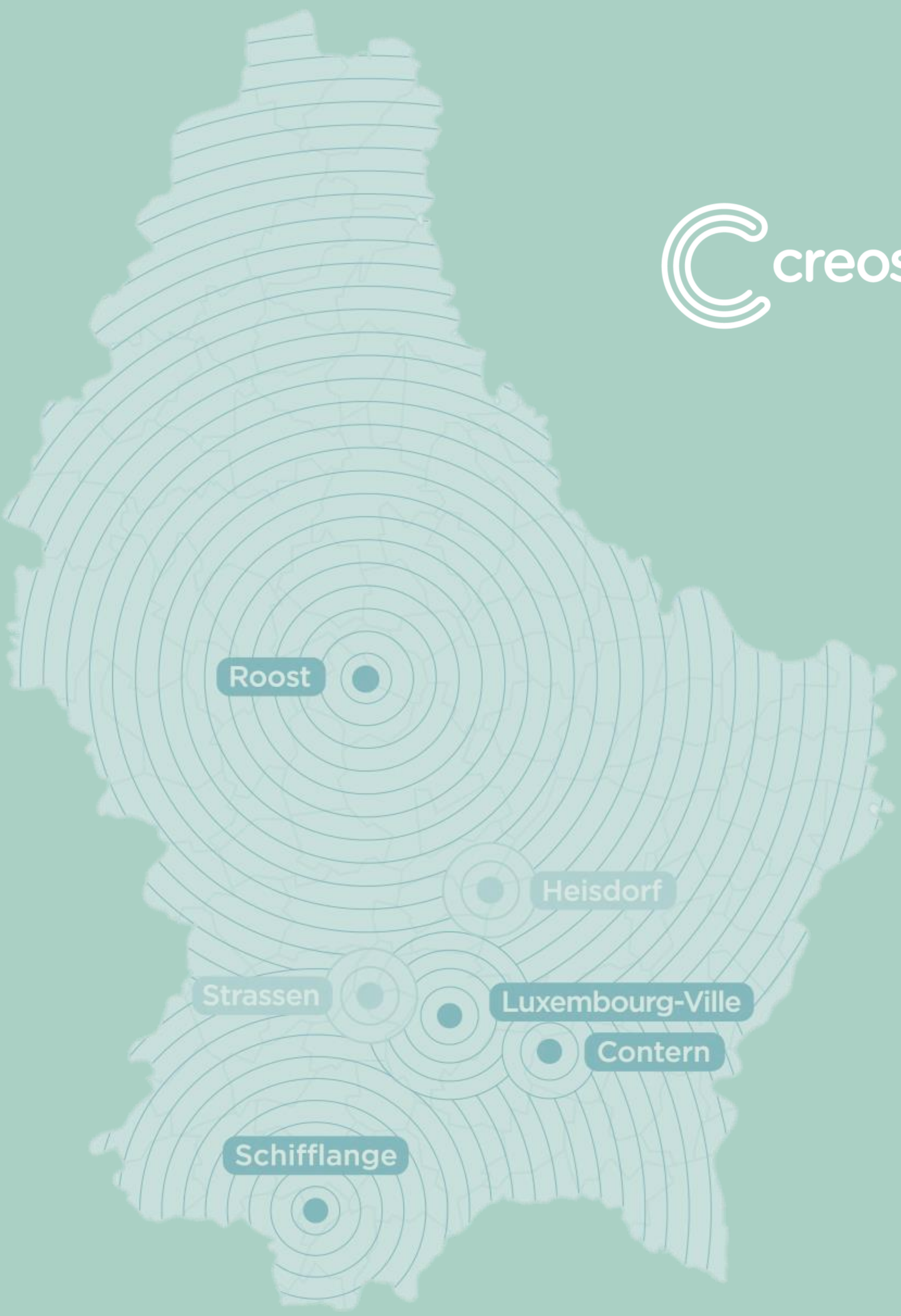
Scenario Report 2040

Version 2020

Electricity Transmission Grid



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Executive summary

The energy transition in Luxembourg is in full swing, and the electricity sector is playing a particularly important role to decarbonize the Luxembourgish energy system. Electricity generation from renewable energy sources is continuously growing, energy end uses such as heat and mobility are being electrified, and new services are on the rise due to enhanced digital technologies and business opportunities. In this context, Creos Luxembourg in its position as transmission system operator is a key player to enable the energy transition going forward.

While Creos actively contributes to the energy transition by developing and operating the grid infrastructure, it also faces a number of challenges. A particular challenge on the transmission system level is that even though the fast-growing renewable energy generation will have to be integrated into the power grid to reduce the overall amount of imported electricity, power consumption is equally increasing. Specifically for times of peak demand, the system must be ready to balance supply and demand, often with the help of imports from our neighbouring countries.

Indeed, statistical data shows that the share of national power generation during periods of high consumption has not grown over the last ten years, despite a doubling of the installed power of renewable energies. The power generated by those units is variable and it cannot be guaranteed that the demand profiles are always covered. Consequently, in order to reach ambitious decarbonisation targets while ensuring security of supply, Luxembourg's import capacities must be dimensioned to withstand periods of high demand and limited domestic power generation.

On the demand side, the following developments contribute to an increasing need for a strong electricity infrastructure:

- Demographic and economic developments, including a general progress in digital solutions and services, bring about a growth in electricity consumption. New energy intensive projects with high peak power are planned.
- Energy end uses are being increasingly electrified. In the mobility sector, the share of electric vehicles is rising, Luxembourg's entire bus fleet is planned to be emission free by 2030 and the expansion of the railway and of the tramway infrastructure is intended. The public e-mobility charging infrastructure is growing constantly with the first super-chargers planned to be operational by the end of 2020.
- Heating will equally switch from fossil fuel to electric sources for new and renovated buildings.

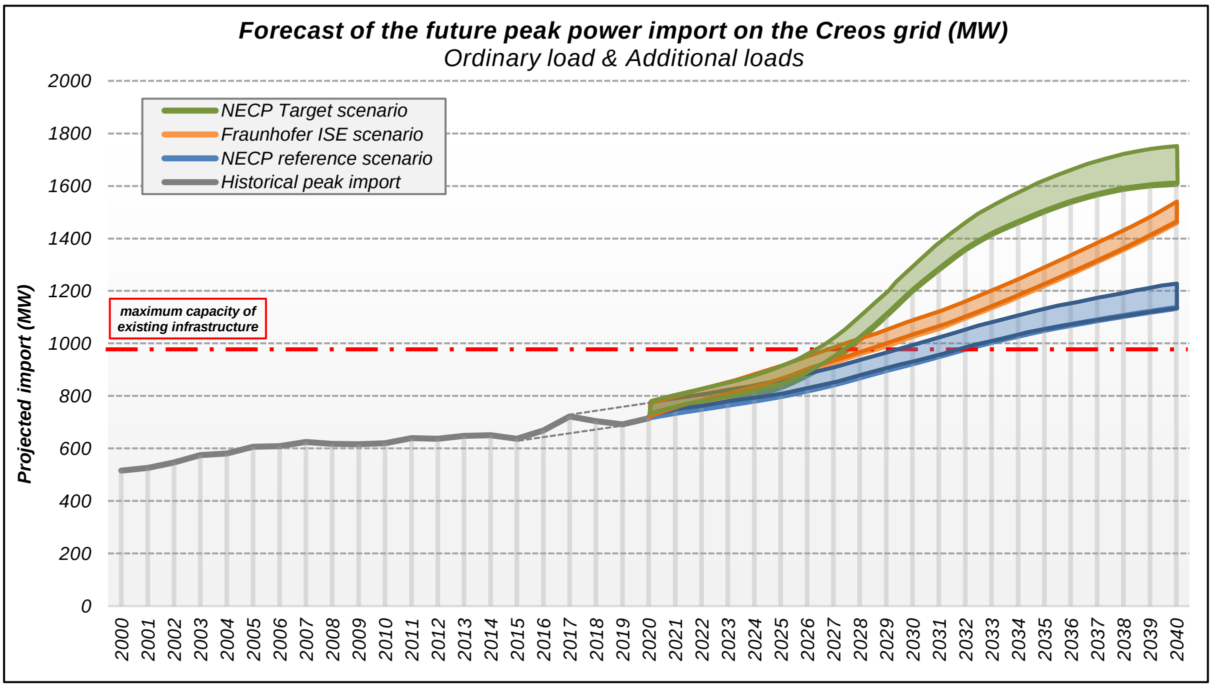
On a political level, all member states of the European Union have recently adopted integrated national energy and climate plans (NECPs) to depict and monitor their progress towards the common goals of reducing greenhouse gas emissions, raising the renewable energy share and improving energy efficiency. The main objective is to achieve a low-carbon, and later on a climate-neutral economy with an affordable, secure and dependency-reduced energy system.

Against this background, the present report elaborates several scenarios for Luxembourg until 2040. The latest political targets have been taken into account by analysing the national energy and climate plan for Luxembourg (NECP LU) published by the Ministry of Energy and Spatial Planning of Luxembourg. Specifically, the present report considers various data and information to derive a detailed view of future electricity needs and peak power on the electrical grids of Creos Luxembourg.

The report takes into consideration different possible scenarios for the future development of the industrial, tertiary and residential sectors, as well as for e-mobility and other consumers which were analysed with respect to their specific characteristics.

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

Finally, the estimated contribution of the different generation capacities during peak demand was subtracted from the peak load projections in order to obtain a prediction of future import needs. As can be seen in the figure below, every forecast scenario analysed in this report is exceeding the current maximum import capacities within the next decade.



Source: Creos Luxembourg

All scenarios developed in this report show that the total peak power demand and the related imports on the Creos grid are steadily growing while the maximum import and transmission capacities of the Creos grid remain limited. Indeed, the secured import capacity from the neighbouring grid operator in Germany is currently limited at 980MW. Furthermore, the existing import lines were constructed more than 50 years ago. Back at that time, the peak power demand reached only 10 to 15% of the installed capacity of these transmission lines. Today, at least 75% of those capacities are used during peak import times.

Due to the limited transmission capacities for energy trades purposes between the different bidding zones of Belgium, France and Germany, the interconnection with Belgium via the phase shift transformer cannot not be considered as an additional permanent infeed for Luxembourg. The full availability of that electrical energy supply cannot be guaranteed at any time. The grid connection with Belgium is a support connection increasing the overall security of supply of Luxembourg and it is mostly useful in case of a major unplanned unavailability on the German side.

Resolute and extensive energy efficiency measures, incentives and political directives are necessary to reach the ambitious objectives of the NECP target scenario. ‘Smart Grid’ solutions are needed to better utilize the existing and future infrastructure. Still, these measures will not be enough to accommodate the future power demands of the country by themselves but will need to be complemented by a stronger grid infrastructure. Creos, as part of the European Network of Transmission System Operators for Electricity (ENTSO-E), also acknowledges the Clean Energy Package as a priority and calls for stronger cross-border cooperation, in order to distribute and resorb the highly variable electricity flows from the renewables and to avoid congestions. To avoid possible constraints, it is therefore appropriate to increase the cross-border transmission capacities, where needed.

Electrical storage solutions like smaller, decentralized battery storages or bigger seasonal “Power to X” storages might emerge in the future in order to accumulate a surplus of generated electricity and to provide it when there is a consumption need. Electrical storage methods could indeed help reduce import peak demands, although in a limited way, and might be of importance then. But as those solutions are not yet fully developed and not cost-effective today, their consideration in the context of this study has been deemed as too speculative.

The future economic and demographic development and the necessary decarbonisation will lead to an increasing importance of electricity in the mix of energy end uses. Moreover, the design of the existing infrastructure dates from 50 years ago. Therefore, a modernisation is needed.

It is clearly necessary to increase the electrical energy import capacity and transmission capacities of the Creos high voltage grid.

Additionally, it is recommended to promote and support all technical or economic means, like smart-charging solutions for electric vehicles, load-shifting or peak-shaving measures, which could help to optimize the utilization of the entire electrical infrastructure.

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 becomes more and more challenging due to the uncertainties of the future economic, social and environmental developments.

In addition to higher electrical energy consumptions, the electrical grids of tomorrow will strongly be influenced by the desired decarbonisation process in the European Union. In order to stay in line with the EU-targets of a reduction of greenhouse gas emissions, an expansion of the use of renewable energies, and an improvement of the energy efficiency, the electrical grids must be adapted consequently. The transition to a post-carbon society will bring huge changes in the economic/industry, mobility/transport and domestic sectors, and will have a direct influence on the electrical energy needs.

The transformation of Luxembourg's economy and society has already begun and is progressing fast. The heavy industry is on the decline, making way for a smaller, specialized, energy-efficient industry and a shift occurs towards services like logistics, e-commerce and electronic data storage and management. The targeted decarbonisation in Europe and Luxembourg will surely lead to a general shift towards electrification for heating purposes and for public and personal transportation and the growing digitalization 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 as fast as the increase of the electricity consumption, thus intensifying the need for a strong electrical transport and distribution grid. A volatile, uncontrollable generation and a high consumption will stress out the electrical networks on all levels during the peak times. Efforts for a possible reduction or shift of the existing and future load during peak times will become necessary in the near future. First concepts and solutions serving this purpose have only recently been implemented.

But, an increase in controllable generation and a certain flexibility on the demand-side, might not be enough. A higher rate of self-consumption of the electricity generated by renewable energies, an optimized interplay between generation and load, and a better utilization of the electrical infrastructures will only be achievable with more smart grid devices in the grid and with the use of electrical storage. It will nonetheless be decisive that the storage is functioning in a "grid-friendly" way, by helping reduce peaks on the electrical grid.

Energy communities are said to become more popular as market entities which may engage in energy activities such as generation, distribution, supply, consumption, self-consumption, aggregation, storage and energy efficiency services. Citizen energy communities and renewable energy communities could then have an increasing occurrence on the Creos grid in the future, so an anticipatory package of grid connection and operation rules, conditions and incentives are absolutely necessary to help obtain the desired flexibility and the targeted grid-friendliness and grid-utility of electrical generation, storage and load in the future.

Considering the most recent developments together with the publication of the National Energy and Climate Plan (NECP), and in order to prepare for coming needs, new forecasts are needed for demand, supply, and infrastructure. Against this background, this report provides an outlook on the developments in Luxembourg's electricity sector, specifically those that are relevant for the high voltage grid of Creos Luxembourg.

Political framework and considerations

Besides the economic development, the European and the national environmental objectives are at least as significant for the projection of the electricity needs.

In accordance with the resolutions of the climate conference in Paris in 2015, with the EU-wide targets for 2030 (EU climate and energy framework 2030) and consistent with the European Green Deal Roadmap, the following European collective goals are provided:

- commitment to continue reducing greenhouse gas emissions, setting a reduction target of 40% by 2030 relative to 1990 levels
- a renewable energy share of at least 32%
- an improved energy efficiency of at least 32,5%

Thus, the framework helps drive progress towards a low-carbon, and then a climate-neutral economy and to build an affordable, secure and dependency-reduced energy system. It was adopted by the European Council in October 2014, and the targets for the renewables and the energy efficiency were revised upwards in 2018.

In context of the greenhouse gas emissions reduction target of 40%, EU emissions trading system (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). As part of the European Green Deal, the Commission aims to propose raising the EU target from 40% to at least 50% and towards 55% in a responsible way later on.

In order to ensure progress towards these common goals and commitments, a governance system has been put in place to monitor and to report the performed development. Under that 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.

Recently the Ministry of Energy and Spatial Planning of Luxembourg published the national energy and climate plan for Luxembourg (NECP LU), with clear and explicitly specified goals for the reduction of greenhouse gas emissions, for raising the renewable energy share and for improving energy efficiency.

In detail, Luxembourg strives 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 contribute at best 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)
- The 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 demands compared the EU-Primes Baseline projection (2007)

For the purpose of this present report, the key figures, facts and statements, relevant for the future electricity need and the future peak power on the electrical grids have been identified from historical values, from the data of new projects and from the NECP LU, and are listed hereafter in the chapters "Main assumptions made for the future electricity needs". They have been considered for the forecasts, here following.

Furthermore, one of the priorities of the European Green Deal is to shift 75% of EU freight traffic from road to rail. But the relevance of the instruments already in place needs to be highlighted, such as the 2011-Transport White Paper (with its ambitious modal shift-targets to rail) and the Shift2Rail Joint Undertaking.

According to the EU 2011 White paper 'Roadmap to a Single European Transport Area', the transport sector has to contribute to the EU climate engagements by reaching a target of 60% emission reduction until 2050. To reach this target, the following goals have been set:

- 50% less 'conventionally-fuelled' cars in urban transport by 2030
- achieve essentially CO2-free city logistics in major urban centers by 2030
- complete phase out of 'conventionally-fuelled' cars in cities by 2050
- shift of 30% of the road freight to rail or waterborne transport by 2030
- shift of 50% of the road freight to rail or waterborne transport by 2050

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

Moreover, in the residential sector, renovations could possibly imply more electricity needs. Fossil fuel sources used for heating will be replaced by heat pumps and / or direct water heating. Low energy houses or passive buildings could decrease or negate that effect. Positive energy buildings could generate their needs locally with solar systems and inject the surplus of electricity in the low-voltage grid at the disposal of others. Consumers could become more and more 'producer – consumers', prosumers. Communities of producers and consumers could act as local or renewable energy communities, trying to lessen their collective consumption impact on the 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 in order to ensure the achievement of a minimum target of 10% of existing electricity interconnections, no later than 2020, with the objective of arriving at a 15% target by 2030.

The association of the European Network of Transmission System Operators for Electricity (ENTSO-E) acknowledges the Clean Energy Package as an important milestone for Europe's green energy transition and sets 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 developments and efficient congestion management. Future system operations will rely upon a system of systems that should work as one in order to ensure the seamless integration of growing shares of decentralised resources. Innovation, cooperation and sector coupling will be key enablers of the future European system operations and electricity markets.
The European electricity demand will increase, driven by market uptake of technologies such as electric vehicles and heat pumps, despite of a huge increase in energy efficiency.

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

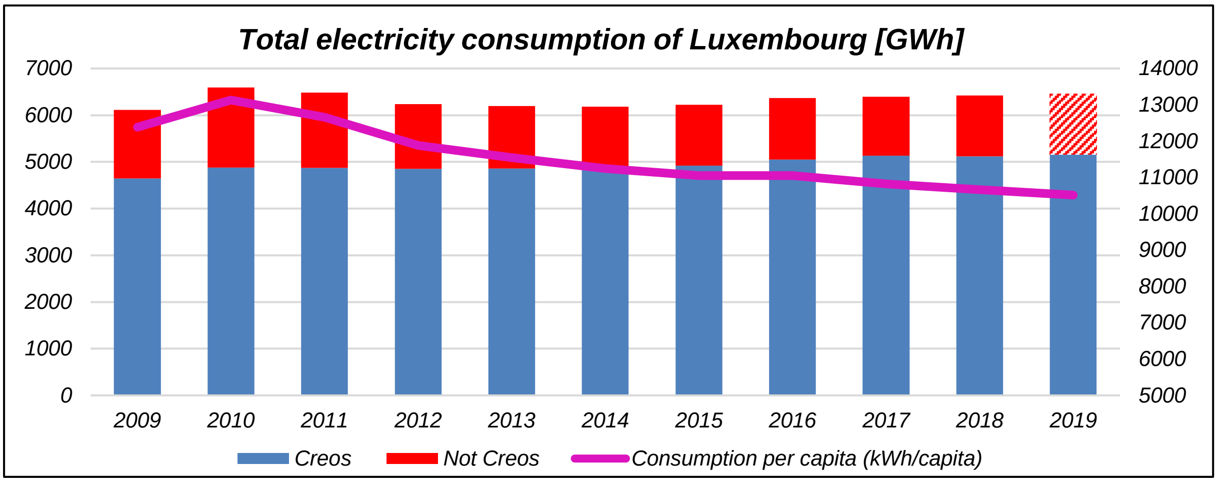
Retrospective

Retrospective of the electricity consumption and sectorial breakdown

The total electricity consumption of the Grand-Duchy of Luxembourg has decreased from 2010 to 2014, but it has increased again steadily after that from 2014 until today. Referring to this, the most recent available data from STATEC has been used:

Electricity tot. Lux.	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
GWh (losses excluded)	6112	6593	6484	6236	6199	6182	6224	6367	6393	6422	6455
Per capita (kWh/cap)	12386	13131	12655	11880	11543	11247	11055	11050	10824	10668	10515
Population (x 1000)	493,5	502,1	512,4	524,9	537,0	549,7	563,0	576,2	590,7	602,0	613,9

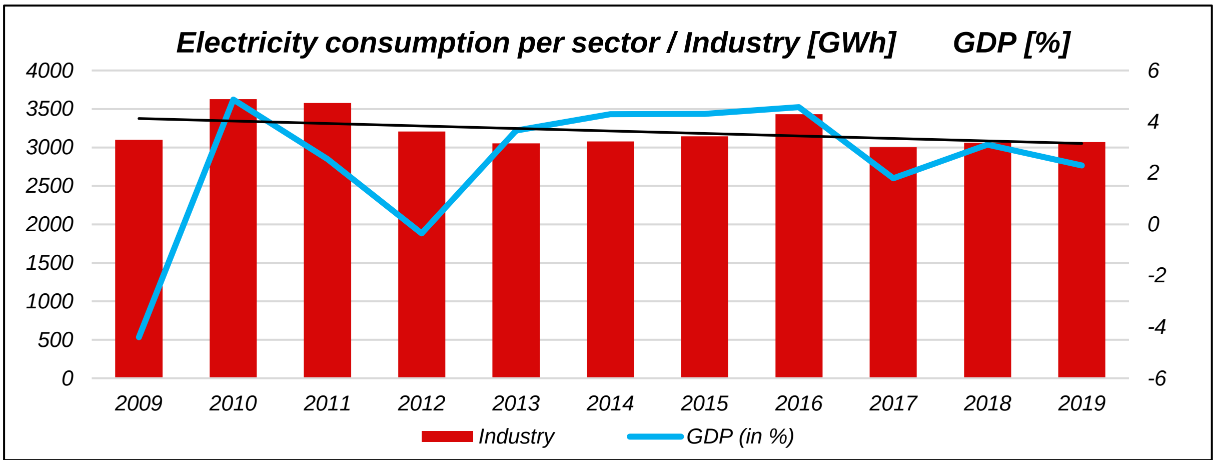
Source: STATEC



Source: STATEC & Creos Luxembourg

The decreasing electricity consumption figures per capita clearly shows an overall increasing energy efficiency. In fact, the electricity consumption per capita decreased by more than 15% in the last 10 years. Despite the clear growth of the population, the electricity consumption only slightly increased by 5,6% over the last 10 years.

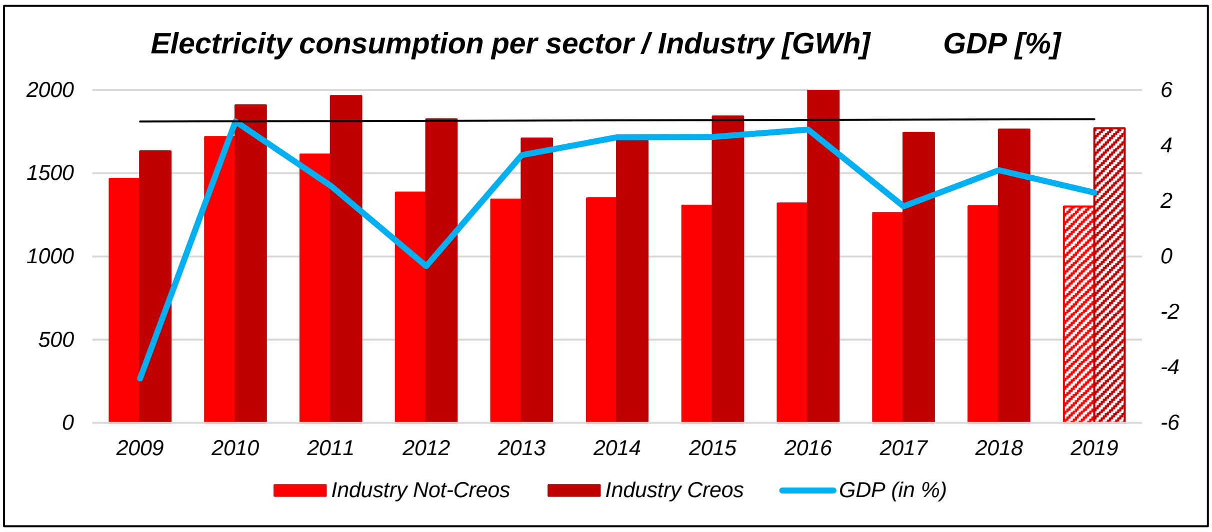
The reduced consumption from 2010 to 2014 was the result of energy saving measures throughout the industry, a decline of this sector and a weaker economic activity, though there has been a slight recovery in 2016, as seen here below.

