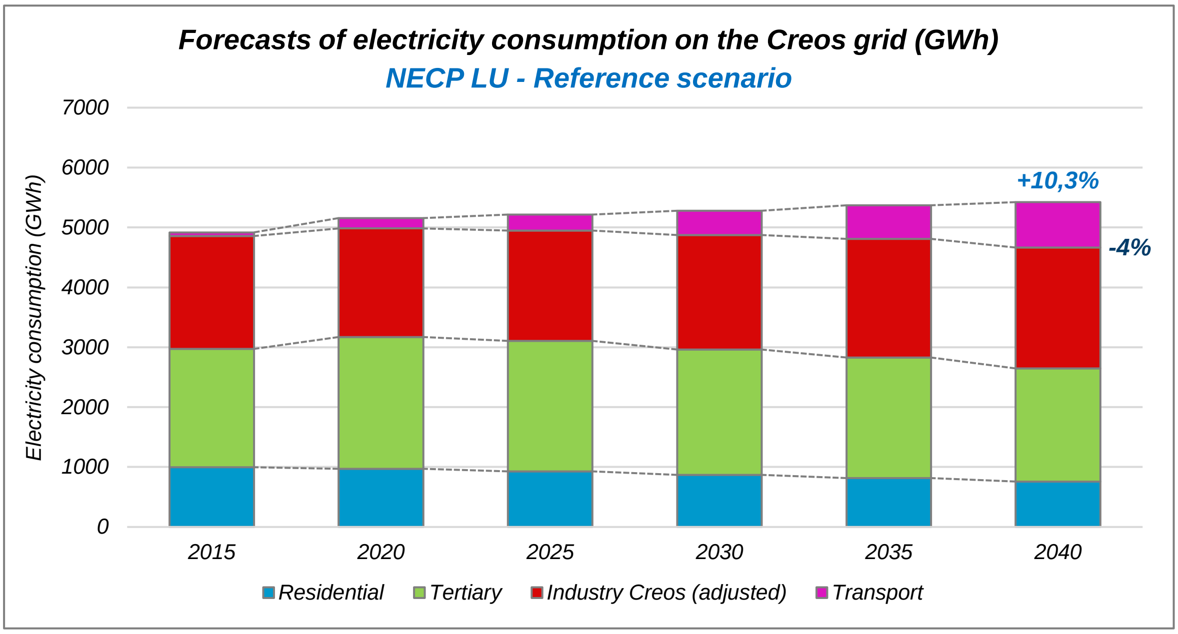


Source: NECP Luxembourg & Creos Luxembourg

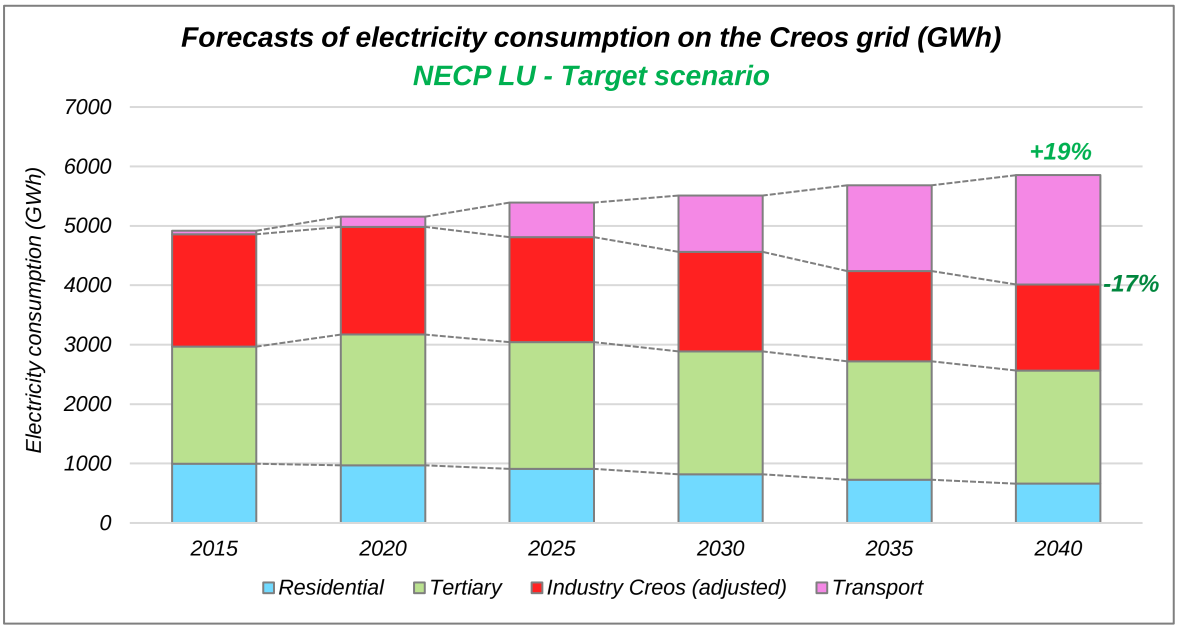
Both forecasts include the electrically driven transport sector. A ratio of about 50% of electric/plug-in hybrid vehicles, or grid-relevant electric vehicles was assumed for the year 2030 for the target scenario.

In the previous chapter 'Retrospective' it has already been shown that past electricity consumption growth on the Creos grid was higher than past national consumption growth. This also confirms that adjustment of the growth figures calculated in the NECP LU seems justified to better represent future electricity consumption on the Creos grid.

In detail, the growth of the different sectors as stated in the NECP LU report is shown hereafter (between 2015 and 2040):

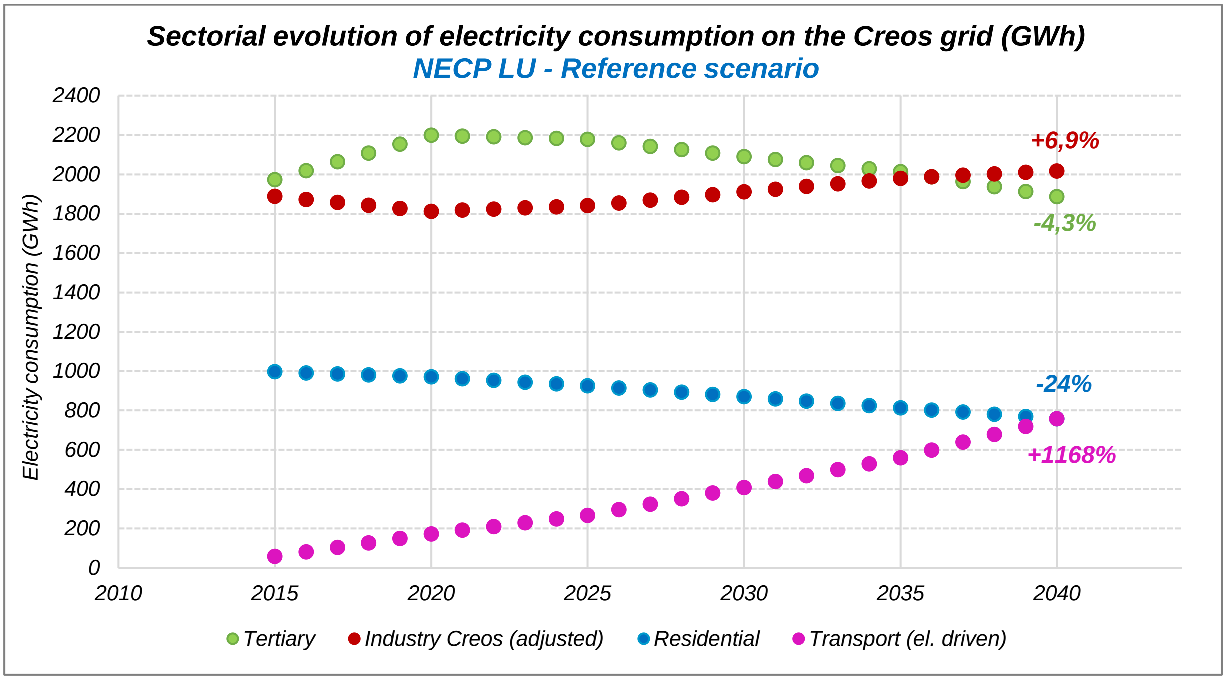


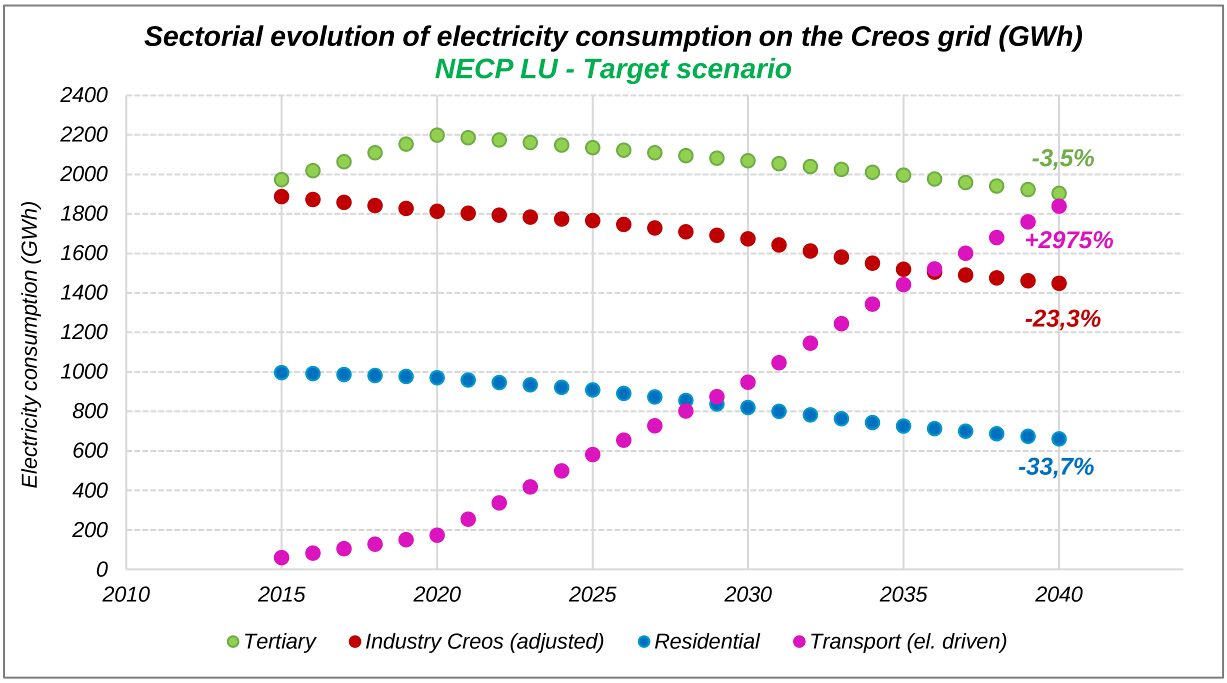
Source: NECP Luxembourg & Creos Luxembourg



Source: NECP Luxembourg & Creos Luxembourg

For the period 2015–2020, the real values were incorporated in the forecast charts, which explains the opposite growth trends of the sectors at the beginning. The growth percentages at the end of the forecasts were calculated relative to the year 2015, in order to be able to compare the values with other assumption scenarios.





Source: NECP Luxembourg & Creos Luxembourg

The NECP and these forecasts do not include extraordinary electricity consumption, projects with high electrical energy needs, such as the data centre project in Bissen/Roost or other data centre projects, nor the industries which are currently connected to the Sotel industrial grid and might be connected to the Creos grid in the future.

This additional consumption and the related peak power must be added separately.

Assumptions: NECP – residential sector

Both scenarios of the National Energy and Climate Plan foresee a decrease of electricity consumption of the residential sector in the future (transport considered separately), despite the expected growth of the population. This can only be achieved with the raising of energy awareness among the population and consistent public behaviour towards rational energy use. The increased energy efficiency of future electric devices should help to reduce electricity needs per inhabitant, but to foresee a decrease of total electricity consumption in the future appears to be very ambitious.

The aim is to achieve this target with an ambitious renovation rate of existing residential buildings and with revised regulations for the construction of new buildings which will not only have to be highly energy-efficient, but could even produce electricity themselves, as plus-energy houses. Another intended measure is to promote alternative and innovative forms of residential living, such as intergenerational living, cooperative living and residential areas without cars.

Assumptions: NECP – tertiary sector

For this sector also, a slight decrease of electricity consumption is foreseen, despite a forecasted increase of the total workforce figures. Newly constructed administrative buildings, offices and other facilities of this sector will certainly be more energy-efficient, so that a lot less thermal and electric energy per employee will be necessary. A decrease of electricity demand of this sector in the future is possible, but opposite to the trend of recent years.

Assumptions: NECP – industry sector

The reference scenario of the National Energy and Climate Plan anticipates a slight increase of electricity consumption of the industry sector in the future. Additional industrial plants and facilities will very probably lead to higher electrical energy consumption, despite the obligation of the industry to improve energy efficiency. Another reason for the assumed increase could be the intensified use of electricity for thermal purposes or a higher degree of automated processes.

On the contrary, the target scenario presumes that future electricity consumption of the industry sector will strongly decrease. It will require huge efforts to fulfil that goal, if a sustained growth of this sector is targeted at the same time. It may only be possible with a reduction of industrial operations.

Assumptions: NECP – transport sector

The NECP LU forecasts for the reference scenario and for the target scenario will be considered without the transport sector to allow the use of own projections for electrically driven transportation. In fact, the NECP LU forecasts only considered future yearly consumption and not total power demand.

TIR / Rifkin - Energy demand scenarios 2050 for Luxembourg

In addition to the scenarios from the National Energy and Climate Plan, the relevant study 'Third Industrial Revolution (TIR)' was considered to give another outlook on the possible future development of electricity consumption.

The 'Third Industrial Revolution (TIR)' strategic study was conducted in 2016 to support Luxembourg's ecological and digital transition. The reflections during this participatory process subsequently contributed to the country's economic policy orientation.

At the beginning of 2021, the three historical partners, the Ministry of the Economy, the Chamber of Commerce and IMS Luxembourg, decided to carry out a '2021 inventory' of the 49 strategic measures of the TIR and thus an assessment of the projects carried out since its publication. This inventory showed that many measures resulting from the TIR process have been implemented over the last few years without necessarily being identified as directly related to this process.

In the context of the TIR study, additional needs for total energy and for electricity have been estimated for Luxembourg for the year 2050 by the Fraunhofer Institute (Energy demand scenarios 2050 for Luxembourg).

The Fraunhofer Institute (ISE) developed two different scenarios for the period 2015–2050, from which only the STATEC scenario was used in the scope of this study:

1) STATEC scenario with a final energy decrease of -44% per inhabitant
2) Ambitious energy efficiency scenario with -63% of final energy demand per inhabitant

With a projected population of about 1,026 million inhabitants by 2050 (+86%), the following figures for the final energy demand have been estimated:

	Unit	2015	2050	Growth
Population	inh.	551.885	1.026.876	86%
Absolute values - Scenario STATEC				
Final energy demand	**GWh**	**25.419**	**25.545**	**0%**
- Electricity demand	GWh	5.895	6.924	17%
- Heating demand	GWh	13.322	13.015	-2%
- Mobility demand	GWh	6.202	5.606	-10%
Values per inhabitant - Scenario STATEC				
Final energy demand	**kWh/inh**	**44.448**	**24.876**	**-44%**
- Electricity demand	kWh/inh	10.308	6.743	-35%
- Heating demand	kWh/inh	23.295	12.674	-46%
- Mobility demand	kWh/inh	10.845	5.459	-50%
Values per inhabitant - Scenario ambitious energy efficiency				
Final energy demand	**kWh/inh**	**44.448**	**16.534**	**-63%**
- Electricity demand	kWh/inh	10.308	5.669	-45%
- Heating demand	kWh/inh	23.295	8.153	-65%
- Mobility demand	kWh/inh	10.845	2.711	-75%
Absolute values - Scenario ambitious energy efficiency				
Final energy demand	**GWh**	**25.419**	**16.978**	**-33%**
- Electricity demand	GWh	5.895	5.822	-1%
- Heating demand	GWh	13.322	8.372	-37%
- Mobility demand	GWh	6.202	2.784	-55%

Mobility: Road without transit, fuel tourism, plus rail

Source: Energy Demand Scenarios 2050 for Luxembourg, Fraunhofer ISE

Especially the following absolute and relative values have been calculated:

Absolute values

Final energy demand 2015

in GWh	Electricity*	Heating	Transport	Total	Share
Residential	753	5.723		6.476	25%
Services and Agriculture	2.091	2.953		5.044	20%
Industry	3.051	4.646		7.697	30%
Transport**			6.202	6.202	24%
Final energy demand	**5.895**	**13.322**	**6.202**	**25.419**	**100%**
Share	23%	52%	24%	100%	

Final energy demand 2050 according STATEC

in GWh	Electricity*	Heating	Transport	Total	Share
Residential	1.202	6.671		7.873	31%
Services and Agriculture	2.929	1.906		4.835	19%
Industry	2.793	4.438		7.231	28%
Transport**			5.606	5.606	22%
Final energy demand	**6.924**	**13.015**	**5.606**	**25.545**	**100%**
Share	27%	51%	22%	100%	

Growth rate 2015 to 2050

in GWh	Electricity*	Heating	Transport	Total	
Residential	60%	17%		22%	
Services and Agriculture	40%	-35%		-4%	
Industry	-8%	-4%		-6%	
Transport**			-10%	-10%	
Final energy demand	17%	-2%	-10%	0%	

* without heating

** Road without transit, fuel tourism, plus rail, electricity for rail included in transport

Source: Energy Demand Scenarios 2050 for Luxembourg, Fraunhofer ISE

It should be noted that the transport sector is listed separately.

There is a slight difference between the values for electricity demand as found in the Fraunhofer study and the historical values given by STATEC. The figures given by STATEC are more accurate than the absolute values in the Fraunhofer study. Nonetheless, this has no influence on the key statements and the relative values of this study.

When comparing the trends of the specific sectors, the historical values from the past 10 years seem to confirm the assumptions of the Fraunhofer ISE concerning the relative growth of electrical energy demand of the sectors.

According to the estimation of the Fraunhofer ISE 'Energy demand scenarios 2050 for Luxembourg', electrical energy need is expected to rise by 17% by the year 2050, respectively by 12% by 2040.

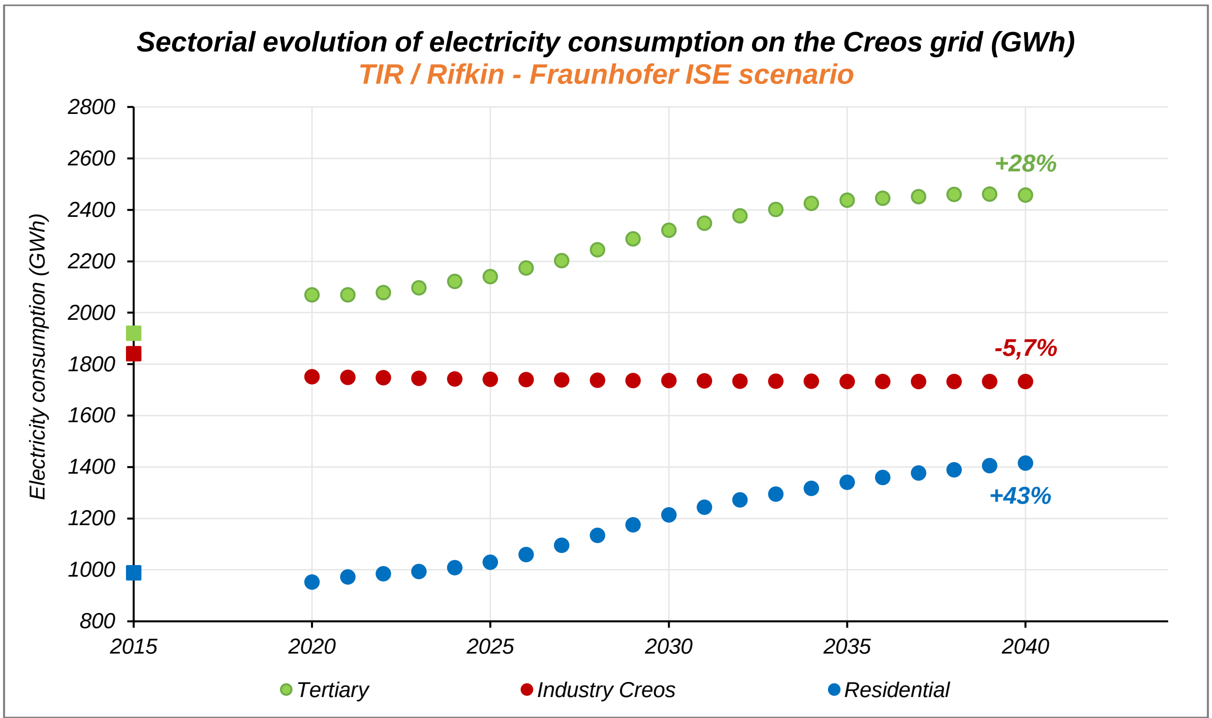
For the year 2040, the following future electricity variations can be calculated for the different sectors:

Variation of electricity consumption	2015 - 2040	2015 - 2050
Residential	+ 43%	+ 60%
Tertiary	+ 28%	+ 40%
Industry	- 5,7%	- 8%
Total	**+ 12%**	**+ 17%**

Source: Energy Demand Scenarios 2050 for Luxembourg, Fraunhofer ISE

Here too, it is necessary to mention that an adjustment of the growth of the industry sector would be more accurate in order to consider the fact that not all industry in Luxembourg is supplied by the Creos grid. In this case, however, a rectification of the growth of the industry sector could not be made because substantial detail data about this sector is not available. We therefore accepted the growth figures as given.

Moreover, it has been assumed that the growth of the industry, tertiary and residential sectors will not occur linearly. A certain saturation might occur at the end of the projection period.



Source: Creos Luxembourg

Assumptions: TIR / Fraunhofer ISE scenario – residential sector

In this scenario, it is assumed that increased electricity demand in the residential sector will come from the direct growth of the population. New construction will certainly be more energy-efficient and additional consumption will be cushioned, but the increase of the number of inhabitants will still lead to higher total electricity consumption.

Assumptions: TIR / Fraunhofer ISE scenario – tertiary sector

Here, the assumption is that the service/tertiary sector will grow in the future and that total electricity consumption will rise accordingly because of the additional workplaces. However, additional electrical energy demand could be reduced by better energy efficiency of newly constructed offices or renovated administrative buildings.

Assumptions: TIR / Fraunhofer ISE scenario – industry sector

A transformation of the current national industry form will certainly take place. Existing heavy industries will be replaced by smaller, more specialised industries with a high degree of know-how and with less energy demand. This could lead to a reduction of electrical energy consumption in this sector. New investments in this field guarantee, through targeted cost efficiency and environmental protection reasons, a more sparing and sustainable use of energy resources.

For this scenario, the expert group of the Fraunhofer Institute made the assumption that the future electricity need of the industry sector will decrease by several percent. In order to stay competitive, future industries will certainly be more energy-efficient than in the past.

E-mobility / transportation operated by electricity

As ambitious political goals in emission limitations have been set, decarbonisation of the transport sector will lead to other propulsion technologies as used today. In combination with electricity from renewable energies, passenger and goods transport using electric vehicles will be emission-free and can replace fossil-fuelled vehicles in the medium and long term. The ongoing evolution of electric vehicles will undoubtedly lead to a lower energy need per inhabitant than in the past and present. Nonetheless, the electricity needed for future transportation, assuming there is a mass shift to e-mobility, will have to be provided by the electrical grids.

The total electrical power needed for the entire transportation sector of the future is difficult to predict, but it is certain that the complete shift of the transport sector from fossil fuels to electricity will put the present electrical grids at all voltage levels to the test and will lead to overloads during peak times. Optimised, smart charging of electric vehicles is a must and will lessen the risks of congestion on the grids, although that will not be enough to prevent the necessity of further electrical grid reinforcements. The situation could be aggravated by 'e-fuel tourism', which would be provoked by attractive domestic electricity costs. Cross-border commuters may also want to charge their electric cars during working hours at their workplace in Luxembourg.

Sustainable mobility is one of the major challenges of the present and the future. The coalescence of transport, electrical grid and communication infrastructure to form a new system is going to be a huge challenge, but it could also offer the chance of better utilisation of the infrastructure and promote more selective investments. Electric vehicles in particular will play a central role in the achievement of clean, future-viable individual transport, because carbon dioxide emissions will be lowered and dependency on fossil fuels will be reduced due to the more energy-efficient drive technologies of these vehicles. Paired with enough electricity generated from renewable energy sources, an ecological energy cycle could be formed with which the ambitious European climate targets could be fulfilled.

To promote e-mobility and to offer public recharging possibilities, eight hundred public charging stations for electric vehicles (1,600 charging points) have been installed in public car parks throughout the country. It is also intended to install eighty-four fast charging and supercharging stations at key locations throughout the country and at major service areas on motorways in the coming years.

Since 2019, generous financial bonuses have been offered for the purchase of low-emission or emission free vehicles, and the installation of a private charging wallbox at home is being subsidised. The offered incentives/ bonuses are working, as registrations for new electric and hybrid vehicles are strongly increasing. With better range capabilities and market prices in the future, there will certainly be even broader acceptance with an accelerated growth of registrations.

Concerning electrically driven transportation, a major distinction can be made between transport on rail and on the road. Those categories must be analysed in detail below.

Electrically driven transportation

on rail	*on road*

Electrically driven transport on rail

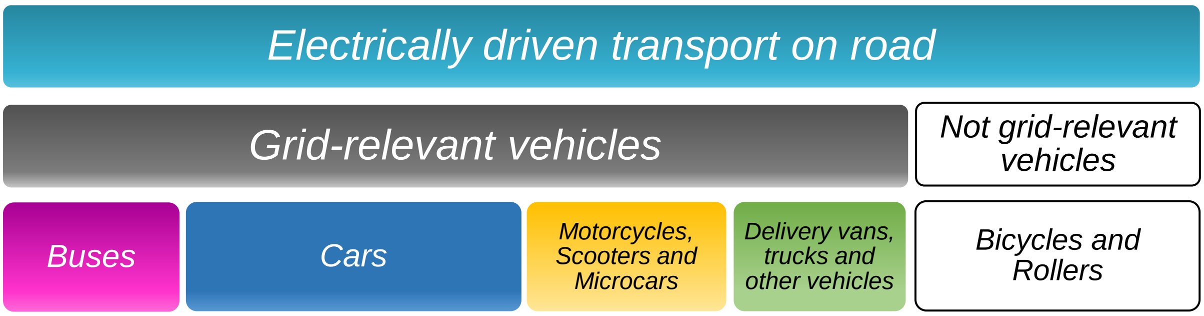
The entire public passenger and the goods transport on rail in Luxembourg is already electrically driven, and all the electrical assets of the national railway company are now connected to the Creos grid.

Besides electrically driven trains, there is a tram network in the capital city, which is powered by electricity. The first sections of this tramway are already in operation and several additional sections are planned. A preliminary project for a fast tramway connection between the capital city and the biggest city in the south of Luxembourg was presented. The extension of the tramway could more than double the future power demand needed for the tram network.

Additionally, a funicular railway, transferring passengers from a train station to a tramway station in the capital city, is in operation since the end of 2017.

As the number of electrical assets of the national railway company is constantly growing, it is rational to expect a rising power demand from electrically driven transport on rail in the future.

Electrically driven transport on road



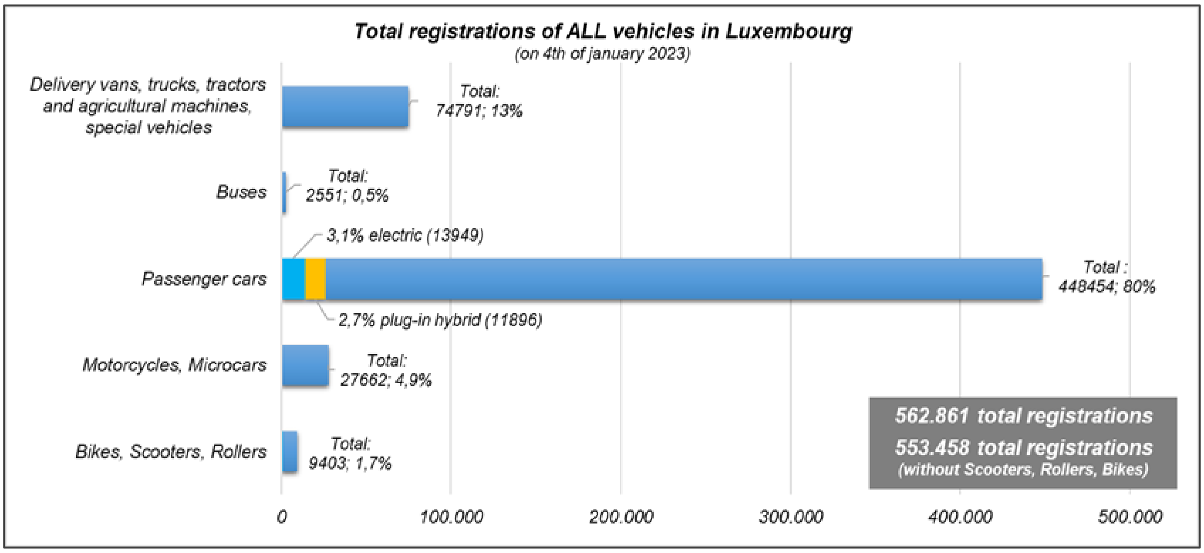
Electrically driven transport on road can be divided in two major categories: grid-relevant vehicles and those vehicles that are not relevant for the power grid.

Grid-relevant vehicles represent all the vehicles which can be connected to the power grid and recharged from it with a significant power.

Not relevant for the power grid are vehicles with no grid connection capabilities, such as hybrid vehicles without external charging plug for the battery, or vehicles with low charging power, such as electric bicycles or scooters. For example, the chargers of e-bicycles and scooters typically have a nominal power range from 0,1 kW to 0,5 kW, which is quite low. Even if these chargers could have a potential impact through the mass of future devices, it is assumed that the additional power needed is already included in the overall growth of the residential sector.

Grid-relevant vehicles can be further subdivided in all the vehicles categories such as: buses, cars, motorcycles, mopeds, microcars, trucks, delivery vans, agricultural machines and other special vehicles.