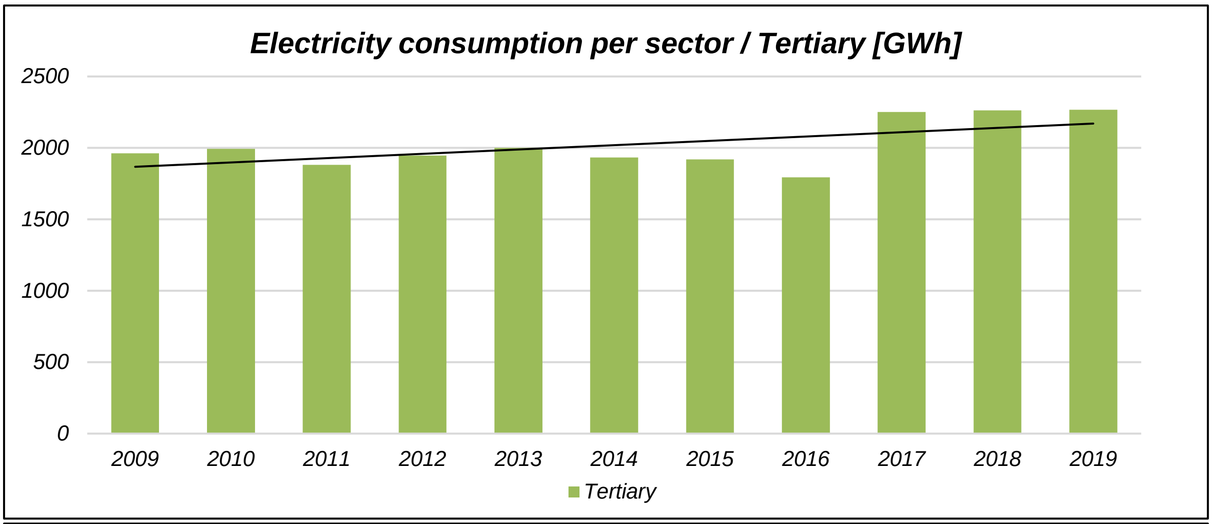


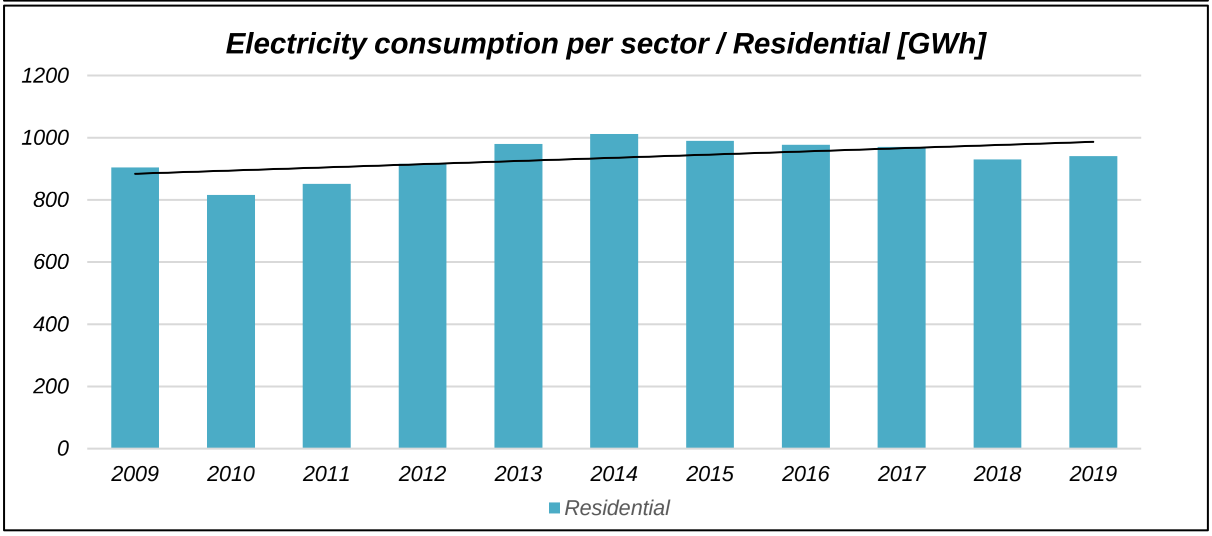
Source: STATEC & Creos Luxembourg

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

The consumption of the tertiary sector rose during the last 3 years and that of the households decreased slightly from 2014 on, but the 10-year trend for both sectors is still an increase of the electricity consumption.

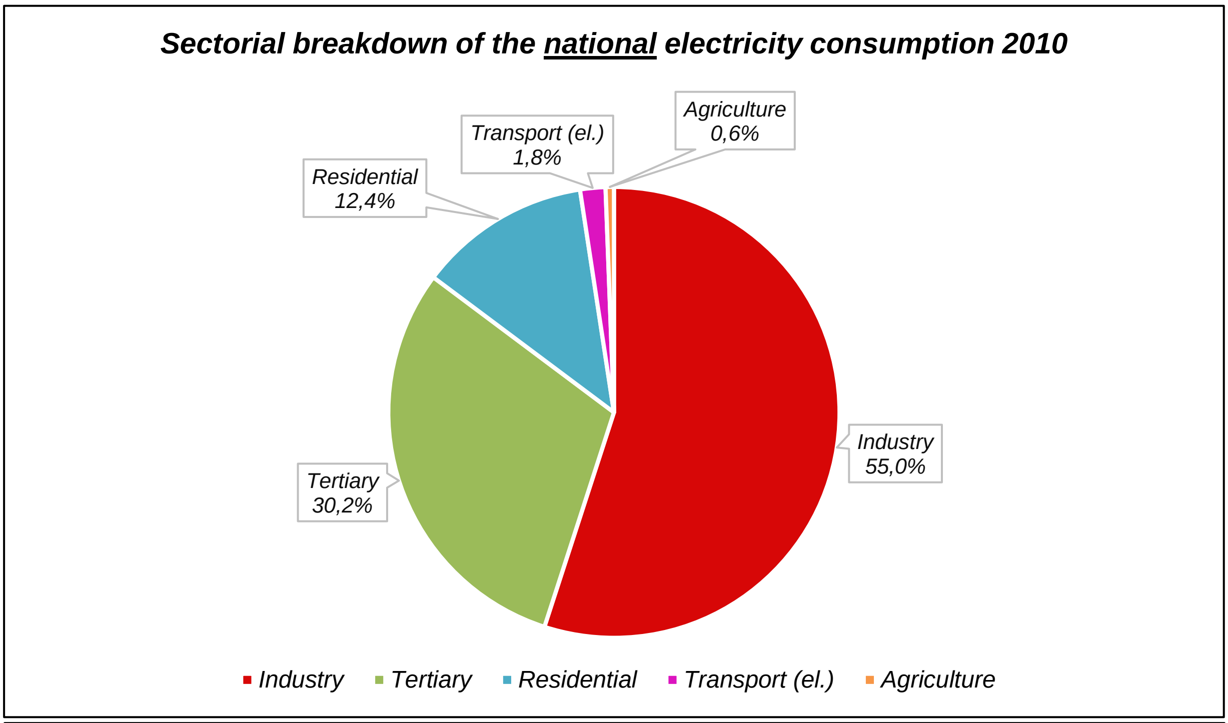


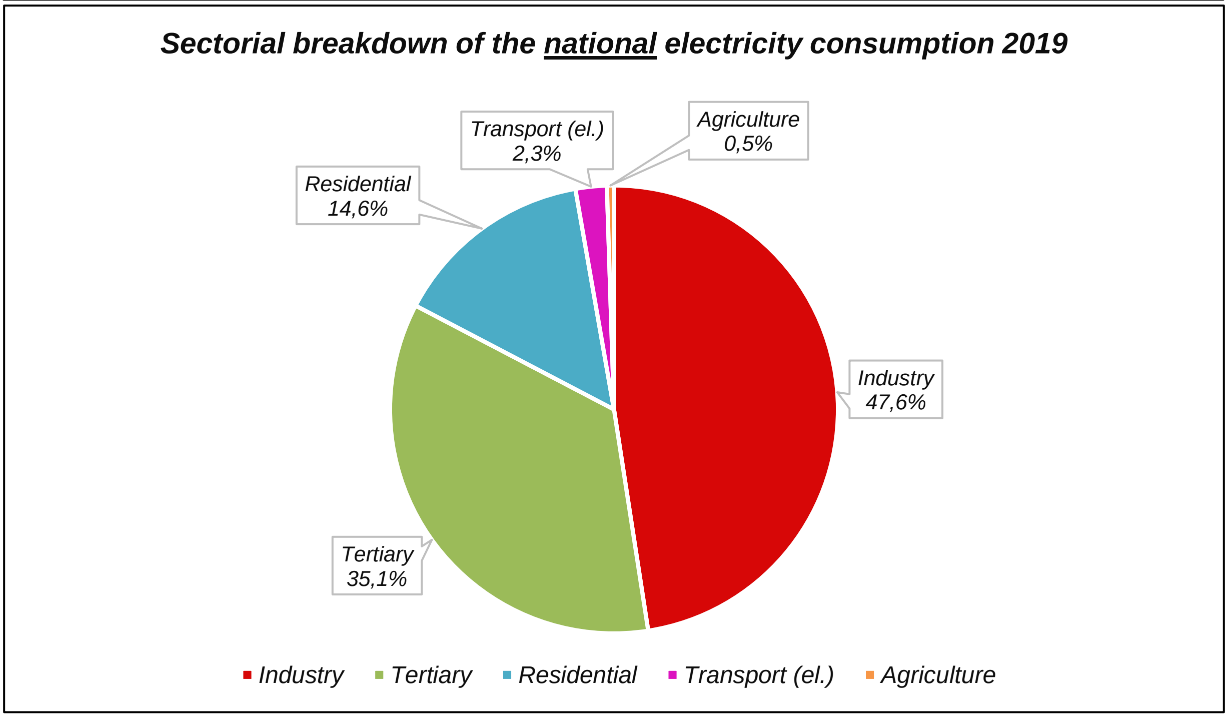




Source: STATEC & Creos Luxembourg

** not included: el. transport, agriculture & losses*



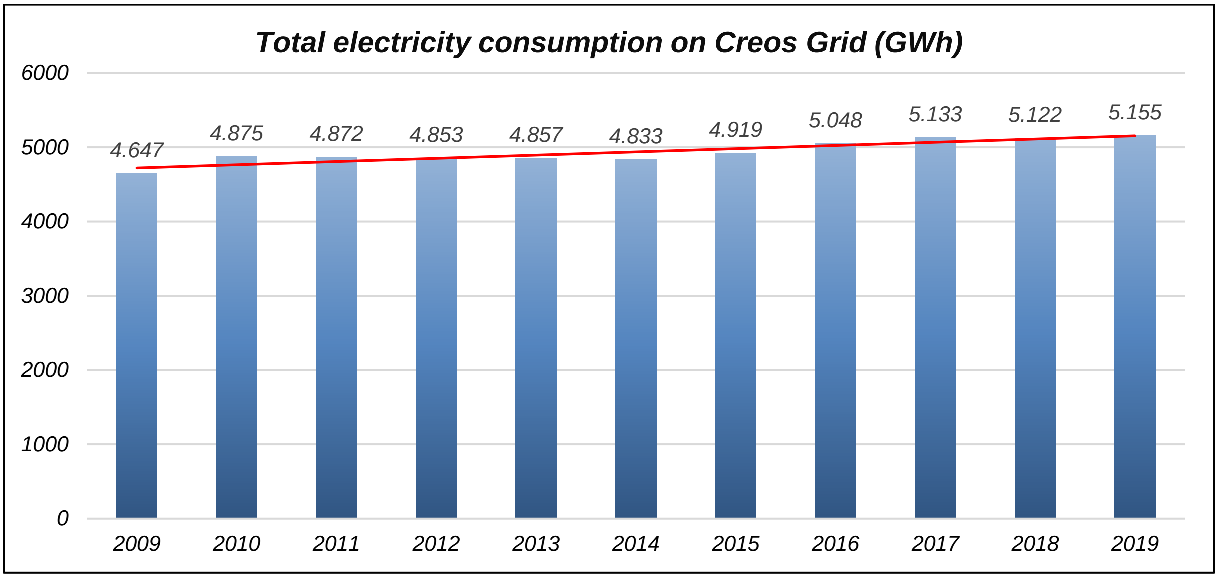


Source: STATEC & Creos Luxembourg

The general trend towards a growth of the residential and the tertiary sector can easily 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.

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

The measured, past consumption values can have temporary stagnating or even temporary negative growth trends, which could be misleading. Only a long-term analysis of the figures can really confirm the assumptions made for the purposes of a forecast. For example, with a large enough period of review, the steady growth of the total electricity consumption on the Creos grid becomes apparent.



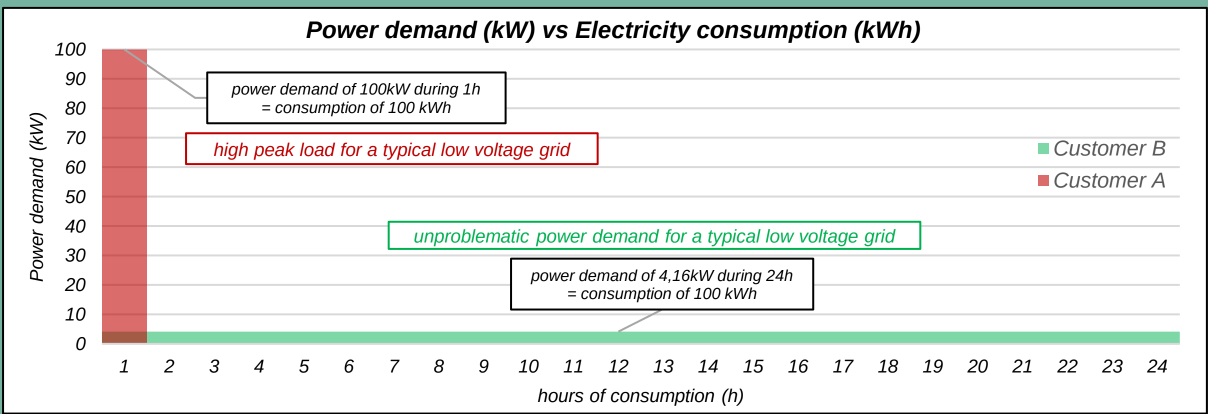
Source: Creos Luxembourg

Here it should be noted that, during the last 10 years, the growth of the electricity consumption on the Creos grid has been twice as high as the growth of the national electricity consumption.

Info box: Electricity consumption and power demand

It is essential to understand the difference between the power demand and the electricity consumption, both should not be confounded. Indeed, identical consumptions 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.

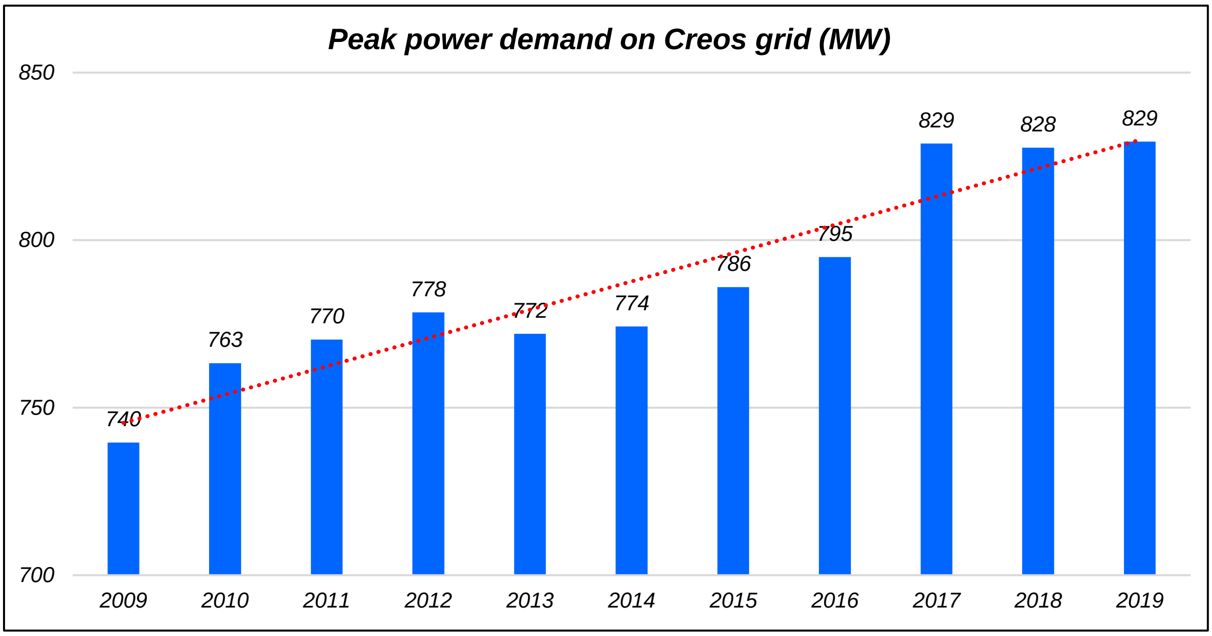
Both customers have the same consumption, but very different grid requirements.

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

Retrospective of the peak power demand

The most important value for the grid dimensioning is the peak power demand. And there has been a clear trend of a sustained growth of the peak power on the Creos grid during the last 10 years. The peak power increased by 12% over the last 10 years.

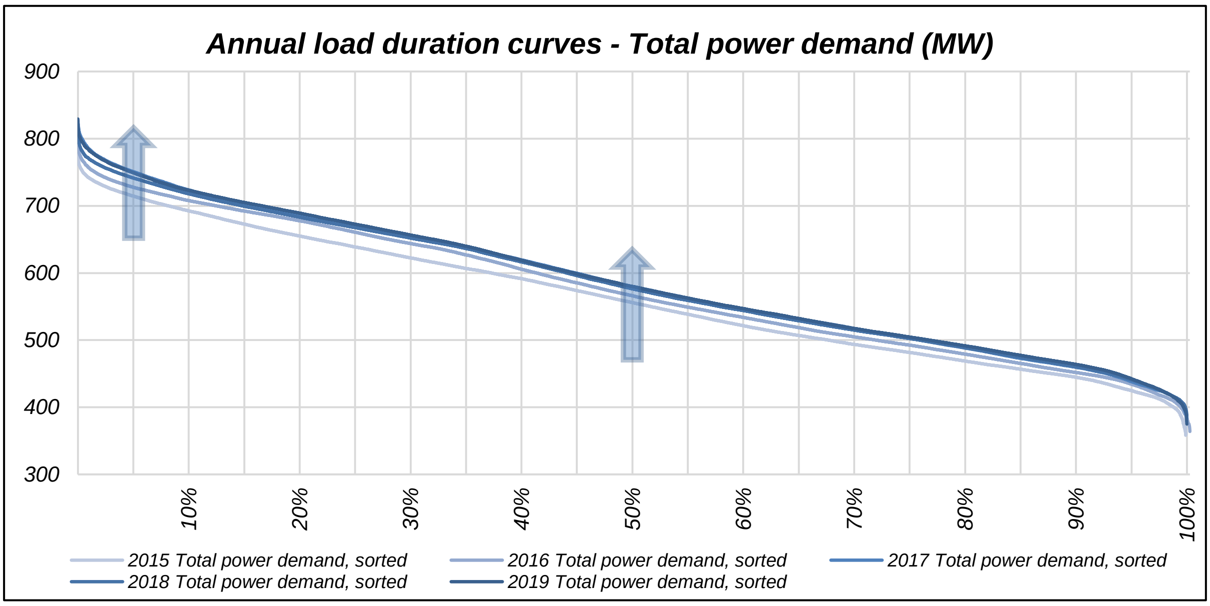
It should be noted that the peak power demand has made an extraordinary leap in 2017, which was mostly caused by the temporary switch of a part of the Non-Creos load on the Creos grid.



Source: Creos Luxembourg

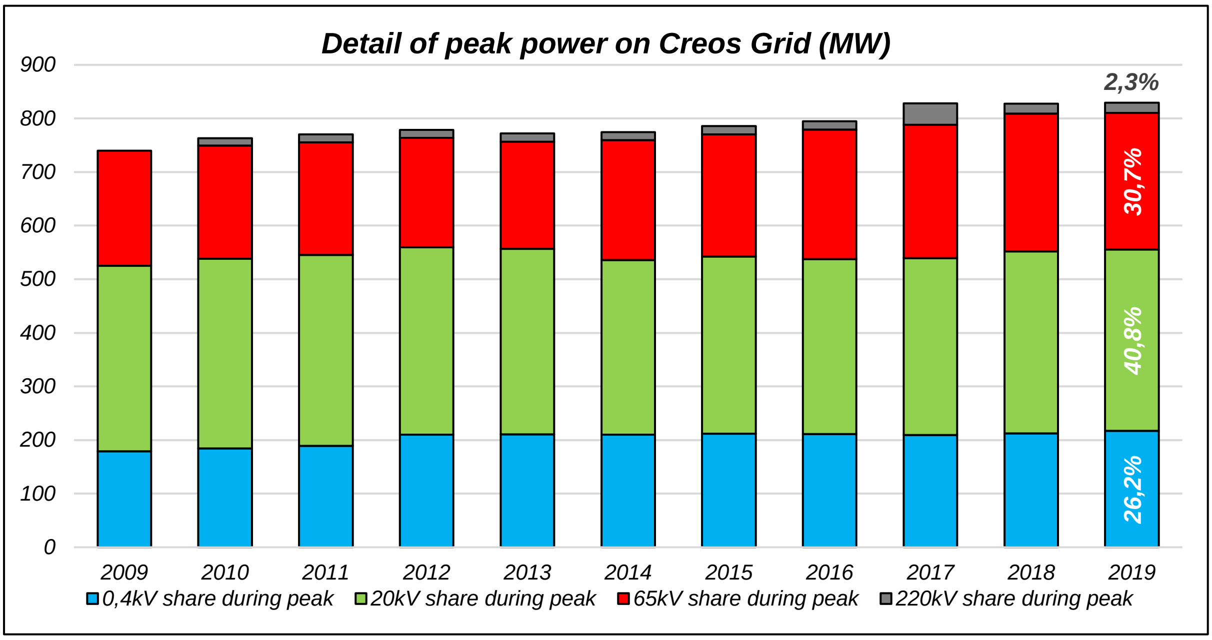
In fact, the total power demand curve keeps rising from year to year, as shown in the figure hereafter. During 5% of the time of the year, that means more than 18 days, a power between 750MW and 829MW was needed in 2019. In 2015, that range was notably lower, between 711MW and 786MW.

More power is needed more often, which shows a trend towards a higher consumption.



Source: Creos Luxembourg

For further grid analysis, the detailed decomposition of the peak power can be valuable, as shown hereafter. It should be mentioned that this subdivision has been calculated for the peak time and has been estimated with the respective energy values for the medium and low voltage share.



Source: Creos Luxembourg

At the moment of highest total power demand in 2019, on the 220kV voltage level, 2,3% of the power was needed for customers connected to the 220kV grid, 30,7% for customers connected to the 65kV grid, 40,8% for customers connected to the 20kV grid and 26,2% for the remaining low-voltage distribution.

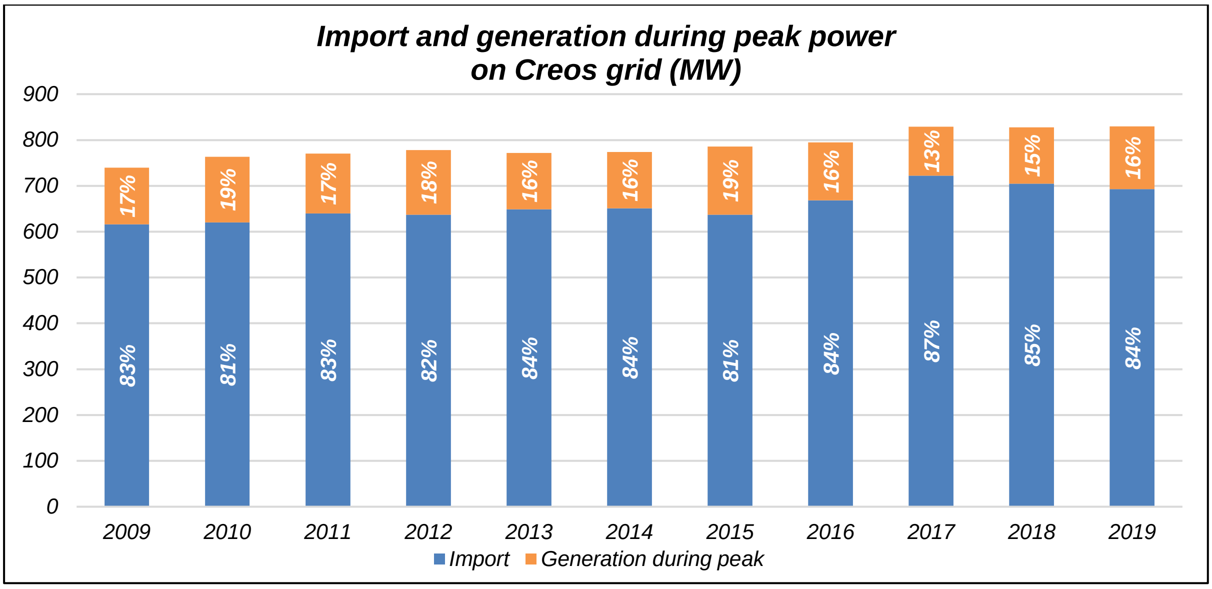
Approximately, the 65kV grid stands for the supply of the bigger industries on the Creos grid, the 20kV grid for smaller industries, big office buildings, commerce and service companies and the low-voltage distribution for the supply of the households and smaller businesses.

As shown above, the 220kV grid has to transport and distribute 100% of the power needed, and the 65kV grids nearly 98% of the total power, as the high voltage levels are also necessary for the supply of the lower voltage levels. This should explain why the biggest investments have to be made on the higher voltage levels.

It must be noted that the different voltage levels have different peak times and that the subdivision, each share, can therefore vary to a certain extent, depending on the time of view.

It is uttermost important to understand that the electrical grid has to be designed to ensure the security of supply for the 2 most critical conditions: the highest power demand for consumption needs with a minimum electricity generation and the highest power generation with a minimum power demand for consumption needs.

Hereafter is shown the breakdown of the total peak demand on the Creos grid and its past evolution, depicting the power generated by national generation assets during peak demand and the remaining import which had to be delivered from neighbouring countries.



Source: Creos Luxembourg

During the highest total power demand in 2019, 84% of it had to be imported and 16% were generated on national territory. During the peak demand in the beginning of 2017, only 13% were generated inland and 87% had to be imported, surely because of the temporary switch of a part of the Non-Creos load on the Creos grid. As can be seen, the relative generation during the peak power demand has not become bigger during the last 12 years and has even diminished between 2015 and 2017.

To satisfy the supply of the peak power demand, and without appropriate electrical storage capacities, electricity has to be generated at the exact time of the peak demand. Luxembourg has made huge efforts and remarkable progress to increase the national electricity generation and to reduce the total electricity import, but the power contribution of those generation units during peak consumption is still modest.

Further details on the electricity generation will be covered in the chapter “Electrical energy generation and renewable energies”.

Main assumptions made for the future electricity needs

National Energy and Climate Plan for Luxembourg (NECP)

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

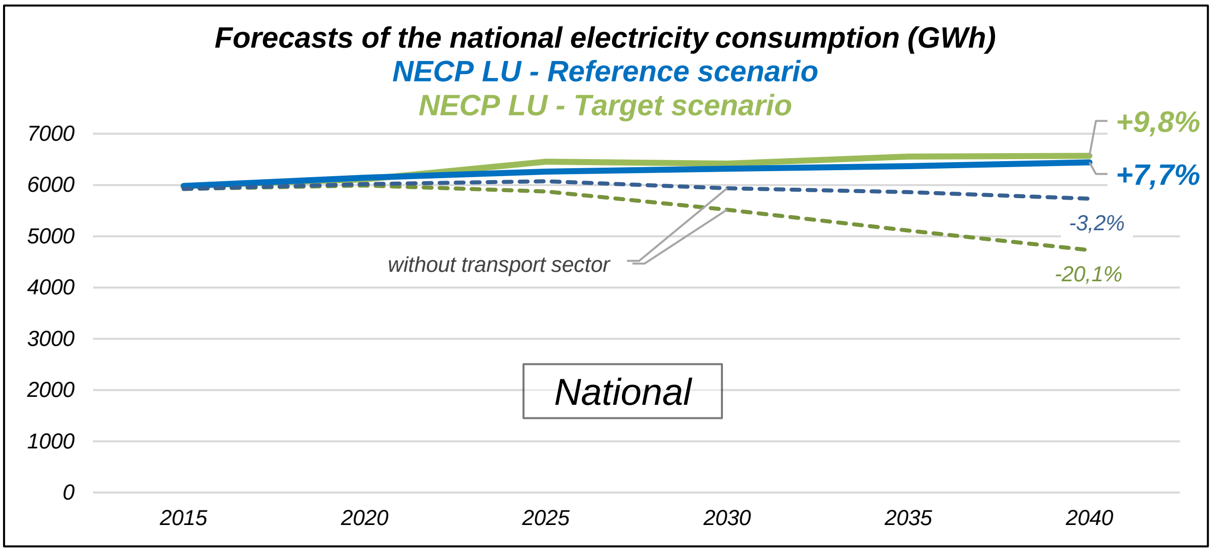
According to the STATEC, the population will rise to 752.000 inhabitants in the year 2030, and up to 870.000 inhabitants in 2040. Furthermore, a long-term economic growth has been presumed by a steady yearly growth of the GDP of 3% from the year 2025 on.

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

It can be reasonably assumed that fossil fuels will mostly be replaced to cover the future final energy demand. A shift towards the use of more electricity will surely take place. For instance, the future electrical transportation means will be more energy efficient as 'conventionally-fuelled' vehicles, but the greater needs for 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 scenarios for future forecasts, a reference scenario with a slight increase of 5,2% of the total final energy demand and a target scenario "Paris Art. 2.1a" with a decrease of 40% of the final energy demand. **For both scenarios however, a relative growth of the national electricity demand has been calculated** (NECP Luxembourg / pages 156 and 186: Comparison of the evolution of the heat requirements and the electricity demand):

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



Source: NECP Luxembourg & Creos Luxembourg

It should be noted that the figures of both forecast scenarios represent future national electricity consumptions and it has to be mentioned that **the actual, absolute values of the**

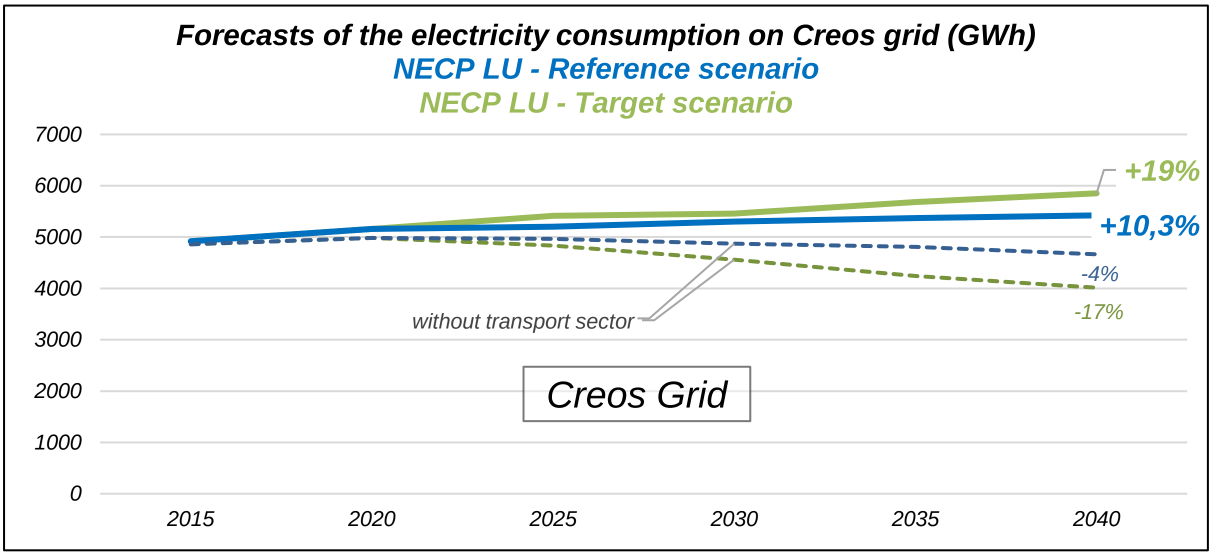
total electricity consumption from the STATEC or from the national regulation institute ILR were already higher than the NECP calculated values for the time period 2015 until today.

The bottom-up model used for the calculations in the NECP LU takes into account all 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). The heavy industries and the aerial transport are under the emission trading system (ETS), the residential, the tertiary sector and the smaller industries are not under emission trading (non-ETS).

For the reference scenario it 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 in fact, 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 of 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 the future electricity consumption on the Creos grid:

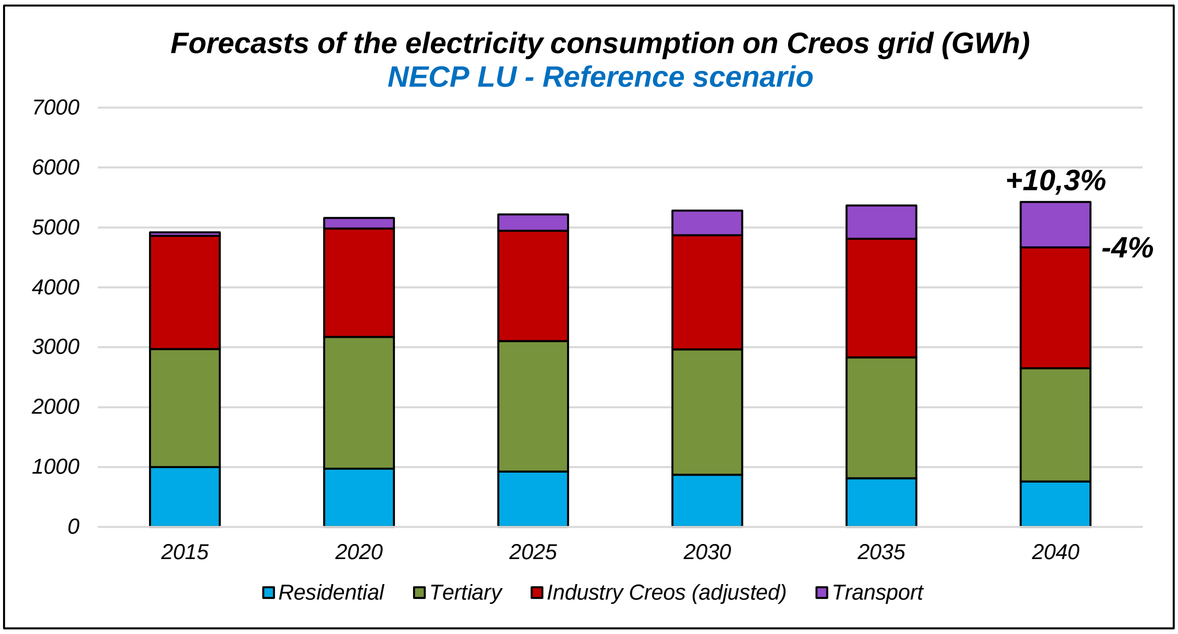


Source: NECP Luxembourg & Creos Luxembourg

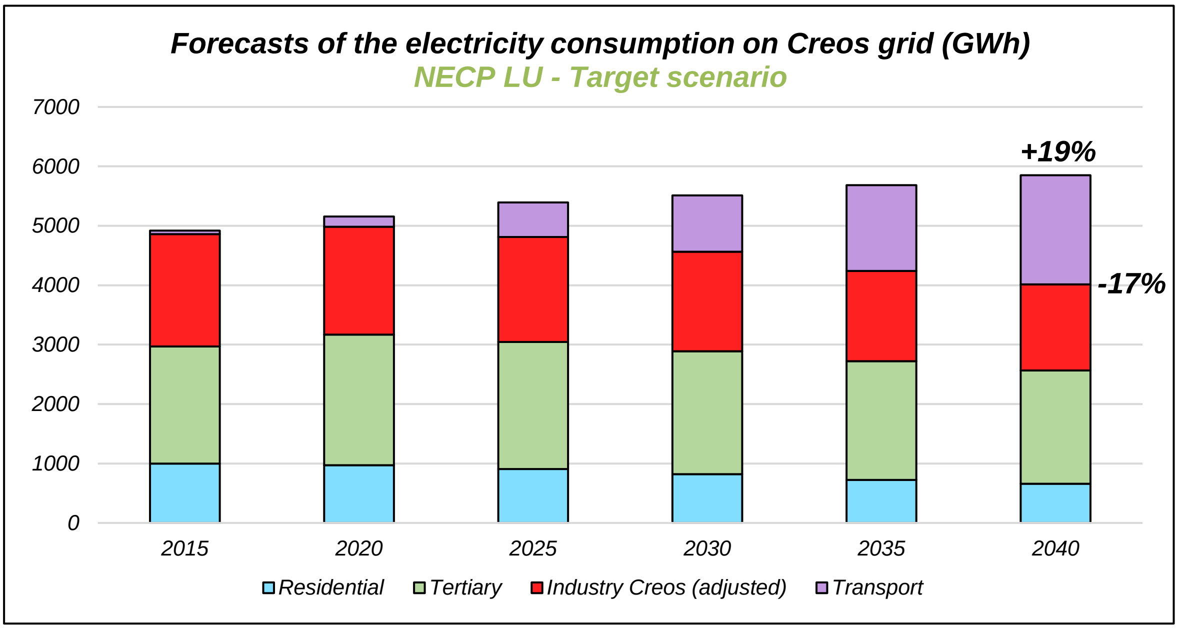
Both forecasts include the (electric-driven) transport sector. A ratio of about 50% of electric / plug-in hybrid vehicles, or grid relevant electric vehicles was assumed for the year 2030 for the target scenario.

During the previous chapter 'Retrospective', it has already been shown that the past electricity consumption growth on the Creos grid has been higher than the past national consumption growth. This also confirms that the adjustment of the growth figures calculated in the NECP LU seems right in order to better represent the 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):

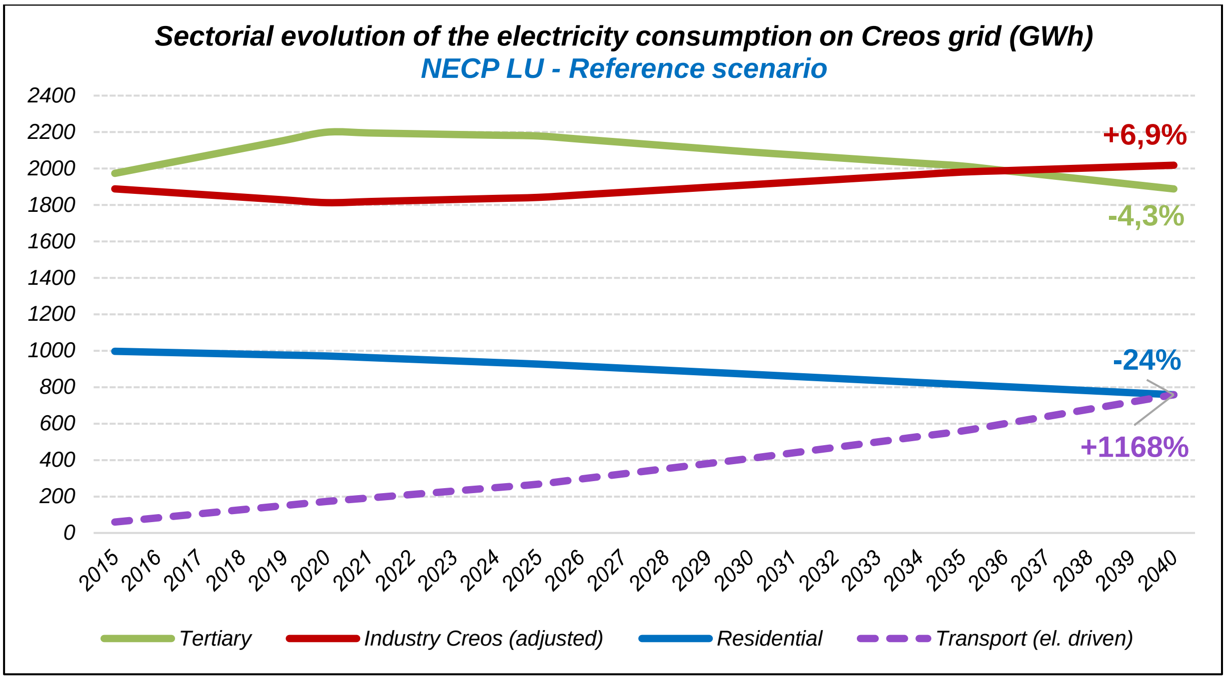


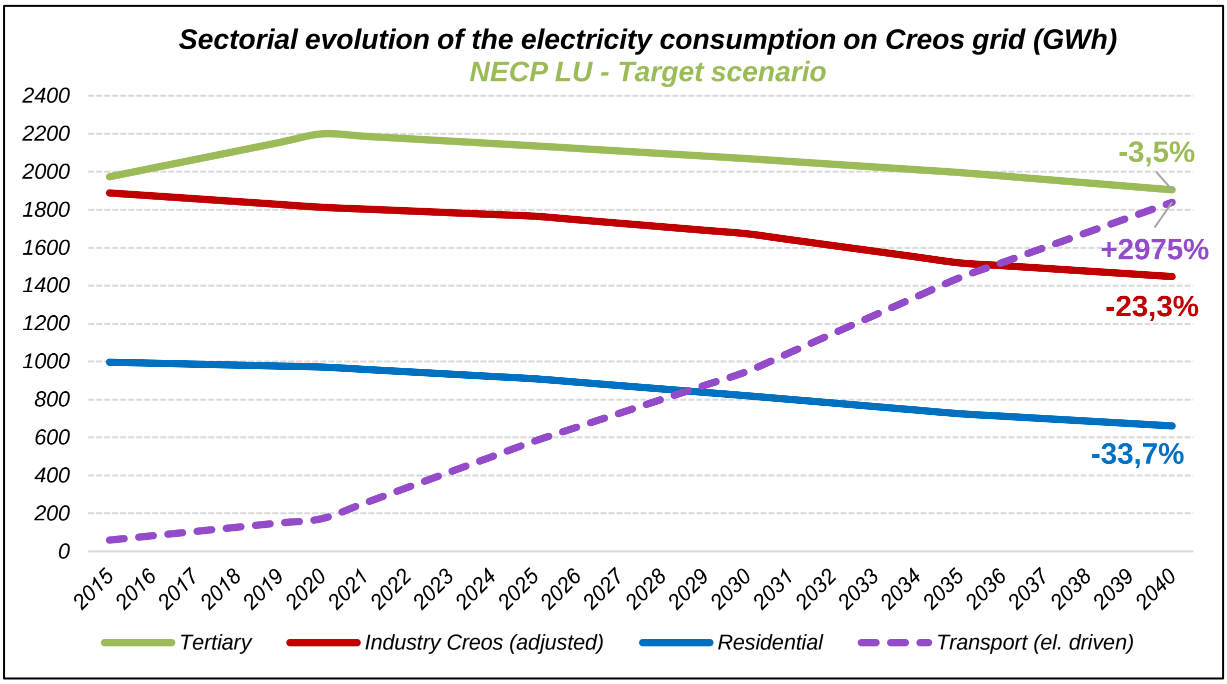
Source: NECP Luxembourg & Creos Luxembourg



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 relatively to the year 2015, in order to be able to compare the values with other assumption scenarios.





Source: NECP Luxembourg & Creos Luxembourg

Nevertheless, those forecasts **do not include** additional electricity consumers such as the datacenter project in Bissen / Roost, other datacenters or all other projects with high electrical energy needs.

Those additional consumptions and their related peak powers must be added to the forecasts separately.

NECP LU - Residential sector

Both scenarios of the National Energy and Climate Plan foresee a decline of the 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 sensibilization of the population, with a necessary energy awareness and a consistent public behaviour. The increased energy efficiency of future electric devices should help to reduce the electricity needs per inhabitant, but to foresee a decrease of the total electricity consumption in the future seems to be very ambitious.

It is aimed to accomplish this target with the modernization and an ambitious renovation rate of the existing residential buildings and with revised regulations for the construction of new buildings which 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.

NECP LU - Tertiary sector

Here also, a slight decrease of the total 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 surely be more energy efficient, so that a lot less thermal and electric energy per employee will be necessary. A decrease of the total electricity demand of this sector in the future is possible, but opposite to the actual and past trend of the last years.

NECP LU - Industry sector

In the reference scenario of the NECP LU, a light increase of the electricity consumption of industry is anticipated in the future. Despite the obligation of the industry to improve the energy efficiency, additional industry plants and facilities would certainly lead to a higher electrical energy consumption. A higher degree in automated processes and an intensified use of electricity for thermal purposes could also explain the increase.

Contrary to that, in the target scenario, a strong decrease of the electricity consumption of this sector is presumed. 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 the industrial operations.

NECP LU - Transport sector

The NECP LU forecasts for the reference scenario and for the target scenario will be considered without the transport sector in order to allow the use of own projections for the electric-driven transportation.

Main assumptions made for the future electricity needs

TIR / Rifkin - Energy Demand scenarios 2050 for Luxembourg

Additionally to the reference and target scenarios from the National Energy and Climate Plan for Luxembourg (NECP LU), another outlook for a possible future development of the electricity consumption was considered.

In the context of the Third Industrial Revolution (TIR) / Rifkin Study, the 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 developed two different scenarios for the time 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 growth of 86% until 2050 (about 1,026 million inhabitants), the following figures 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 of the electricity demand as found in the Fraunhofer study and the historical values given by the 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 the electrical energy demand of the sectors.

In accordance with the estimation of the Fraunhofer ISE 'Energy demand scenarios 2050 for Luxembourg', the electric energy need is supposed to rise up to 17% till the year 2050 (till the year 2040, about 12%).