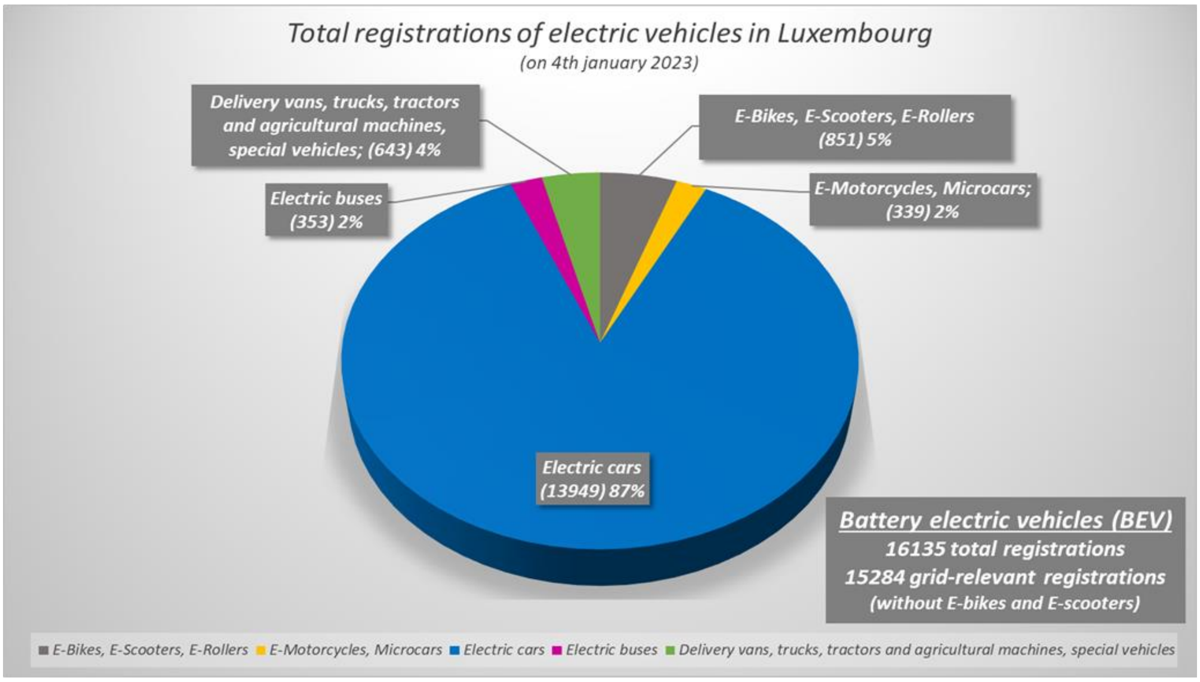
Total registrations of all vehicles on the road in Luxembourg on 4 January 2023, using all fuel types, are illustrated below. As can be seen, the most registered vehicles are passenger cars, delivery vans, utility vehicles and trucks.



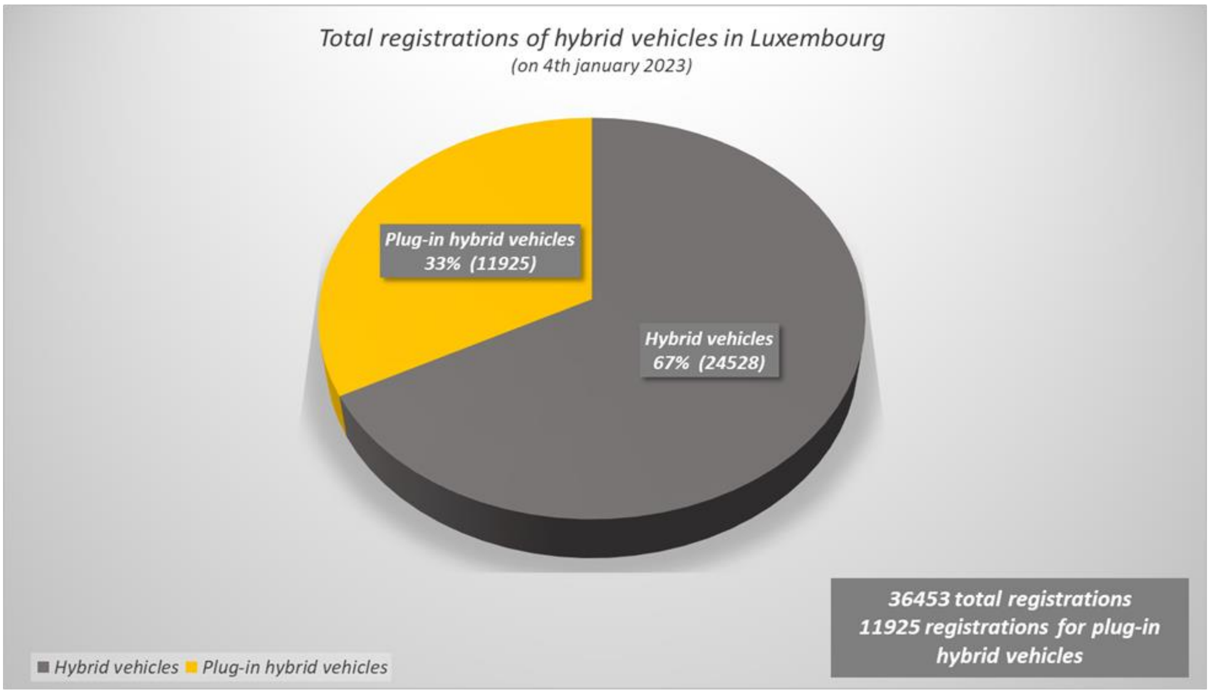
Source: SNCA & Creos Luxembourg

Grid-relevant vehicles include battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV). Both categories have been quite popular in recent years and registrations of these vehicles are rising exponentially. Currently, about 3,1% of all passenger cars are electric cars and 2,7% of all passenger cars are plug-in hybrid cars.

In fact, on 4 January 2023, there was a total of 15.284 grid-relevant battery electric vehicles registered in Luxembourg, most of which are cars. Additionally, another 11.925 plug-in hybrid vehicles have been registered up to this date.



Source: SNCA & Creos Luxembourg

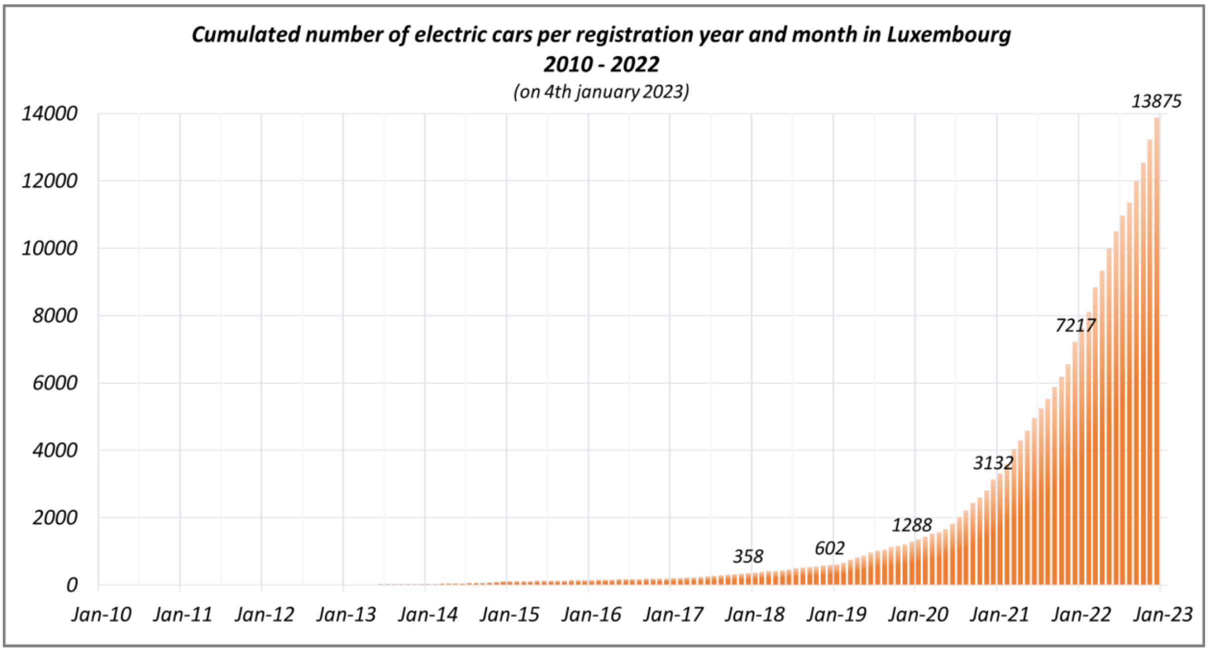


Source: SNCA & Creos Luxembourg

Electric cars, electric motorcycles and electric utility vehicles

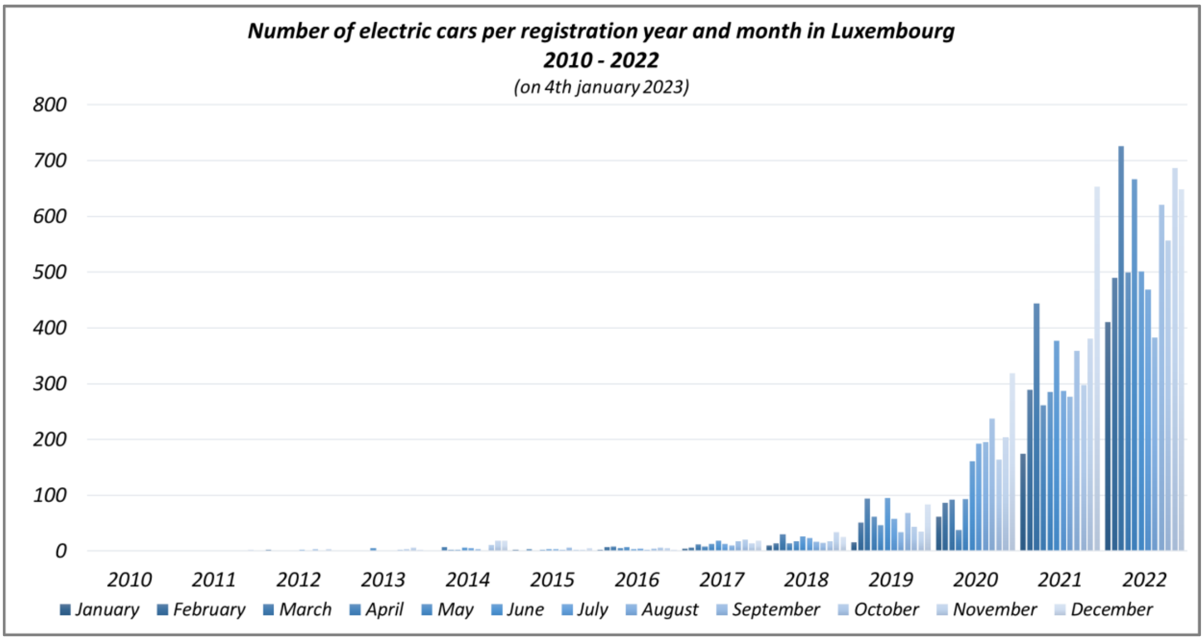
All kinds of electric vehicles are coming more and more into use. Already over 150 electric motorcycles and about 150 microcars were registered up to January 2022. Furthermore, more than 500 electric delivery vans, several other light utility vehicles and one electric truck are currently on the road in Luxembourg.

The biggest share of grid-relevant vehicles comes from electric cars, and this will certainly have the most important impact on the electrical power grid in the future. During the last five years, there was a substantial increase in registrations of electric cars, as depicted here:



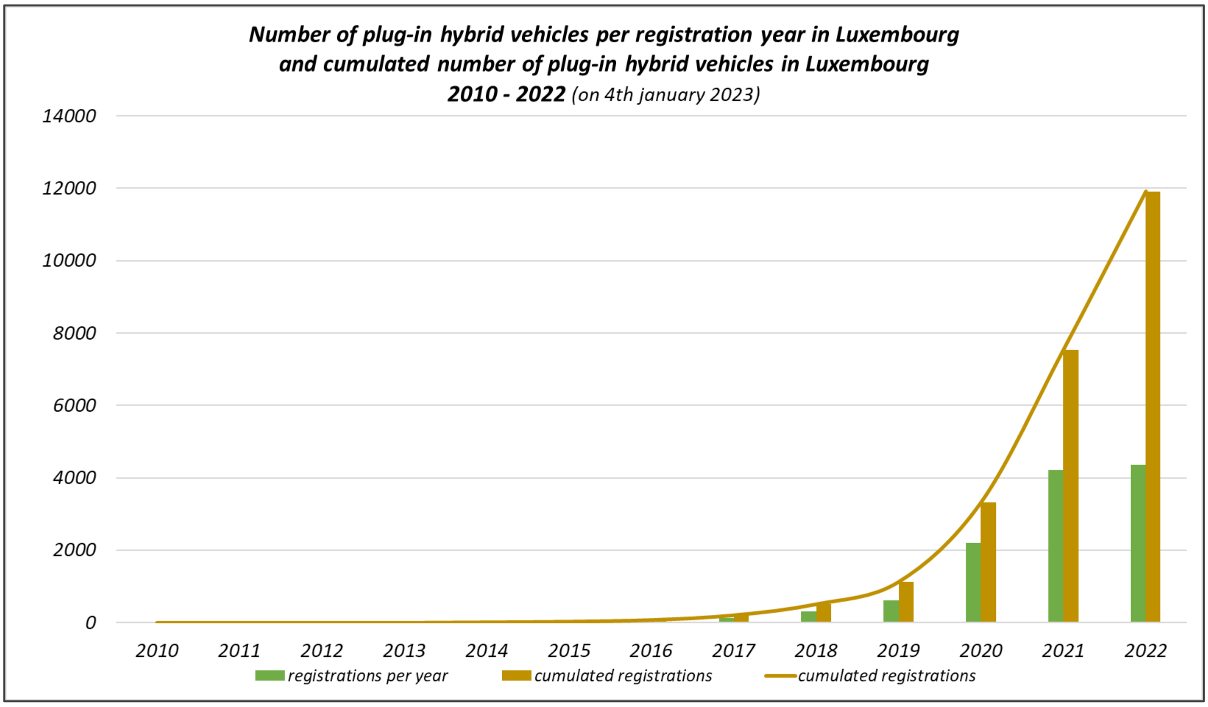
Source: SNCA & Creos Luxembourg

The yearly growth is undeniable, and the increase will certainly be more than just linear in the future.



Source: SNCA & Creos Luxembourg

The rise in registrations of plug-in hybrid vehicles in recent years is equally impressive. It is noteworthy that nearly all of these vehicles are cars.



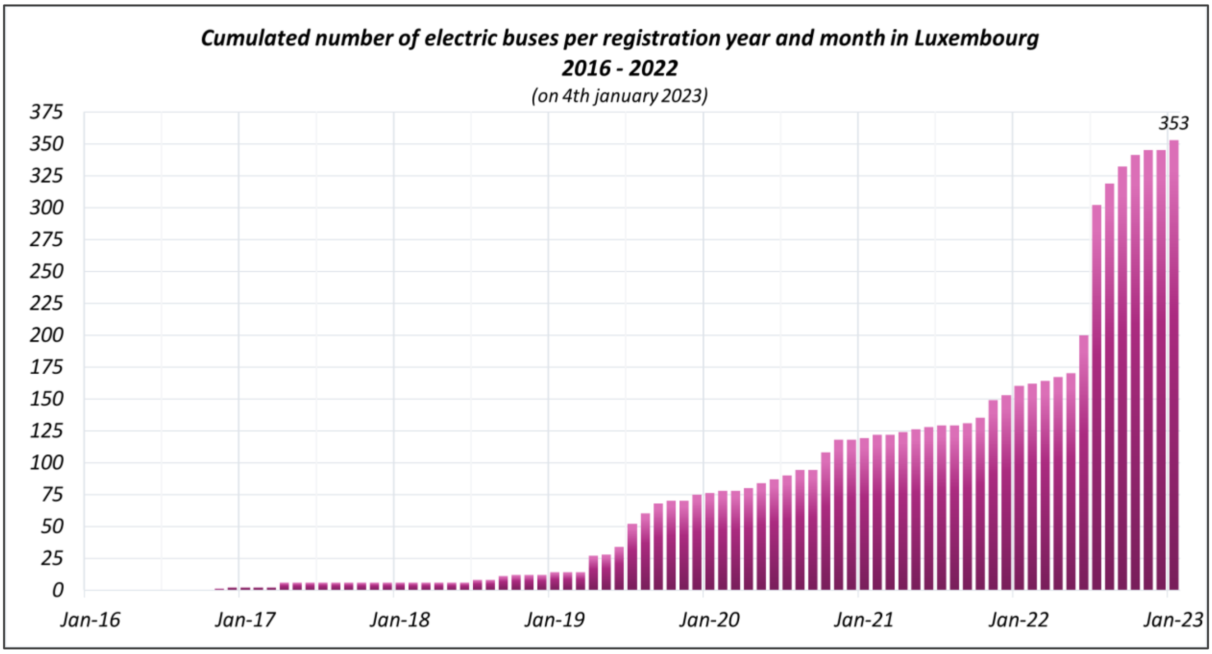
Source: SNCA & Creos Luxembourg

Plug-in hybrid vehicles can be seen as a 'bridge technology' and will probably be replaced by full electric vehicles in the medium and long term. Nonetheless, these vehicles should be considered for their impact on the power grid, because the size of the batteries of newer plug-in hybrid cars is increasing and the charging powers of these vehicles are increasing accordingly.

Electric buses

To reduce carbon dioxide emissions, it is intended to completely electrify public bus transport by 2030. This means that there will be a huge shift from conventionally-fuelled buses to electric buses in the near future. The electrical energy necessary to recharge these vehicles will have to be delivered by the electrical grid.

Indeed, the use of electric buses for public transport is rising quickly, totalling about 353 electric buses on the road today (4 January 2023).



Source: SNCA & Creos Luxembourg

Currently, there are about 2,500 buses driving on the country's roads, together covering over 60 million km per year.

Recent practical experiences have shown that the average energy consumption of electric buses is about 2.2 kWh per km. In total, this would give electrical energy consumption of:

$$\text{Total electrical energy consumption e-buses} = 60{,}000{,}000 \text{ km x } 2.2 \frac{kWh}{km} = 132 \text{ GWh}$$

Assuming that energy has to be recharged overnight, i.e. from 11:00 pm to 5:00 am, which would represent an average charging power of:

$$\text{Average power during overnight charging e-buses} = \frac{132 \text{ GWh}}{(8h \text{ x } 365 \text{ days})} = 60 \text{ MW}$$

With regard to overnight charging, several charging stations at existing bus depots have already been put into operation and additionally, about 25 connection requests for charging stations at existing or new bus depots have been made lately with a total of more than 50 MW.

During daily operation, e-buses may also need to quickly recharge their batteries on their respective routes with the aid of opportunity charging stations. The operating power of opportunity charging stations ranges from 250 kW to 550 kW.

Electric trucks

Battery electric drive systems have the highest efficiency among alternative drive systems and that is why battery electric trucks will play a major role in the decarbonisation process of road freight transport. Road freight and particularly heavy-duty vehicles account for at least 40% of the carbon dioxide emissions in the transport sector.

The biggest truck manufacturers are determined to drive the electric truck revolution forward in Europe and are already proposing a wide range of electric vehicles for the market. Most of these companies' sales targets envisage that half of their total truck sales will be electric trucks by 2030. If enough charging stations for electric trucks are rapidly installed across the European Union, the market uptake of these trucks will increase exponentially over the coming years.

In 2021, a total of 346 electric trucks (>16 tonnes) were already registered in Europe.

Three major truck manufacturers have made an agreement to establish a joint venture for public charging infrastructure for long-distance transport. They intend to establish and operate a public high-performance charging network for battery electric heavy-duty long-distance trucks and coaches in Europe. This charging network should be available to fleet operators in Europe, regardless of brand.

In addition, major truck manufacturers are participating in the 'high-performance charging in long-distance truck transport' (HoLa) project. The goal of the project, under the patronage of the German Association of the Automotive Industry (VDA), is the planning, construction and operation of a selected high-performance charging infrastructure for battery electric long-haul trucking. Two high-performance charging points with the 'Megawatt Charging System (MCS)' will be set up at four locations in Germany and tested in real-world use. Various other consortium partners from industry and research are involved in the project.

Today, the battery capacities of electric trucks range from about 200 kWh to over 600 kWh, with AC charging and DC supercharging capabilities. DC supercharging powers range currently from 50 kW to 350 kW. High-performance charging (MCS) is still in the test phase but will certainly be adopted as the new standard supercharging power in the medium term.

The future charging infrastructure of both the light electric trucks and the heavy-duty long-distance trucks driving in and across Luxembourg will certainly have a substantial impact on the power grid in Luxembourg. That is why it is important to pinpoint the major recharging locations where electric trucks need supercharging stations and where electric trucks will recharge their batteries overnight or over longer periods of time during day.

In 2022, a study was conducted by the Fraunhofer Institute for Systems and Innovation Research (ISI) on behalf of the European Automobile Manufacturers' Association (ACEA) which aims to help governments and infrastructure operators prioritise where to start installing charging points for electric trucks across Europe. The study stipulates that, as truck operators make the switch to electric vehicles, it will be unlikely that they will change their driving behaviour. The aim of the study was therefore to map out exactly where drivers make their stops today, and which of these truck stops are most frequently used.

Fraunhofer ISI analysed the GPS coordinates of some 400.000 trucks in operation throughout Europe over a period of 12 months, focusing on the duration of stops at individual locations.

The analysis found that 10% of the locations most frequented by trucks in Europe (over 3.000) account for some 50% of the total stops that trucks make, about 78.000 stops, and ACEA is calling on national governments to ensure that the top 10% truck stop locations are equipped with suitable electric chargers by 2027 at the latest.

For Luxembourg, the most frequented truck stop locations are shown and listed below.

Source: ACEA & Creos Luxembourg

Frequency of stop locations	Description	Town /Area
Top 5%	**Aire de Wasserbillig**	**Mertert**
Top 5%	**Aire de Capellen**	**Mamer**
Top 5%	**Aire de Berchem**	**Berchem**
Top 5%	**Luxair Cargocenter Findel**	**Senningerberg**
Top 10%	**Arcelor European Logistics Center - Z.I. Haneboesch Niedercorn**	**Niederanven**
Top 10%	**Transports Wallenborn Munsbach**	**Schuttrange**
Top 10%	**Parking Bord de Route - Route de Longwy - Rodange**	**Petange**
Top 50%	Aire de Pontpierre - Direction Lux.Ville	Mondercange
Top 50%	Parking Rond-Point Raemerich à- Arcelor Portal Nord - Esch/Alzette	Esch-sur-Alzette
Top 50%	Parking Schengerwis - Remerschen	Schengen
Top 50%	Parking Restaurant Chez nous-Chez vous - Route d'Arlon - Martelange	Martelange
Top 50%	Port de Mertert	Mertert
Top 50%	Intermodal Eurohub Bettembourg	Bettembourg
Top 50%	CFL Multimodal - Z.A. Wolser A - Bettembourg	Bettembourg
Top 50%	Station de service Total - Rondpoint - Wandhaff	Koerich
Top 50%	Arcelor Mittal - Z.A. Wolser B - Bettembourg	Bettembourg
Top 50%	Goodyear - Av. Gordon Smith - Colmar-Berg	Colmar-Berg
Top 50%	Carlex Glass - An den Längten - Potaschbierg	Grevenmacher
Top 50%	Avery Dennison Materials - PED Av. de l'Europe - Petange	Lamadelaine
Top 50%	Kronospan Z.A. Gadderscheier - Sanem	Soleuvre
Top 50%	LuxPET - Z.I Laangwiss / Op Zaemer - Bascharage	Bascharage
Top 50%	Kuehne + Nagel Warehouse - Z.I. Rue Edmond Reuter - Contern	Contern
Top 50%	Hydro Aluminium Clervaux - Op der Sang - Lentzweiler	Clervaux
Top 50%	Eau minérale Beckerich - Rue Jos-Seyler - Beckerich	Beckerich
Top 50%	Ekabe Eschweiler (Junglinster)	Junglinster
Top 50%	GN Logistics - Z.I. Krackelshaff - Bettembourg	Bettembourg
Top 50%	Offergeld Logistics - Z.I Laangwiss / Op Zaemer - Bascharage	Bascharage
Top 50%	Leaseplan - Z.I. Drosbach - Leudelange	Leudelange

Source: ACEA & Creos Luxembourg – List of top 50% truck stop locations identified by the Fraunhofer study

All the truck stop locations analysed by the study and identified for Luxembourg add up to 53 locations (5x in top 5%; +3x in top 10%; +21x in top 50% and 25x in 50% least frequented locations).

Assuming a future charging capacity of 4 MW per identified site, this would give total charging power of 200 MW for electric trucks. Even with a modest simultaneity, this could have a serious additional impact on the power grid.

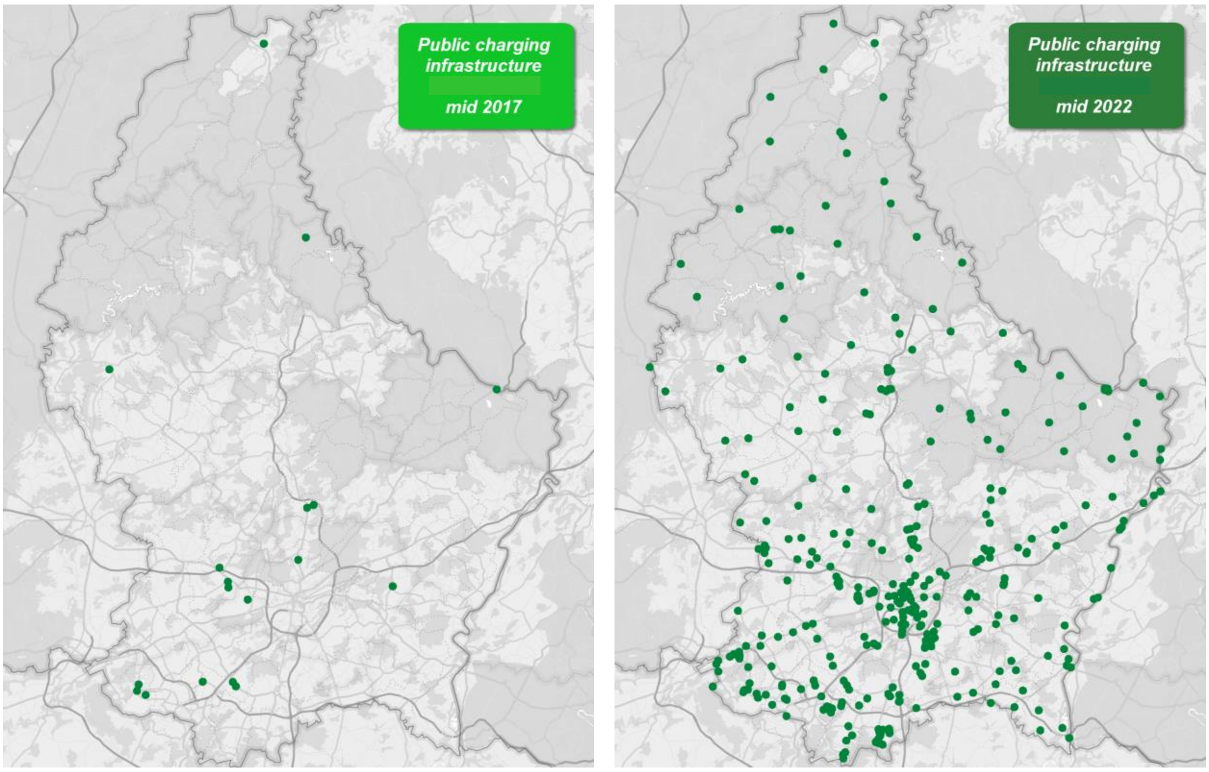
At best, the study from the Fraunhofer Institute and ACEA and the ensuing listing should be seen as a first step in the attempt to identify the future charging locations of electric trucks. More studies and enquiries should be made to better assess the future charging needs and locations for electric trucks throughout the country.

Public and private charging infrastructure

The public and private charging infrastructure for recharging electric vehicles is evolving impressively.

The public charging infrastructure grew from about 40 charging stations in the middle of the year 2017 to 800 charging stations in 2022. These public charging stations offer 2 charging points per station, with a recharging power of 22 kW per charging point.

In total, this infrastructure has now reached a charging power capacity of 34 MW.

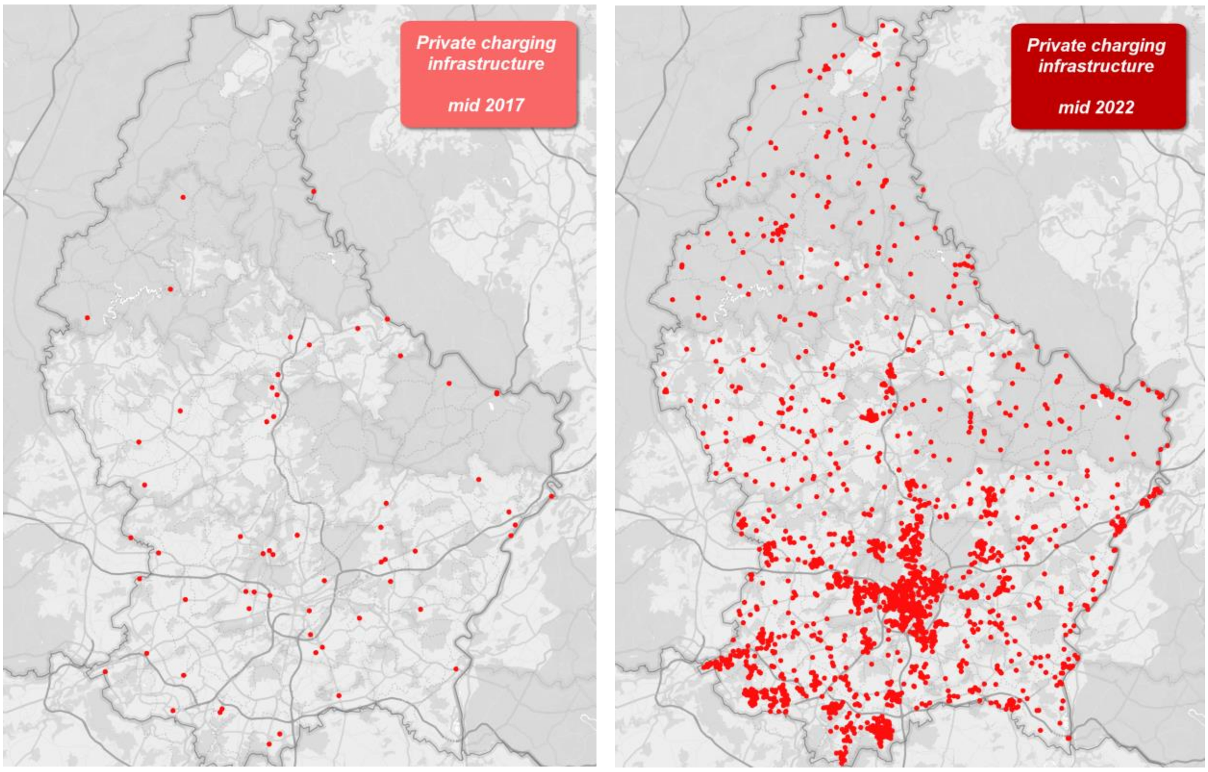


Source: Creos Luxembourg

During the year 2021, about 190.000 charges were performed at all public stations and a total of about 2.700.000 kWh were consumed through these stations. 37% of this total, about 1.000.000 kWh, were consumed at the public charging stations in the territory of the capital city. The charging data shows that the average occupancy of the charging poles and points in the territory of the capital city is over twice as high as the national average occupancy.

As a further commitment to promoting e-mobility, it is intended to install eighty-four fast chargers and superchargers at key locations throughout the country and at major service areas on motorways. Several superchargers, offering DC charging power between 150 kW and 350 kW, have already been installed.

Regarding the private charging infrastructure, by the middle of the year 2022, about 11.000 private wallboxes or poles for charging an electric vehicle were already connected to the Creos grid, with a total installed power of 108 MW.