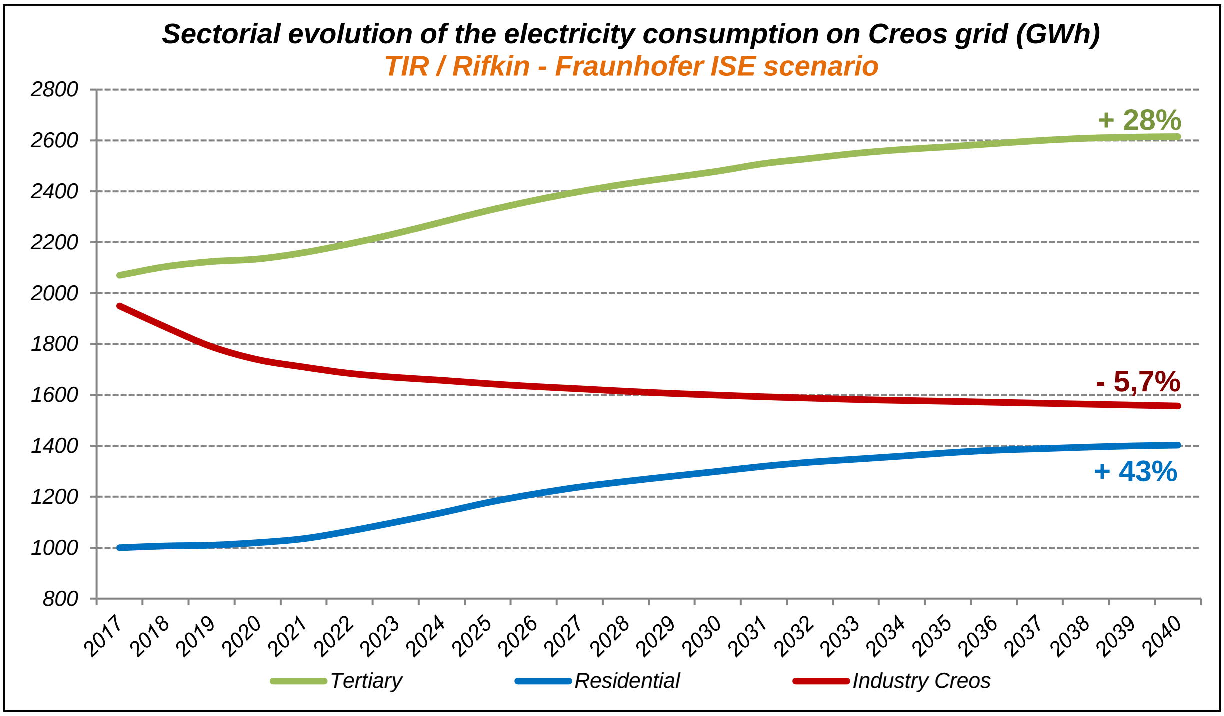
For the year 2040, the following future energy variations can be calculated for the different sectors:

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

Source: Energy Demand Scenarios 2050 for Luxembourg, Fraunhofer ISE

Here too, it is necessary to mention, that an adjustment of the growth of the industrial sector would be more accurate, in order to consider the fact that not all the industry of 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 that 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

TIR / Fraunhofer ISE - Residential sector

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

TIR / Fraunhofer ISE - Tertiary sector

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

TIR / Fraunhofer ISE - Industry sector

As already mentioned, a transformation of the current European industry form will surely occur. Existing heavy industries tend to be replaced by smaller, more specialized industries with a high know-how and lesser energy hunger. This could lead to a reduction of the electrical energy consumption of this sector. New investments in this field guarantee, throughout a 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 surely be more energy efficient than in the past.

Nonetheless, during the past years, grid connection requests have been made for several new industry facilities, as can be seen in the table below.

List of projects and demands with high electrical energy needs						
Industry						
Voltage level	*Locality*	*Adress*	*Name of partner or project*	*power requested*	*n° project*	*Comments*
65kV	*Niederkorn*	*Z.I. Hahneboesch*		*7,5MVA phase 1* *32MVA final phase*		*carbon industry*
65kV	*Sanem*	*Z.I. Gadderscheier*		*+10MVA*		*power increase from 20 to 30MVA*
65kV	*Wiltz*	*Z.I.Salzbaach*		*+6MVA*		*metallurgical industry* *expansion planned for 2021*
20kV	*Riedgen*	*Z.I. Riedgen / Eurohub*		*8MVA*		*metallurgical industry*
20kV	*Riedgen*	*Z.I. Riedgen*		*4,5MVA phase 1* *9MVA phase 2* *13,5MVA phase 3*		*tire industry / second site*
20kV	*Mertert*	*Rte de Wasserbillig*		*6MVA*		*awaiting official request*
20kV	*Diekirch*	*Z.I. Fridhaff*		*4MVA phase 1* *6MVA phase 2* *8MVA phase 3*		*awaiting official request* *phase 3 needs to be confirmed*
Subtotal				***46MVA short term*** ***83,5MVA long term***		

Source: Creos Luxembourg

Forecast of the future electricity need and peak power demand (p.1)

Ordinary load

To sum up, the following figures have been used for the growth of the electricity consumption, representing the **ordinary load**, on the Creos grid for the different scenarios:

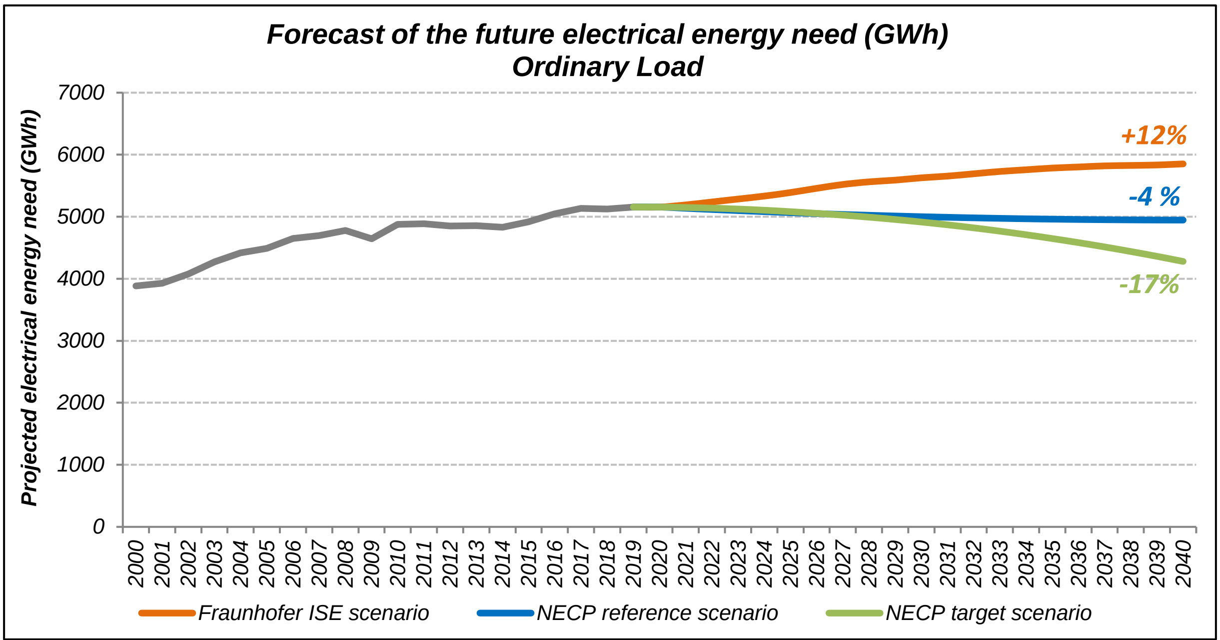
Variation of the electricity consumption 2015 - 2040	NECP LU Reference scenario	NECP LU Target scenario	TIR / Fraunhofer ISE scenario
Total growth ratio	*+10,3%*	*+19%*	*/*
Total growth ratio (without transport sector)	*-4%*	*-17%*	*+12%*

Source: NECP Luxembourg & Creos Luxembourg

In accordance with the estimation of the Fraunhofer ISE, the electric energy consumption is supposed to rise by 12% until the year 2040. According to the National Energy and Climate Plan, the electricity consumption is supposed to rise between 10,3% and 19% up to the year 2040, depending on the scenario. Though, those growth figures include the transport sector. In order to compare those figures with the figures from the Fraunhofer ISE study, the transport sector has been subtracted from the values of the NECP LU.

Because there is already a difference between the projected values from the NECP report, the Fraunhofer ISE estimation and the real values for the time period 2015-2020, it has been decided to neglect that period, and to apply the growth ratio of the three scenarios from the year 2020 on.

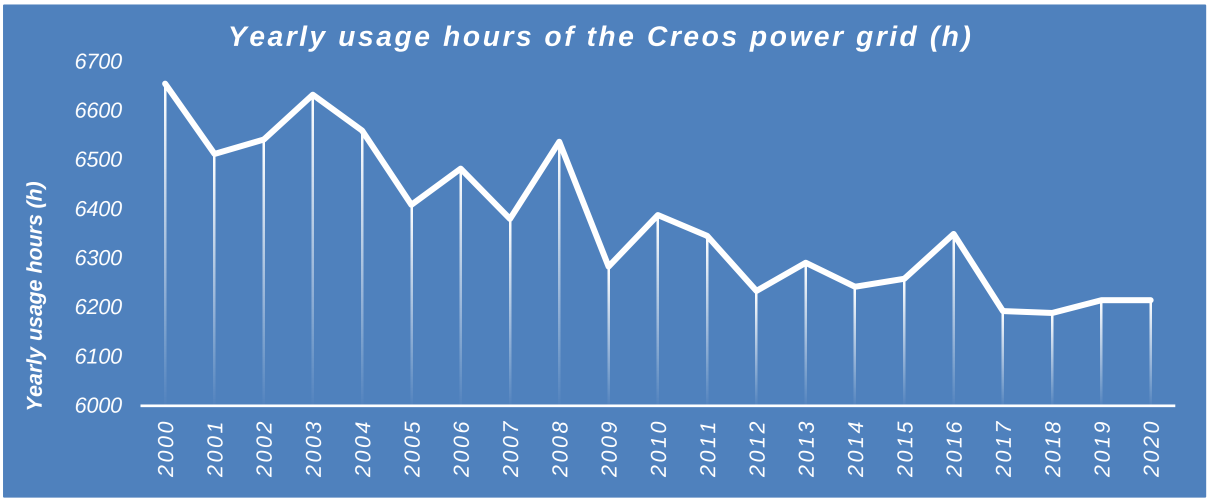
The forecast of the future electrical energy need of the ordinary load can be seen hereafter:



Source: Creos Luxembourg

Later on, the electric-driven transport will be added as supplementary load for all the scenarios here analysed.

It is a fact that the yearly usage hours of the power grid have decreased during the last 20 years:

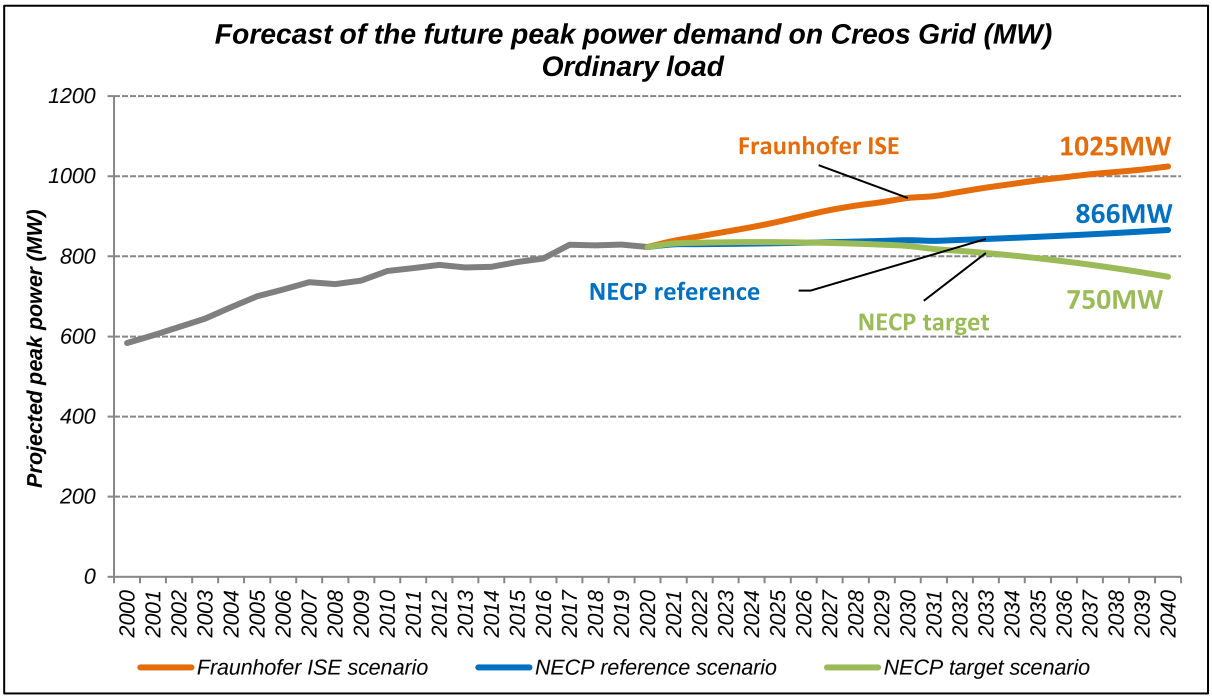


Source: Creos Luxembourg

That could possibly mean that the peak power demand has grown faster than the electricity consumption. If the consumption and the power demand would have grown at the same pace, the yearly usage would have been stable.

The usage hours will further decrease in the future, the power demand may become more erratic, possibly for shorter periods of time, creating more peak power demands. **Thus, the peak power demand may even grow, although the overall electricity consumption becomes less.** Without a better control of the electrical load, without a higher degree of control of the electricity generation, and without any electrical storage capabilities, the future grid must be built to satisfy these erratic and growing peak power demands.

The related future peak power on the Creos grid can be calculated with the forecast of the future electricity need and with the degressive yearly usage hours.



Source: Creos Luxembourg

However, additional loads such as E-mobility, data centers and all other projects with high energy needs must not be forgotten.

Typically, data centers have high usage hours per year and the e-mobility has very low usage hours for the power that is needed, that is why the estimation of those loads using their respective energy needs may not be accurate enough. **Those supplementary loads must be added separately to the forecasts**, and they will be described in detail in the following chapters.

Additional loads

Transportation operated by electricity / E-mobility

The future need of electrical energy of the transportation sector is the most difficult to predict. As ambitious political goals in emission limitations have been set, a 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 would be emission free and could replace fossil fuelled vehicles in the middle and long term. The on-going evolution of electric vehicles will undoubtedly lead to a lower energy need per inhabitant as in the past and present. Nonetheless, the electricity needed in future for transportation of any kind, assuming there is a mass shift to E-mobility, will have to be provided by the electrical grids.

A complete shift of the energy needs of the transport sector from fossil fuels to electricity would exceed the present grid capacities on all voltage levels and would lead to overloads, because of the characteristic power demand curves of electric vehicles. Optimized, smart charging of electric vehicles is a must and could lessen the risks of congestions on the grids, although that will not be enough to prevent the necessity of further electrical grid reinforcements. This situation could be aggravated by an ‘E-fuel tourism’, which would be provoked by attractive inland electricity costs. Cross-border commuters could also want to charge their electric cars during the working hours on their workplace in Luxembourg.

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

In order to promote the E-mobility and to offer public recharging possibilities, eight hundred public charging stations for electric vehicles (1600 charging points), under the label ‘Chargy’, are currently being installed on public parking lots throughout the country. Included in that total number of charging stations, it is intended to install eighty-four fast charging and super charging stations on key points throughout the country and on the major service areas on the motorways.

Since January 2017, tax incentives have been offered for the acquisition of electric and hybrid vehicles. Since 2019, financial bonuses have been given for low-emission or emission free vehicles and even more generous bonuses have been introduced this year. Furthermore, the installation of a private charging station at home, a so-called wallbox, is being subsidized. The offered incentives and bonuses seem to work, **as the registrations for new electric and hybrid vehicles are strongly rising**. With better range capabilities and better market prices in the future, there may be even a broader acceptance with an accelerated growth of the registrations.

Concerning the electric-driven transportation, a first, major distinction can be made between the transport on rail and on the road:

Electric-driven transportation

on rail | *on road*

Those categories must be analysed more in detail hereafter.

E-mobility / Electric-driven transport on rail

Electric-driven transport on rail

Train | *Tramway* | *Funicular*

It is important to note that the public passenger and goods transport on rail in Luxembourg is already electrically driven, and that the electrical assets of the national railway company are constantly increasing. After the completion of a new additional connection point at the end of the year 2020, all the electrical assets of the national railway company will be connected to the Creos grid.

Besides the electric-driven trains, there is also a railcar network in the capital city, which is powered by electricity. The first section of this tramway is already in service and several additional sections and extensions are planned, which could double the needed power demand for the railcar network in the future.

Recently, a preliminary project for a fast tramway, connecting the capital city and the biggest city in the south of Luxembourg, was presented. But the power demand for that project is still unknown and thus, has not been listed hereafter.

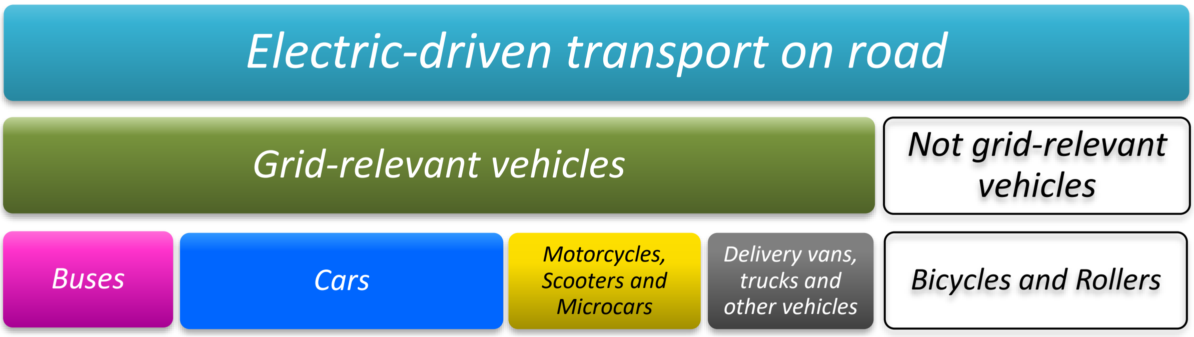
Furthermore, at the end of 2017, a new funicular railway was put into operation in the capital city, transferring passengers from a train station to a tramway station.

Resulting from these facts, it is rational to expect a rising power demand from the electric-driven transport on rail in the future.

List of projects and demands with high electrical energy needs						
Electrically driven transport on rail						
Voltage level	*Locality*	*Adress*	*Name of partner or project*	*power requested*	*n° project*	*Comments*
220kV	*Flebour*	*/*	***CFL***	*30MVA*		*about 2020*
20kV (phase 1) *65kV (phase 2)*	*Luxembourg*	*Kirchberg*	***Luxtram***	*4MVA phase 1* *6MVA phase 2* *8,5MVA phase 3* *10MVA phase 4*	*37092*	*railcar in the capital city*
Subtotal				***34MVA short term*** ***40MVA long term***		

Source: Creos Luxembourg

E-mobility / Electric-driven transport on road



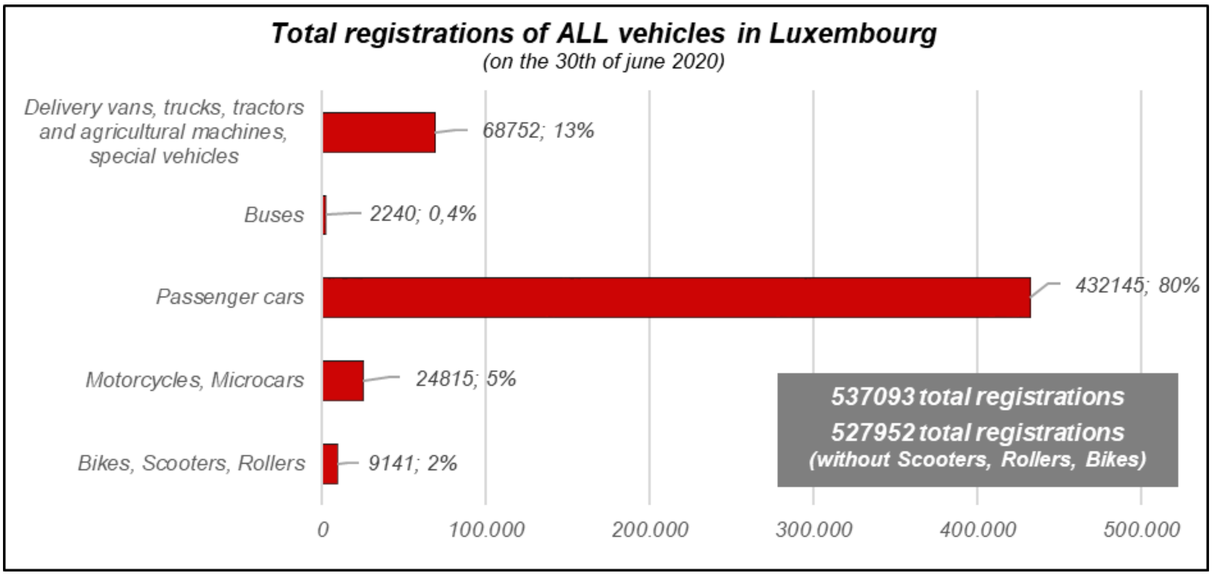
The electric-driven transport on road can be divided in two major categories: the grid-relevant vehicles and those vehicles that are not relevant for the power grid.

The **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 a low charging power, such as electric bicycles or rollers. For example, the chargers of E-bicycles and rollers typically have a nominal power range from 0,1kW to 0,5kW, 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.

The grid-relevant vehicles include battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV), they can be further subdivided in all the vehicles forms such as: buses, cars, motorcycles, scooters, microcars, trucks, delivery vans, agricultural machines and other special vehicles.

Illustrated hereafter are the actual total registrations of all the vehicles on the road in Luxembourg, that means vehicles using all fuel types. As can be seen, the most are passenger cars, trucks and utility vehicles.

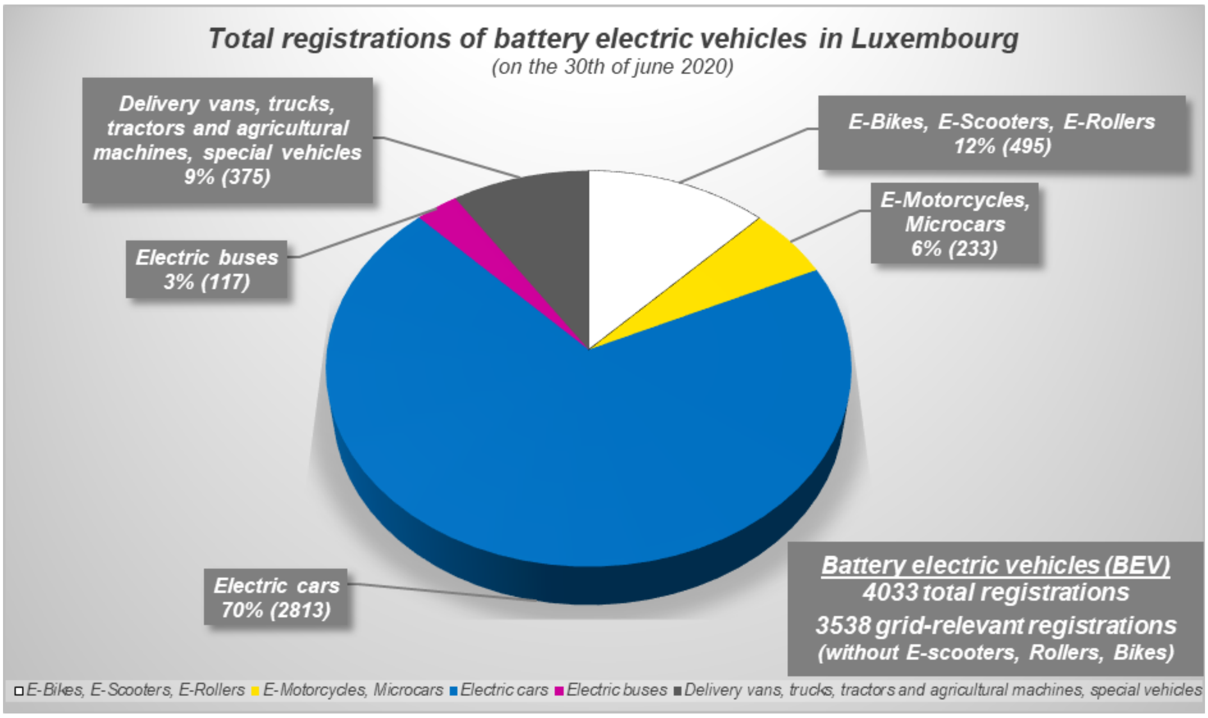


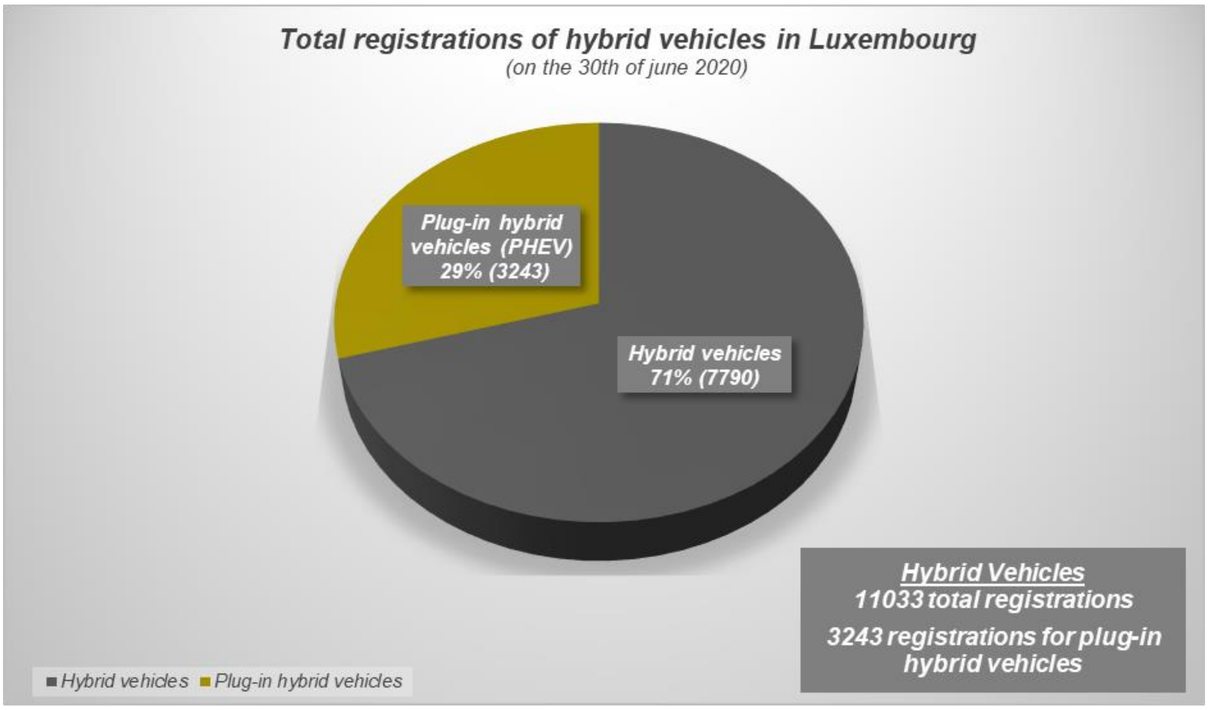
Source: SNCA

As already mentioned, concerning power grid-relevant vehicles, a distinction can be made between battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV).

Both categories have been quite popular in the last years and the registrations of those vehicles are rising exponentially.

In fact, on the 30th of June 2020, there was a total of 3538 grid-relevant battery electric vehicles registered in Luxembourg, with a majority of electric cars. Additionally, another 3243 plug-in hybrid vehicles have been licensed until that day.





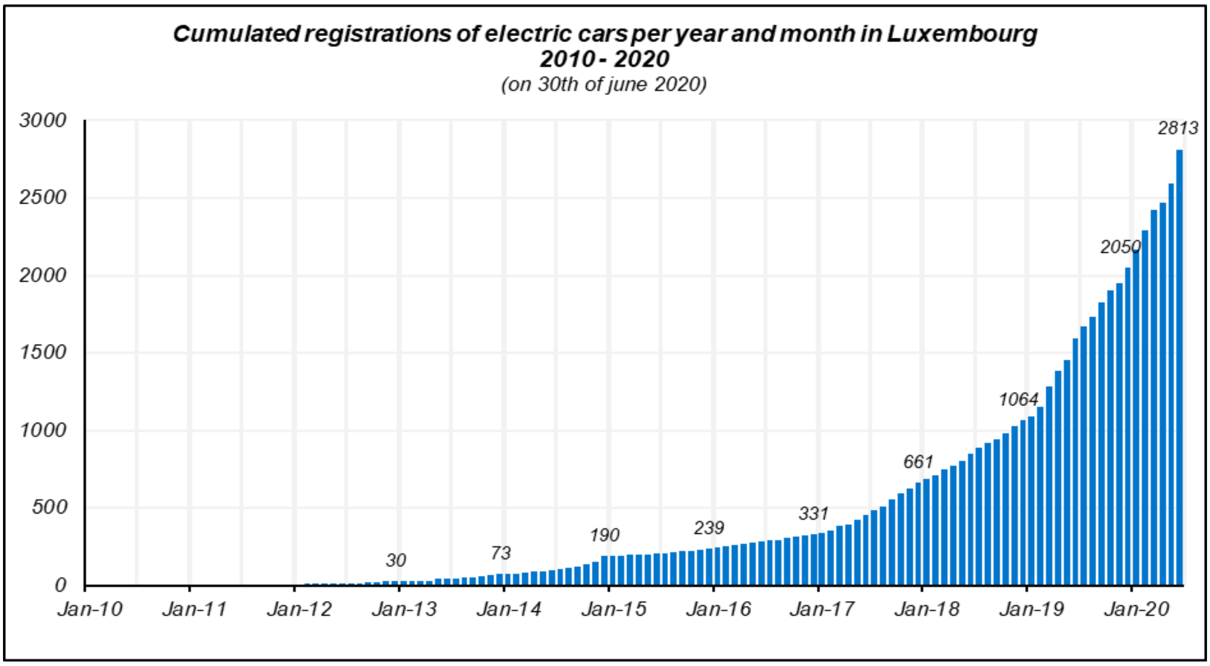
Source: SNCA

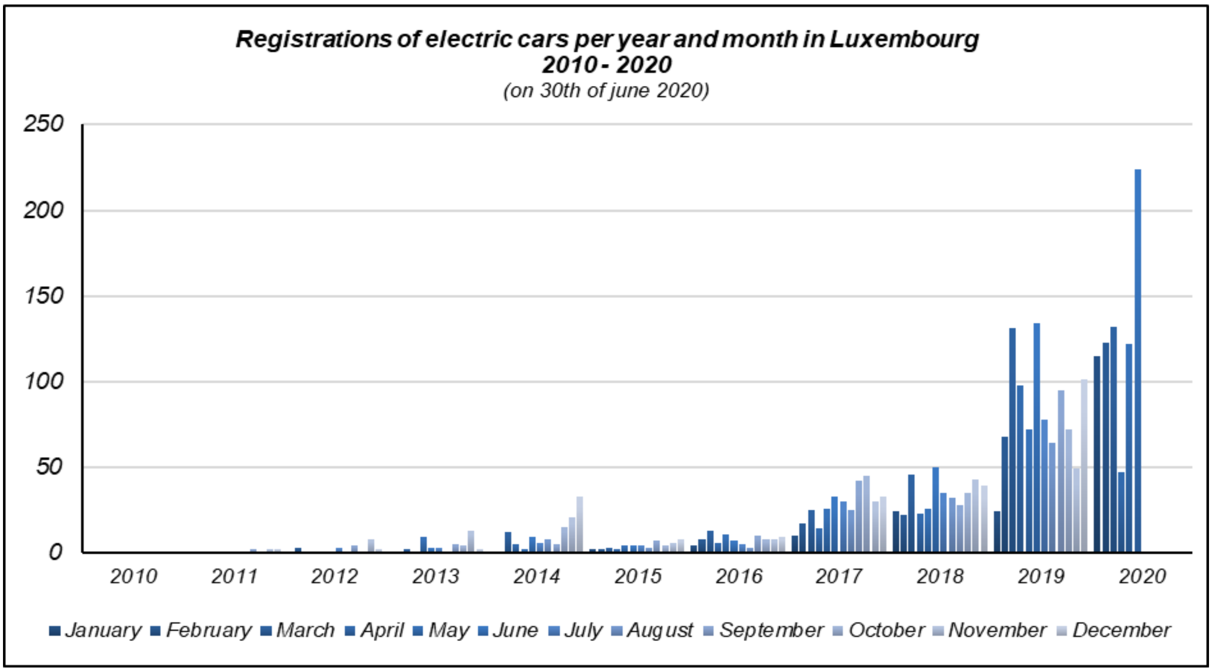
Electric cars, electric motorcycles and electric light utility vehicles

All kinds of electric vehicles are coming more into use recently. Already over 200 electric motorcycles and a few microcars are registered, and over 350 electric light utility vehicles, like electric delivery vans and other working machines are circulating in the country.

The biggest share of the grid-relevant electric vehicles comes from the electric cars and it will surely have the most important impact on the electrical power grid in the future.

During the last five years, there was a substantial increase of the registrations of electric cars, as depicted here:

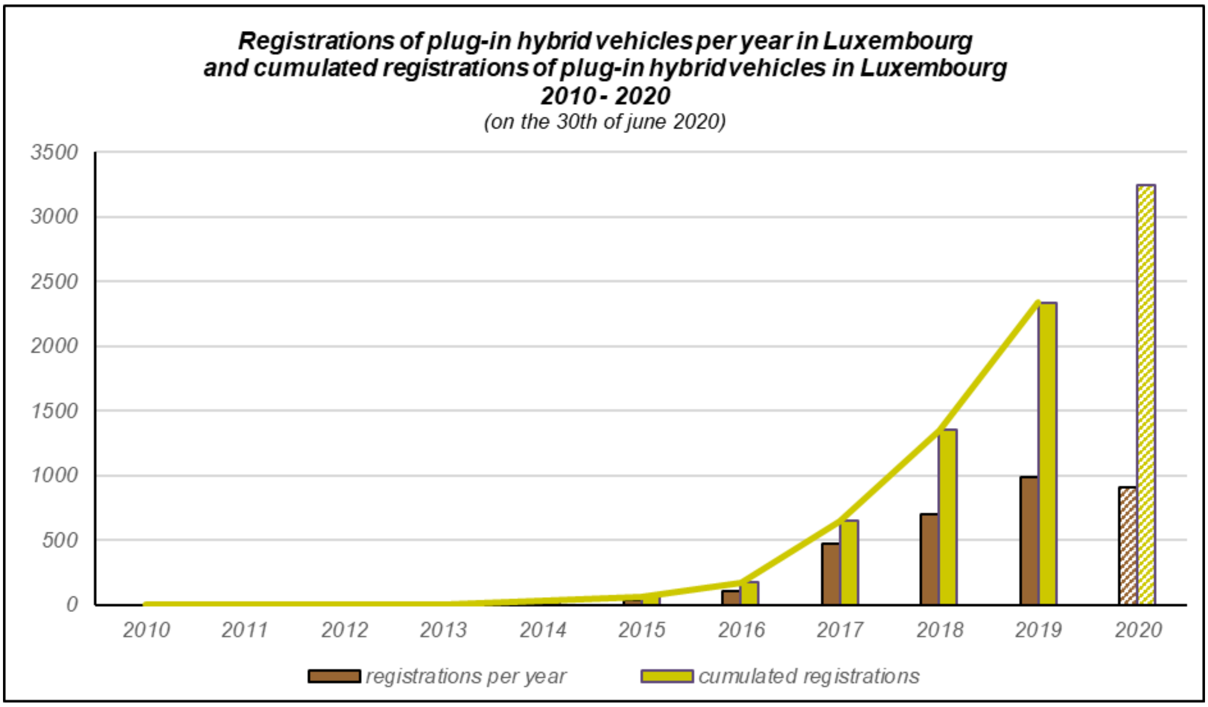




Source: SNCA

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

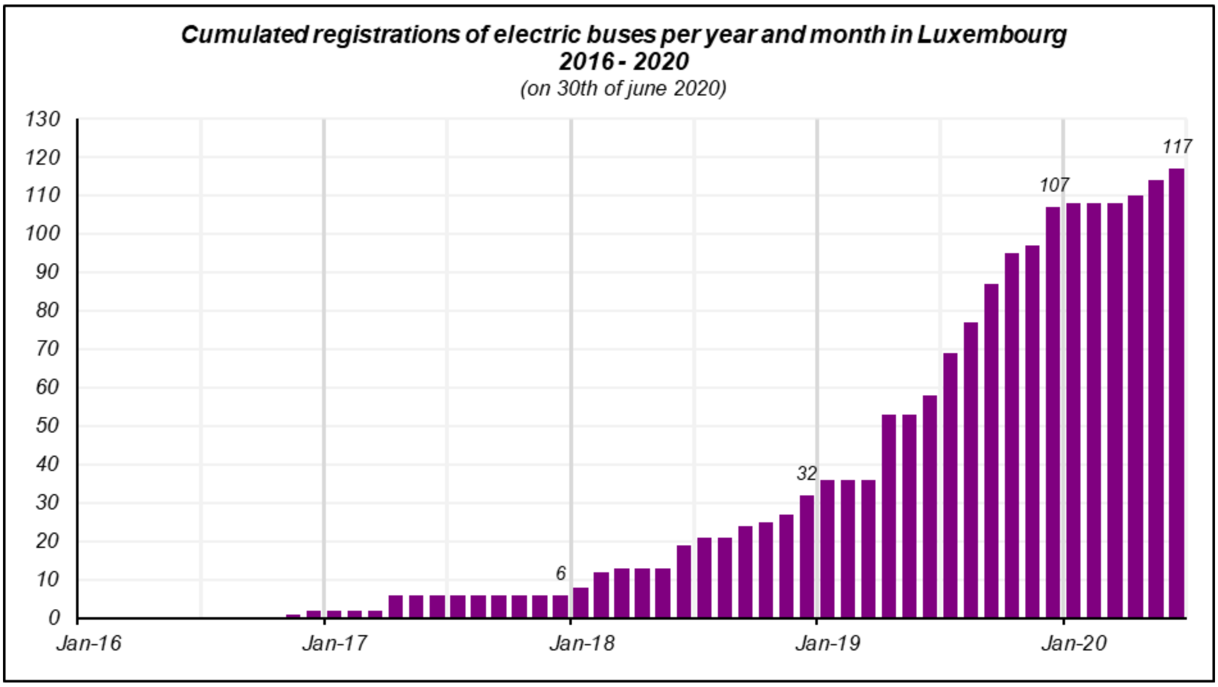
The rise of the registrations of plug-in hybrid vehicles in the last years is equally impressive. It is noteworthy that nearly all of those vehicles are plug-in hybrid cars.



Source: SNCA

Electric buses and electric trucks

The use of electric buses for public transport is rising quickly, totalling about 117 electric buses on the road today.



Source: SNCA

Here also, there will certainly be a huge shift from conventionally fuelled buses to electric buses in near future. The necessary electrical energy and power will have to be delivered by the electrical grid.

Currently, there are about 2200 buses shuttling on the roads of the country, together making approximately 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, that would make an electrical energy consumption of:

$$\textit{Total electrical energy consumption E-Buses} = 60.000.000\ km \times 2.2 \frac{kWh}{km} = 132\ GWh$$

Assuming, that energy has to be recharged overnight, i.e.from 23h to 5h, which would represent an average charging power of:

$$\textit{Average power during night-charging E-Buses} = \frac{132\ GWh}{(8h \times 365days)} = 60\ MW$$

In daily operation, E-buses may 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 250kW to 550kW.

If only 10% of all the buses would recharge their batteries during the day with these stations, the cumulative power would be:

Power needed for opportunity charging E-Buses = 10% x 2200 buses x 300kW = 66 MW

Those power needs have been considered in the projection curves for the additional load of the E-mobility.

In fact, a lot of projects for E-bus charging stations are already planned:

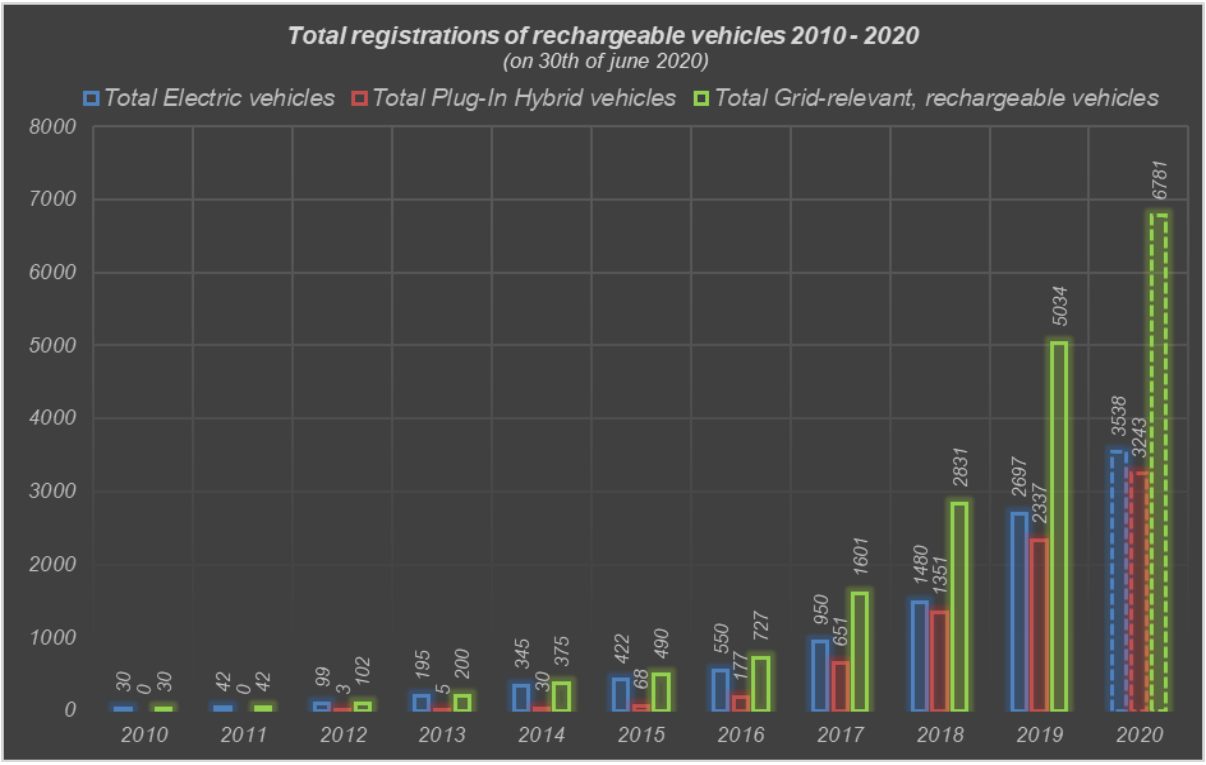
E-Bus charging stations / projects			
Locality	***Street / Place***	***Partner / Customer***	***Installed power (kVA)***
Luxembourg	Rue de Cents	/	1000
Bertrange	Rue de l'industrie	/	400
Differdange	Rue M. Rodange	/	1000
Differdange	Avenue de la Liberté	/	1000
Alzingen	Rue Thionville / Rue Roeser	/	400
Bascharage	Rue Laangwiss	/	2000
Canach	Rue d'Oetrange	/	400
Luxembourg	Merl près poste Belair	/	2100
Luxembourg	Hollerich / Dépot bus	/	3000
Bettembourg	Z.I. Scheleck	/	2000
Luxembourg	Bonnevoie / Dépot bus	/	1250
Echternach	Dépot bus	/	1000
Luxembourg	Parc&Ride Howald		630
Luxembourg	Rue Laurent Menager / Pfaffenthal		40
Total			16220
in 3 - 5 years			
Luxembourg	*Cloche d'Or près nouv. Stade*	*/*	*15000*

Source: Creos Luxembourg

Currently there are no electric heavy trucks registered in Luxembourg. But several manufacturers have already developed or are in the end phase of developing electric heavy-duty vehicles. We think that it is appropriate to expect a rising occurrence of those vehicles in the future.

E-mobility / Forecasts of the electric-driven transport on road

By adding the figures of the actual registrations of grid-relevant electric vehicles and those of the plug-in hybrid vehicles, a total of more than 6700 grid-relevant, rechargeable vehicles is resulting from it at the 30th of June 2020.



Source: Creos Luxembourg

As the evolution of the E-mobility is difficult to predict with certainty, and as the power demand necessary for the cumulative charging of electric vehicles grows quite severely with the number of EV, 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 the E-mobility are summed up hereafter.

NECP - Reference scenario:

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

With those figures, own assumptions have been made to calculate the number of future electric vehicles: With a yearly electric consumption of 20 - 21kWh per 100km and a yearly distance of 18000km per car, this electricity need would represent 202.000 electric / plug-in hybrid vehicles. After subtracting **10% of utility vehicles,** that would make about 182.000 electric / plug-in hybrid cars in 2040.

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

NECP - Target scenario:

Share of 29% for the electrical energy need of the transport sector in 2040 (NECP, page 181).
A share of 29% corresponds to 1850GWh of annual electricity, or 1720GWh without 100% E-Buses in 2040.

With those figures, own assumptions have been made to calculate the number of future electric vehicles: With a yearly electric consumption of 19 - 20kWh per 100km and a yearly distance of 16000km per car, this electricity need would represent 554.000 electric / plug-in hybrid vehicles in 2040. After subtracting **15% of utility vehicles**, that would make about 472.000 electric / plug-in hybrid cars.

- ➔ 49% of the total projected cars would be electric / plug-in hybrid cars in 2030
- ➔ 82% of the total projected cars would be electric / plug-in hybrid cars in 2040

An amount of 49% of electric cars in 2030 (referring to the total projected number of cars) is also stipulated in the NECP at the page 41.

TIR / Fraunhofer ISE scenario:

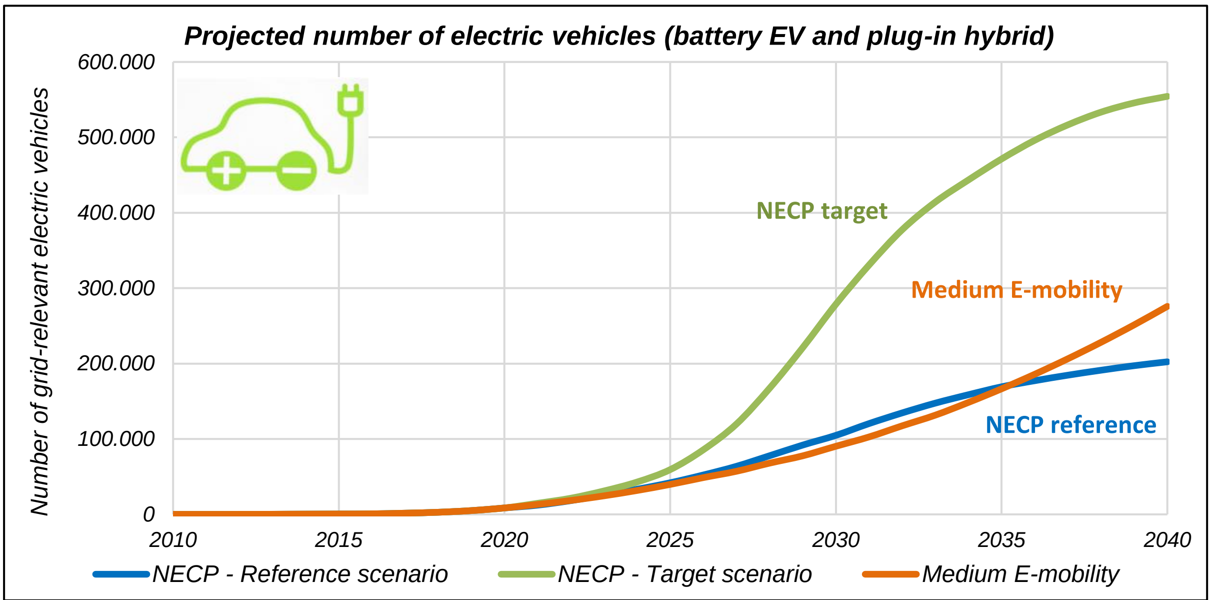
For adding the future transport sector to the ordinary load forecast of the Fraunhofer ISE scenario, own assumptions have been made with a steady, non-linear increase, which roughly represents the actual growth trend of the grid-relevant vehicles. This assumption is designated as "medium e-mobility acceptance" 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 the total projected cars would be electric / plug-in hybrid cars in 2030
- ➔ 43% of the total projected cars would be electric / plug-in hybrid cars in 2040

Those three different acceptance levels for the E-mobility were taken into account for 2040:

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



Source: Creos Luxembourg

Cross-border commuters, which would like to recharge the batteries of their electric vehicles on their workplace in Luxembourg, using conventional charging means, have been partly considered in those projected figures.