Source: Creos Luxembourg

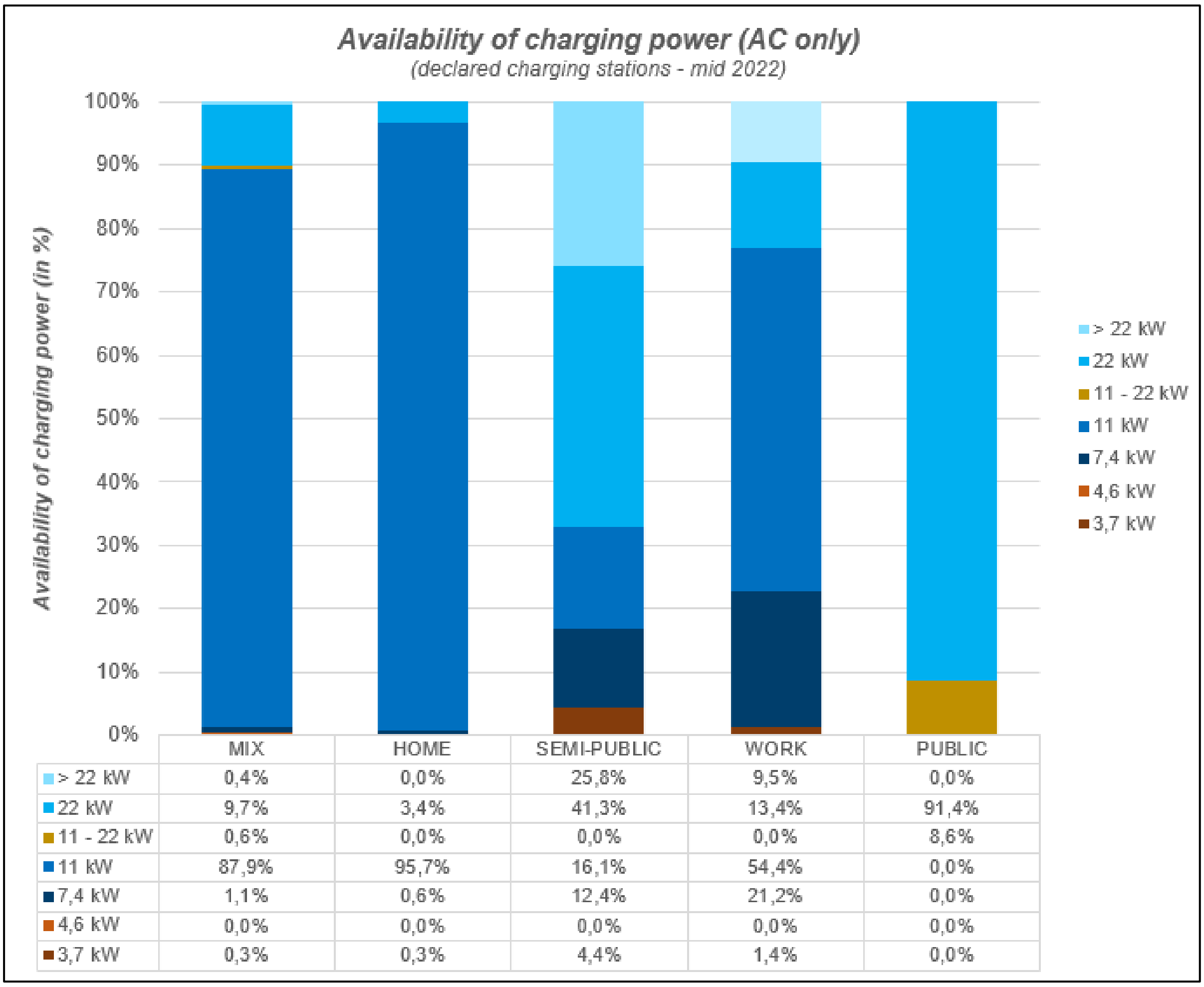
The number of connection requests for new wallboxes is strongly rising and will certainly increase in the future. The power grids at all voltage levels must be prepared for a large number of electric vehicles and their charging infrastructure.

Availability of charging power (AC only)

Details of the charging power available on all the declared wallboxes and charging poles currently installed (only alternative current – AC), can be seen below.

The following categories were defined for the different installation locations of the wallboxes and charging poles:

- HOME: Wallboxes/poles installed at private homes
- WORK: Wallboxes/poles installed at private companies, commercial or administrative buildings, where public access is restricted
- SEMI-PUBLIC: Wallboxes/poles installed in private car parks, administrative or commercial buildings like shopping centres, where public access is not restricted, but not guaranteed either
- PUBLIC: Wallboxes/poles installed at public parking spaces, where public access is guaranteed
- MIX: All the declared wallboxes and charging poles in the mix



	MIX	HOME	SEMI-PUBLIC	WORK	PUBLIC
> 22 kW	0,4%	0,0%	25,8%	9,5%	0,0%
22 kW	9,7%	3,4%	41,3%	13,4%	91,4%
11 - 22 kW	0,6%	0,0%	0,0%	0,0%	8,6%
11 kW	87,9%	95,7%	16,1%	54,4%	0,0%
7,4 kW	1,1%	0,6%	12,4%	21,2%	0,0%
4,6 kW	0,0%	0,0%	0,0%	0,0%	0,0%
3,7 kW	0,3%	0,3%	4,4%	1,4%	0,0%

Source: Creos Luxembourg

In Luxembourg, every house or apartment has the possibility to install a wallbox with a charging power of 11 kW. However, this must be declared and registered by the grid operator. In exceptional cases, installation of wallboxes with a higher charging power might be possible if the grid conditions on the specific locations are good, but formal approval by the respective grid operator is needed.

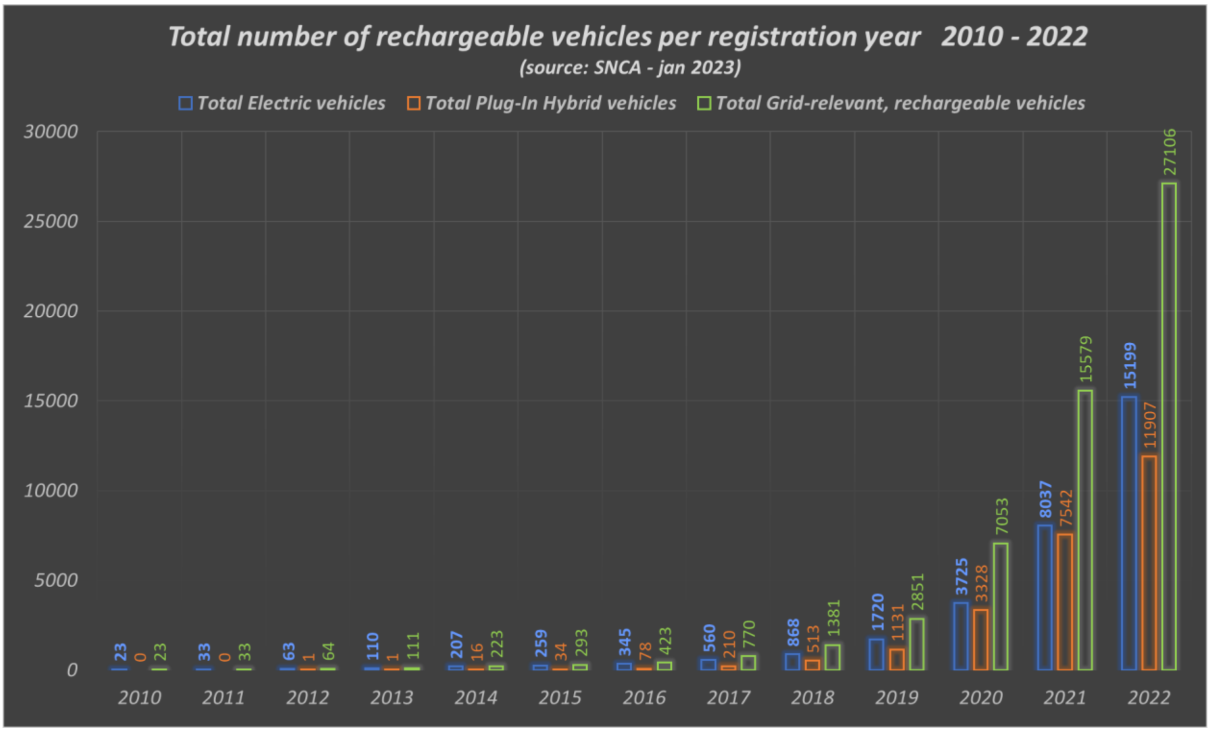
In residential buildings, the cumulative charging power available for e-mobility in the specific building may be limited to a certain amount, depending on the local connection situation. In this situation, a mandatory smart charging system will then distribute the available power between all the connected wallboxes.

In fact, 96% of the declared chargers at home have a charging power of 11 kW. In the public infrastructure, the available charging powers are higher, with mostly 22 kW per charging point. And in administrative or commercial buildings, at semi-public places or at work, the power of the wallboxes or poles varies more widely.

By the middle of the year 2022, 88% of the entire charging infrastructure for electric vehicles in Luxembourg consisted of wallboxes with 11kW of charging power, while 10% of wallboxes/poles had 22 kW. This must be considered for the assessement of the impact of the electric vehicles on the power grids.

Forecasts of electrically driven transport

A total of about 27.000 grid-relevant, rechargeable vehicles were included in the registration figures on 4 January 2023. 15.199 grid-relevant battery electric vehicles and 11.907 plug-in hybrid vehicles were registered at the end of 2022.



Source: SNCA & Creos Luxembourg

As the evolution of e-mobility is difficult to predict with certainty, and as the power demand necessary for the cumulative charging of electric vehicles grows quite significantly with the number of EVs, establishing and analysing multiple scenarios seems appropriate. The future number of rechargeable vehicles will very likely grow in a non-linear way. For this reason, multiple projected increases have been assumed with the help of polynomial curves of various orders.

The assumptions made for the reference scenario, the target scenario of the NECP and the TIR / Fraunhofer ISE scenario concerning e-mobility are summed up below.

NECP - Reference scenario:

Share of 11% of the electrical energy need of the transport sector in 2040 (NECP, page 162).
A stipulated share of 11% corresponds to 760 GWh of annual electricity, or 710 GWh without 35% e-buses in 2040.

With these figures, own assumptions have been made to calculate the number of future electric vehicles: With an average electric consumption of 20–21 kWh per 100 km and a yearly distance of 18.000km per car, this electricity need would represent 202.000 electric/plug-in hybrid vehicles. After subtracting **10% of utility vehicles,** this would give about 182.000 electric /plug-in hybrid cars in 2040.

- ➔ 20% of total projected cars would be electric/plug-in hybrid cars in 2030
- ➔ 32% of total projected cars would be electric/plug-in hybrid cars in 2040

NECP – target scenario:

Share of 29% of the electrical energy need of the transport sector in 2040 (NECP, page 181).

A share of 29% corresponds to 1.850 GWh of annual electricity, or 1.720 GWh without 100% e-buses in 2040.

With these figures, own assumptions have been made to calculate the number of future electric vehicles: With an average electric consumption of 19–20kWh per 100 km and a yearly distance of 16.000km per car, this electricity need would represent 554.000 electric/plug-in hybrid vehicles in 2040. After subtracting **15% of utility vehicles**, this would give about 472.000 electric/plug-in hybrid cars.

- ➔ 50% of total projected cars would be electric/plug-in hybrid cars in 2030
- ➔ 82% of total projected cars would be electric/plug-in hybrid cars in 2040

An amount of 50% of electric cars in 2030 (referring to the total projected number of cars) is also stipulated in the NECP on page 41.

TIR / Fraunhofer ISE scenario:

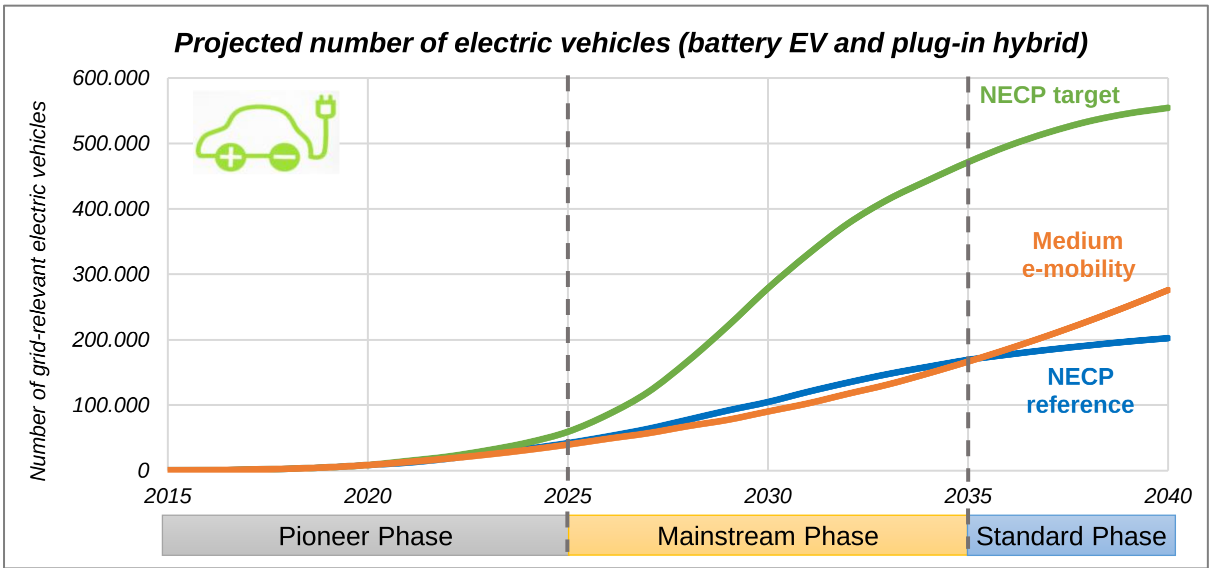
For adding the future transport sector to the ordinary load forecast of the Fraunhofer ISE scenario, own assumptions have been made with a steady, non-linear increase, which represents a moderate growth trend of grid-relevant vehicles. This assumption is designated as a 'medium e-mobility acceptance' scenario.

With about 90.000 grid-relevant vehicles (81.000 electric/plug-in hybrid cars) in 2030 and 275.000 grid-relevant vehicles (248.000 electric/plug-in hybrid cars) in 2040, that would make:

- ➔ 17% of total projected cars would be electric/plug-in hybrid cars in 2030
- ➔ 43% of total projected cars would be electric/plug-in hybrid cars in 2040

These three different acceptance levels for the e-mobility were considered for 2040:

- ➢ **Acceptance representing a medium level of e-mobility with a total of 275.000 EVs**
- ➢ **Acceptance compliant with the NECP reference scenario totalling 202.000 EVs**
- ➢ **Acceptance compliant with the NECP target scenario totalling 554.000 EVs**



Source: Creos Luxembourg

Recharging the batteries of several hundred thousand electric vehicles will be the major challenge for the electrical grids of tomorrow. The number of electric vehicles, their charging capacities, and the time and duration of charging are of importance for the total additional electrical load. Smart charging management solutions are therefore a necessity to reduce the impact of the cumulative charging of electric vehicles.

The highest relative load of e-mobility will occur on the low-voltage grids because the simultaneity is much higher when a few EVs are recharging at the same time at home or at a public charging station on the low-voltage grid. For example: A typical electric car with a medium or large battery capacity has a charging power ranging from 11 kW to 22 kW.

Medium-voltage grids will benefit from the smaller probability of a simultaneous charging of many EVs, and will therefore be, relatively viewed, less loaded.

The high-voltage grid will be relatively speaking the least loaded because of the interplay of the numerous, various times of the recharges and of the power demands. The overall simultaneity will be at the lowest here.

To determine the cumulative load of the projected electric vehicles, we considered various studies which addressed this specific topic. The two most conclusive documents are listed below:

- Forschungsstelle für Energiewirtschaft (FfE) – Kurzstudie Elektromobilität:
  Modellierung für die Szenarienentwicklung des Netzentwicklungsplans (2020)
- VDE / FNN – Netzintegration Elektromobilität:
  Leitfaden für eine flächendeckende Verbreitung von E-Fahrzeugen (2019)

The FfE study, which uses the results from the data collection 'Mobility in Germany – MiD' from the infas Institute for Applied Social Sciences, incorporates the regionalisation of electric vehicles and the derivation of the charging / load profiles in detail for Germany. It actively contributed to the latest German scenario framework paper (Szenariorahmen der deutschen ÜNB's 2023 – 2037/2045), which will be used for the elaboration of the next German network development plan – electricity transmission grid – NEP 2023-2037.

Here, the calculations of the analysed vehicle fleet resulted in a cumulative peak power of 12,4 GW for 12 million vehicles, with due consideration of various load profiles and multiple charging powers. **On average, this represents about 1,03kW per electric vehicle in Germany.**

The VDE / FNN guideline stipulates a simultaneity of about 10% for a charging power of 11 kW, **which would lead to an average peak power of 1,1kW per car.**

Although those studies give good indications on the average peak power per electric car which could be used for the calculations, some adjustments may be necessary for the specific situation in Luxembourg.

Most owners of electric cars in Luxembourg will use private wallboxes with a charging power of 11 kW at home in the future. Today, there are about 11.300 battery electric cars and about 10.500 plug-in hybrid cars registered in Luxembourg, for about 11.000 private wallboxes (plus 1.600 public charging points). It is reasonable to suppose that most of the owners of battery electric cars are currently using a private wallbox with 11 kW and that most of the owners of plug-in hybrid cars are using a common single-phase socket with a power of 2,3 kW or 3,7 kW to recharge their vehicles.

In the future, more and more owners of plug-in hybrid cars will have to install private wallboxes to enable higher charging capacities because the size of the batteries of the newer plug-in hybrid cars is increasing and the charging powers of these vehicles are increasingly accordingly. Also, a good share of plug-in hybrid cars will very probably be replaced by battery electric cars.

Furthermore, the future availability of charging power will very probably be higher in Luxembourg than the assumptions made in the FfE study for Germany. This would lead to a slightly higher average charging peak power per car.

It also has to be considered that the overall simultaneity of charging events decreases with the number of vehicles. The forecasted 12 million electric vehicles in Germany will generate a lower simultaneity than 500.000 projected electric vehicles in Luxembourg.

For these reasons, a slightly higher peak power, **1,3 kW per car,** was determined and set to calculate the total peak power necessary for charging large numbers of electric vehicles in Luxembourg. → **Peak power of 1,3 kW per car on the HV grid.**

Smart charging systems which will help reduce power needs during peak times through better usage over time have been included in the forecasts below. **It has been assumed that a reduction or peak-smoothing effect of 10% to 30% will be achieved through smart charging,** with a moderate impact until 2030 and with a pronounced effect from 2030 to 2040. (Please refer to the chapter ‘Flexibility’)

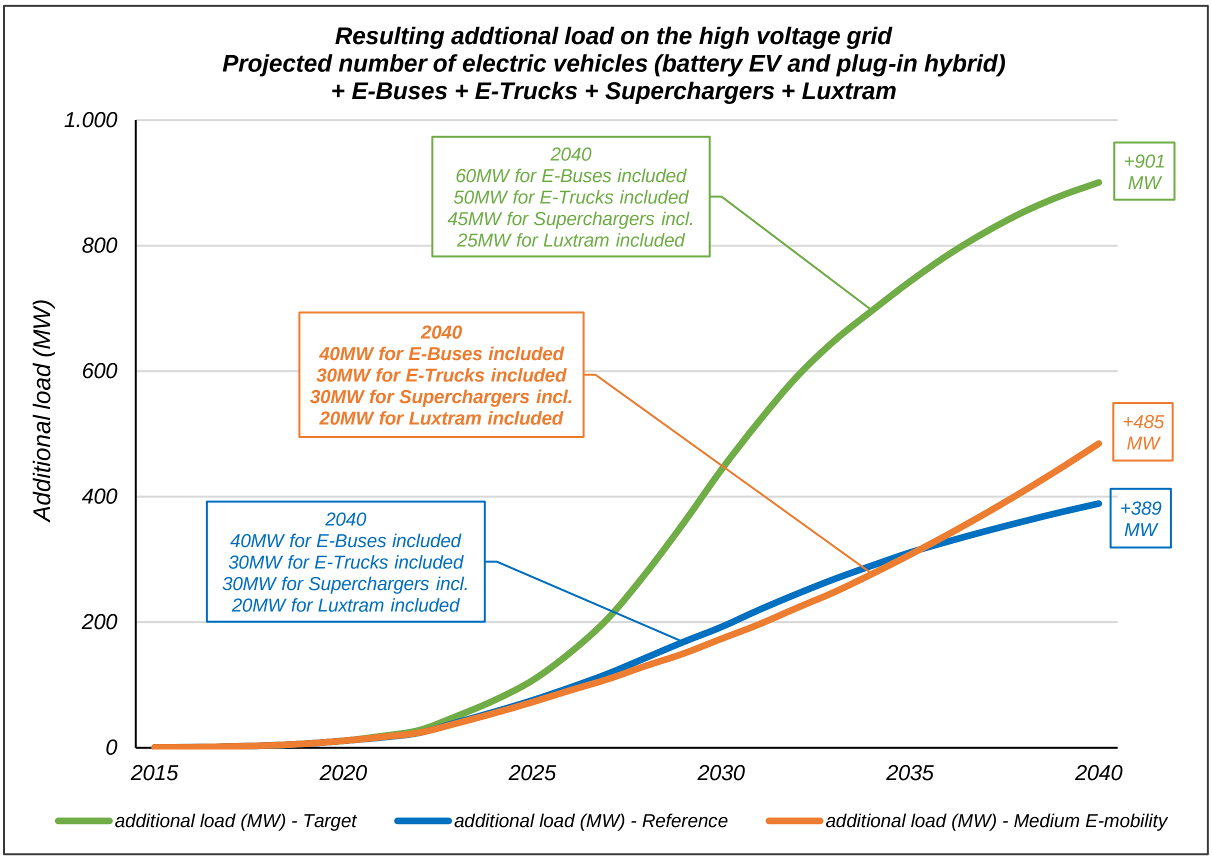
Cross-border commuters, who would like to recharge the batteries of their electric vehicles at their workplace in Luxembourg using normal AC charging poles or wallboxes, have been partly considered in the projected number of total electric vehicles.

Attractive domestic electricity costs, compared to electricity prices in neighbouring countries, will provoke a related extra load on the electrical grid, which will also have to be considered. Superchargers at service areas on motorways will produce important peak loads that cannot be shifted in time, nor can they be flattened over a certain period. This could become an issue at higher voltage levels as the simultaneous usage of those superchargers will be very high. Local energy storage might be favourable to reduce these peak loads.

Besides the projections for the power needs of future electric cars, trucks, buses and all other electric vehicles on road, the prospective load of the supercharging infrastructure has been estimated at best and has been included in the forecast below.

The forecasts also include the power needs for the tram extensions in the capital city and the planned fast tramway section.

The total additional load of future e-mobility on the high-voltage grid can be seen in this chart:



Source: Creos Luxembourg

Regarding ‘vehicle to grid’ approaches, it must be taken into consideration that e-vehicle owners may not agree with third-party use of the battery packs of their EVs for energy storage purposes. Grid operators could theoretically make use of the stored energy of the batteries of the EVs to counter brief shortages or avoid possible overloads, but the durability of the expensively acquired batteries of the e-vehicle owners would eventually suffer from the additional charging cycles. Legal aspects would also have to be considered. A bidirectional use of the storage capacities of electric vehicles for grid purposes therefore remains questionable.

More probable is a ‘vehicle to home’ solution, where the battery capacity of an EV could be used as a home storage system. Combined with an installation for electricity generation and a management / control unit, the storage capacity of the EV could help optimise the owner’s home consumption and generation profiles. This would have a grid-friendly effect and might even have more impact than smart-charging systems alone.

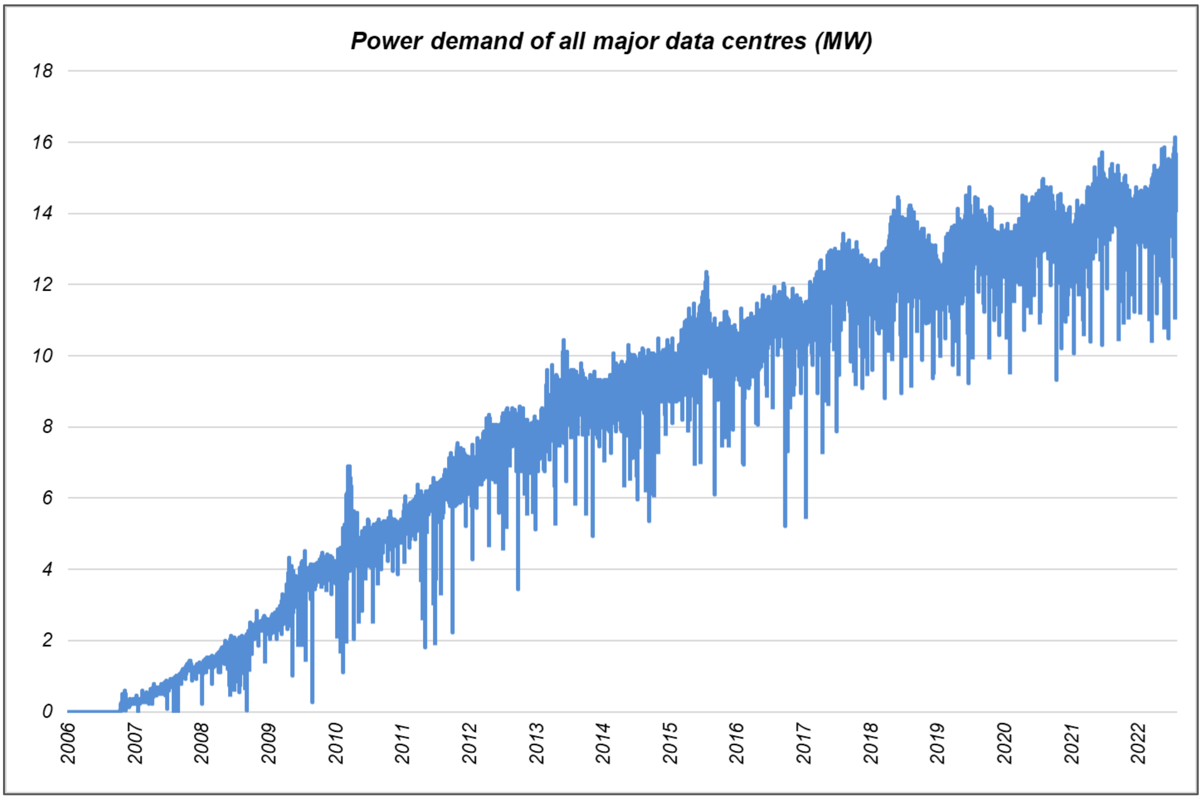
Today however, there are not many vehicles on the market which have a power inverter capable of charging and feeding back into the home installation or the grid, and it is not yet discernible that bidirectional inverters will be used in future electric vehicles as new standard by all the car manufacturers.

Data centres with high energy needs

Actual and contractually agreed power of the existing data centres

At the end of the year 2006, major data centres began to be connected on the Creos power grid. Today, there are five major data centres connected to the Creos grid, and several others are already planned. The consumption of other smaller data centres, which are integrated in administrative or commercial buildings and banks, is not considered since it cannot be clearly identified. The operators, the exact locations and the individual consumption details are not mentioned or illustrated for confidentiality reasons.

In the following chart, the increase of the power need of all the major data centres can be clearly identified:



Source: Creos Luxembourg

The five major data centres were successively put into operation from 2006 to 2012 and their power need has kept growing since the beginning of their commissioning.

The moderate actual power needs do not match the contractually agreed powers of these data centres. In our experience, the initial high power requests and the contractually agreed power demands have not been reached or used so far. However, based on contractual agreements with the operators of these data centres, the agreed connection power capacity must be guaranteed. These values must be considered for future grid planning.

In summary, existing data centres have the following power needs so far:

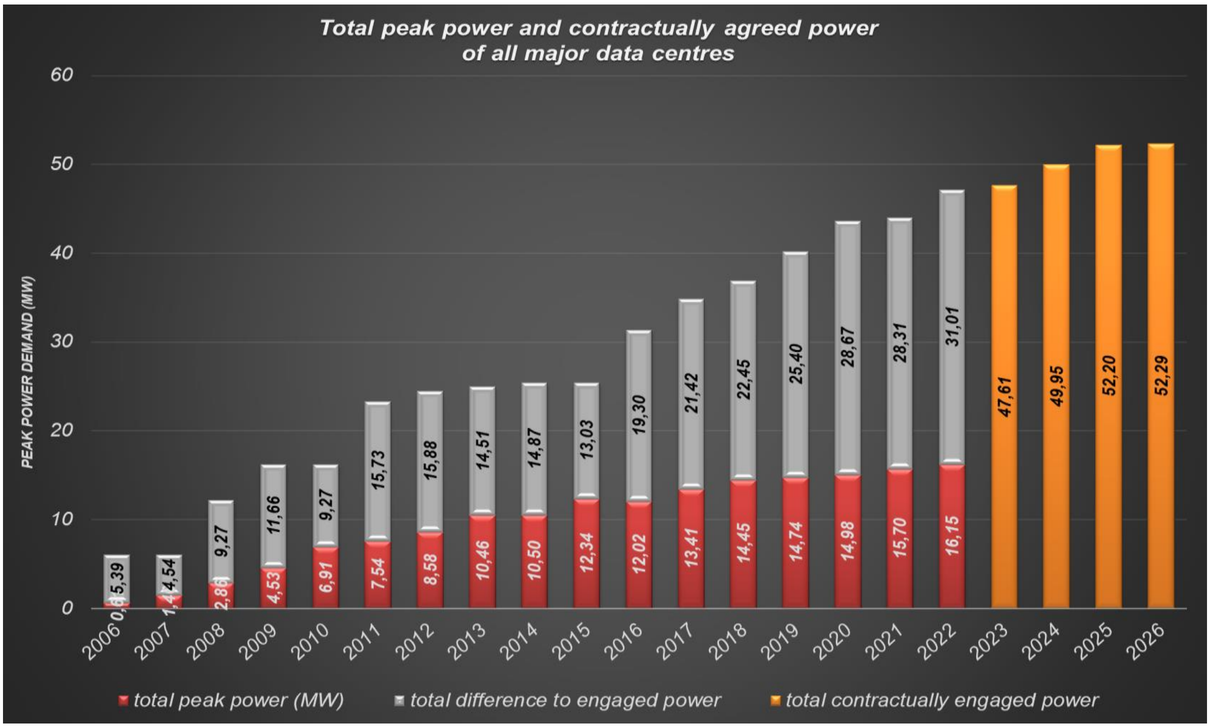
Existing data centre	In operation since	Requested power	Contractually agreed power	Peak power 2022
N°1	October 2006	10,5 MW	10,35 MW	~ 4,2 MW
N°2	March 2008	10 MW	6,48 MW	~ 3,3 MW
N°3	December 2009	21 MW	17,1 MW	~ 3,4 MW
N°4	August 2011	13,5 MW	5,22 MW	~ 3,2 MW
N°5	February 2012	21 MW	4,5 MW	~ 2,9 MW

Source: Creos Luxembourg

Once, and for quite a long period, the data centre industry measured the power needed in data centres in watts or kilowatts per square metre. Common power densities of existing data centres in Luxembourg vary between 0,8 and 2,5 kW/m^2.