Attractive inland electricity costs, compared to the prices of electricity in neighbouring countries, could provoke a related extra load on the electrical grid, which would have to be considered additionally. Superchargers on highways during summer travel period could produce important peak loads that could neither be shifted in time, neither be flattened over a certain time period. This could become a major issue on the higher voltage levels as the simultaneous usage of those superchargers could be very high. Local energy storage might be favourable to reduce peak demands but the economic viability of such a system is still unsure. It should be noted that this speculative additional load has not been included in the forecast hereafter.

The charging of the batteries of the electric vehicles will stress the electrical grids on all voltage levels. In addition to the number of electric vehicles, their charging capacities and the charging time are of importance for the overall additional electric load. **Smart-charging management solutions are therefore an absolute necessity in order reduce effectively the impact of the cumulative charging of electric vehicles.**

The highest relative load of the E-mobility will occur on the low-voltage grids, because the simultaneity is much higher when a few EV are recharging during the same time at home or on 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 11kW to 22kW.**

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

The high-voltage grid will be relatively 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.

In order to determine the cumulative load of the projected electric vehicles, we considered various studies which addressed this specific topic. Here below are listed three conclusive studies we picked out:

- BDEW – Draft of the application aid ‘Power grids for the E-mobility’ (2020)
- FGH – Meta study ‘Grid Integration – E-mobility’ (2018)
- University of Stuttgart - Doctorate dissertation ‘Implications of the E-mobility on the energy system analysed with probabilistic grid calculations’ (2014)

In 2014, the University of Stuttgart published the dissertation ‘Implications of the E-mobility on the energy system analysed with probabilistic grid calculations’ [Dr. Alexander Probst, engineer] which provides values for common charging capacities. With the analysis of commercially available vehicles (65 available on the market) and their charging capabilities, a stochastically calculated peak power per car has been determined, which can be used to assess the cumulative load on the high-voltage grid.

In fact, this study foresees that, because of frequency and the mix of different vehicles with charging capabilities between 3,7kW and 22kW, the resulting average charging power per car should be about 7,66kW in the year 2030, on the low voltage grid. Most vehicles are expected to use only 3,7kW, roughly a quarter of the vehicles 11kW and about 10% a charging power of 22kW or above.

Extrapolated on the high-voltage grid, this should lead a simultaneously occurring peak power of only 1kW per car. According to the study, this rather low power can be explained by a low daily energy consumption and the associated charging time.

The German research community FGH 'Forschungsgemeinschaft für Elektrische Anlagen und Stromwirtschaft e.V.' commissioned by the VDE FNN and BDEW, published at the end of 2018 the meta study 'Grid Integration – E-mobility' which regroups the results from 25 different references and sources, including the dissertation from the University of Stuttgart. The lowest simultaneity factor from this meta study is 0,2. **Which would imply a charging power of roughly 2kW per car, if the EV's are considered together.**

Currently, in mid-2020, a draft version of an application aid for 'Power grids for the E-mobility' is getting drawn up by the BDEW 'Bundesverband der Energie- und Wasserwirtschaft e.V.'. With the help of a chart, this document indicates **a variable, degressive simultaneity factor** depending on the connection level and number of electric cars. With a high number of EV's, the degressive simultaneity factor tends to the value of 0,12 for individual charging powers of 22kW and 0,2 for charging powers of 11kW. **This would again result in a charging power of 2kW per car, if the EV's are considered together**. However, most applications examples are for low voltage or medium voltage grids.

Today, the real effects of the E-mobility on the high voltage electrical grids are still unknown, because there are no practical experiences with a very high number of electric vehicles charging simultaneously.

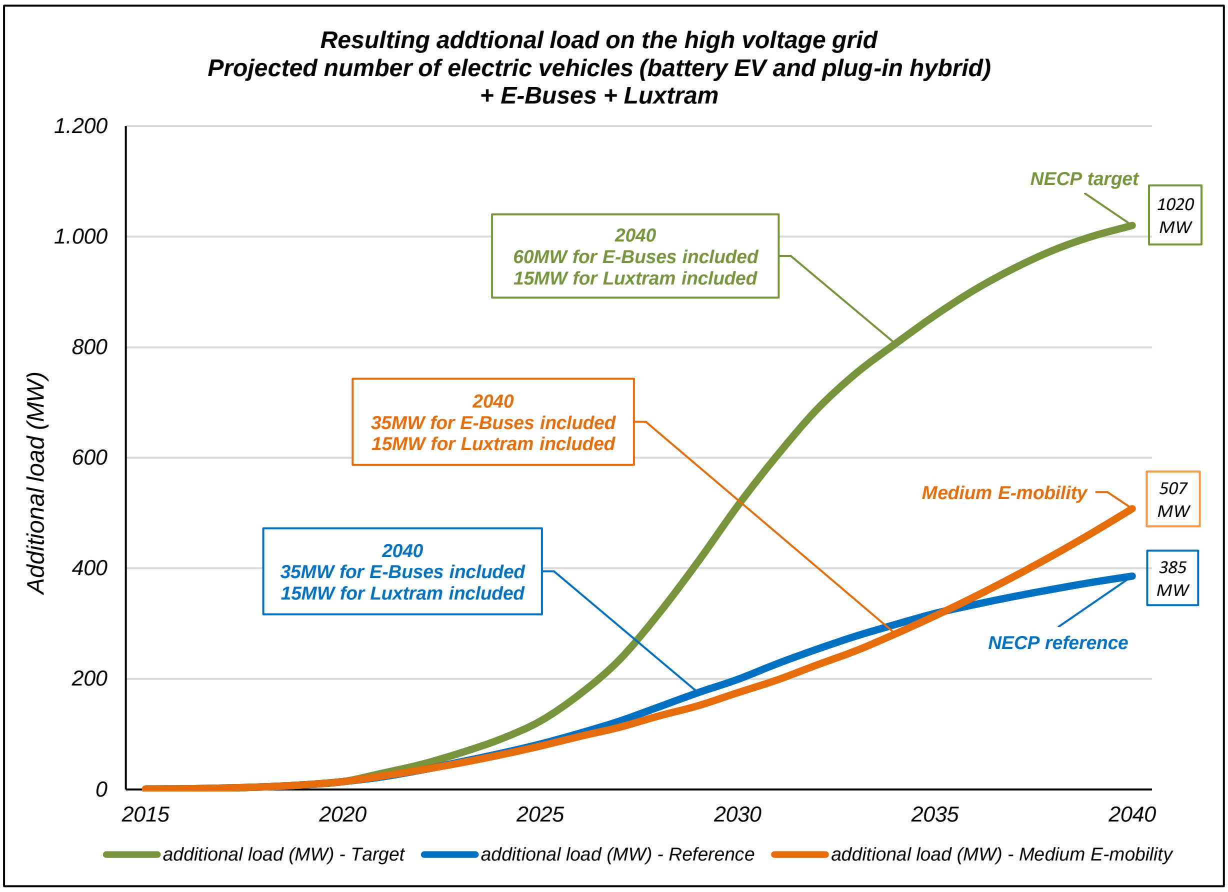
For this reason, we decided to take the average peak load of several impact studies to calculate the total peak power necessary for charging large numbers of electric vehicles in Luxembourg and are quite confident about it.

- ➔ **We suppose a peak power of 1,66kW per car on the HV grid**

Recent studies and calculations have determined that with a homogeneous distribution of the charging points and electric vehicles, and with a mix of charging capacities as available today, a "light" acceptance of electric vehicles (100.000 electric vehicles) should lead to few or no overloads on the low and medium voltage grids.

Nevertheless, the additional load of a "light" acceptance of electric vehicles **would almost use up the entire remaining power reserve of the existing high-voltage grid**, even with smart-charging management solutions.

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



Source: Creos Luxembourg

Smart-charging solutions could slightly reduce the power needed during peak times, with a better usage throughout the day or during night.

In regard to 'vehicle to grid' approaches, it has to be taken into consideration that E-vehicles owners may not agree with a third-party use of the battery packs of their EVs for energy storage purposes. Network operators could theoretically use 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-vehicles owners, would eventually suffer from the additional charging cycles. Legal aspects would also have to be considered.

The ability of a bidirectional use of these storage capacities remains questionable.

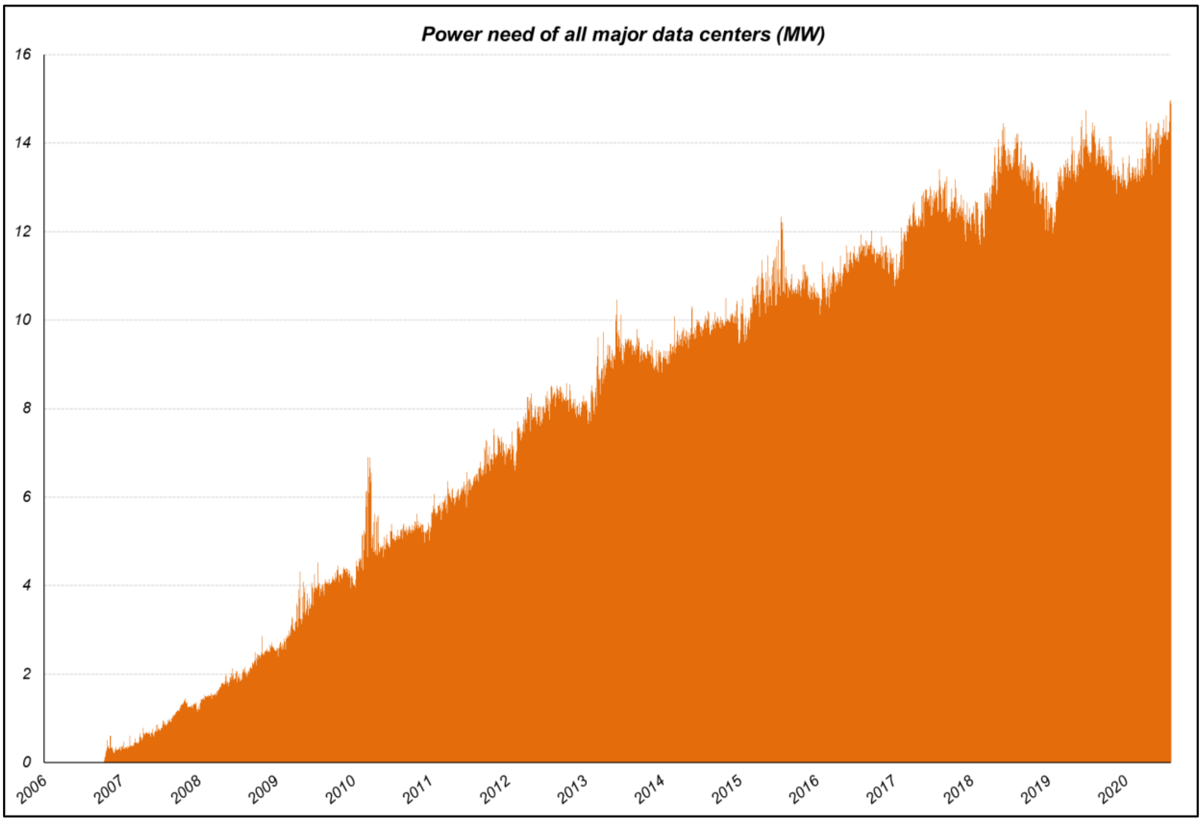
Additional loads

Data Centers with high energy needs

Contractually agreed power and actual peak power of the existing data centers

Since the year 2006, major data centers started to be connected on the Creos power grid. Today, there are five major data centers connected to the Creos grid, and several others are already planned. The consumptions of other smaller data centers, which are integrated in administrative or commercial buildings and banks, are not considered since they 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 centers can clearly be identified:



Source: Creos Luxembourg

The five major data centers were put into operation successively between 2006 and 2012. Their power need kept growing from year to year after that and is still increasing up to this day.

The high power demands, which the customers requested initially, do not match with the more moderate actual power needs and the contractually agreed powers of these data centers. We experienced that the initial high power requests and the contractually agreed power demands have not (or not yet) been reached or used.

However, based on contractual agreements with the operators of these data centers, the agreed connection power capacity must be guaranteed. These values have to considered for the future grid planning.

Summarising, the existing data centers have the following power needs so far:

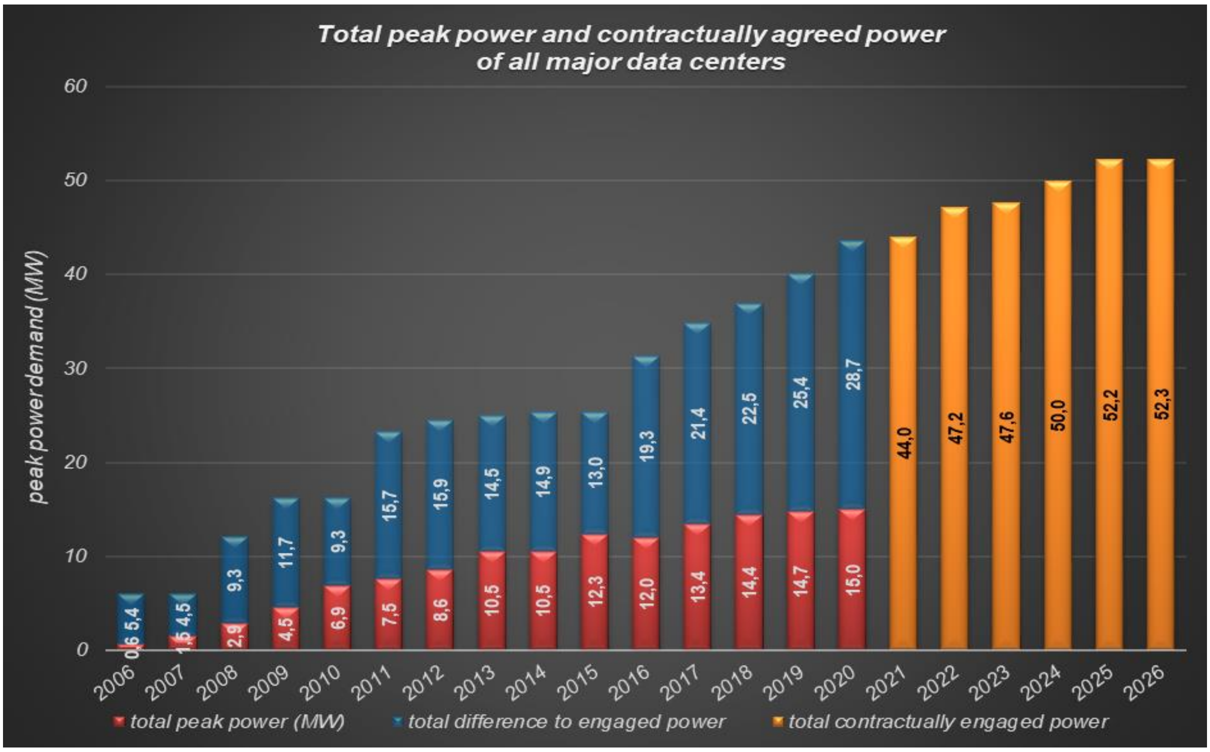
Existing data center	*In operation since*	*Requested power*	*Contractually agreed power*	*Peak power 2019 / 2020*
N°1	*October 2006*	***10,5 MW***	***10,35 MW***	***~ 4,3 MW***
N°2	*March 2008*	***10 MW***	***6,48 MW***	***~ 3,3 MW***
N°3	*December 2009*	***21 MW***	***17,1 MW***	***~ 3,6 MW***
N°4	*August 2011*	***13,5 MW***	***5,22 MW***	***~ 2,7 MW***
N°5	*February 2012*	***21 MW***	***4,5 MW***	***~ 2,4 MW***

Source: Creos Luxembourg

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

Today, power densities in data centers are measured in kilowatt per rack (kW/rack) with a rising tendency, with 10 kW racks becoming the norm in today's data center ecosystem, and even 15 and 25 kW racks in some hyperscale facilities. Experts 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.

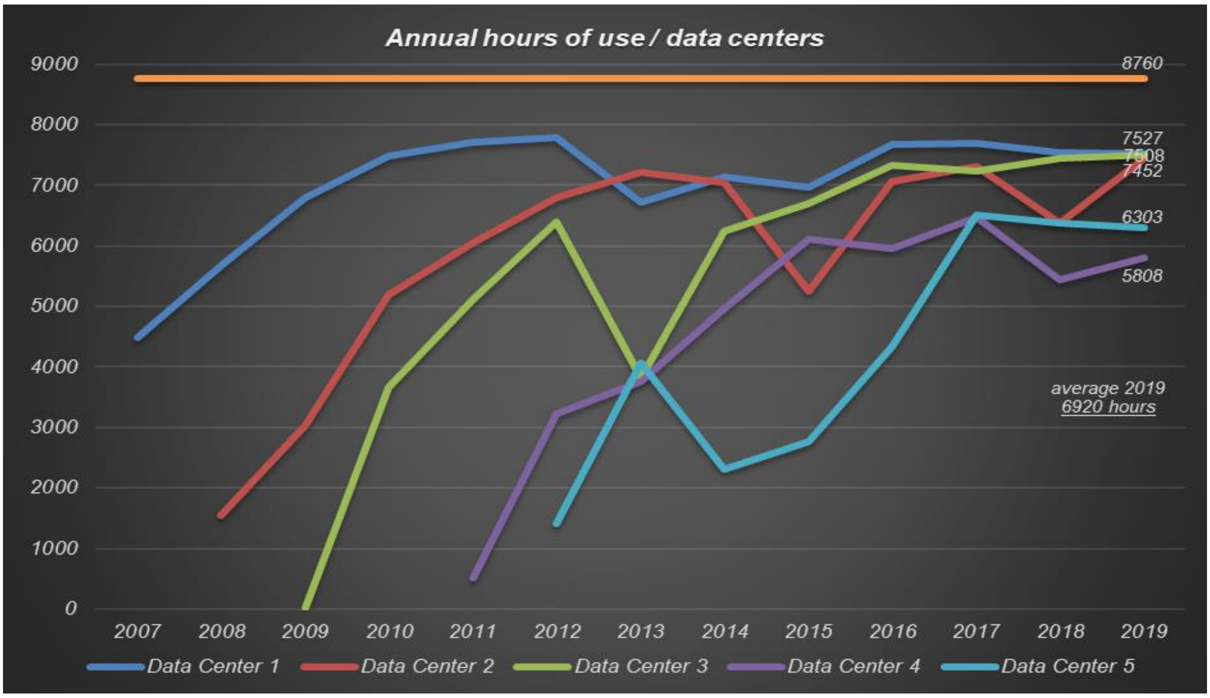
As already mentioned, Creos must be able to provide the contractually agreed powers at any time. Therefore, it must be assumed that the original high power requests could occur at a later stage, with full operational readiness and extensive use or due to upgrades and expansions of the data center.



Source: Creos Luxembourg

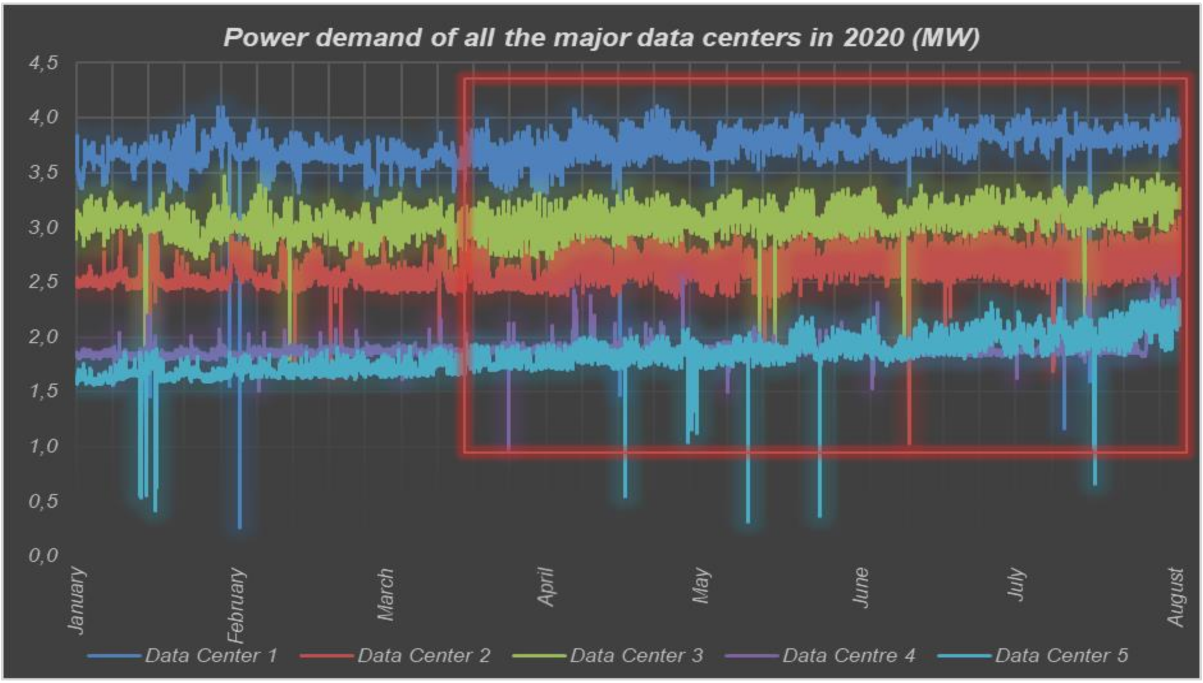
Annual hours of use of data centers

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



Source: Creos Luxembourg

Covid-19 sanitary crisis and its impact on the major data centers



Source: Creos Luxembourg

During the Covid-19 sanitary crisis, the social lockdown greatly encouraged the intensive use of the digital communication forms and of the "home office" for many employees.

A closer look on the power curves of the data centers indicates the intensified utilization of those centers and the related increase of the power demand.

The Covid-19 sanitary crisis will surely result in a long-lasting and more intensive use of the existing data centers and will promote and accelerate the emergence of additional data centers in the country.

Supplementary data centers projects

At the end of July 2020, already several additional data centers are planned, as can be seen in the list hereafter:

Data Centers						
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	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
65kV	Marnach	Marbuergerstrooss		4MVA phase 1 8MVA phase 2		datacenter
20kV	Grass	Z.I. Zaro		1,25MVA phase 1 2,5MVA phase 2	17-00017	datacenter
Subtotal				/ short term / long term		

Source: Creos Luxembourg

The full operational readiness of the existing data centers and the construction of future ones have been taken into account **with a total amount of 100MW**, which includes the remaining, still unused power of the existing data centers and a certain amount of new facilities (data center project of Google excluded).

Data center project of Google

Creos has been approached by Google with a project to build and operate a massive data center with a high energy need in Bissen / Roost.

It is planned that the first power demand of the data center might begin as early as the year 2023 and will step up linearly after that.

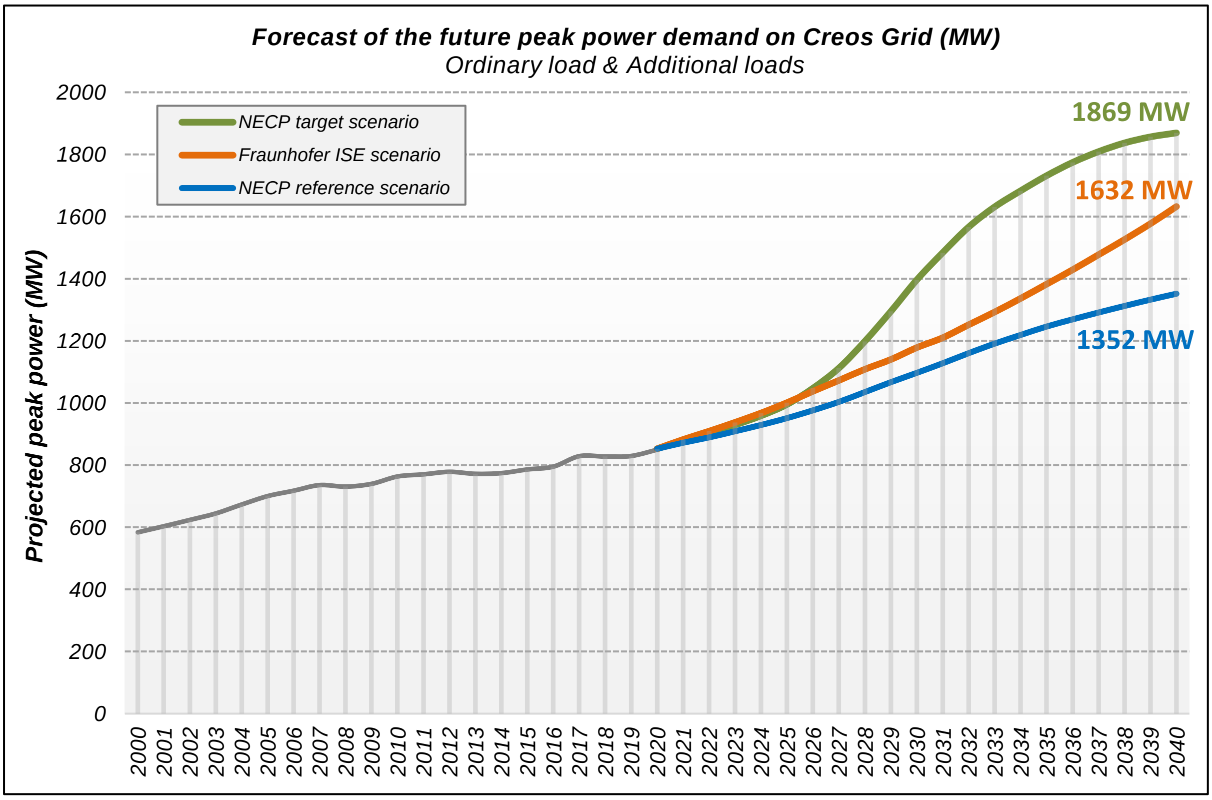
As the project has not yet been definitely confirmed, the ramp-up data of that data center has been analysed but has not been added to the scenarios of the peak power projection.

It is nonetheless certain that the power demand of that project would lead to a fast depletion of the import capacity reserves.

Forecast of the future electricity need and peak power demand (p.2)

Ordinary and additional loads

As seen before, the future peak power of the ordinary load was calculated with the forecast of the future electricity need and with degressive yearly usage hours. The additional loads for the e-mobility and for the data centers were added to that ordinary peak power curve of all the scenarios and resulted in the total forecasts here below.



Source: Creos Luxembourg

The loads considered in this study do <u>not</u> include potential additional loads presently connected to Belgium and France via the Sotel grid. That would represent about 280 MW. This additional load is of importance in any major grid extension project as it would allow the Sotel load to be switched away from the BE and FR markets to the more attractive DE-LU market and would contribute to the financing of a new infrastructure.

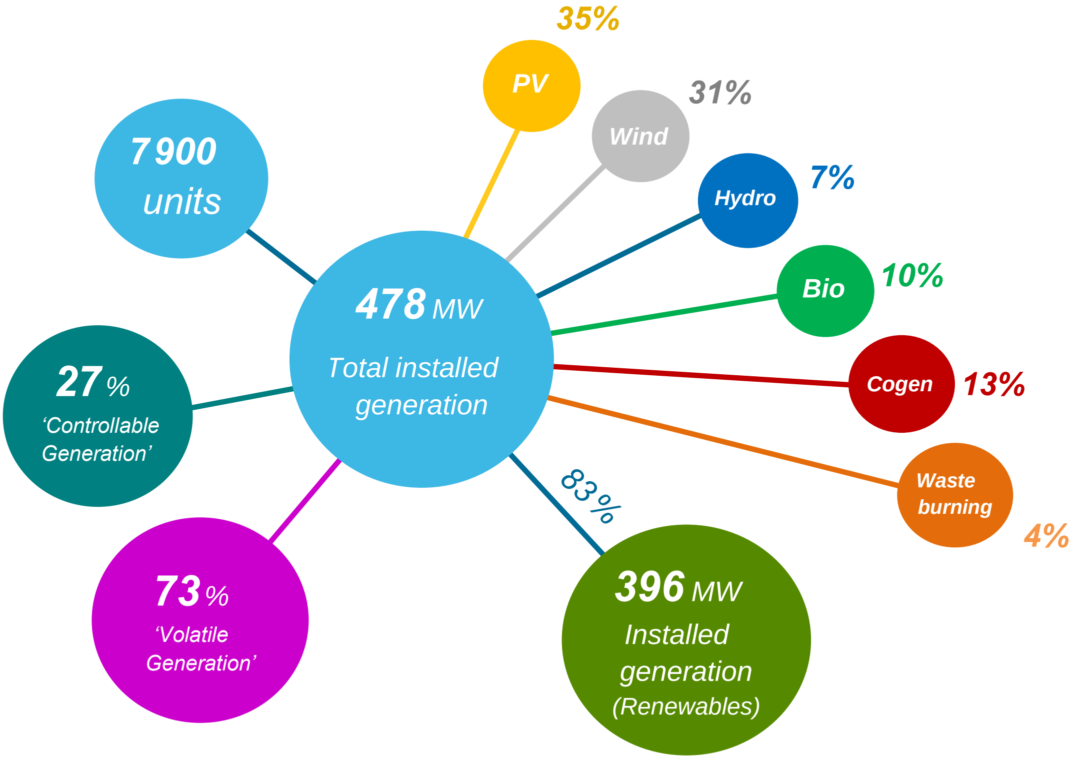
With a forecast of the future inland electrical energy generation, an assessment of the remaining import can be established.

Electrical energy generation and renewable energies

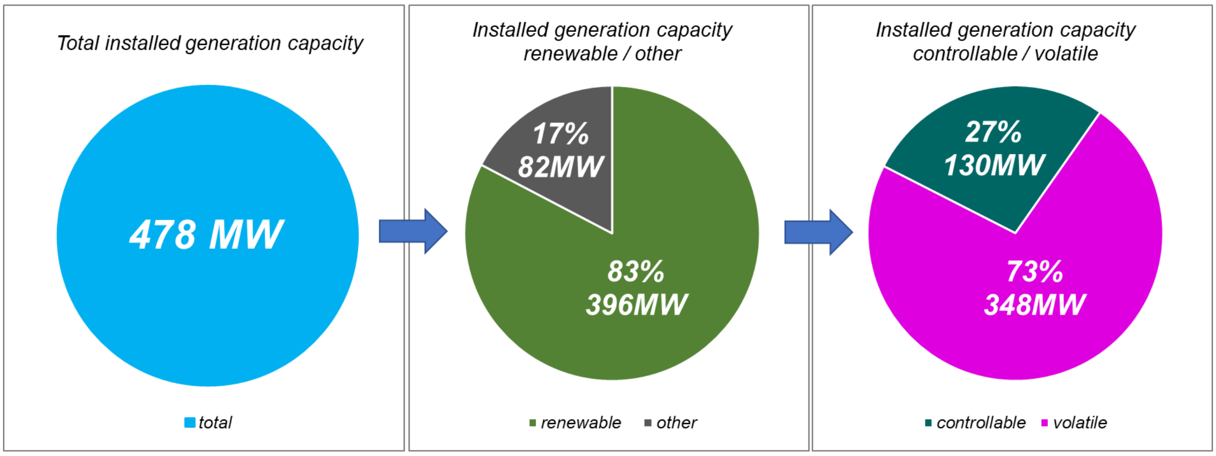
Currently installed electricity generation capacity

By the end of July 2020, the installed generation capacity on the Creos grid was about 478MW in total. That total does not include the generation connected to the subordinated grids of other operators. The impact of those few units on the Creos grid is comparatively low and has been indirectly taken into account through the net power demand of those operators.

Most of the installed 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 83% of the total installed generation capacity.

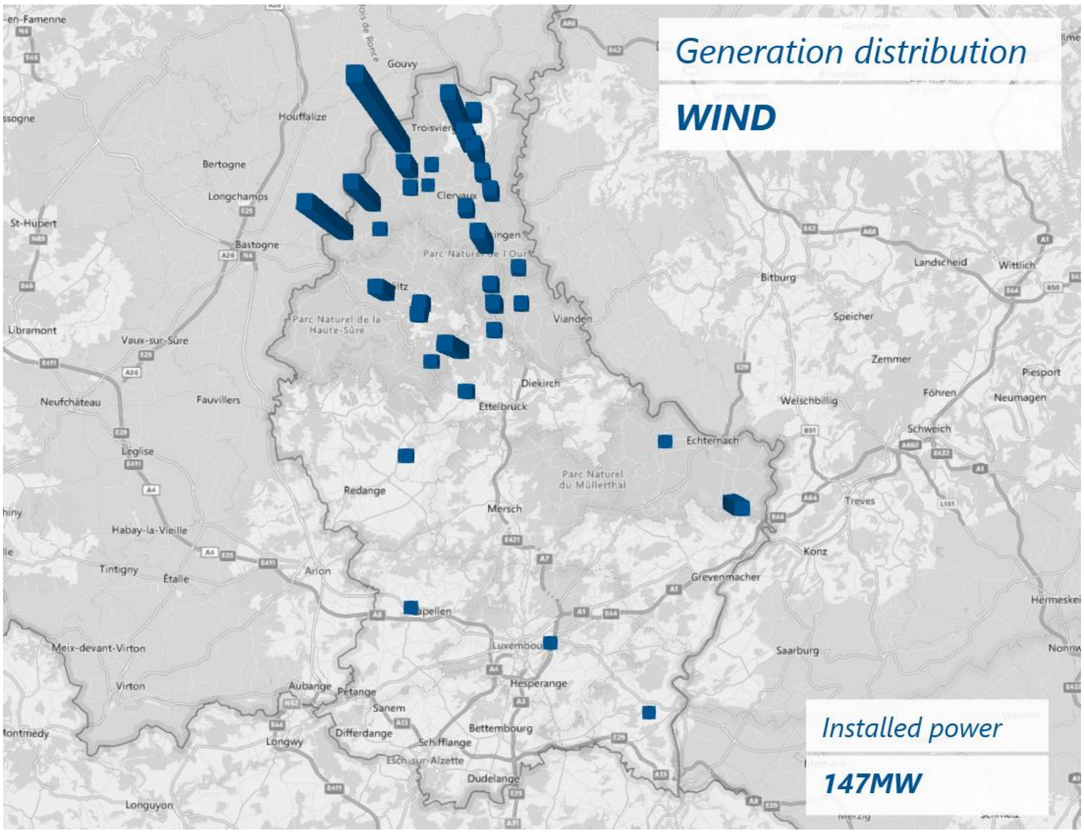


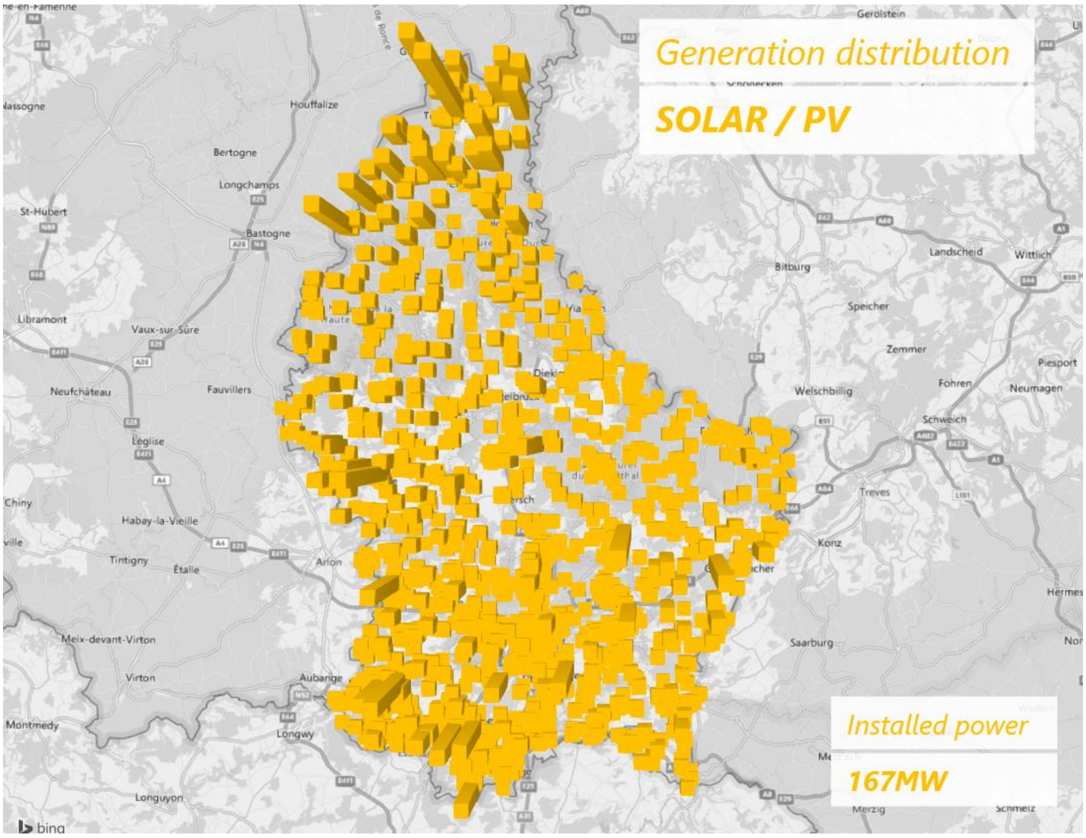
A further distinction should be made between the controllable generation (cogeneration systems, incineration, biomass and biogas plants), and the 'volatile', uncontrollable generation (solar-, wind-, and hydroelectric power generation).



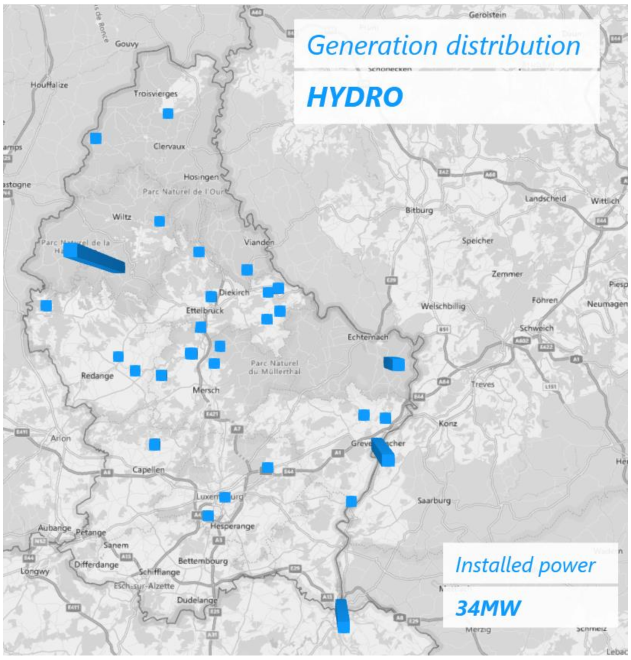
Source: Creos Luxembourg (at the end of July 2020)

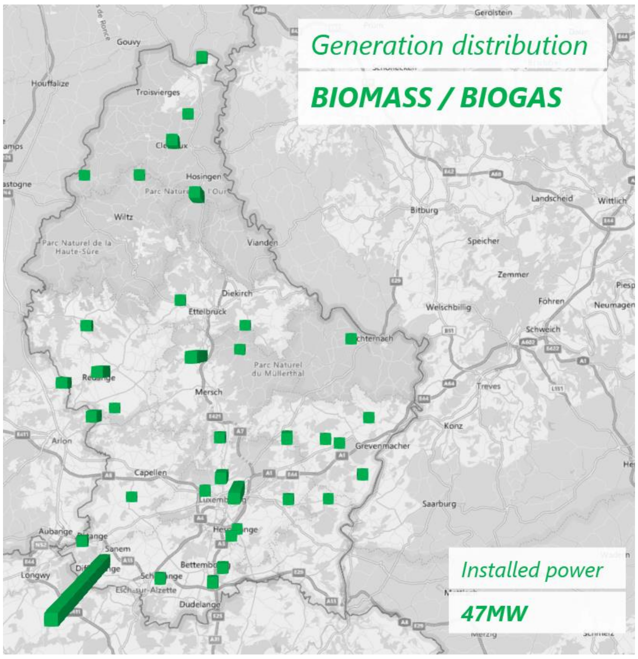
The regional distribution maps of the different forms of electricity generation might be of interest. Most of the wind turbines and wind farms are currently located in the north of Luxembourg, whereas the solar installations are distributed over the whole country. However, the biggest cumulative installed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



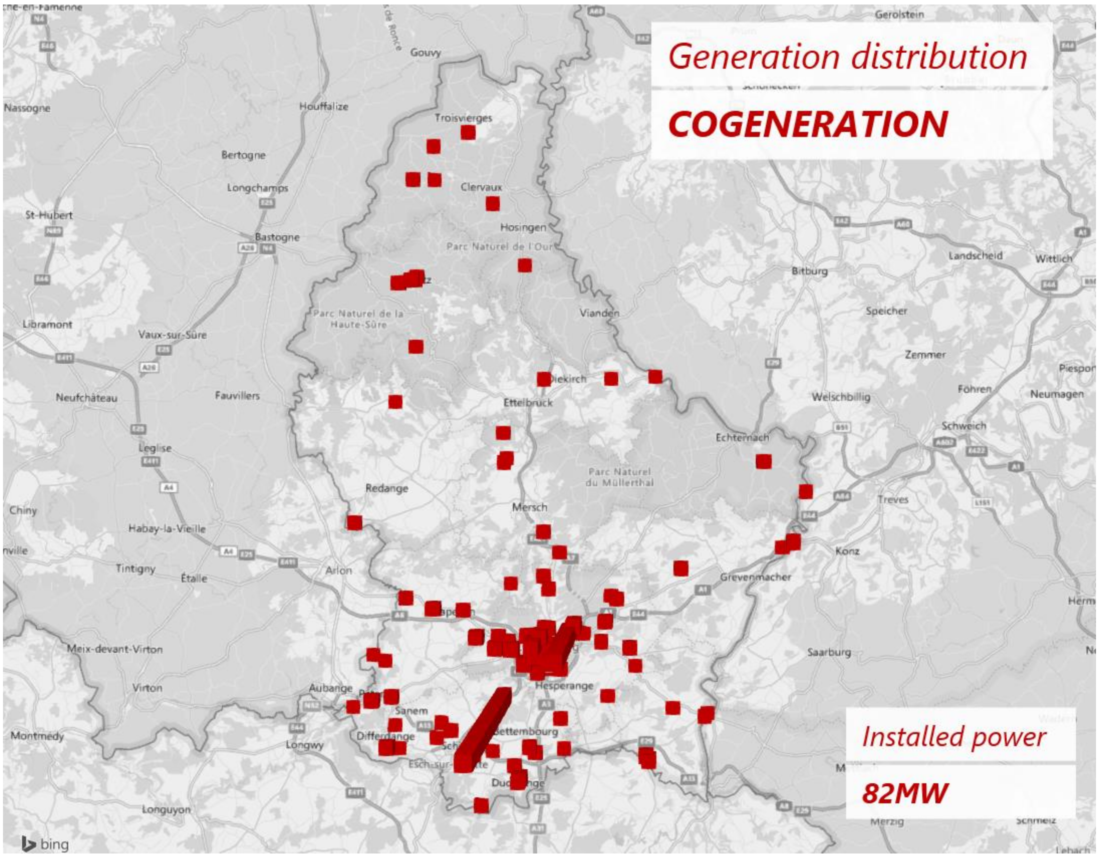


The largest hydro-electric plants are obviously located by the major rivers or by the water reservoir of Esch/Sûre. The biggest biomass power plants are located near Sanem in the south-west of the country and in the capital city, the rest of the biomass or biogas units are roughly distributed over the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



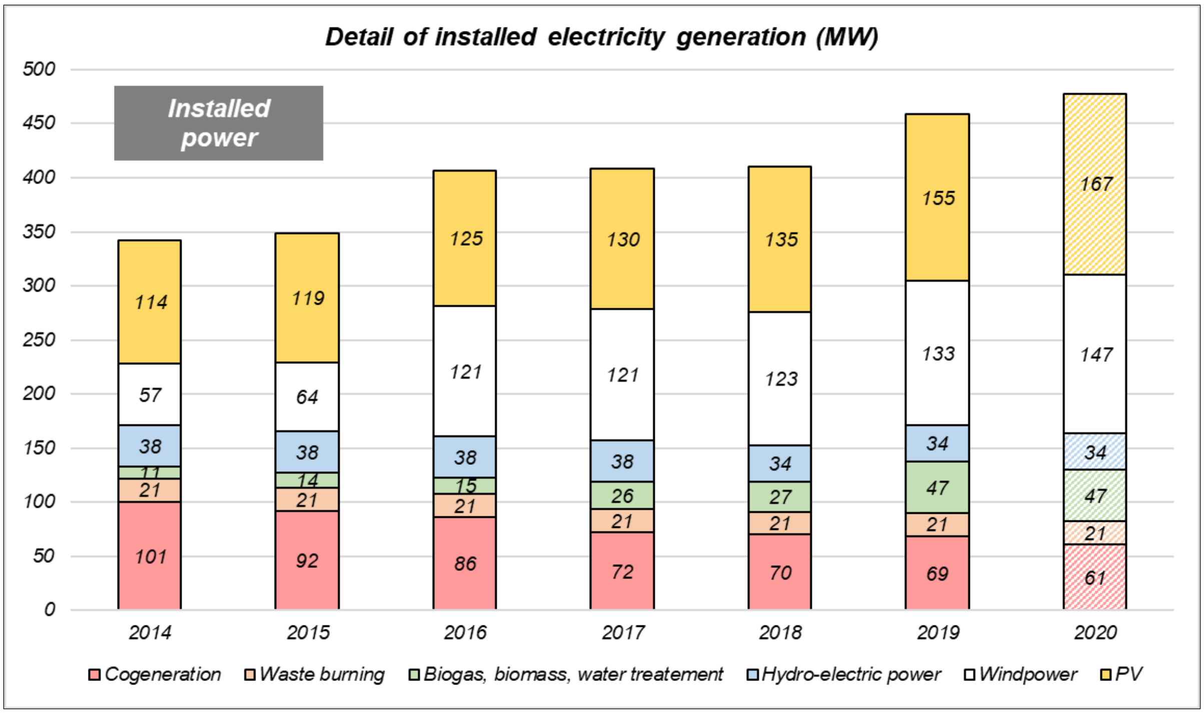


Presently, most of the combined heat and electricity generation units are located in or around the capital city or in the south of Luxembourg. It should be noted that the waste burning plant of Sidor in Leudelange has been added to the cogeneration units here, explaining the additional power peak at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



Past evolution of the installed electricity generation capacity

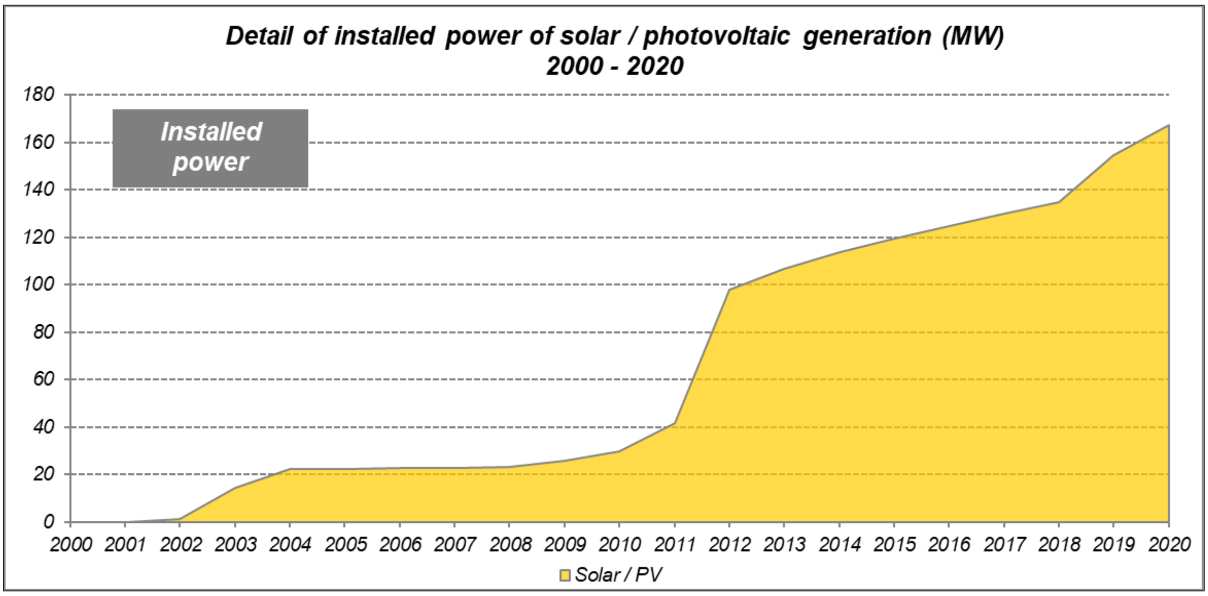
The total installed power of all the electricity generation units on the Creos grid has risen from 342MW in 2014 to 478MW by the end of July 2020, with the following segmentation throughout the years:



Source: Creos Luxembourg (2020: at the end of July 2020)*

Solar power plants and wind turbines are the electricity generation types which have been the most installed during the last years. With a total of 147MW in 2020, the installed power of all the wind turbines is nearly three times as high as in 2014.