Today, power densities in data centres are measured in kilowatts per rack (kW/rack) with a rising tendency, with 10 kW racks becoming the norm in today's data centre ecosystem, and even 15 and 25 kW racks in some hyperscale facilities. Expert predictions highlight that forecasted power densities of about 50 kilowatts (kW) per rack are possible by the year 2025. Although that means that energy efficiency is getting better, it could also lead to higher absolute power demands as more energy-dense racks could be installed in the same space.

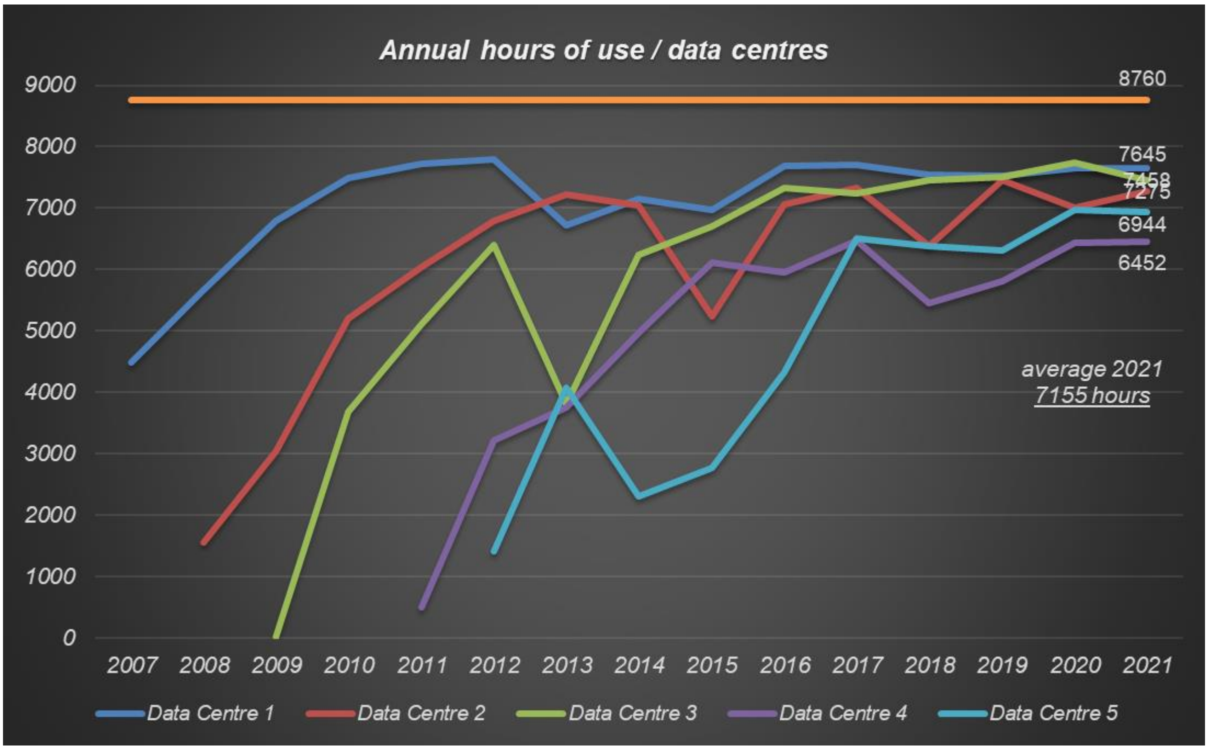
As already mentioned, Creos must be able to provide the contractually agreed powers at any time. Therefore, it must be assumed that the original high power requests could occur at a later stage, with full operational readiness and extensive use or due to upgrades and expansions of the data centre.



Source: Creos Luxembourg

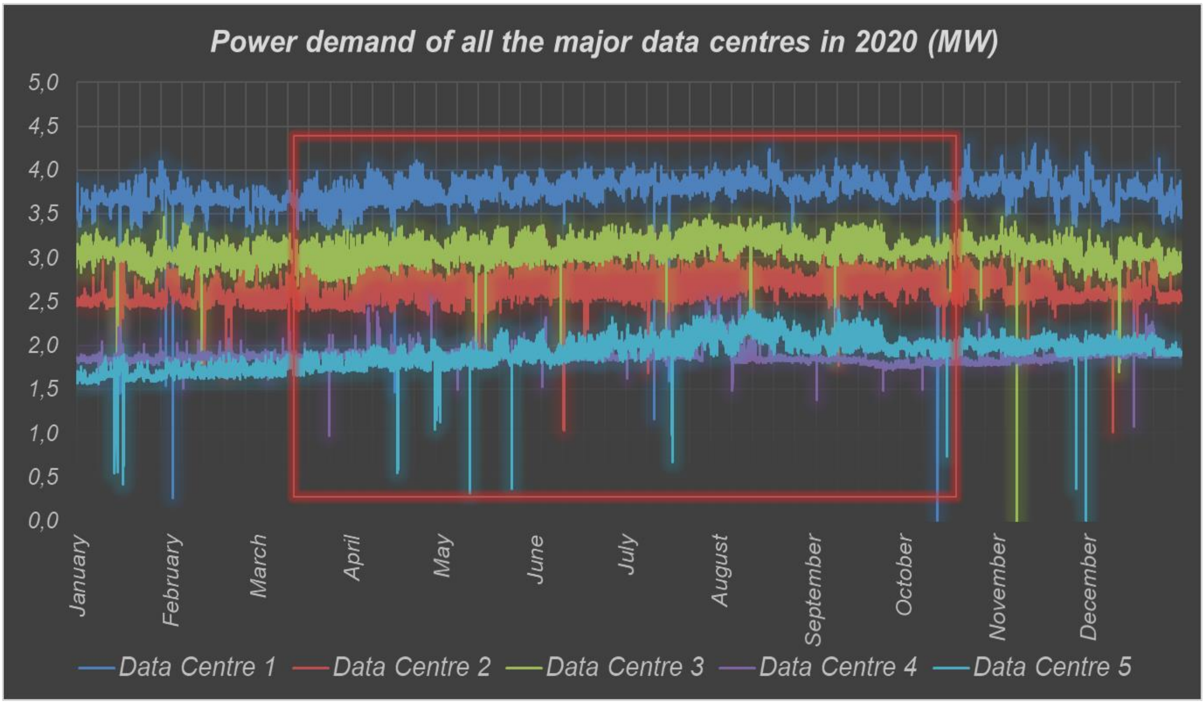
Annual hours of use of data centres

The annual hours of use of data centres are quite high compared to the yearly usage hours of the whole grid, and the trend of the annual usage hours of the data centres is opposite to the trend of the grid. That's why the peak power requirement of the data centres must be added separately to the power requirement of the country.



Source: Creos Luxembourg

COVID-19 health crisis and its impact on major data centres



Source: Creos Luxembourg

During the COVID-19 health crisis, the social lockdown greatly encouraged the intensive use of the digital communication forms and of the ability to work from home for many employees.

A closer look at the power curves of the data centres indicates the intensified utilisation of these centres and the related increase of the power demand since then.

The COVID-19 health crisis certainly resulted in long-lasting and more intensive use of existing data centres and probably influences the emergence of additional data centres in the country.

Other data centre projects

Until the end of August 2022, Creos received several connection requests or inquiries for the grid connection of additional data centres. Those projects are listed hereafter:

Data Center projects						
Voltage level	*Locality*	*Adress*	*Name of partner or project*	*power requested*	*n° project*	*Comments*
220kV	*Roost / Bissen*	*/*		*Not yet confirmed*		*datacenter awaiting final confirmation*
65kV	*Marnach*	*Marbuergerstrooss*		*4MVA short term* *24MVA long term*		*datacenter*
65kV	*Bissen ou Bettembourg*	*Z.A.C. Klengbousbierg* *Z.I. Krakelshaff*		*10MVA phase 1* *20MVA phase 2*		*datacenter*
65kV	*Bofferdange*	*164, Rte de Luxembourg*		*12MVA*		*datacenter*
20kV	*Ehlerange*	*Zare*		*2,8MVA*		*datacenter*
20kV	*Junglinster*	*Rue Jean Pierre Ries*		*3MVA*		*datacenter*
Subtotal				***32MVA short term*** ***62MVA long term***		

Source: Creos Luxembourg

A few years ago, Creos has been approached by a big company for the connection of a huge data centre with a high energy need, which was planned to be built and operated near Roost/Bissen. The project suffered from several delays and setbacks, so that its realisation is currently unsure. If the project is implemented, the first power demand of the data centre might only begin in the year 2025 and would step up linearly after that.

As the project has not yet been confirmed, the ramp-up data of that data centre has been analysed but has not been added to the scenarios of the peak power projection. It is nonetheless certain that the power demand of that project would lead to a fast depletion of the import capacity reserves.

The full operational readiness of the existing data centres and the construction of future ones have been taken into account **with a total power of 100 MW**, which includes the remaining, still unused power of existing data centres and a certain number of new facilities. As already mentioned, the power need of the data centre project in Roost/Bissen has been excluded.

New loads: Decarbonisation with electricity

Electrification of heat and processes in industry

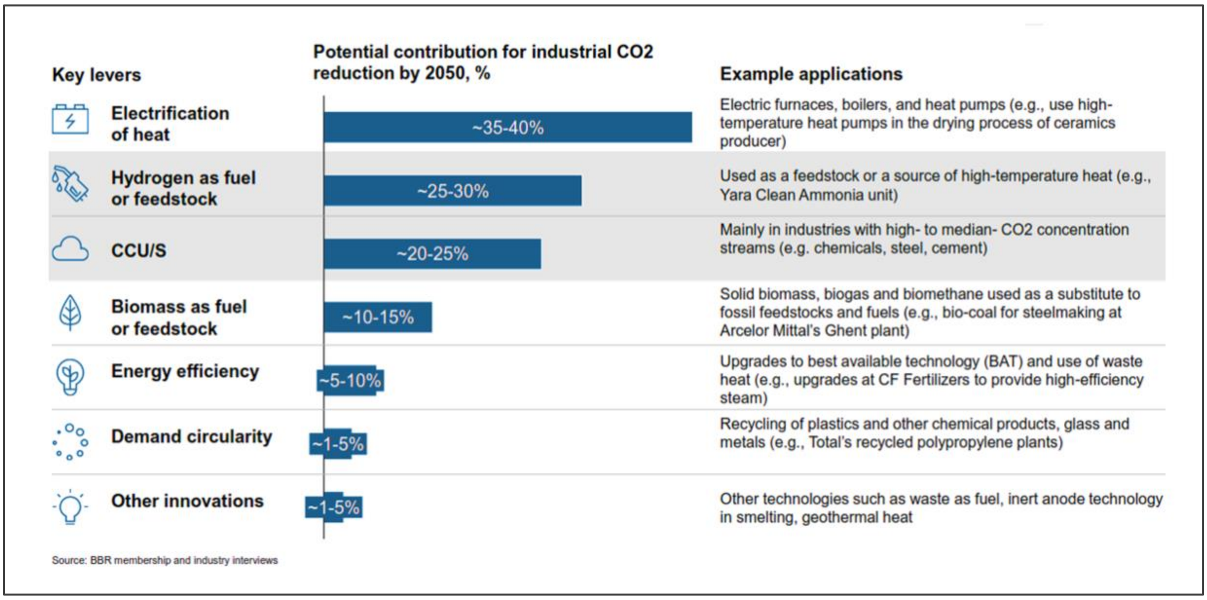
The government's ambitious target is to reduce greenhouse gas emissions at national level by 55% by 2030, compared to the year 2005. This objective includes all the emissions allocated to Luxembourg, except those covered by the EU Emissions Trading System (EU ETS) and those resulting from land use, land-use change and forestry (LULUCF).

The industry sector will have to contribute to the common target by reducing the sector's emissions and by decarbonising production processes. In fact, this sector has to reduce greenhouse gas emissions by 52%, compared to the year 2019, by 2030.

The use of electricity could play a key role in the decarbonisation strategy of industrial companies in the near future. For example, some production processes might allow a switch from natural gas to electricity for heating purposes.

Supplying heat using electricity is regarded as one of the cleanest ways to heat industrial processes, provided that the electricity comes from a renewable energy source. Electrifying furnaces, boilers and high-temperature heat pumps could reduce emissions by 35% to 40% in industrial applications.

Although the potential contribution of 'green' hydrogen in reducing carbon dioxide emissions in the industry sector by 25% to 30% seems interesting, the challenge will be to source large quantities of hydrogen made from renewable energy sources.

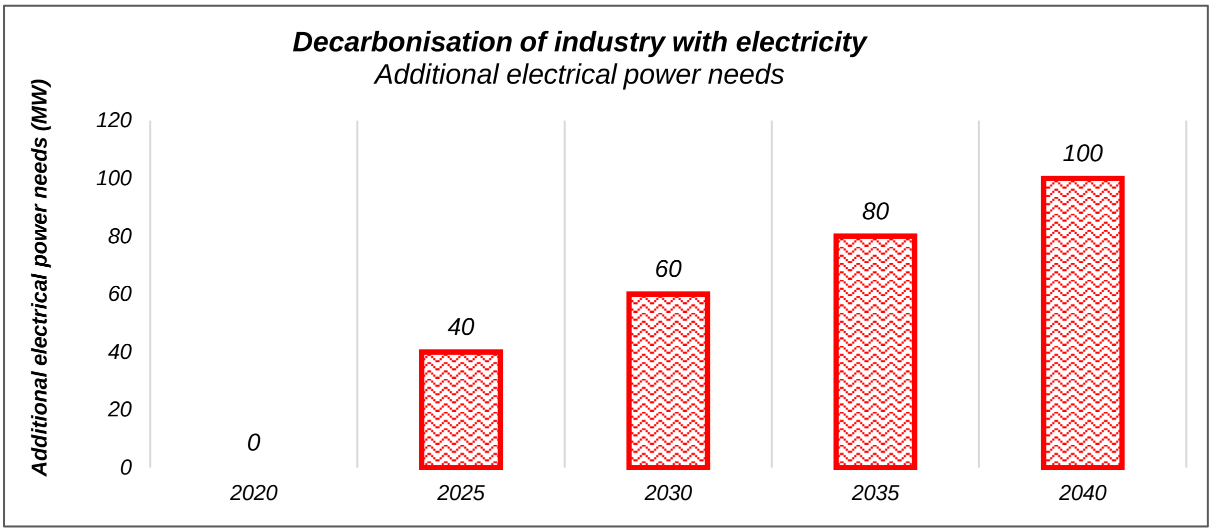


Source: Benelux Business Roundtable – BBR

A lot of companies in the industry sector in Luxembourg are small and medium sized entreprises (SME) with a national business focus, which already have a high level of electrification in their production processes. But there are also about a dozen companies in the industry sector whose operations rely on significant fossil energy consumption, primarily natural gas. It seems clear that not all industrial processes allow electrification, but the switch from natural gas to electricity of several companies with significant consumption might have a serious impact on the power grid.

Creos recently received several requests for a substantial power increase on existing grid connections in the context of the decarbonization strategies of different industries and it can be assumed that other industrial companies will follow this example.

Although a deeper assessement and survey of the future electrical needs of various industrial companies is still in progress, the following preliminary total additional power demand has been estimated:



Source: Creos Luxembourg

Electrification of heat in the residential and tertiary sector

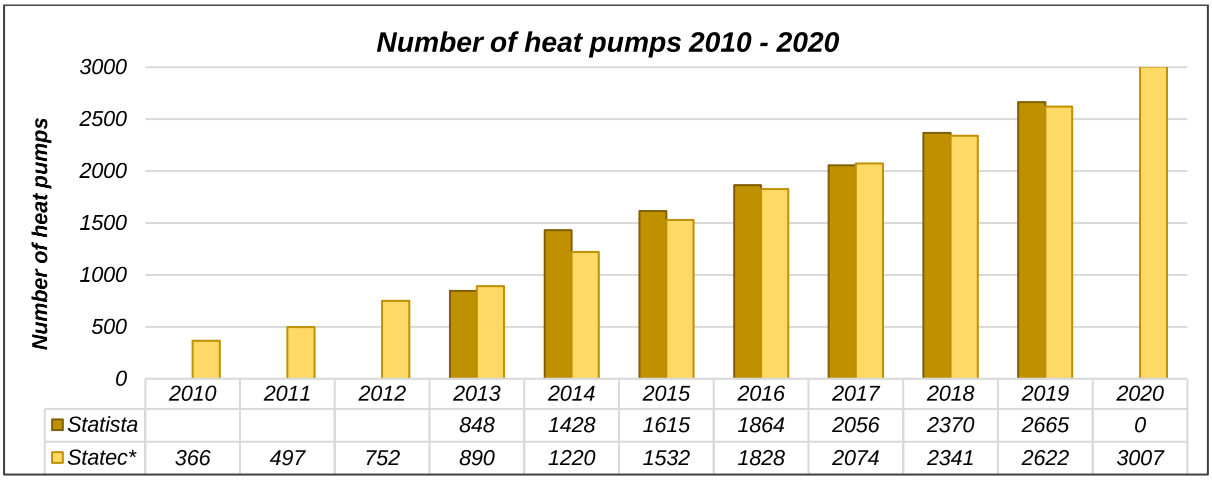
The easiest way to decarbonise the heating of residential, commercial and administrative buildings is to use less heat, through increased energy efficiency, better insulation and heat recovery systems.

Indeed, energy efficiency is considered a top priority in achieving Luxembourg's energy and climate objectives, and that is why an ambitious renovation objective for the existing housing stock has been set in the context of the National Energy and Climate Plan. This shall be achieved by combining better building insulation with the replacement of fossil heating systems. For the construction of new buildings, strict requirements have been in place since 2017 and will be extended in the short term (A + energy class).

For the replacement of existing heating systems and for new construction, heat pumps are considered the main renewable technology in the housing sector and are therefore promoted.

The impact of the switch from natural gas and heating oil to electricity for heating purposes ought to be covered by the analysis and calculations made in the context of the National Energy and Climate Plan. Nevertheless, some figures are shown below to provide an overview of the current and projected situation concerning heat pump technology.

The current installed number of heat pumps in Luxembourg can be found at www.statista.com or can be calculated with the total thermal / electrical power data available from Statec.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Statista				848	1428	1615	1864	2056	2370	2665	0
Statec*	366	497	752	890	1220	1532	1828	2074	2341	2622	3007

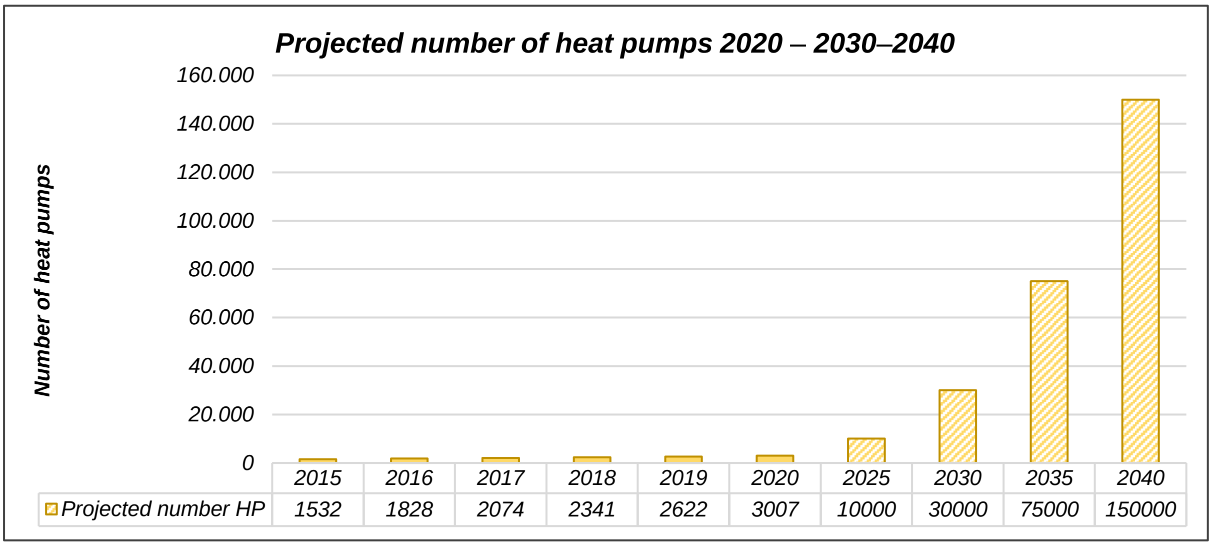
Source: www.statista.com, STATEC (calculated number of heat pumps from thermal values)*

In 2020, there were about 3.000 heat pumps installed in Luxembourg, most of which are probably installed in new buildings. It is a fact that in the European Union, heat pumps register the highest market share of all heating technologies in newly built houses.

The EU market is expanding quickly, with around 1,8 million households purchasing a heat pump in 2020 (12% average growth per year since 2015, and 7,5% growth relative to 2019, despite the pandemic). Annual growth in Luxembourg in recent years was already higher than the average growth in the European Union.

With an uptake of heat pumps in existing buildings, the number of heat pumps could rise steeply in the future.

According to Statec, about 147.000 buildings were inhabited in Luxembourg in 2020. Nearly all of those buildings in addition to newly built ones could have a heat pump by 2040.



	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040
Projected number HP	1532	1828	2074	2341	2622	3007	10000	30000	75000	150000

Source: Creos Luxembourg

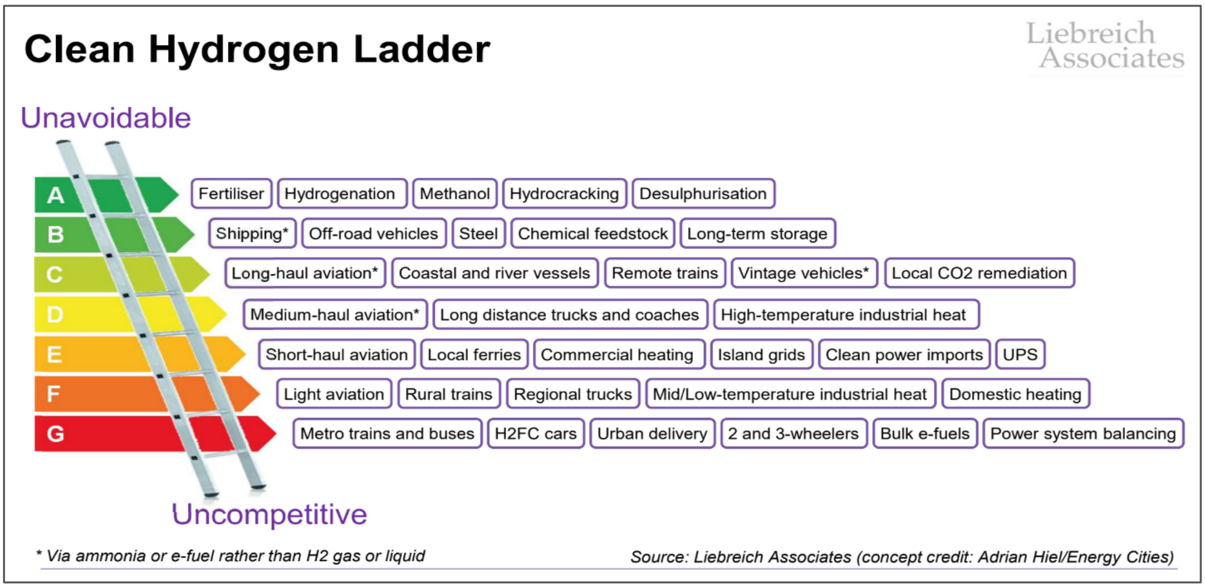
New loads: Decarbonisation with hydrogen

Green hydrogen production (H2) with electricity - Electrolysers

As described in the document 'Hydrogen Strategy of Luxembourg' of the Ministry of Energy and Spatial Planning, the government wants hydrogen to be part of the energy transition to achieve climate neutrality by 2050, especially in the mobility sector, in industry and as an energy storage vector.

However, priority is given to energy efficiency measures and direct electrification, which can be more easily applied. The total energy demand shall be reduced through energy efficiency measures, while electricity from renewable energy sources will be used to decarbonise all processes that can be electrified directly.

'Green' hydrogen, produced with renewable energy sources, is seen as a promising decarbonising alternative in sectors that are difficult to decarbonise through direct electrification, such as the steel and chemical industry. In general, the use of hydrogen should be limited to appliances for which there is no alternative.



Source: Liebreich Associates

Currently, about 450 tonnes of fossil hydrogen are consumed in Luxembourg, mainly by heavy industry, which must import this hydrogen. Luxembourg does not have a hydrogen infrastructure nor does it have any production capabilities for hydrogen at present.

The intermediate objective in the hydrogen strategy of the government is to substitute this presently used fossil hydrogen by green / renewable hydrogen first, before achieving the gradual decarbonisation of other processes that are not yet using hydrogen and that are difficult to decarbonise through electrification.

In the future, between 125.000 and 300.000 tonnes of hydrogen could be needed in the country. This demand cannot be met only locally, Luxembourg will have to import most of it, just like many countries in the European Union. Mass production of green hydrogen in Luxembourg is neither envisioned nor planned by the government, as it makes more sense to produce green hydrogen in countries like Portugal and Spain, which have abundant and economic solar generation, or in countries which have ample onshore wind generation.

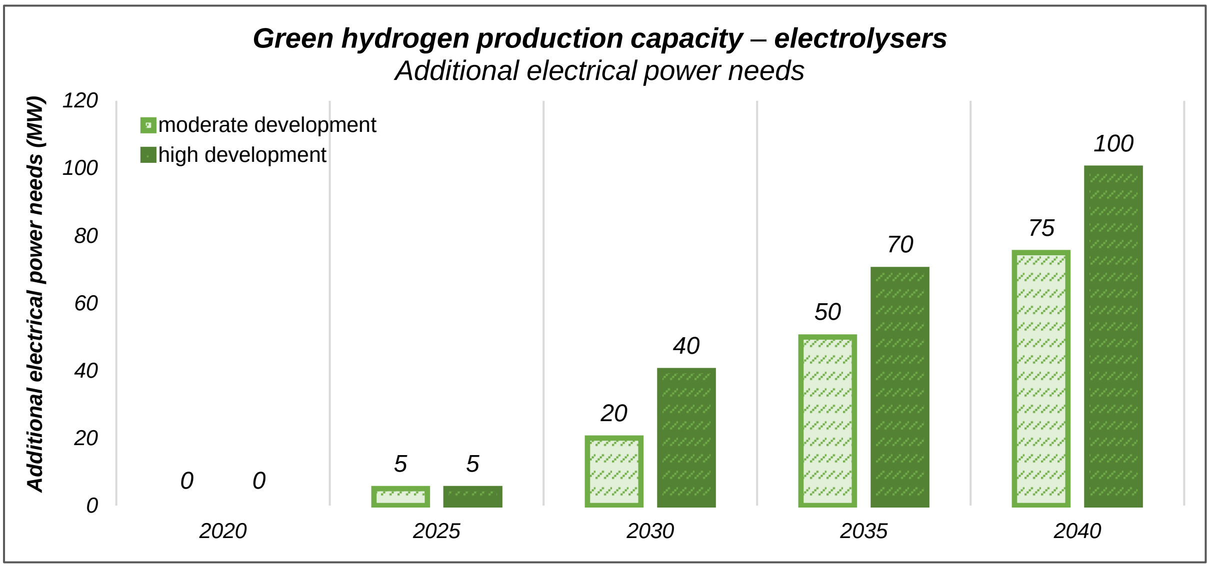
The government has the will to concentrate on cooperation with international partners at different levels and on a variety of subjects related to renewable hydrogen, in order to promote the creation of a transmission, storage and distribution infrastructure for hydrogen and thereby to facilitate the trade of renewable hydrogen on an internal market.

For this purpose, Creos Luxembourg is already assessing different options with neighbouring countries to connect Luxembourg to a cross border hydrogen infrastructure by 2030. Creos is part of the European Hydrogen Backbone (EHB), an initiative which aims to accelerate Europe's decarbonisation journey by defining the critical role of a European-wide interconnected hydrogen infrastructure.

On a smaller scale, local production of green hydrogen in Luxembourg remains possible, e.g. R&D projects or projects from private investors. In the frame of pilot projects, Creos Luxembourg already received specific requests for the connection of electrolysis facilities.

Despite the planned cross-border hydrogen infrastructure and the probable import of most of the future hydrogen demand, it seems reasonable to also expect a certain local production capacity of green hydrogen in the future.

After internal evaluation, Creos Luxembourg estimated the following additional power needed in the future to produce green hydrogen with the help of electrolysis facilities:



Source: Creos Luxembourg

For the forecast profiles, high usage over the year has been assumed for these projected electrolysis facilities.

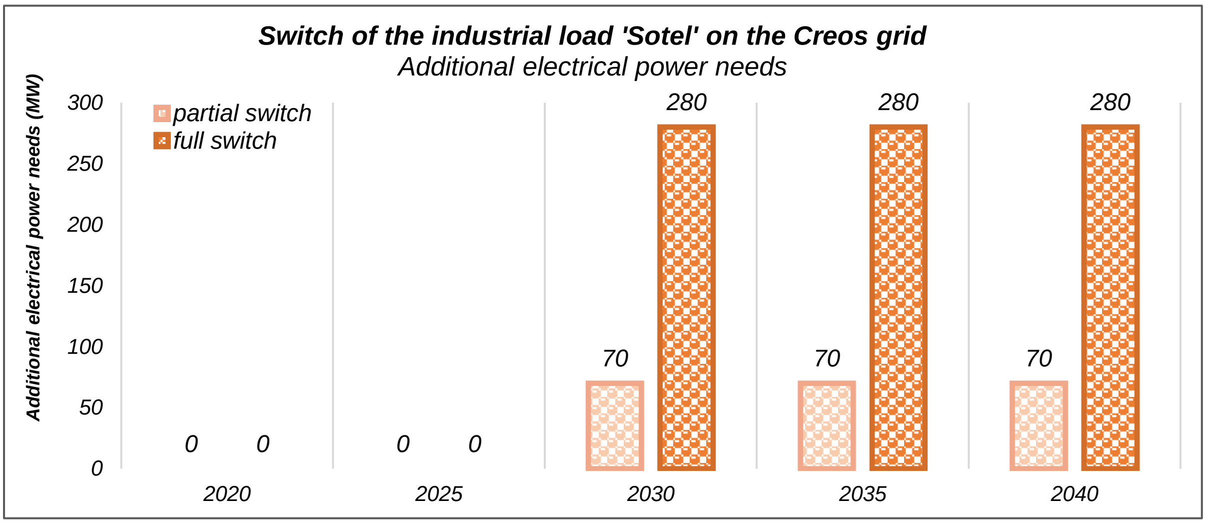
New loads: Industries connected to the Sotel grid

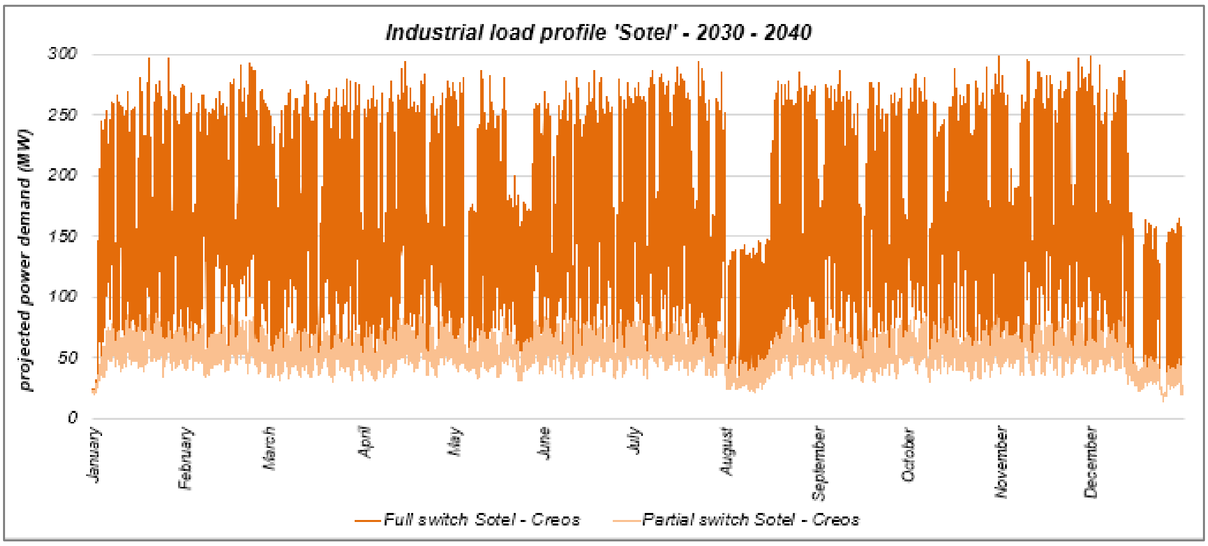
Currently there are several industries in the south of Luxembourg, composed of mainly the heavy steel industry and its facilities, which are not connected to the Creos grid but are connected to a separate industrial grid.

This industrial grid is maintained and operated by Sotel Réseau & Cie and supplied by the company Sotel SC (Société de Transport d'Energie Electrique du Grand-Duché de Luxembourg). The electrical energy supply of these industries is currently ensured by the Belgian and French markets.

In the past, electricity prices were often lower on the German / Luxembourgish market and might be more attractive than on the Belgian and French markets in the future. But, due to the remaining grid capacities on the existing Creos grid, a switch of the entire industrial load 'Sotel' on the Creos grid is presently not possible. Grid capacity reinforcement measures towards Germany are a precondition to fully switch Sotel grid customers to the Creos grid, so that a switchover can only be expected from 2027 to 2030 on.

Considering the total additional load of those industries is of importance for any major grid extension project, as it would allow these industries to be switched away from the Belgian and French markets to the German / Luxembourgish market.





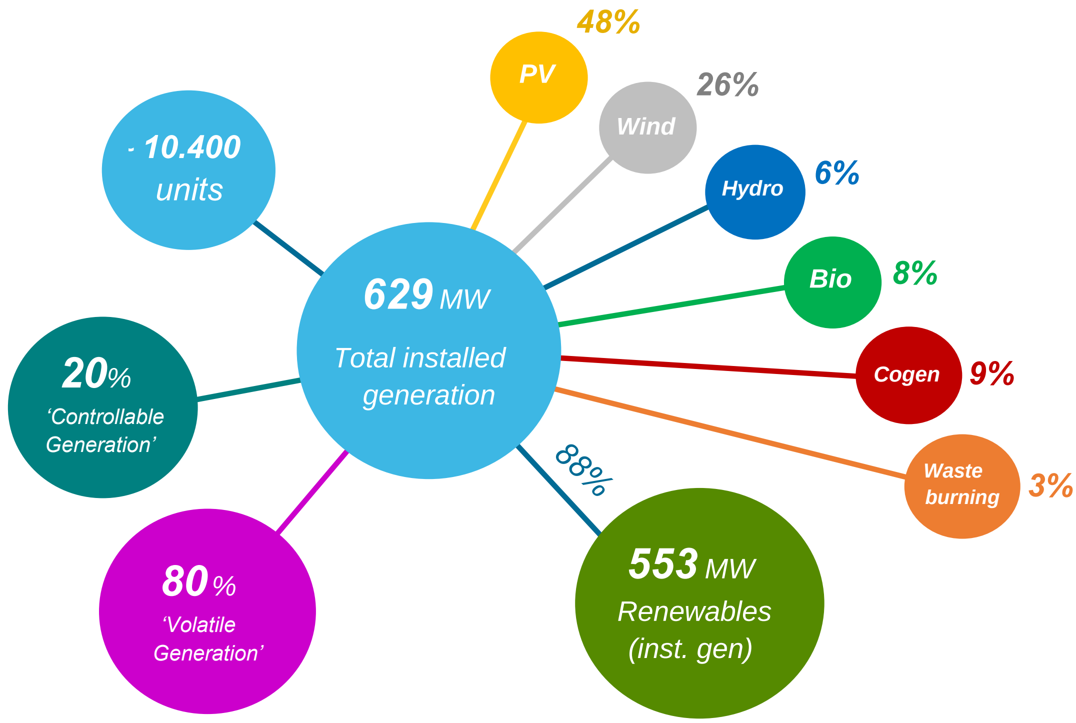
Source: Creos Luxembourg

Electrical energy generation and renewable energies

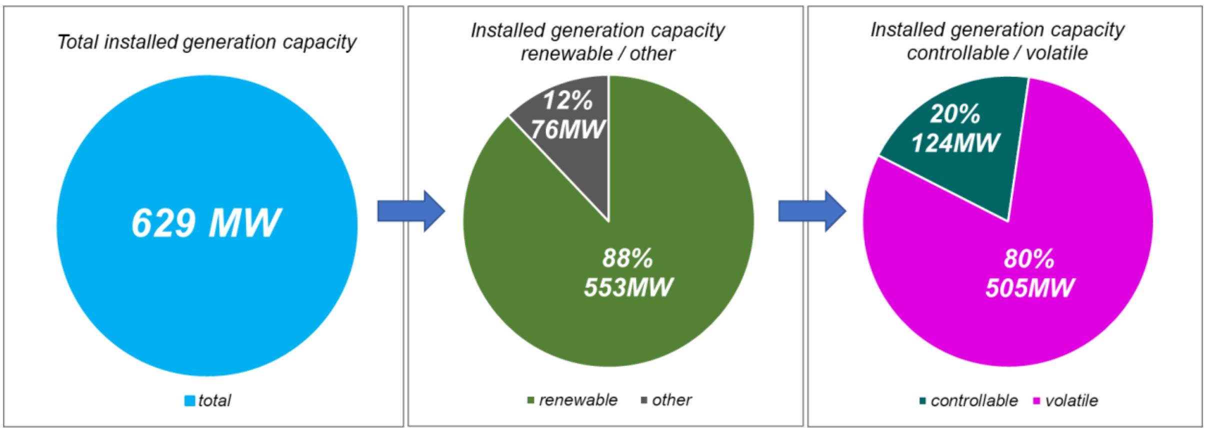
Currently installed electricity generation capacity

On 31st of December 2022, the total installed generation capacity on the Creos grid was about 629 MW. This does not include the generation capacities connected to the subordinated grids of other operators. However, the impact of these few units on the Creos grid is comparatively low and has been indirectly considered through the net power demand of these operators.

Most of the installed generation capacity can be attributed to solar power systems and to wind turbines. Indeed, the installed power of all the units using renewable energy sources already represents 86% of the total installed generation.

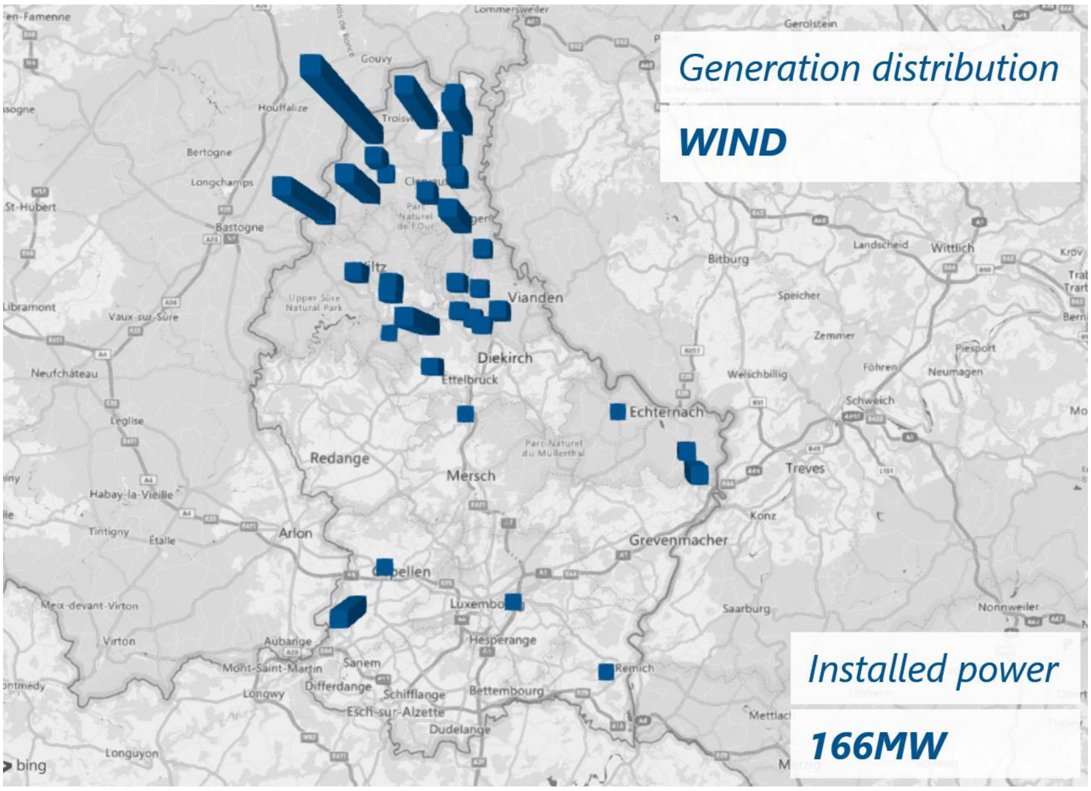


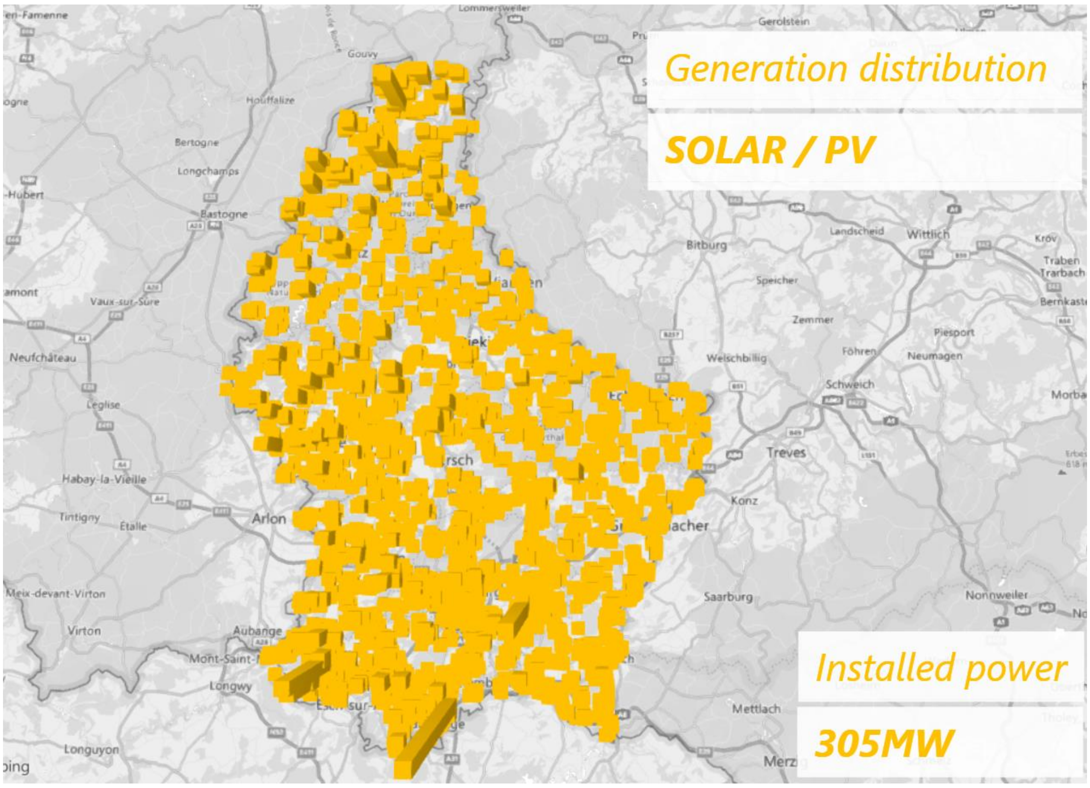
A further distinction should be made between controllable generation (combined heat and power plants, waste burning, biomass and biogas plants), and 'volatile', uncontrollable generation (solar, wind and hydroelectric power generation).



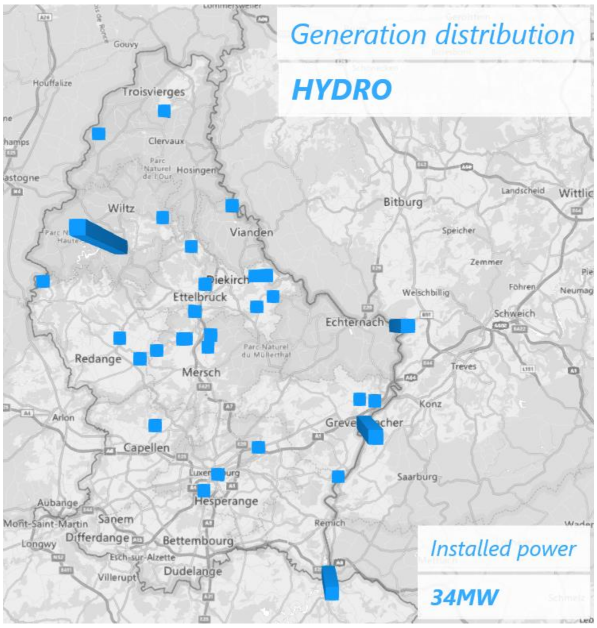
Source: Creos Luxembourg (on 31 December 2022)

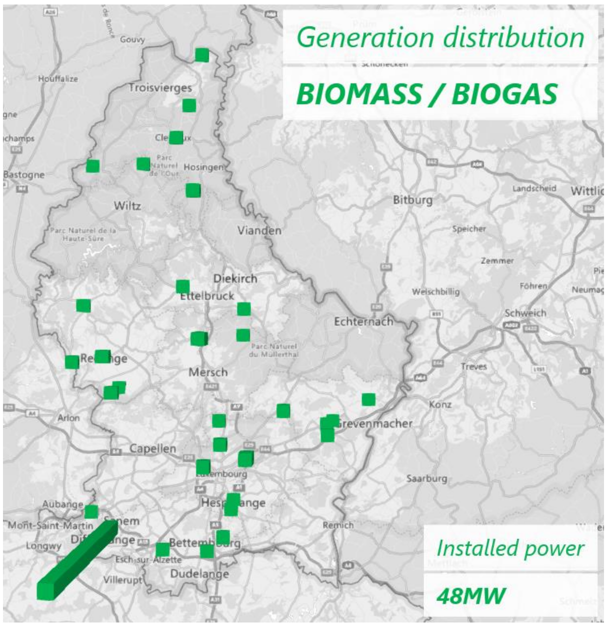
The regional distribution maps of the different forms of electricity generation might be of interest. Most of the wind turbines and wind farms are currently located in the north of Luxembourg, whereas the solar installations are distributed over the whole country. However, the biggest cumulative installed powers of photovoltaic installations are located in the north, east and west of Luxembourg.



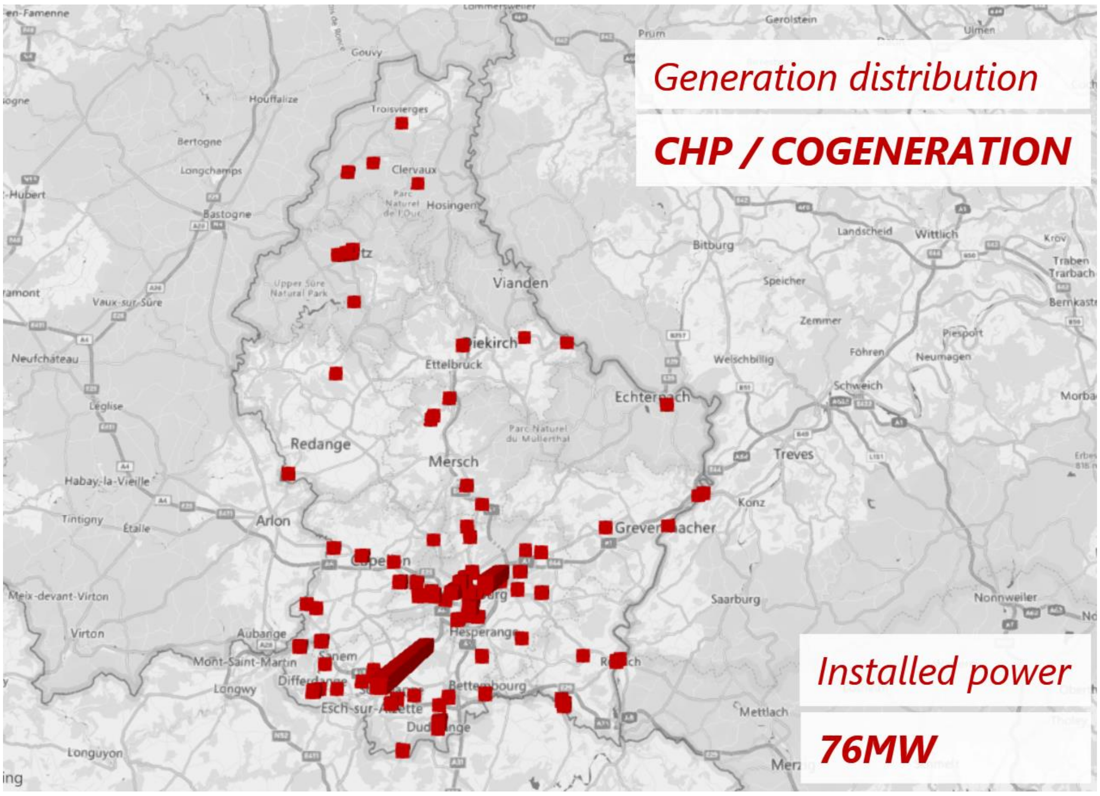


The largest hydroelectric plants are obviously located by the major rivers or by the water reservoir of Esch/Sûre. The biggest biomass power plants are located near Sanem in the south-west of the country and in the capital city, while the rest of the biomass or biogas units are broadly distributed around the country.





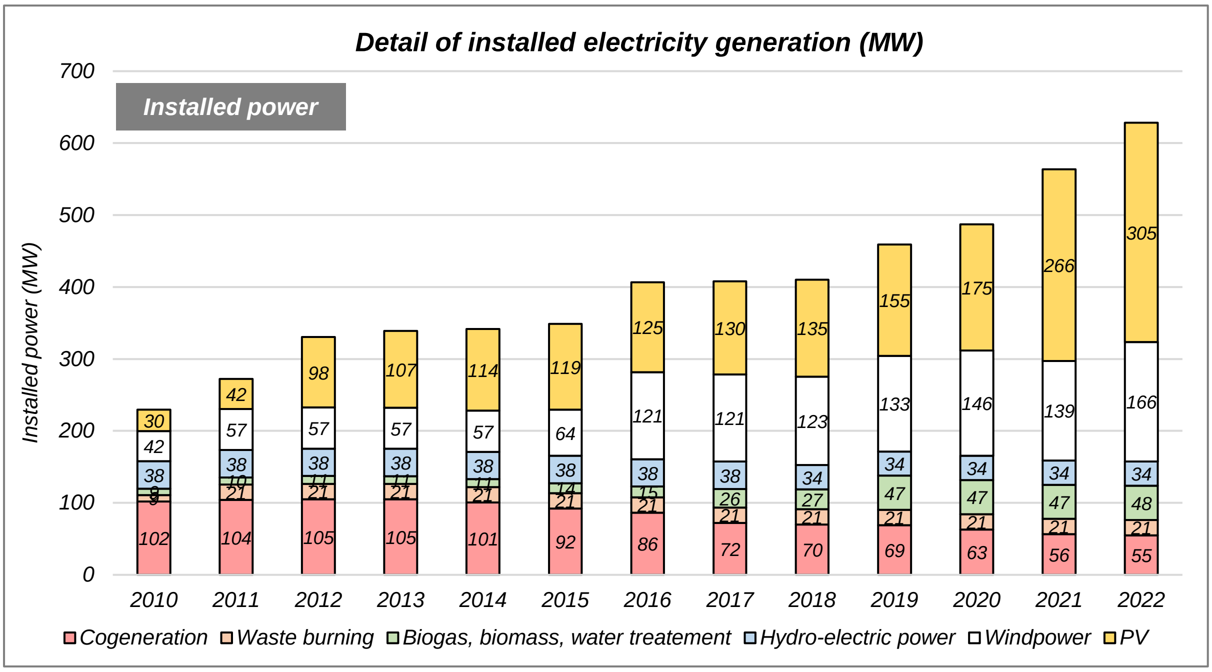
Presently, most of the combined heat and power generation units are located in or around the capital city or in the south of Luxembourg. It should be noted that the waste burning plant of Sidor in Leudelange has been added to the cogeneration units here, explaining the peak at this location.



Source: Creos Luxembourg (on 31 December 2022)

Past evolution of the installed electricity generation capacity

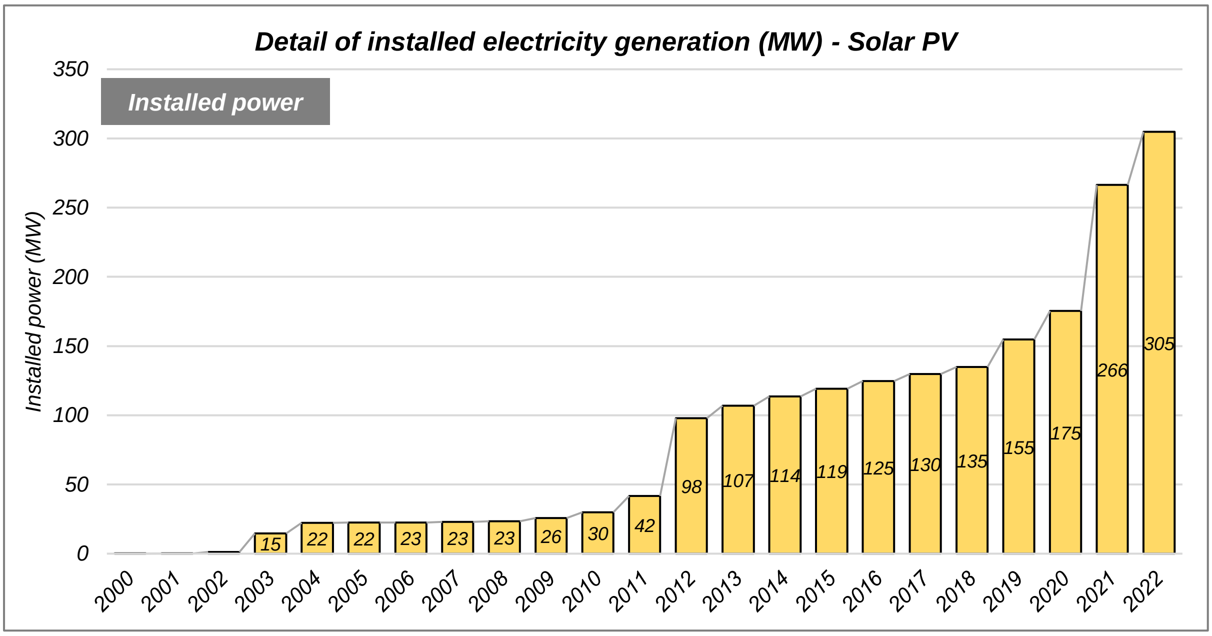
The total installed power of all the electricity generation units on the Creos grid has risen from 229 MW in 2010 to 629 MW on 31 December 2022, with the following segmentation throughout the years:



Source: Creos Luxembourg (on 31 December 2022)

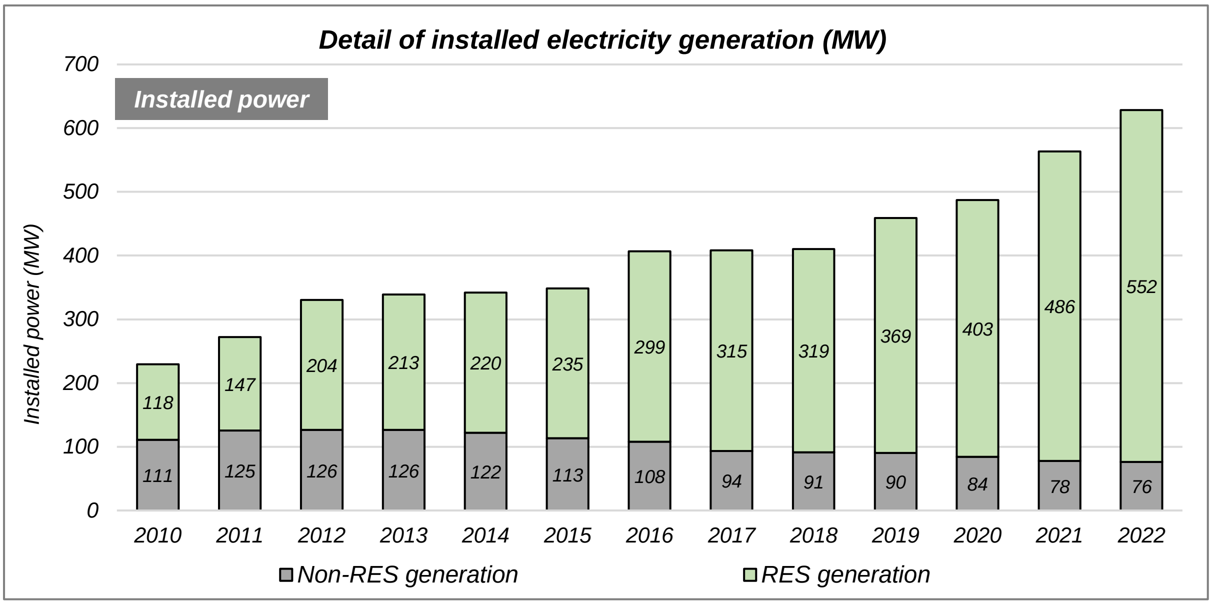
This impressive increase of the total generation capacity has solely come from additional solar PV installations, wind turbines and biomass / biogas power plants.

Indeed, the evolution of solar / photovoltaic installations shows steep increases in 2012 and 2022. Photovoltaic installations increased from just a few units in the year 2000 to a total of 10.237 units on 31 December 2022 with a combined installed power of 305 MW.



Source: Creos Luxembourg (on 31 December 2022)

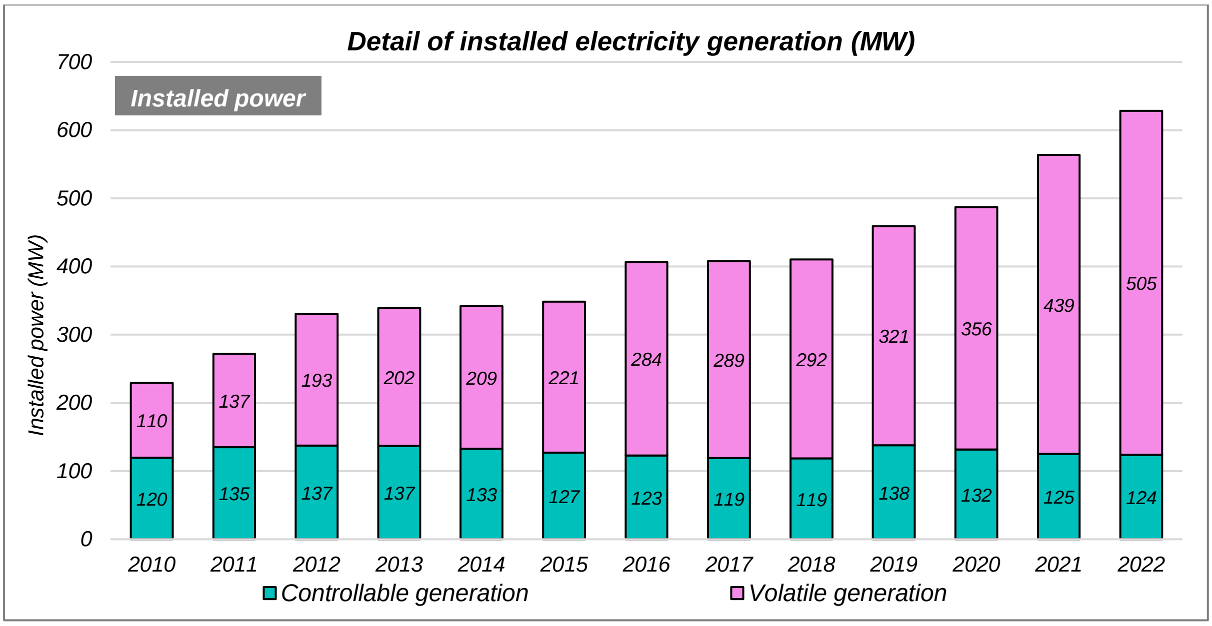
More biomass and biogas plants have also been installed and the largest growth in this share came from the addition of a big biomass plant near Sanem. The installed capacity of hydroelectric generation has been nearly constant in the recent past, with only a few installations which have been shut down. The total capacity of the combined heat and electricity generation is noticeably declining with a steady decommissioning of these units. Cogeneration units using fossil fuels as the primary energy source will certainly disappear in the next few years.



Source: Creos Luxembourg

Due to all these developments, it is evident that the share of installed electricity generation based on renewable energy sources went from 52% in 2010 to 88% at present.

It should be noted that the share of uncontrollable, 'volatile' generation has steadily increased over the past, rising from 48% in 2010 to 80% in 2022, and will certainly further increase in the future.



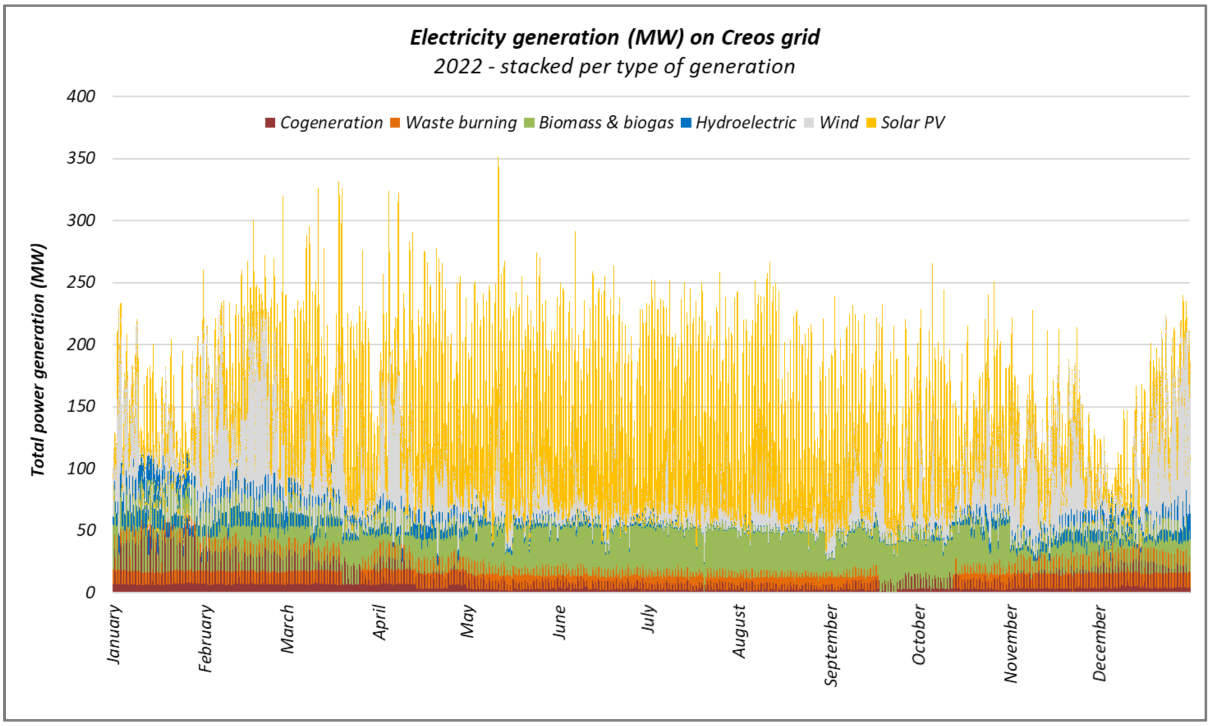
Source: Creos Luxembourg

This development could be problematic for the electricity grids because the fluctuation of the power generated by these units can be very high.

Current effective electricity generation

The chart below shows the effective electrical power generation during the year 2022, stacked by type of generation.

The controllable generation is at the bottom of the chart, starting with CHP / cogeneration, then generation due to waste burning and biomass and biogas generation. On top of these follow the volatile generation types like hydroelectric, wind and solar PV generation.



Source: Creos Luxembourg

Generation from combined heat and power plants decreases during the summer months because there is less need for heat.

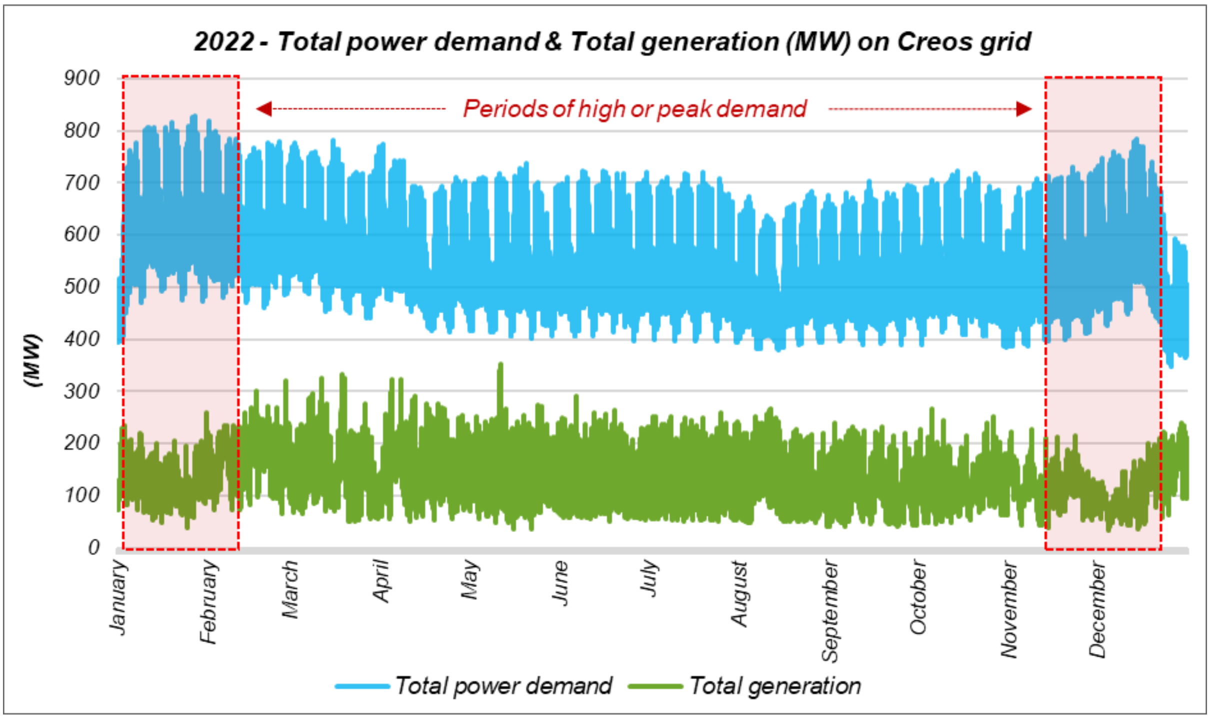
Generation from biomass and biogas plants is fairly constant over the seasons with only occasional dips.

Hydroelectric power decreases in the summer months, especially if the season is dry or if there is a drought.

Wind generation can be high during the winter months and during spring. But power generation from wind can also be very low, occasionally during the winter months and regularly during the summer months.

The power generated from solar PV installations naturally increases with the solar radiation during spring / summer and is less during the winter months. During the spring and summer months, solar PV generation reaches its maximum on sunny days.

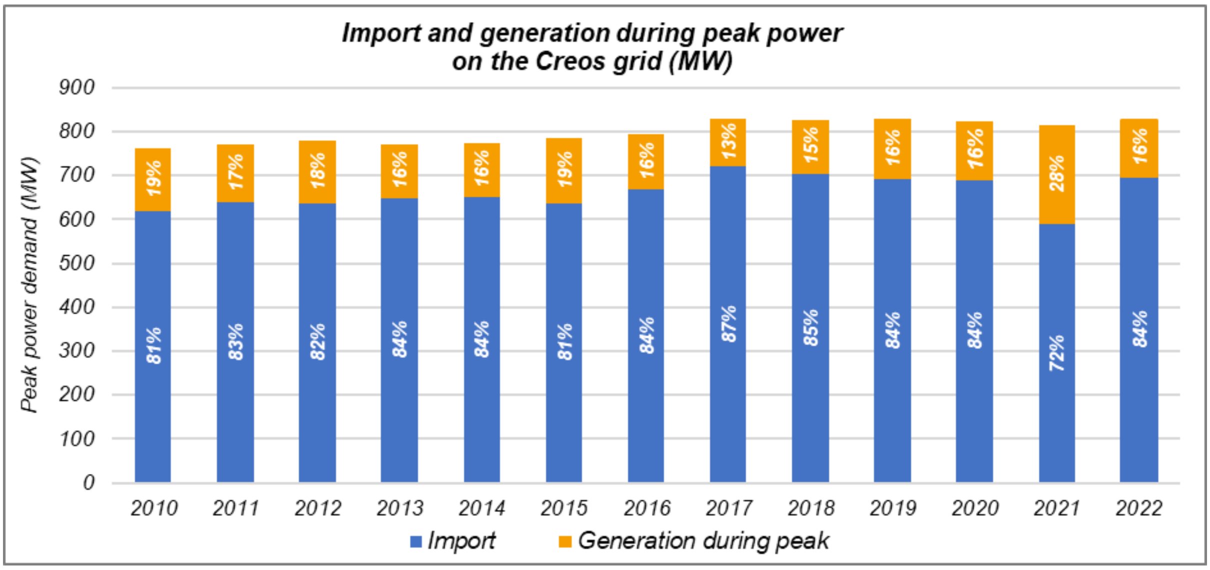
Overall, the highest power generation happens during the spring months and not during the winter months when high or peak demands occur.



Source: Creos Luxembourg

The relative contribution of domestic generation during peak power demand has not really grown over the last decade despite the increase of the installed generation capacity.

From 2010 to 2020, the contribution of generation during peak power demand varied between 13% and 19%. 81% to 87% of the power needs during these peak times had to be imported.

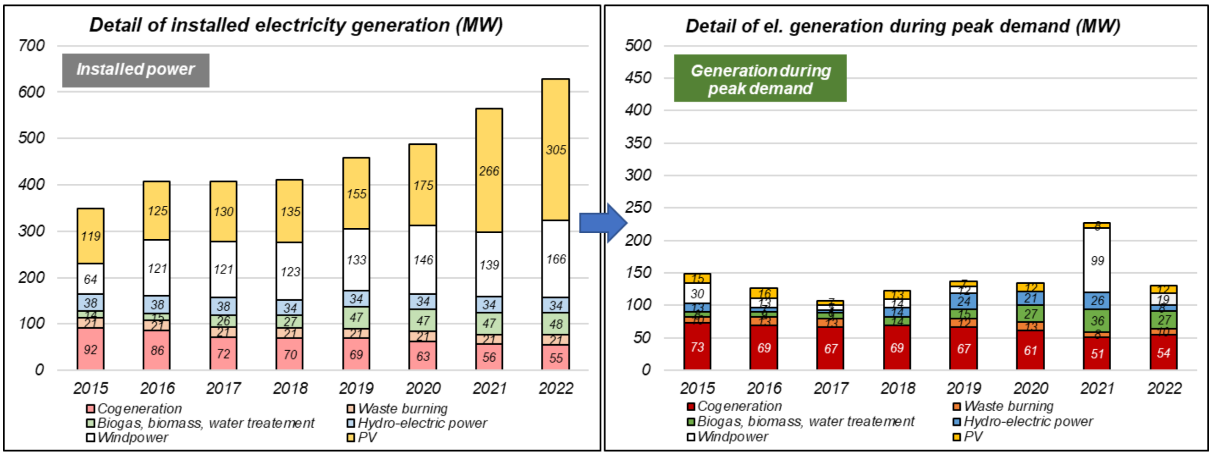


Source: Creos Luxembourg

In 2021, the contribution of generation during peak demand was extraordinarily high, with 28%. But during the peak day in early 2022, it was again only 16% of the peak power demand.

Luxembourg has made huge efforts and remarkable progress to increase national electricity generation, but the power contribution of these generation units during peak demand is still modest. The evolution of the annual electricity volume generated by national assets is very meaningful for reducing national energy dependencies, but of secondary importance for the dimensioning of the electrical grid.

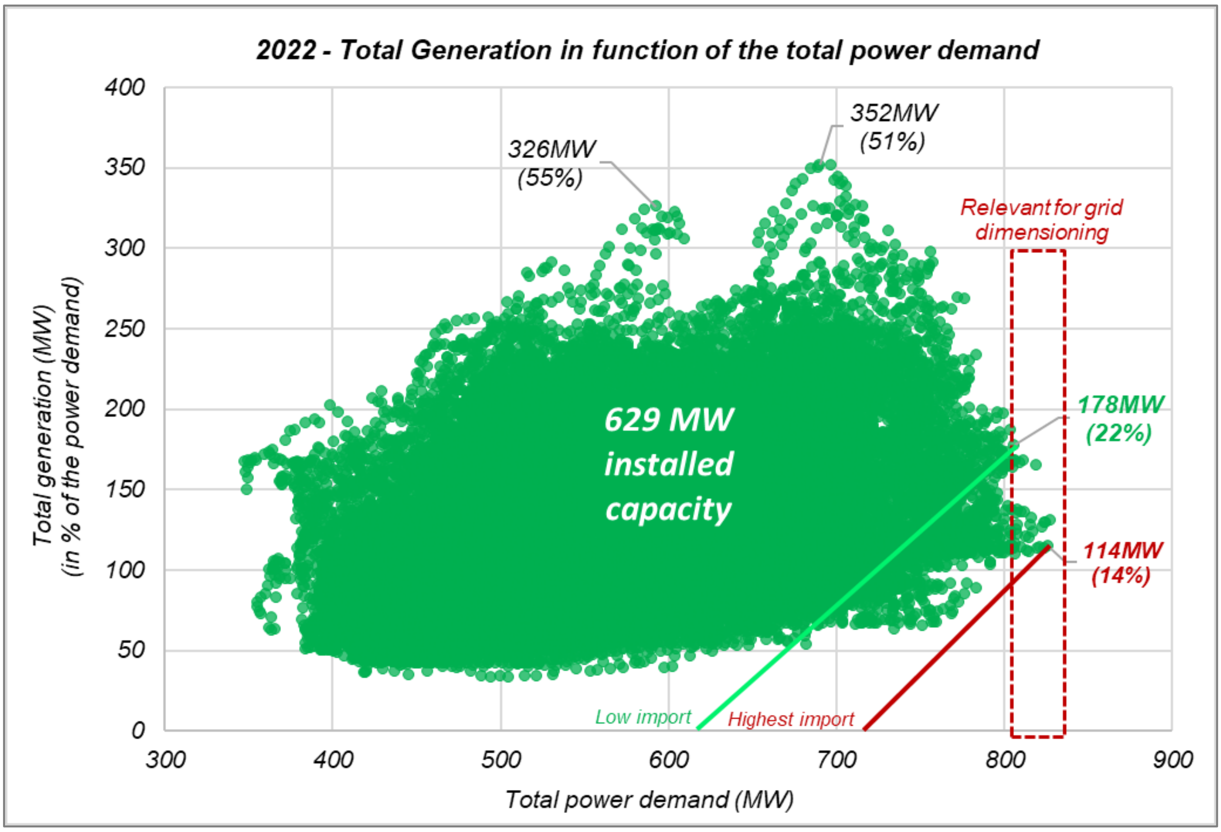
During the moment of peak demand on the Creos grid, only a certain amount of power is generated by all domestic generation assets. At that moment, on the day of the highest electrical power demand, there is usually no direct sunlight, low solar radiation and no or only light wind.



Source: Creos Luxembourg

The chart below shows total domestic power generation for each ¼ hour as a function of peak power demand for the year 2022. The highest absolute power generated in total was 352 MW, but at a time where demand was only about 689MW. The highest relative generated power even rose to 55% (326 MW) but when power demand was not high.

During peak demand in 2022, only 131 MW (16% of the power demand) contributed to the reduction of the import. At another time of high demand, more power was generated, 178 MW (22% of the demand), which shows the fluctuation of generation during high demands.



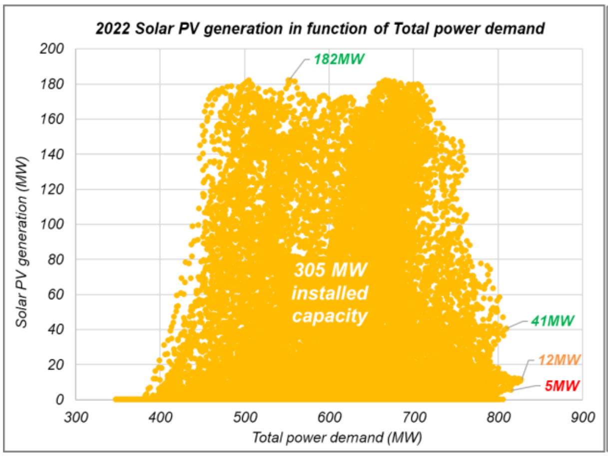
Source: Creos Luxembourg

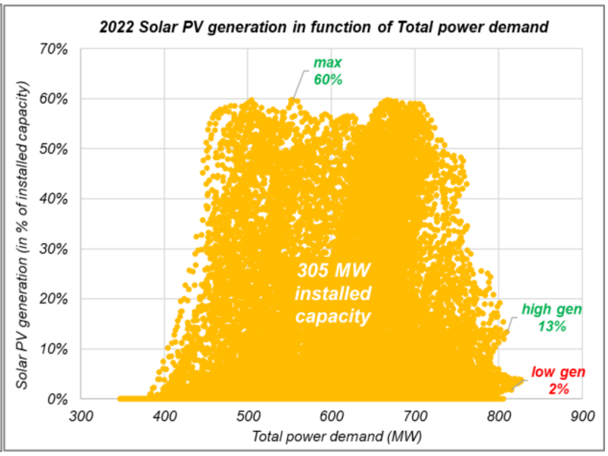
Three insights can be identified from the chart:

- Peak generation does not occur at the moment of the highest demand
- During very high demand there are two possible generation ranges, a group of high generation cases and a range of low generation cases
- The effective highest generation is substantially lower than the total installed power, as the different generation types are not generating at the same time with their maximum power. Only a certain percentage of the total installed capacity is reached

For the further procedure of establishing forecasts for electricity generation, it is meaningful to calculate the percentage of power that is actually generated compared to the respective installed capacities and at what power demands this generation occurs.

Solar / PV 2022:

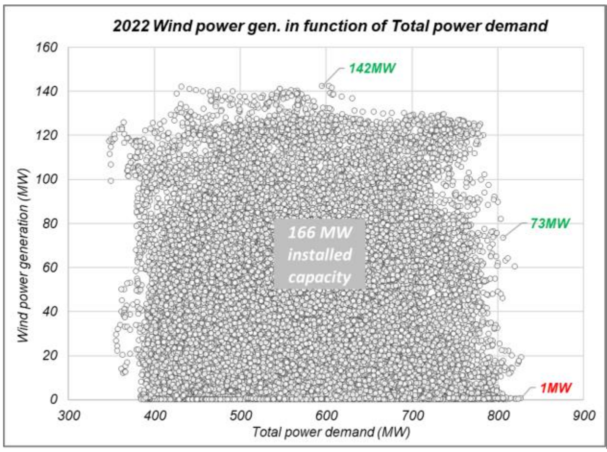


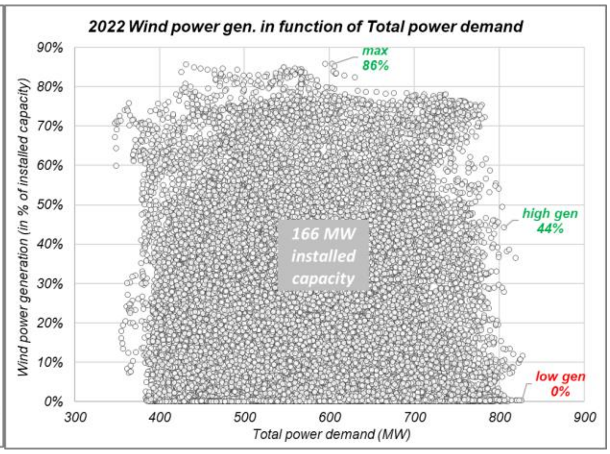


Source: Creos Luxembourg

It is apparent that during periods of high power demand, especially in the winter months, only a small percentage of PV generation contributed to the reduction of the import. In the appropriate consideration window, it is clear that only a maximum of 13% of the installed PV capacity generated power during the periods of high consumption in 2022. It should also be noted that only 60% of the total installed capacity was effectively generated at a maximum during spring and summer. This is partly due to the various orientations of the individual installations, but also because the installed capacity value was a snapshot from the end of the year, whereas the actual installations and the measurements were made during the course of the year.

Wind power 2022:



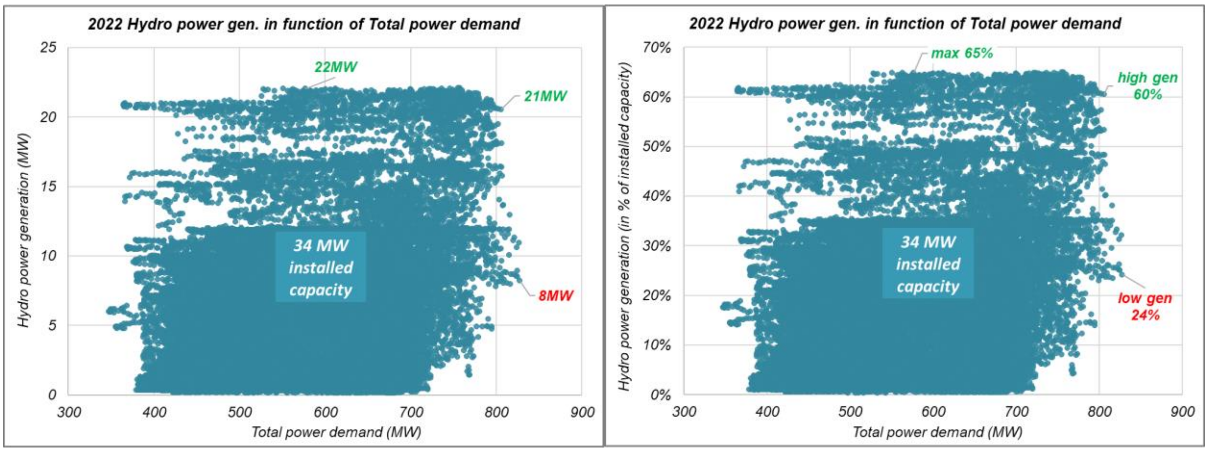


Source: Creos Luxembourg

The maximum delivered power of all the wind turbines did not exceed 86% of their installed capacity. This is also due to the fact that the value of the installed capacity (166 MW) reflects the status on 31 December 2022, but the measurements were made throughout the year while there was some work done on the wind turbines (Repowering/Commissioning during the year).

However, during peak demand, wind power generation varied widely between 0% and 44% of its installed capacity.

Hydroelectric power 2022:

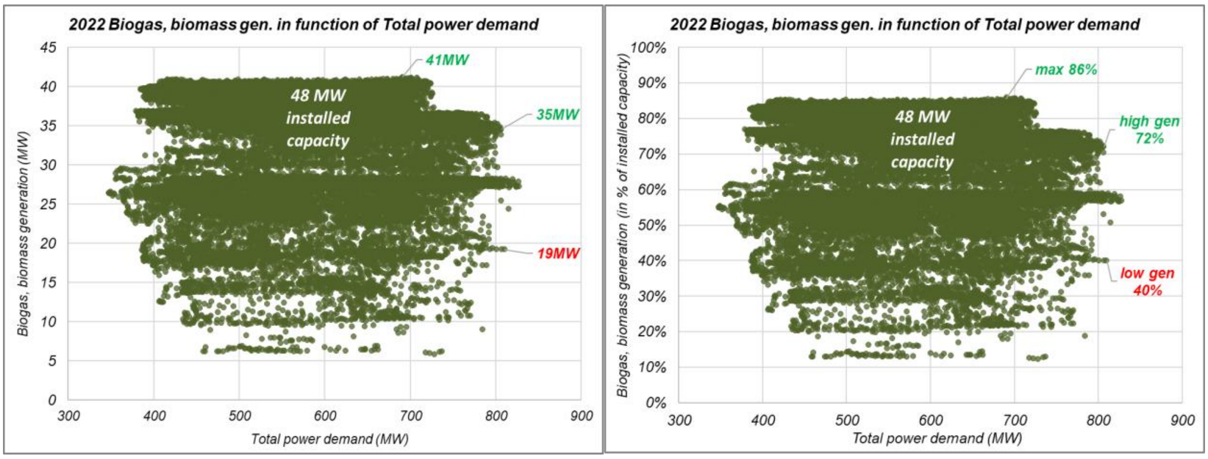


Source: Creos Luxembourg

The hydroelectric power plants in Luxembourg are mostly run-of-river hydroelectric power plants and the reservoir power plant in Esch/Sûre. The power generation of these plants depends of the seasonal water supply, which cannot be influenced.

During times of high demand for consumption needs in 2022, the hydroelectric power varied from 24% to 60% of the installed capacity. The pumped-storage power plant of Vianden is connected to the German high-voltage grid and supports the energy supply of Luxembourg only indirectly. Therefore it cannot be considered in this study.

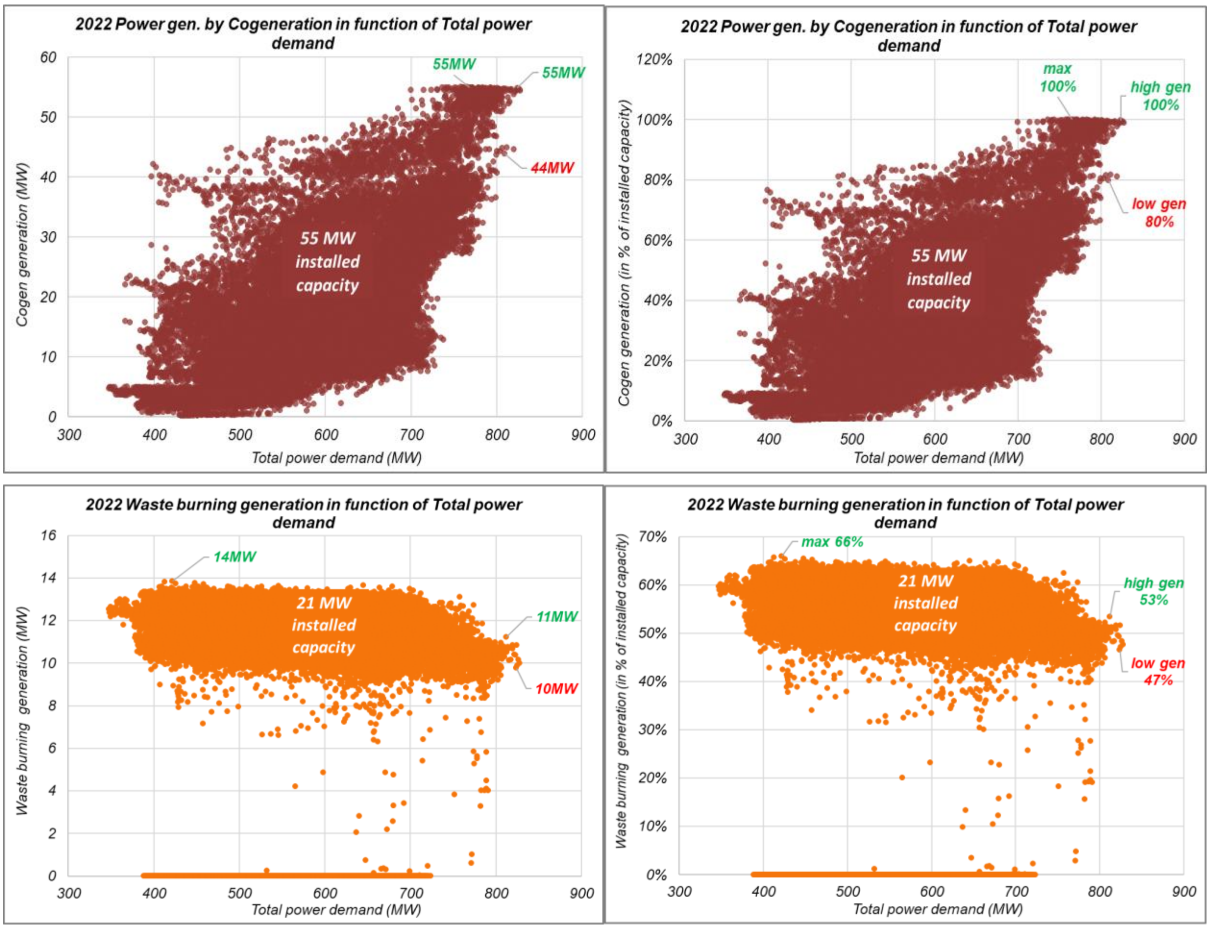
Biogas and biomass power generation 2022:



Source: Creos Luxembourg

Provided that their primary energy requirement is covered, the biomass and biogas power plants can be seen as controllable generation. Their contribution during peak demand times is higher and reliable, and was between 40% and 72% of the installed capacity in 2022.

Power generated by cogeneration systems *and* ***by the waste burning power plant 2022:***



Source: Creos Luxembourg

The combined heat and electricity generation units are controllable, and these units benefit from special incentives in order to activate them during times of peak consumption, which explains the very high availability range of 80% and 100% during these times. The waste burning plant was slightly less available when consumption needs were high, between 47% and 53% of the installed capacity was injected during these times in 2022.

To confirm the prior statements and figures from 2022, all the 15 min measurements from 2015 to 2022 have been charted and analysed, and the summary of the analysis is listed in the spreadsheet on the next page.

For the different years, high generation and low generation cases have been determined for a whole range of high demand values. For every year, high generation and low generation points situated in the highest power demand field of about 3% have been identified. For example, for the year 2022, this field has been selected between a power demand of about 804 MW and peak power of 828 MW.

The summary of the analysis of the power generation during high demand is listed here:

Solar / PV	2015	2016	2017	2018	2019	2020	2021	2022	Average
Installed gen. capacity	119 MW	125 MW	130 MW	135 MW	155 MW	167 MW	266 MW	305 MW	/
High generation*	14%	13%	19%	10%	5%	12%	8%	13%	**12%**
Low generation*	1%	2%	0%	0%	1%	3%	1%	2%	**1%**
Wind power	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
Installed gen. capacity	64 MW	121 MW	121 MW	123 MW	133 MW	147 MW	139 MW	166 MW	/
High generation*	71%	55%	48%	60%	45%	78%	100%	44%	**63%**
Low generation*	1%	0%	0%	9%	1%	0%	0%	0%	**1%**
Hydro power	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
Installed gen. capacity	38 MW	38 MW	38 MW	34 MW	34 MW	34 MW	34 MW	34 MW	/
High generation*	66%	73%	32%	72%	73%	66%	76%	60%	**65%**
Low generation*	25%	13%	8%	35%	39%	34%	19%	24%	**25%**
Biogas/mass	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
Installed gen. capacity	14 MW	15 MW	26 MW	27 MW	47 MW	47 MW	47 MW	48 MW	/
High generation*	56%	60%	35%	53%	75%	75%	77%	72%	**63%**
Low generation*	46%	48%	30%	36%	31%	57%	60%	40%	**44%**
Cogeneration	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
Installed gen. capacity	92 MW	86 MW	72 MW	63 MW	62 MW	61 MW	56 MW	55 MW	/
High generation*	81%	85%	96%	98%	98%	99%	100%	100%	**95%**
Low generation*	73%	77%	87%	87%	81%	83%	76%	80%	**81%**
Waste burning	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average**
Installed gen. capacity	21 MW	21 MW	21 MW	21 MW	21 MW	21 MW	21 MW	21 MW	/
High generation*	56%	64%	65%	64%	100%	62%	58%	53%	**65%**
Low generation*	42%	5%	55%	0%	49%	47%	36%	47%	**35%**

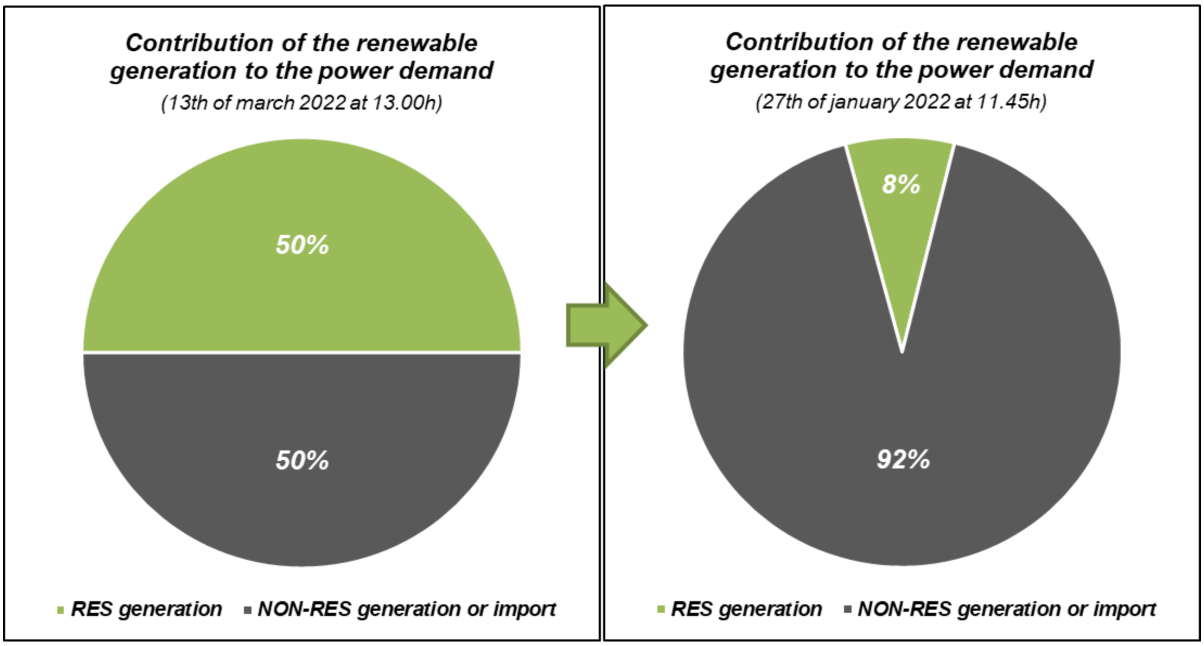
Source: Creos Luxembourg (in % of respective installed capacity during high power demand)*

With these average figures applied to the installed capacity of 31 December 2022, total generation could theoretically vary between 86 MW (low generation case) and 240 MW (high generation case) during the times of highest power demand.

During the peak demand on 27 January 2022 at midday, a total generation of 131 MW was measured. The average figures should have good validity for further use, but it is important to note that power generation can also be lower than the average (see values from spreadsheet here before).

It is obvious that the power generated by renewable energy sources, especially solar PV and wind power, is not at its maximum during the periods when the power demand, the consumption of electricity, is highest. The power delivered by these installations can vary widely during the consumption periods.

This can be seen as volatile and extreme grid situations are the consequence:



Source: Creos Luxembourg

On 13 March 2022 at 1:00 pm, 50% of the electricity consumed on the Creos grid was generated by domestic renewable energy sources, while 50% was generated by non-renewable energy sources or had to be imported.

During peak consumption on 27 January at 11:45 am, only 8% of consumption was generated by RES units and 92% was generated by non-RES units or had to be imported.

This should demonstrate that the expansion of renewable energy sources is not preventing grid reinforcements but could make them even necessary at all voltage levels.

Generation varies strongly throughout the year and is generally highest during the spring and summer months, at times when power demand or electricity consumption is not at its peak.

At present, power generation never exceeds power demand at national level. However, in the future, the power generated during times of moderate consumption will very probably grow higher than consumption. At that point, it will be power generation that must be considered for grid dimensioning, because generation might surpass the grid capacities for consumption needs.

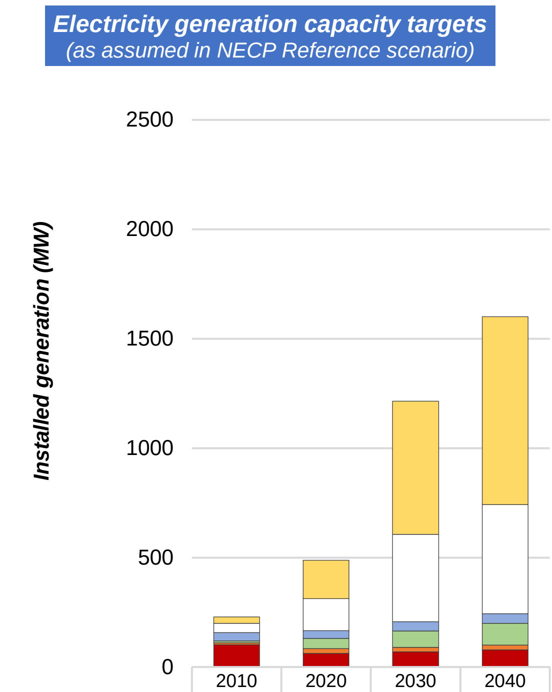
Future installed electricity generation capacity

The Integrated National Energy and Climate Plan for Luxembourg (NECP) gives some major indications about future electricity generation capacities. The main assumptions for both scenarios, the reference scenario and the target scenario, can be found on pages 163, 169 and 201 of the NECP document.

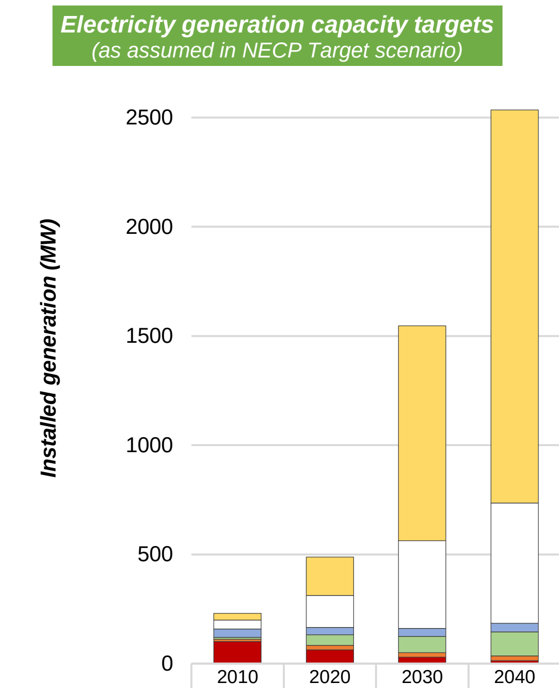
Besides a moderate increase of biomass generation, wind power and solar PV generation in particular are expected to have continued strong growth in the reference and target scenarios.

The details of the installed generation capacity per type have been calculated with the help of the gross electricity generation values on page 163 of the NECP LU, and with the total installed capacity values found on the pages 169 and 201 of the NECP LU.

The details are shown and listed below:



	2010	2020	2030	2040
Solar PV	30	175	608	857
Wind	42	146	400	500
Hydro	38	34	42	43
Biogas, biomass	9	47	75	100
Waste burning	9	21	21	21
Cogeneration	102	63	69	79
Total installed Gen.	229	487	1215	1600



	2010	2020	2030	2040
Solar PV	30	175	984	1800
Wind	42	146	400	550
Hydro	38	34	37	40
Biogas, biomass	9	47	75	110
Waste burning	9	21	21	21
Cogeneration	102	63	29	14
Total installed Gen.	229	487	1546	2535

Source: NECP LU / Creos Luxembourg (2040: figures from NECP LU; 2030: extrapolated values; 2010,2020: historical values)

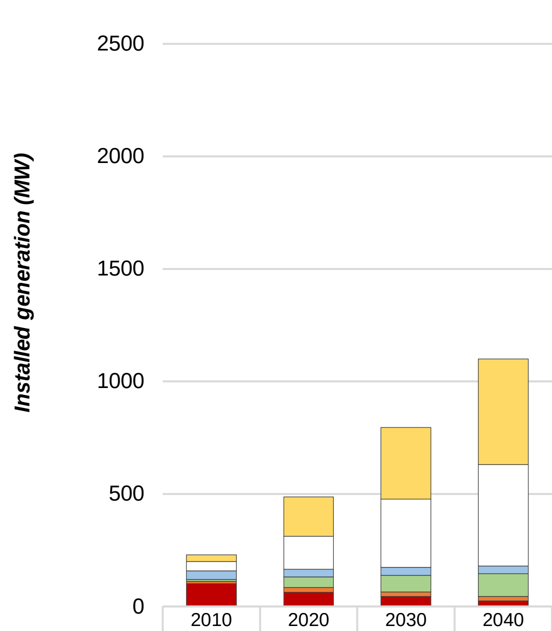
For the reference scenario, the total non-RES generation is assumed to be about 100 MW in 2040. Today, non-RES generation is already smaller than that, but the given value has been considered. This shall be considered as a maximum since this type of generation will probably not grow in the future. On the contrary, we assumed a pronounced decline of these units for the target scenario.

In addition to the preceding scenarios, we would like to add our own assumption scenario for generation growth with less ambitious generation targets. The result from this scenario will be subtracted from the TIR / Rifkin – Fraunhofer ISE peak power projection, so it has been labelled accordingly.

Here, a growth of 15 MWp per year for solar PV installations was assumed and the completion of 75% of the projects for wind farms or wind turbines that are known today. Biomass/biogas generation is also expected to increase.

For comparison, the assumed yearly increase of the solar PV installations for the reference scenario is about 35 MWp per year and about 80 MWp per year for the target scenario.

Electricity generation capacity targets
(as assumed in TIR/Fraunhofer scenario)



	2010	2020	2030	2040
Solar PV	30	175	318	470
Wind	42	146	303	450
Hydro	38	34	35	35
Biogas, biomass	9	47	74	100
Waste burning	9	21	21	21
Cogeneration	102	63	44	24
Total installed Gen.	229	487	795	1100

Source: NECP LU / Creos Luxembourg (2040: figures from NECP LU; 2030: extrapolated values; 2010,2020: historical values)

With these different scenarios and their values of future installed generation, the future effective generation profiles have been projected for the years 2023 to 2040.

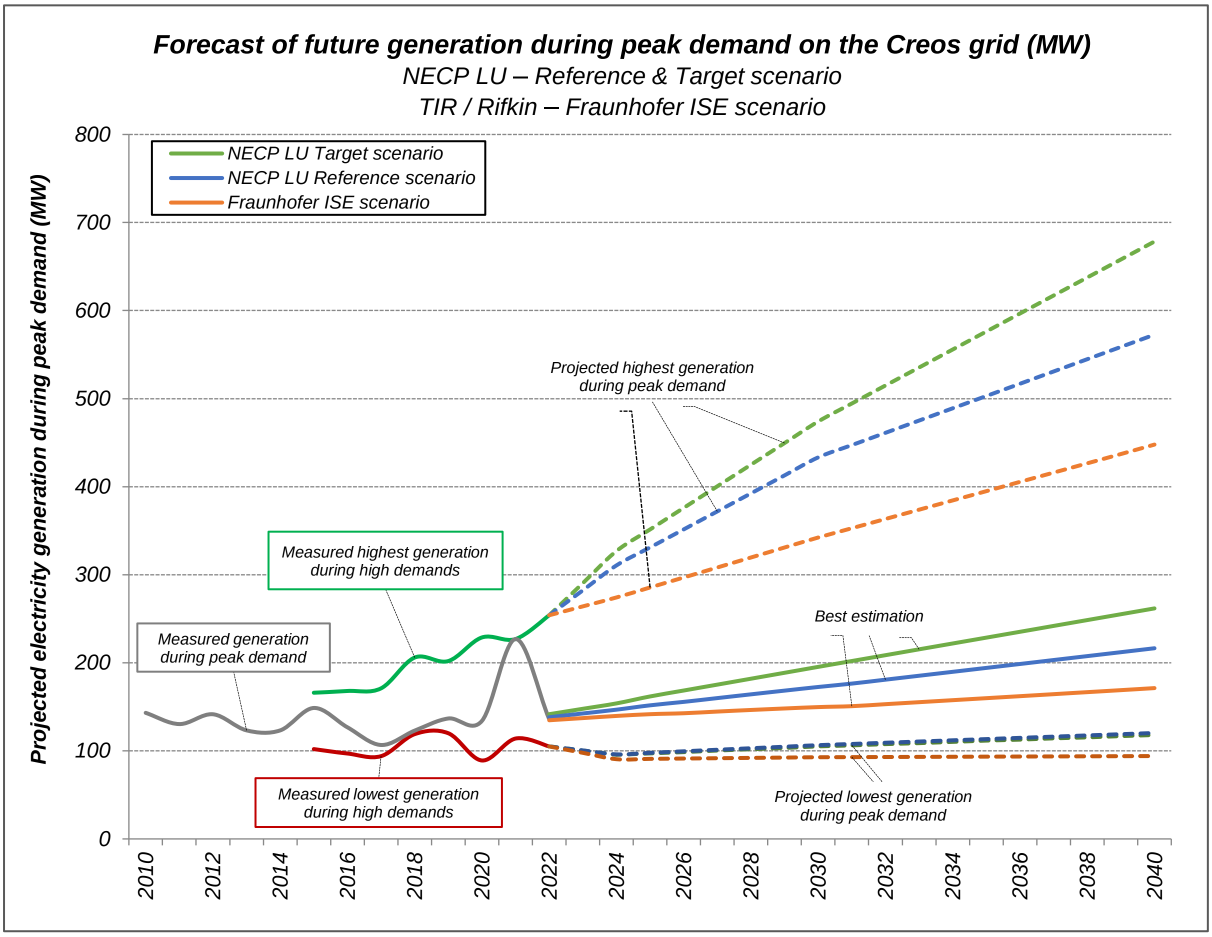
In combination with the past average variation of generation during high demand, an assessment of the future generation range to expect during peak demand has been made (Future electricity generation during peak demand).

Equally, the future generation range to expect during low demand has been evaluated with the projected generation profiles (Future electricity generation during low demand).

Future electricity generation during peak demand

Future generation will vary between a low and high generation range of values during peak demand.

The projections of the highest generation during peak demand and the lowest generation during peak demand are shown in the chart here below. In addition, the most probable future generation during peak demand has been estimated. Although the projections of the lowest generation represent the worst case, because these will result in the highest peak import values, the 'best estimation' forecast of generation during peak demand was added to give a more realistic view.



Source: Creos Luxembourg

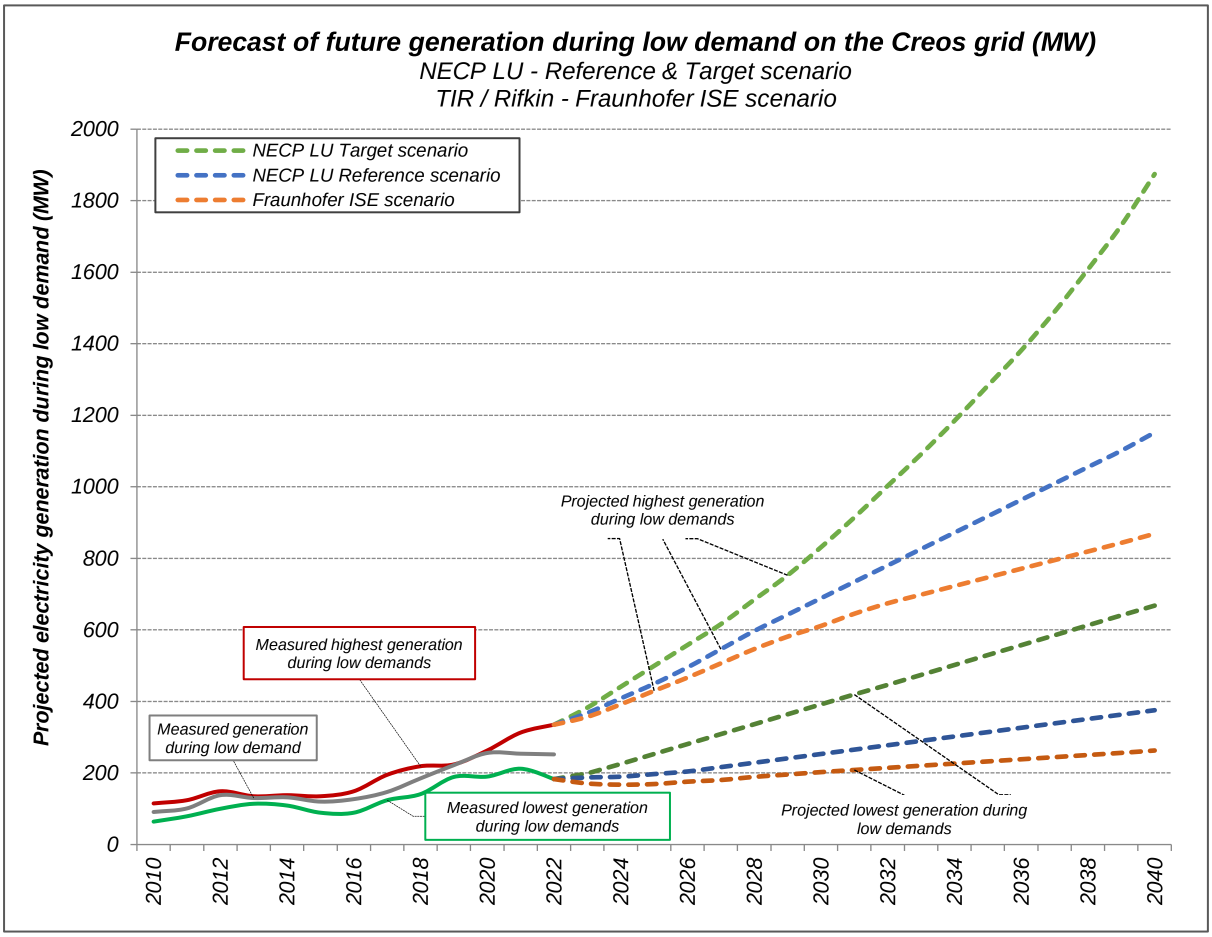
From the past few years, the measured values of generation during peak demand have been added to the chart, has have the measured highest and lowest generation variation during these years.

Future electricity generation during low demand

As the future installed generation capacity is expected to rise over the current transport capacity of the high-voltage grid, it is necessary to analyse the grid situation which might occur when there is a high generation and a low demand at the same time.

With the assumption that in the future, 60% to 75% of the installed capacity will effectively be generated at a maximum, the highest expansion scenario – the NECP target scenario – with 2500 MW of installed generation could then lead to **1900 MW of effective power generation.**

Even though there will be consumption during that time, most of the generated power will have to be transported and exported over the existing 220 kV high-voltage transport grid.



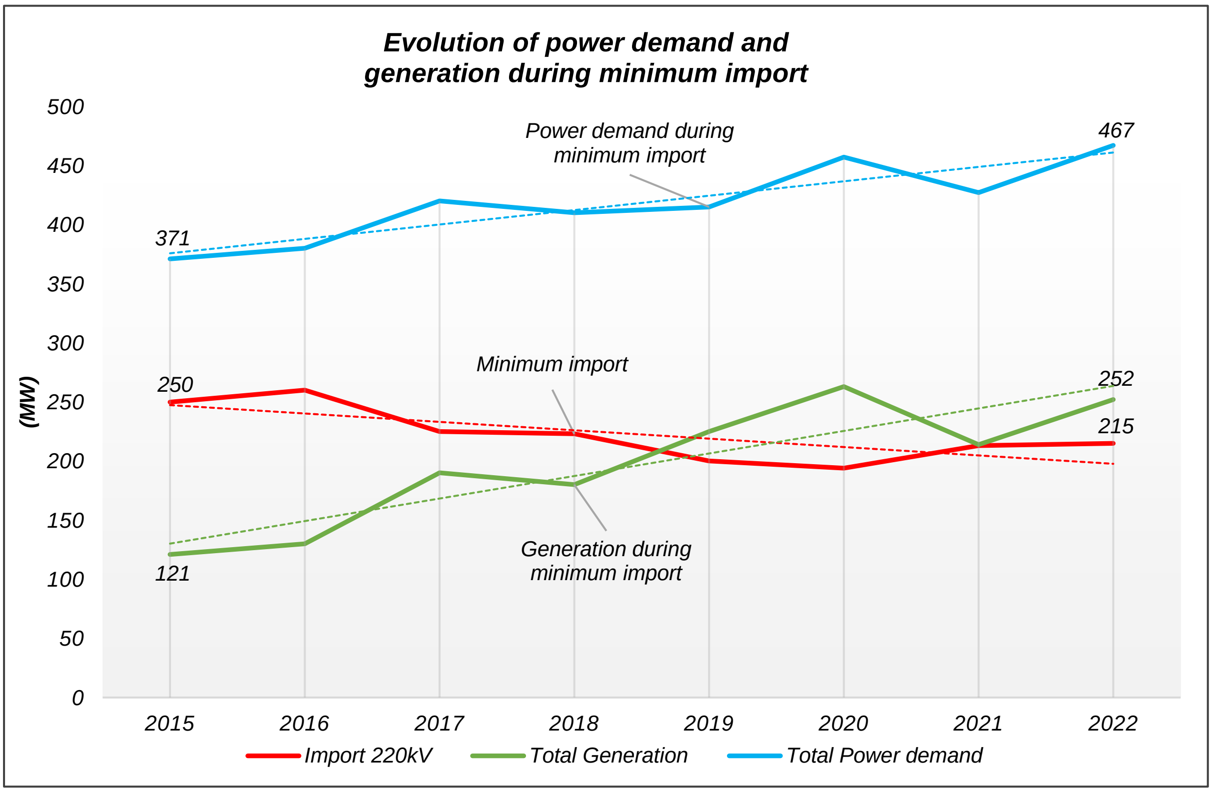
Source: Creos Luxembourg

Currently, power consumption does not fall under a certain value on the high-voltage transport grid during periods of higher electricity generation.

It has been estimated that power consumption could range between 450 MW and 550 MW during periods of high electricity generation in the future. The excess generation which would have to be transported and exported in case of a high generation and a low consumption would still exceed the transport capacity of the existing grid.

This excess generation could reach about 1,400 MW on the high-voltage transmission grid in the future.

The past evolution shows that the minimum import decreased due to the growth of generation during periods of lower consumption, even if the power demand itself increased during these times.



Source: Creos Luxembourg

If the installed generation capacity is steadily increased as it is planned, effective generation will certainly surpass power demand at times of low consumption in the future. As a result, the generated power at that time will be exported from the Creos grid.

Depending on the expansion speed of the additional generation capacity, this could happen within the next 10 years.

The total projected peak power is expected to rise even more than the generated power, so that the future power demand for consumption needs will be the determining value for the dimensioning of the future high-voltage transport grid.

It should be noted that although future excess generation will likely not be the decisive factor for the dimensioning of the high-voltage transmission grid (220/380 kV), it might be the determining factor for grid reinforcements on the high-voltage distribution grid (65/110 kV), the medium-voltage (20 kV) and low-voltage (400 V) distribution grids. Here consumption could temporarily fall back to nearly zero and all the generated power would have to be transported to the higher voltage levels.

Electrical energy storage

Electrical energy storage will be fundamental in the carbon-neutral power system of the future, in which there will be a high share of electricity generated by renewable energies. Besides a growing need for flexibility such as demand-side management, storage solutions will be necessary to balance the power system.

The European Association for Storage of Energy – EASE has estimated that the European Union will require about 200 GW of energy storage by 2030 and 600 GW by 2050, of which two-thirds are a no-regret option for energy shifting provided by 'power-to-X-to-power' technologies.

Storage can help meet peak demand if the power system has enough storage capacities and has allowed those capacities to store enough power during previous periods of lower demand. It is essential that the storage systems are functioning in a 'grid-friendly' way by reducing the load on the electrical grid during peak demand and that the storage systems do not worsen peak loads on the grid during their charging phase.

By balancing power grids and saving surplus energy, energy storage represents a concrete means of improving energy efficiency and integrating more renewable energy sources into electricity systems.

The most used and oldest form of storing energy/electricity is pumped hydroelectric storage. There is a project to add a reservoir to the hydroelectric facility of Esch/Sûre, but the overall effect of this project on the interplay of power demand and electricity generation at national level will certainly be modest.

'Power-to-X' storage facilities like power-to-hydrogen and power-to-synthetic fuel/gas seem promising and offer the possibility of sector coupling. But currently there is only a first project for a medium-sized storage system which would be capable of storing electricity over one or several seasons by converting electricity to another energy form. The primary purpose of this project is to produce green hydrogen with the help of renewable energies. In a second step, it is intended to enhance the project so that electricity can be generated with a fuel cell and the stored hydrogen and provided back to the power grid when there is a consumption need. It is planned to start producing green hydrogen on this site by the year 2025. Such electricity storage methods could indeed help smooth the consumption and generation peaks and reduce peak imports.

It is more likely that battery storage devices will also become one of the key enablers of a low-carbon society, especially with a decarbonisation path using mainly electricity.

The occurrence of smaller, decentralised battery storage systems, behind-the-meter storage systems, is growing across the European Union. However, it is driven by national political aspects and/or national subsidies, by feed-in tariffs and by electricity prices, which explains why there are currently over 400,000 'home' battery storage systems installed in Germany, but almost none in Luxembourg. Also, there are hardly any tangible projects for bigger battery storage systems throughout the country at present.

Nonetheless, it seems very likely that behind-the-meter battery storage systems will emerge in the future, will contribute to the system adequacy, and must therefore be considered within the framework of this study. **We assume that these future battery systems will reduce peak demand and peak generation values by 5% in 2030 and by 10% in 2040.**

Flexibility

Creos Luxembourg, Luxembourg's Institute of Science and Technology (LIST) and the Interdisciplinary Centre for Security, Reliability and Trust (SnT) are currently conducting a common study called 'FlexBeAn' for Flexibility Behaviour Analysis, to better assess the potential of demand-side flexibility of industry, the residential and tertiary sectors and e-mobility in Luxembourg. Although this study has not yet been completed, initial insights are already proving helpful.

Flexibility on the demand side: e-mobility

In summary, electrically driven transport on road with several hundred thousand electric vehicles will create the biggest additional load on the Creos grid in the future, with total peak power ranging from 400 MW to 900 MW. But with an increasing number of electric vehicles, there is also valuable potential for flexibility. Smart charging systems and a degree of charging flexibility from the consumer side will help reduce peak power demand and will help integrate more renewable energies into the energy system, making better use of the grid capacities.

Different studies already quantified the potential amount of e-mobility flexibility based on multiple charging scenarios. Of course, available flexibility will change throughout the day depending on charging patterns and the number of vehicles involved. Worst case scenarios from these studies resulted in peak demand reductions of 10% to 15%, whereas best case scenarios estimated reduction/time shifting potential of between 30% and 40%.

Within the framework of this report, it is assumed that by 2040, a reduction of 10% to 30% of peak demand caused by all the electric vehicles will be achieved due to the enabling of flexibility.

Flexibility on the demand side: load management in industry

Industrial companies or SMEs also offer a certain potential for demand-side flexibility. Peak demand could be possibly and partly reduced by load shifting and peak shaving measures, depending on the exact processes of the respective industry.

Pending the results of the FlexBeAn study for Luxembourg, the exhaustive German study 'Regionale Lastmanagementpotenziale: Quantifizierung bestehender und zukünftiger Lastmanagementpotenziale in Deutschland' from the Forschungsstelle für Energiewirtschaft (FfE) seems appropriate for estimating the overall peak reduction potential from industry.

The average power demand of industry in Germany was about 25,6 GW in 2019 and could increase to 37 GW (hydrogen scenario) or even up to 44 GW (electrification scenario) in 2045. Peak consumption values are estimated to be 30% higher, with 33,3 GW in 2019 and ranging from 48 GW to 57 GW in 2045.

The load management potential resulting from the study could rise from 1,2 GW in 2019 up to 9,6 GW in the hydrogen scenario and up to 13,5 GW in the electrification scenario. This corresponds to 3,6% of peak demand of German industry in 2019 and between 20% and 24% of peak demand of German industry in 2045.

Regarding Luxembourg, we assume that, by 2040, a reduction of 15% of peak demand caused by industry might be achieved with load management systems.

Flexibility on the demand side: flexible control of heat pumps

With the rising occurrence of heat pumps in residential buildings in the future (or even in commercial and administrative buildings), flexibility potential might also grow.

Because heating systems in general very often have a thermal storage capacity, it is possible to shift the electric power demand of heat pump systems over a few hours in time without any loss of comfort. Hybrid heat pumps offer even more flexibility as they can switch between electricity and gas. At times when electricity prices are low, they can run entirely on electricity and when electricity is scarce, they can be fully gas-fired.

At present, however, hardly any heat pumps are connected and controllable over distance. Also, some consumers have concerns when it comes to interfering with the heating system of their house. To enable the flexibility of heat pump systems in the future, price incentives that reward flexibility are needed and the heat pumps must be prepared and connected for flexible control.

Considering this, we assume a reduction of peak power demand in the residential sector, which has risen from 10% to 35% over the years, due to flexible control of heat pumps in the future.

Flexibility on the supply side: feed-in management

Due to the energy transition, more flexibility is needed in the entire electricity system, especially in relation to future electricity generation. The increasing share of wind power and solar PV generation in the future electricity mix will generate electricity in a volatile manner. The related peak generation could lead to extreme grid situations during certain hours of the year.

Better control of the generation assets and flexibility from electricity producers will be needed in the future during times of low power demand and high generation. A so-called feed-in management could limit peak generations of wind turbines and solar PV installations to a certain level during the few hours when grid congestion arises due to increased excess generation. Flexibility and control on the supply side must, however, avoid impeding the injection of renewable energies in the electrical grids as effectively as possible, in order to keep the loss of feed-in remuneration at a minimum for the electricity producers.

It is estimated that feed-in management systems could reduce or limit future peak generation (of wind and solar PV) by 5% to 15%.

Flexibility on the grid side: DLR – dynamic line rating

There is another way to achieve or provide flexibility, not on the demand side or on the supply side, but on the grid side. Grid operators can use dynamic line rating systems to efficiently enhance the transmission capacity of overhead lines under certain conditions. By monitoring the exact conductor temperatures and with beneficial weather conditions, the maximum transmission capacity of overhead lines can be slightly increased.

Experiences with a dynamic line rating system on the Creos grid showed that the nominal transmission capacity of overhead lines can be exceeded during beneficial weather conditions, mainly during cold and windy days. At best, overhead lines with DLR could be operated with up to 110% of their nominal transmission capacity.

Forecasts

The dimensioning of the electrical grid is predetermined by the specific moments when the highest currents occur on the grid sections, and the most relevant situations when those currents can happen, are:

- when there is high power demand and low electricity generation, leading to maximum electrical energy import, and
- when there is high power generation and low power demand, leading to maximum excess electricity generation.

The following projections have been established to give an outlook on possible developments and to help determine the appropriate grid infrastructure for the future:

- Forecast of future total peak power demand
- Forecast of future total peak import
- Forecast of future total peak generation
- Forecast of future total peak excess generation

Forecast of future peak power demand and import

For the forecasts of future total peak power demand and future peak import, current quarter-hourly profiles were scaled up for the years 2023 to 2040, constructed profiles for the e-mobility, for data centres and for the additional loads 'Decarbonisation with electricity', 'Decarbonisation with hydrogen' were added.

The constructed profiles for e-mobility are based on real consumption profiles and partly on normalised profiles found in studies and literature. The profiles of the future power demand of data centres are based on real measured values. For the profiles for the additional load 'Decarbonisation with electricity', current consumption profiles were scaled up, which are specific to the industry involved. For the new load 'Decarbonisation with hydrogen – electrolysis', assumptions concerning the yearly usage hours have been made and synthetic profiles have been constructed. For the new load 'Industries connected to the Sotel grid', real consumption time series were used.

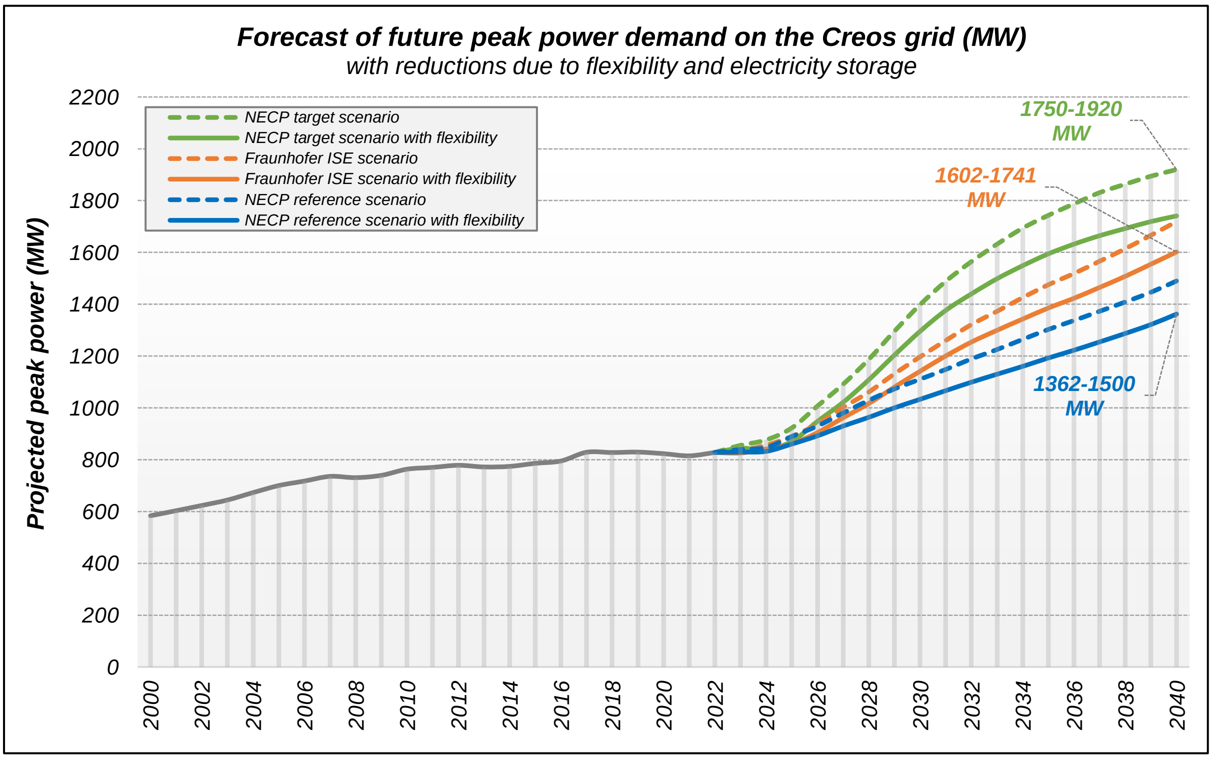
It is assumed that future power demand will be reduced by a certain amount due to the achieved flexibilities on the demand side, as described in the previous chapter. The reductions due to flexibilities have been fully accounted for in the respective loads (e-mobility & industry); concerning the flexibility of heat pumps, an intensified reduction effect has been assumed over time and the number of heat pumps.

A quarter-hourly profile for the industrial load 'Sotel' in case of a full switch of the industrial load of Sotel on the Creos grid has also been added and the summarised results of these forecasts have been illustrated in a separate chart.

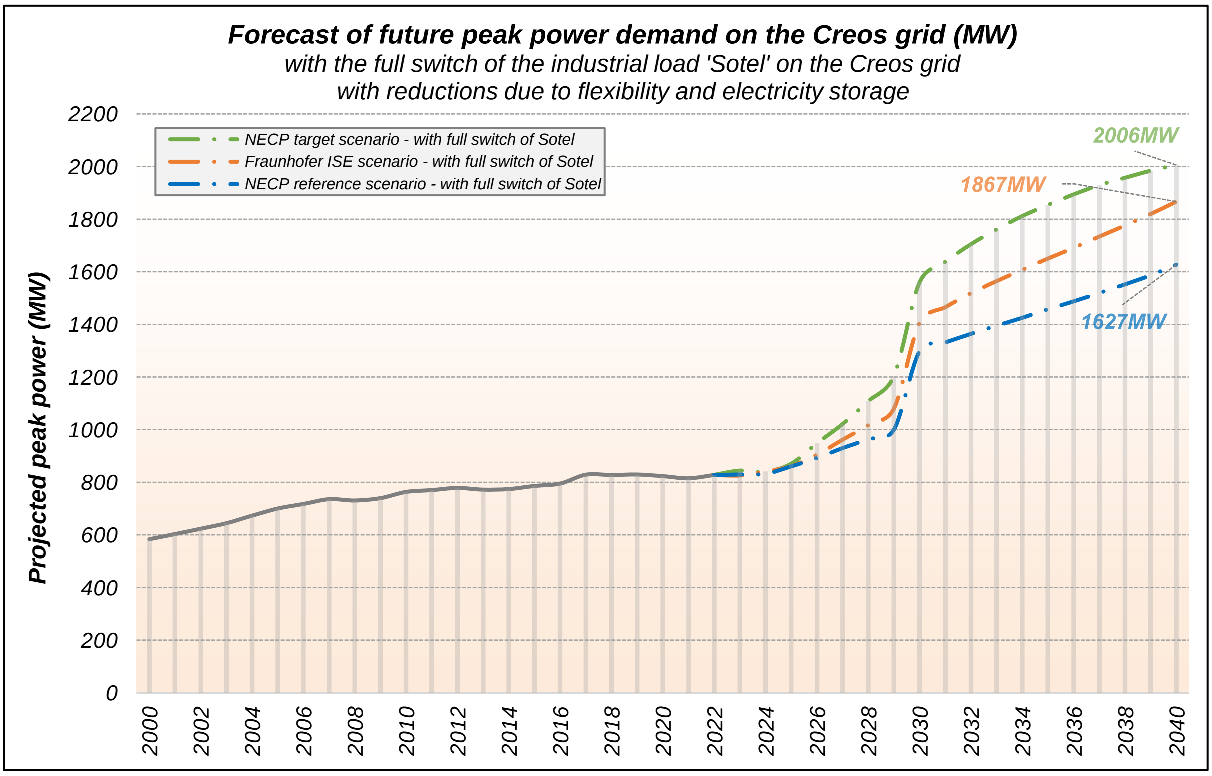
The future import profiles have been established using the profiles of future power demand and by subtracting the projected generation profiles of the lowest generation (resulting in the 'worst case' import) and the 'best estimation' generation.

To provide a clearer overview, only the peak values per year of the projected profiles of total power demand and peak import are shown below.

Forecast of future peak power demand

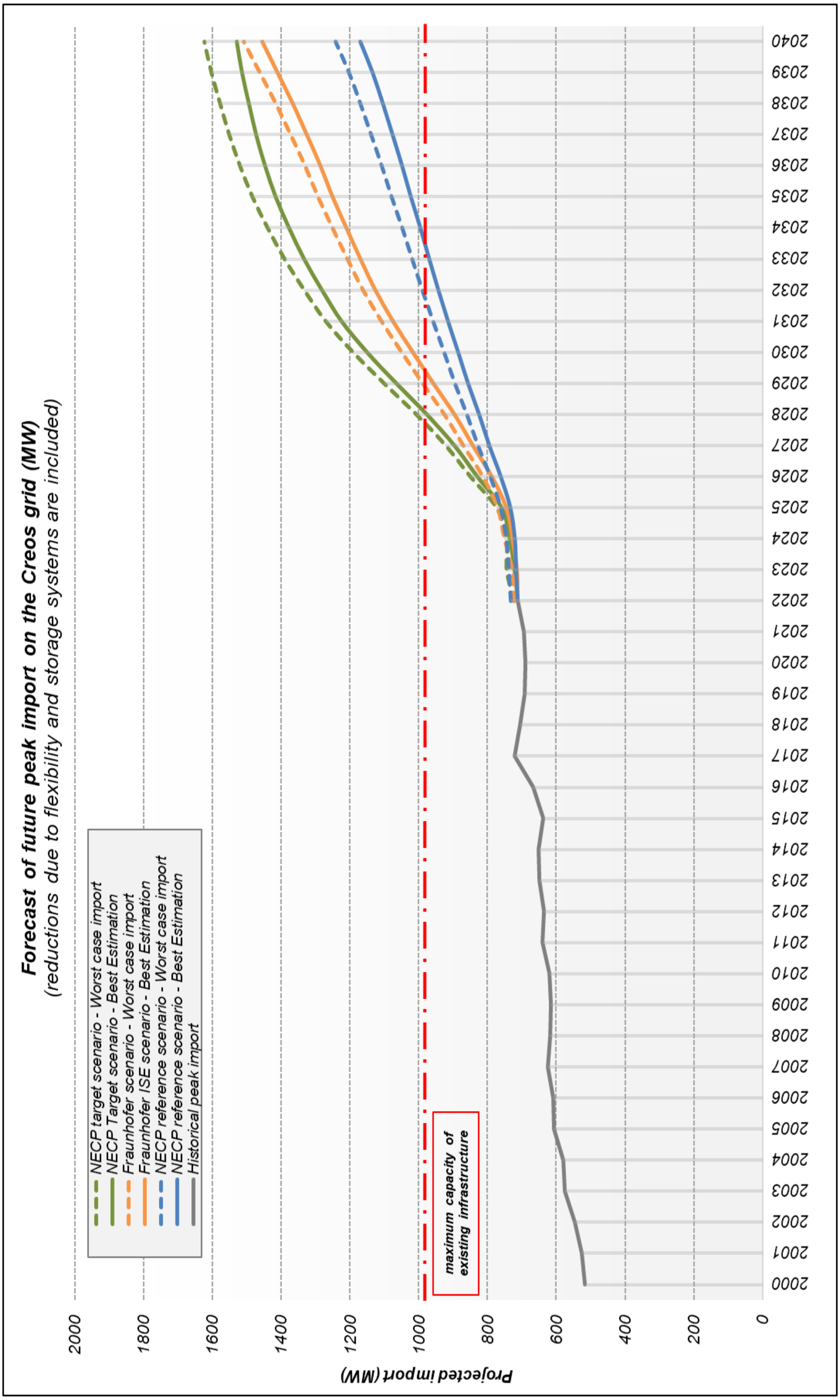


Source: Creos Luxembourg

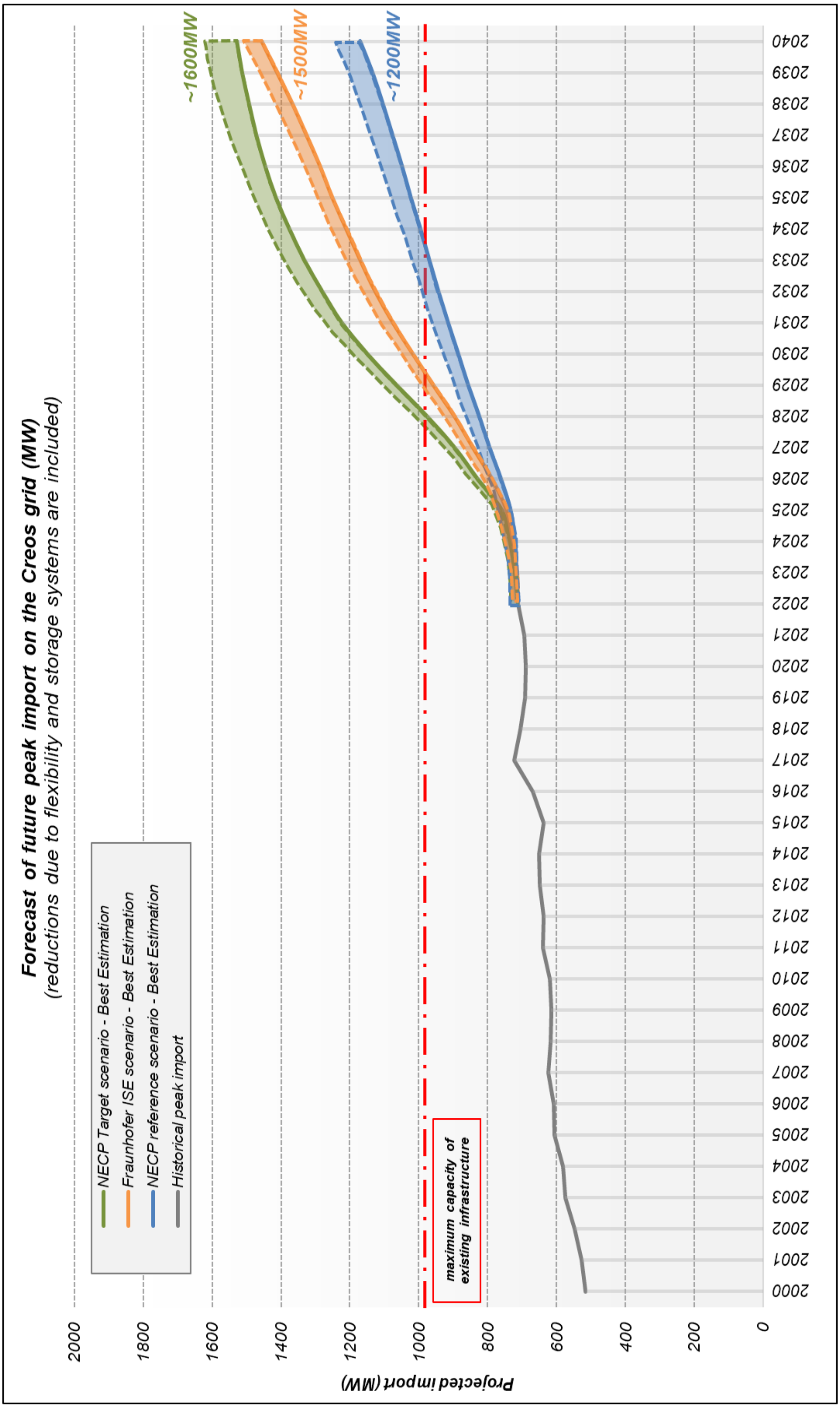


Source: Creos Luxembourg

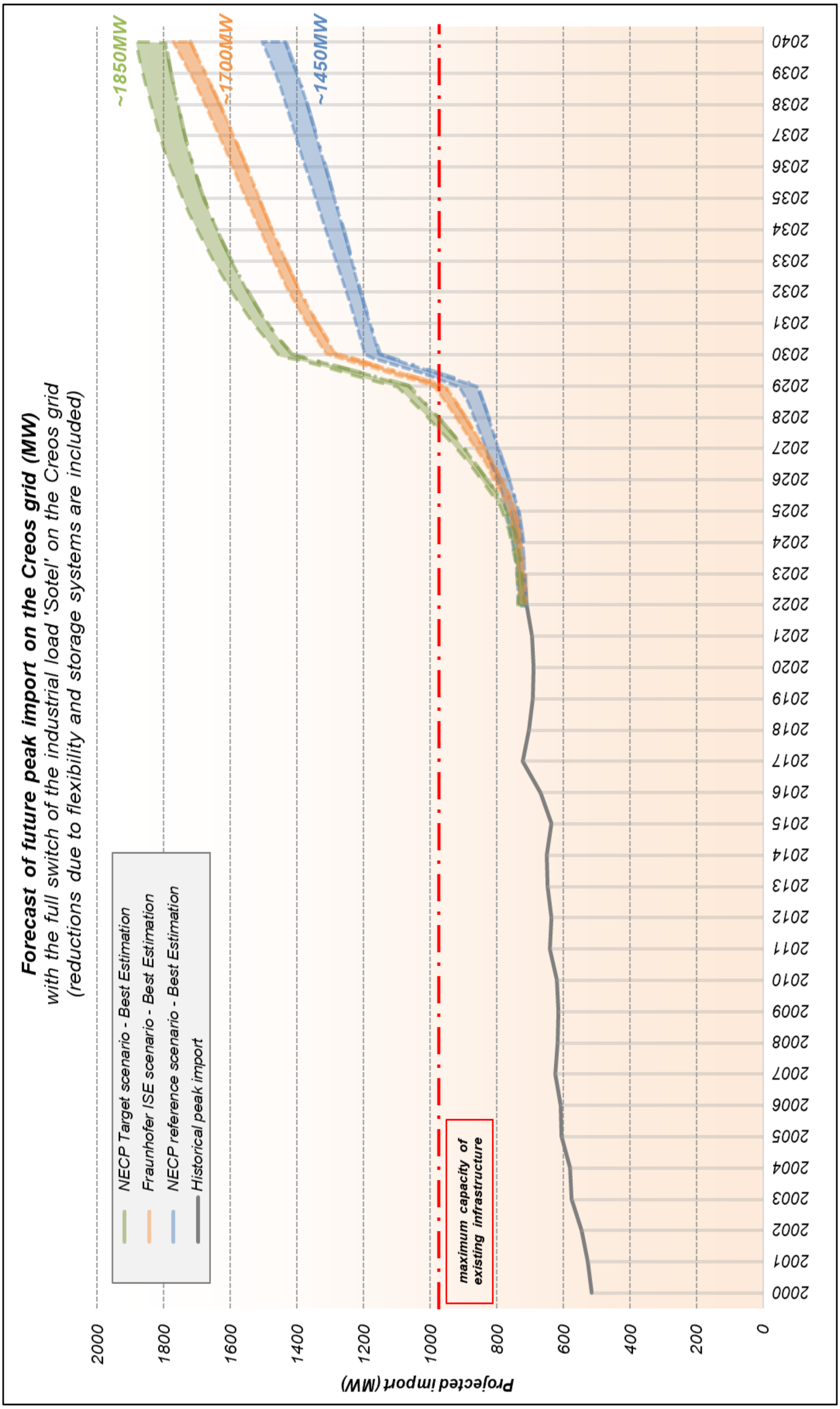
Forecast of future total peak import



Forecast of future total peak import – aggregated view



Forecast of future total peak import (with the industrial load 'Sotel')



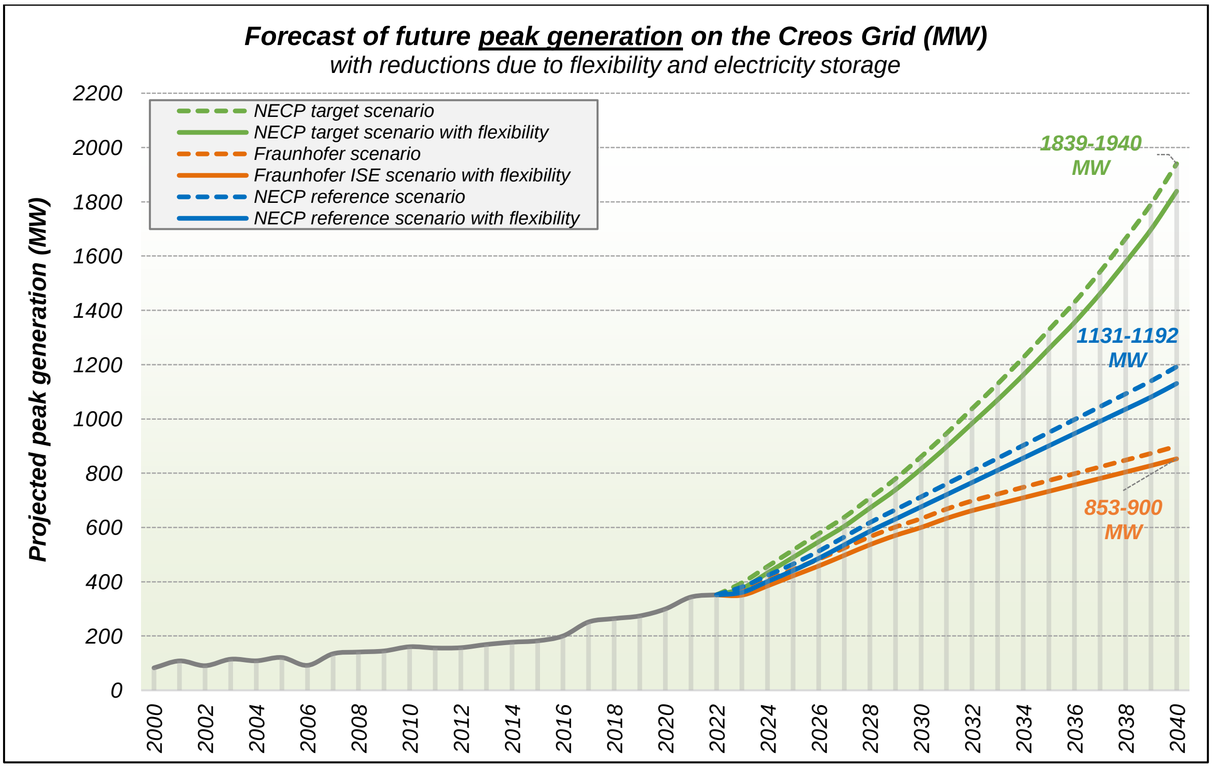
Forecast of future peak and excess generation

For the forecast of the future total peak generation, recent quarter-hourly average profiles were scaled up for the years 2023 to 2040 with the help of the future installed capacity figures and the insights of the effective generation figures.

It is assumed that future generation can be reduced by a certain amount due to the achieved flexibilities on the supply side, as described in the previous chapter. The reductions due to flexibilities have been fully accounted for in the respective generation forms (Solar PV & Wind power).

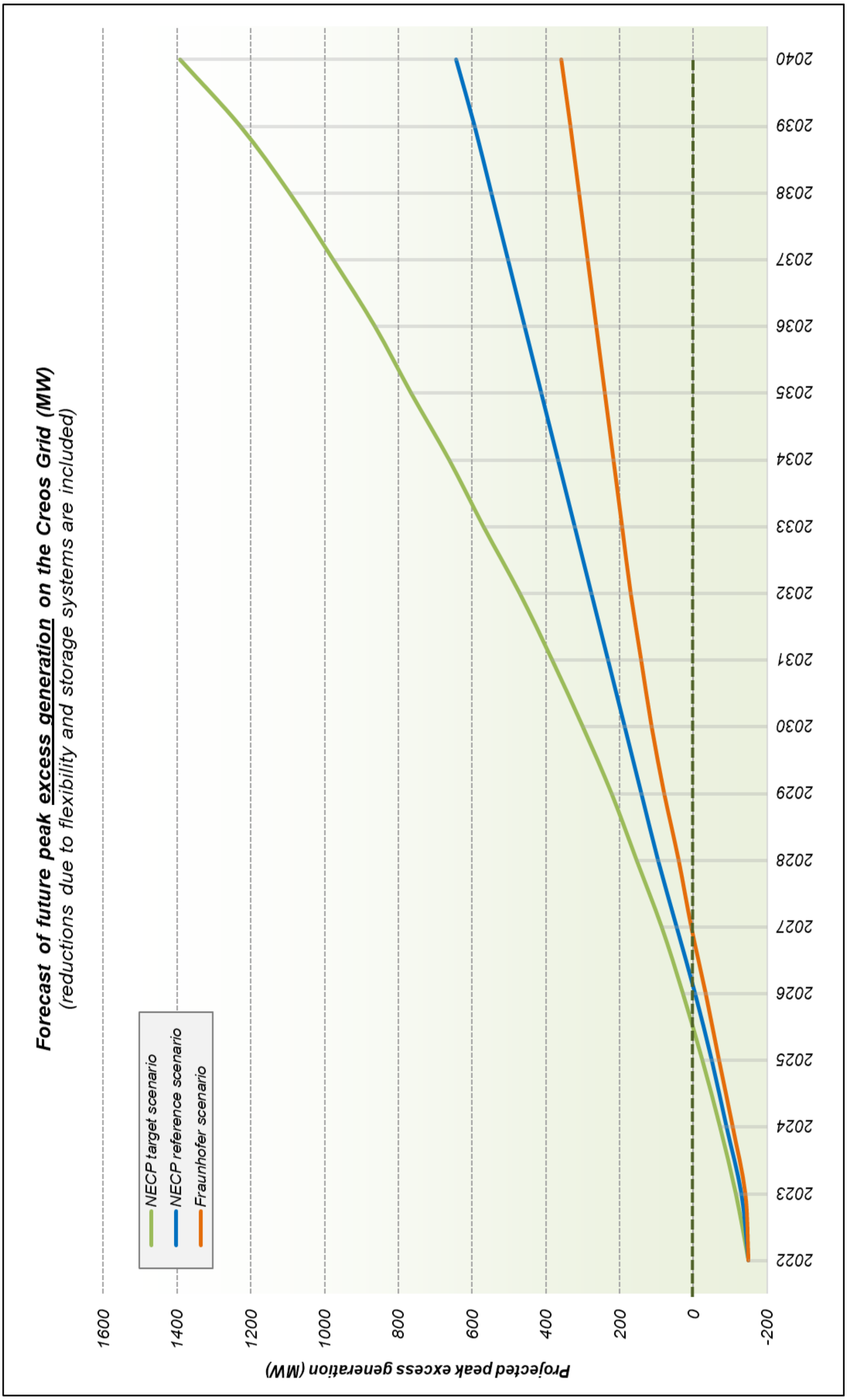
To provide a clearer overview, only the peak values per year of the projected profiles of total generation are shown below.

Forecast of future total peak generation

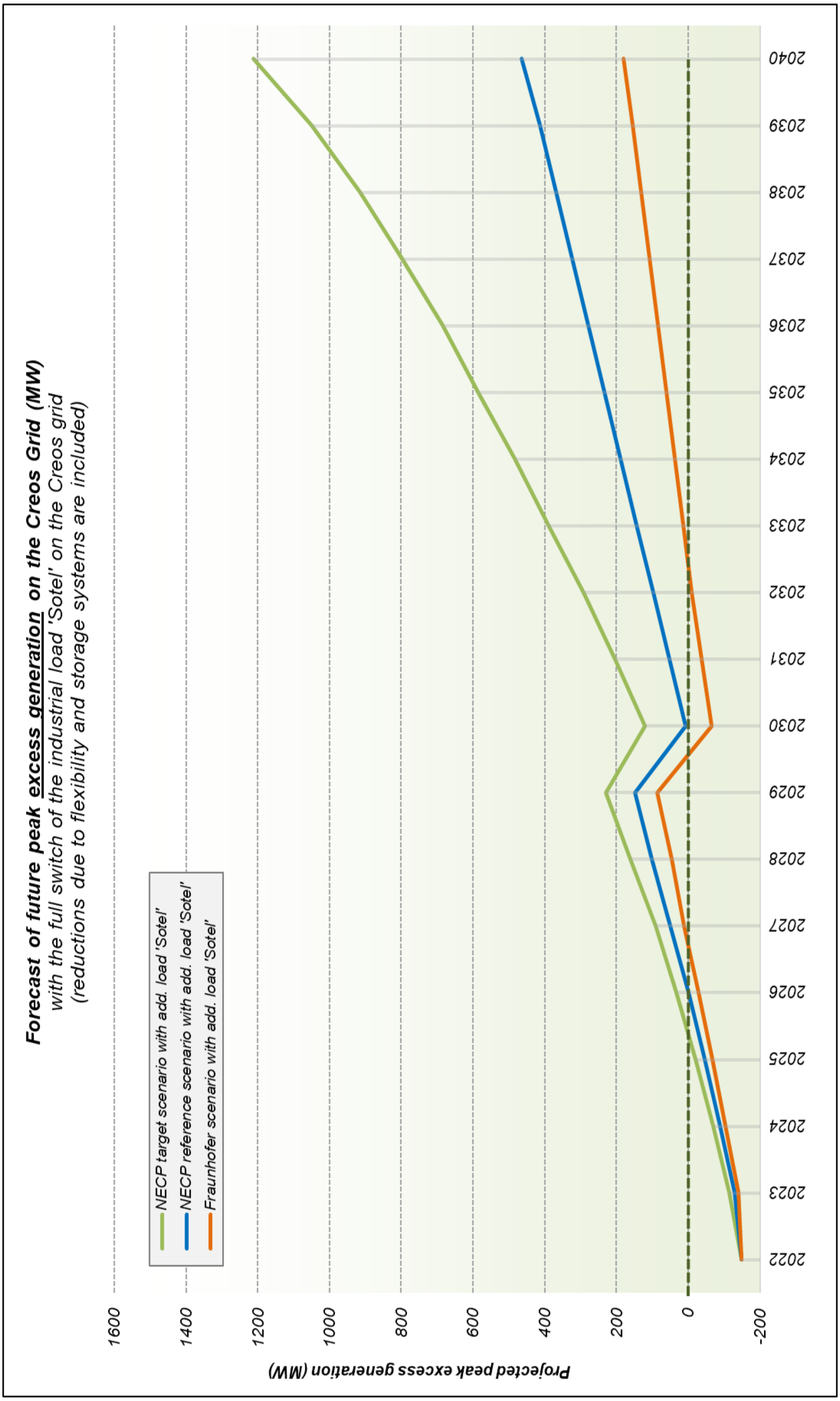


Source: Creos Luxembourg

Forecast of future total peak excess generation



Forecast of future total peak excess generation (with the industrial load ‘Sotel’)



Conclusion and recommendations

The European Network of Transmission System Operators for Electricity (ENTSO-E), of which Creos is a member, set the timely implementation of the Clean Energy Package as a priority.

Since a strong and secure transmission network is a widely recognised prerequisite to meet European energy and climate policy goals, Transmission System Operators are valuable enablers of the European Green Deal.

ENTSO-E calls for stronger cross-border cooperation to resorb and distribute the highly variable electricity flows from the renewables and to avoid congestion. A lack of grid capacity not only hinders further integration of renewable energy sources, but also puts system security and sustainability goals at risk. Cross-border transmission capacities shall be increased where appropriate and needed.

In addition to the electrical energy generated in Luxembourg, electricity can be supplied by two main supply lines from Germany and by a complementary supply from Belgium over a phase-shifting transformer.

The secured import and transmission capacity of the existing supply lines coming from Germany is currently 980 MW. The concept and design of these supply lines was created over 50 years ago, at a time when the peak power demand reached only 10% to 15% of the total capacity. Today, about 75% of the total import and transmission capacity is already used during peak import, even more if energy transit occurs from Germany to Belgium.

Since electrification is a very efficient path to decarbonisation, more electricity will be used in the future. Besides the economic and demographic growth of the country, the switch from fossil fuels/gas to electricity for heating purposes and in particular the development of electric transportation will inevitably lead to higher electricity consumption and involve a substantial increase of power demand on the Creos grid in the future.

Despite a certain degree of electrical storage capacity and even with enabled flexibilities on the demand side, such as smart charging systems, demand-side management or flexible control of heat pumps, total power demand could more than double in the next 20 years.

Increased investment in renewable energies will certainly reduce the total yearly electricity import amount but will not be enough to guarantee security of supply in Luxembourg at all times, thus requiring an increase of import capacities.

Referring to the preceding considerations, it should be noted that all the analysed forecast scenarios exceed the current maximum transmission and import capacity. With or without data centre projects, with more or fewer projected electric vehicles, the projected import of every analysed scenario lies well above the current maximum transmission and import capacities.

Creos Luxembourg already identified the need for an increase of the electrical energy import transmission capacities of the high-voltage grid in the past and therefore launched a future-oriented replacement construction project in 2017 that will provide a better cross-border connection between Luxembourg and Germany. Studies on the environmental impact of “PROJET 380” are well underway and should lead to a swift conclusion, after a public consultation. The construction phase is planned to start in 2024 after all the administrative authorisations have been requested and duly acquired. It is Creos’ objective to commission the project by 2028.

In addition, Creos is developing various other projects to ensure a safe and efficient grid operation in the near and longer-term future. The overall planning of the grid, both on transmission and distribution level, will be outlined in the respective network development plans.

Complementary, in order to enable the potential of all flexibilities and to help optimise the operation of the electricity infrastructure, a necessary legal framework will need to be set up, and technical and economic incentives will need to be provided for electrical storage systems, smart charging systems for electric vehicles and for all kinds of demand-side and feed-in management systems.

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