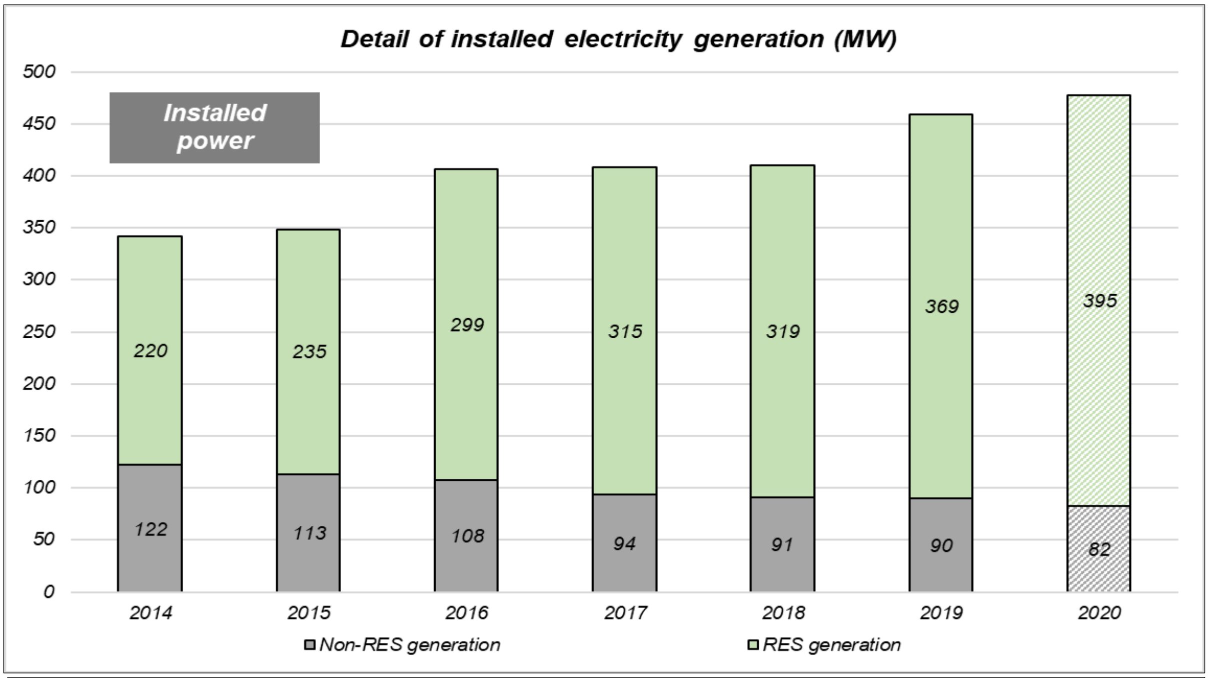
The past evolution of the solar / photovoltaic installations is even more impressive, with a steep increase of 56MW in 2012 and a steady increase since then. Photovoltaic installations stepped up from just a few units in the year 2000 to a total of 7700 units with a combined installed power of 167MW nowadays.

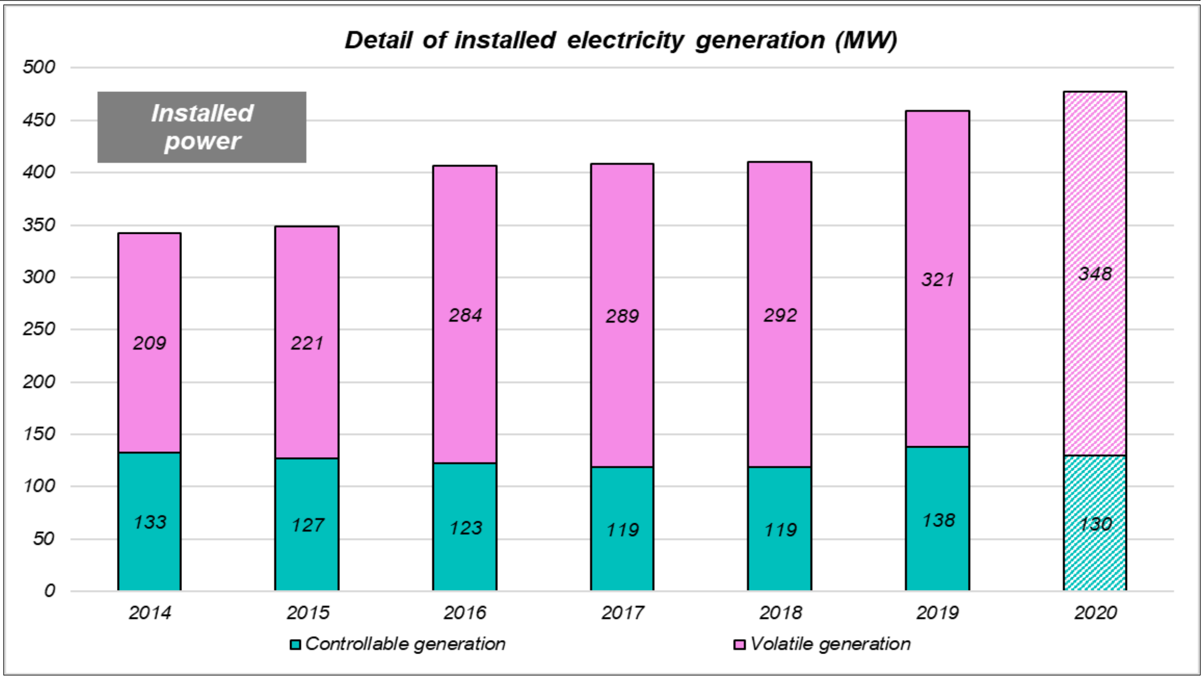


Source: Creos Luxembourg (2020: at the end of July 2020)*

More biomass and biogas have also been installed, the largest growth in this share came from the addition of a big biomass plant near Sanem. The installed capacity of the hydro-electric 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 those units. Cogeneration units using fossil fuels as primary energy source will surely disappear after the ending of the related subsidies after 15 years of lifetime.

Regarding all these developments, it is evident that the share of the installed generation capacity based on renewable energy sources passed from 64% in 2014 to 83% nowadays.





Source: Creos Luxembourg (2020: at the end of July 2020)*

It should be noted that the uncontrollable, 'volatile' generation has steadily increased over the past, reaching 73% today, and will certainly increase in the future. This represents a hazard, as the power generated by those units is fluctuating and may not generate any power on certain occasions.

Current electricity generation

As mentioned before, Creos must guarantee the security of supply at all times.

The two most extreme situations are:

- the highest power demand and the lowest domestic electricity generation, and
- the highest power generation and the lowest power requirement.

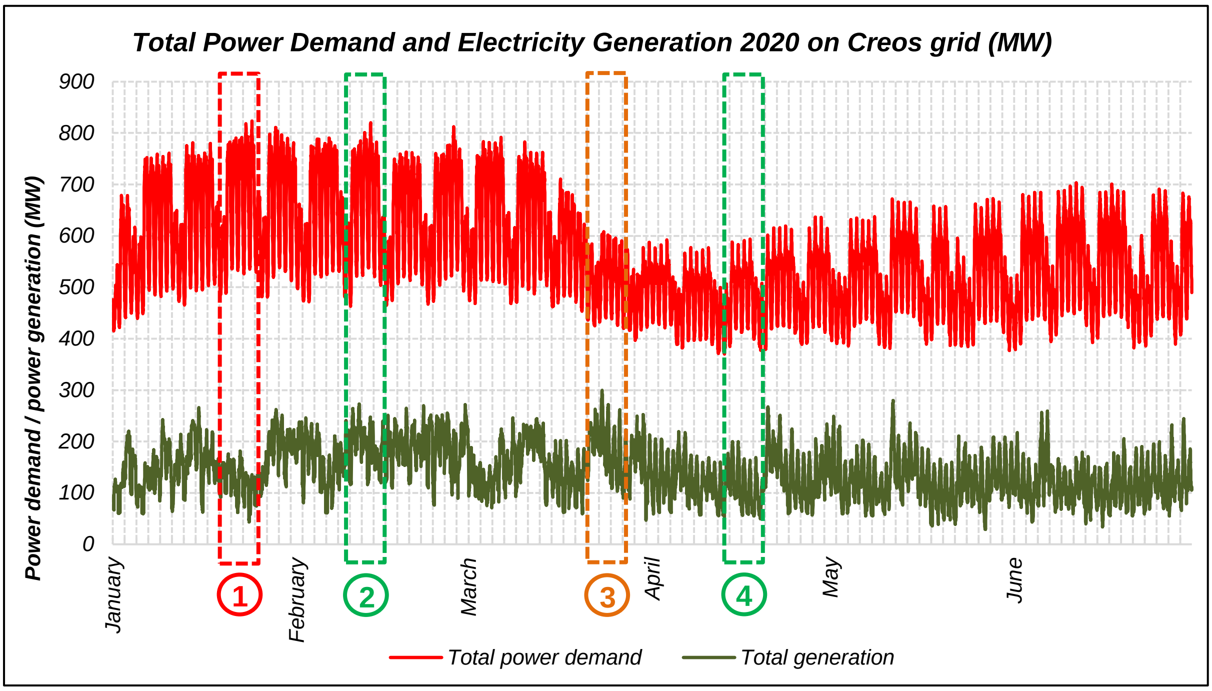
From the detailed timeline of the total power demand and the total generation in 2020 here below, four events can be highlighted which may help to understand the most critical grid situations:

1) **High power demand and low power generation**
   The import is at its maximum and the grid must be properly dimensioned in order to transport the required power for as long as needed.

2) **High power demand and high power generation**
   This situation is not critical for the grid, as the import is lower than during a low generation period.

3) **Low power demand and high power generation**
   This situation is not yet critical for the grid, for as long as the power consumption is higher than the generation. The moment the generation will grow higher than the consumption, the power generated must be transported where it is needed, or even exported. Then the power generation will be the decisive factor for the grid dimensioning.

4) **Low power demand and low power generation**
   This situation is uncritical as the grid is the least loaded.

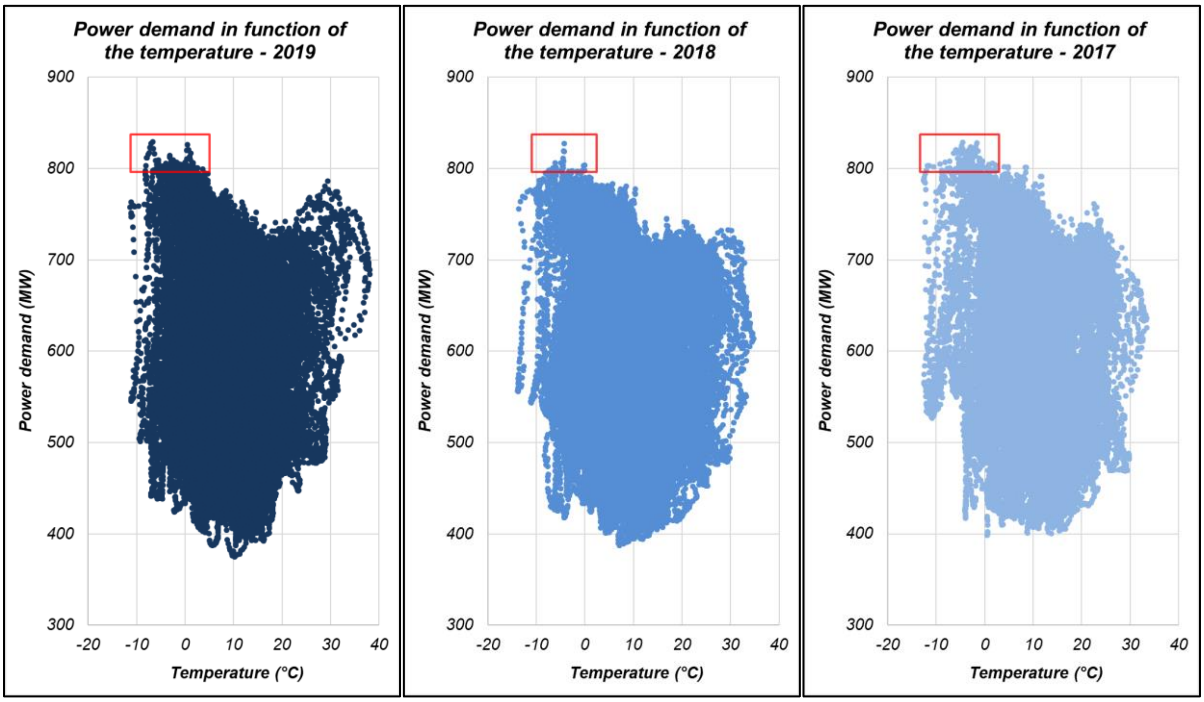


Source: Creos Luxembourg

The dimensioning of the electrical lines is based on the moment the greatest currents occur on those lines.

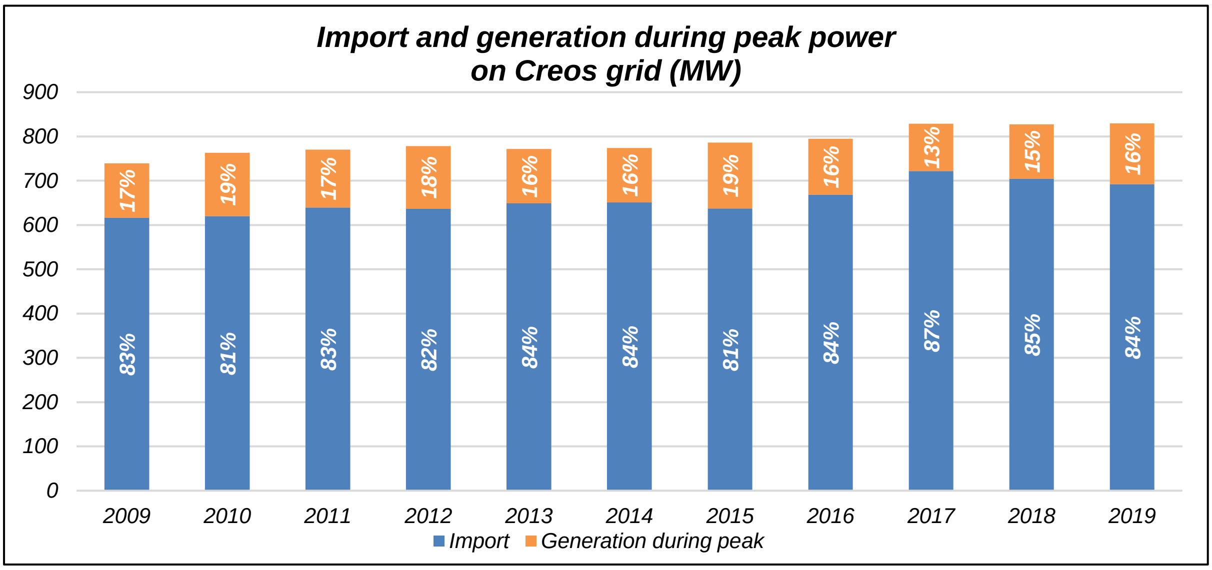
The charts hereafter show all the ¼ hour consumption values from one whole year in function of the temperature. As can be seen the highest peak demand always occurred during cold periods during the winter months. The temperature during the peak times of the power demand ranges between -15°C and a few degrees Celsius as can be seen in the charts from 2017 to 2019 here below.

Each dot in those charts is representing a 15min measurement point.



Source: Creos Luxembourg

For the moments of peak power demand, the domestic power generation and the import from neighbouring countries is shown hereafter for the last 12 years.

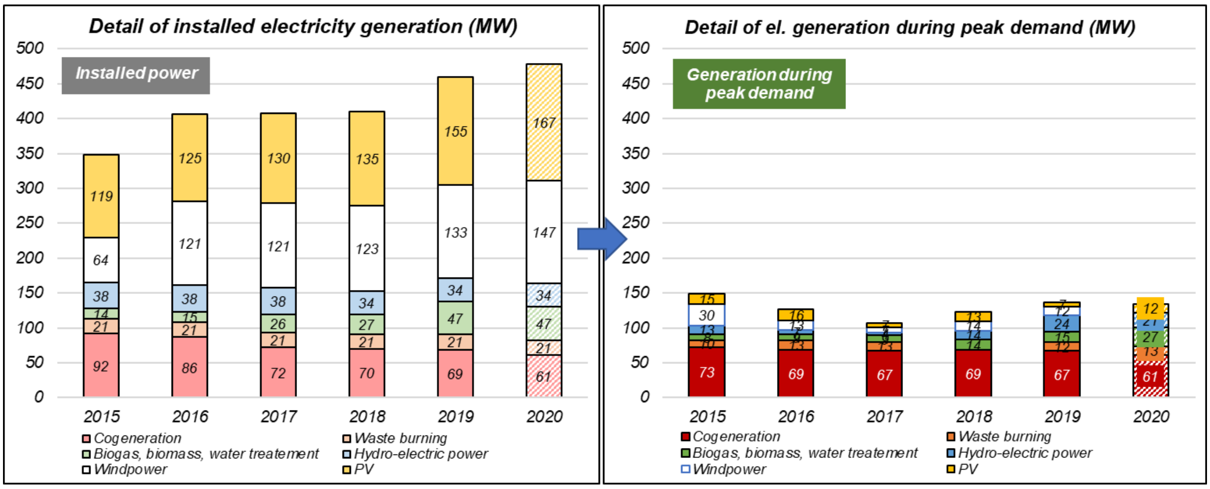


Source: Creos Luxembourg

It is a fact that the relative contribution of the inland generation during the peak demand has not grown during the last 12 years, despite the increase of the installed generation.

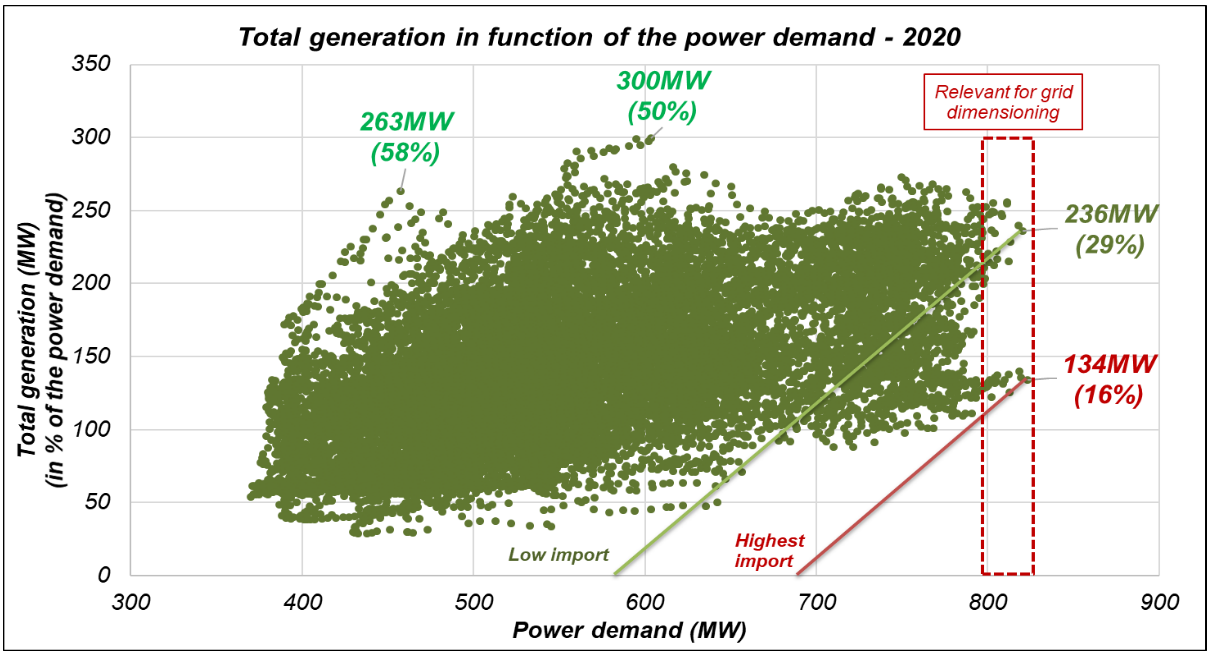
Luxembourg has made huge efforts and remarkable progress to increase the national electricity generation and to reduce the total electricity import, but the power contribution of those generation units during peak consumption is still modest. **The evolution of the annual electricity volume which is generated by national assets is meaningful, but of secondary importance for the dimensioning of the electrical grid.**

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



Source: Creos Luxembourg

The following chart shows the total domestic power generation for each ¼ hour based on the peak consumption for the year 2020. The highest absolute power generated in total was 300MW, but at a time where the demand was only slightly above 600MW. The highest relative generated power climbed up to 58% (263MW), when the power demand was low. During the peak demand, only 134MW (16% of the power demand) contributed to the reduction of the import. At another time of high demand, considerably more power was generated, 236MW (29% of the demand), which shows the high fluctuation of the generation.



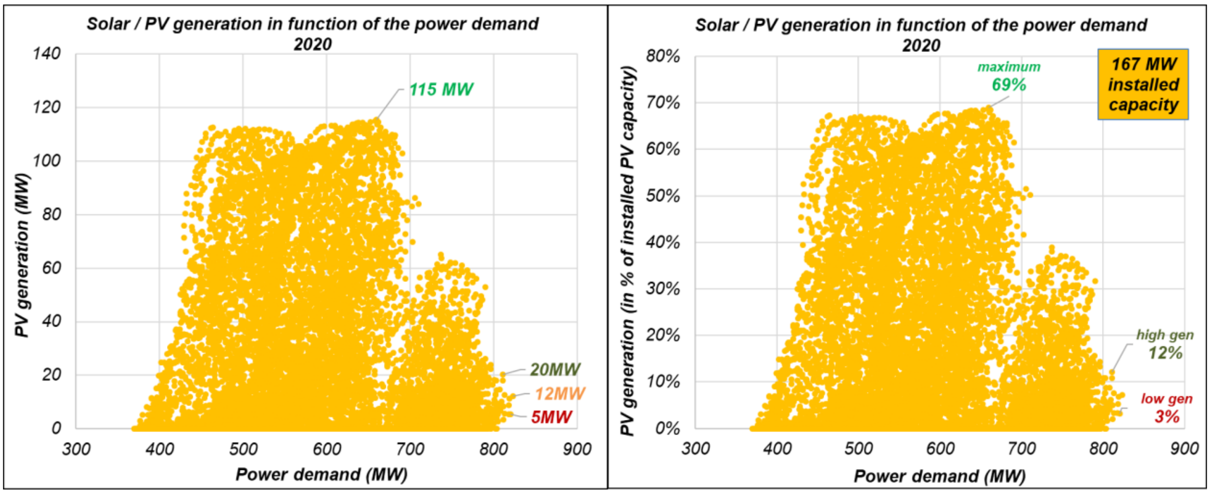
Source: Creos Luxembourg

Three insights can be identified from the chart:

- 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.
- The peak generation does not occur at the moment of the highest demand.
- During very high demands there are two possible generation ranges, a group of high generation cases and a range of low generation cases.

For the further proceedings of establishing forecasts of the electricity generation, it is meaningful to calculate the percentage of the power which is actually generated compared to the respective installed capacities and at what power demands those generations occur.

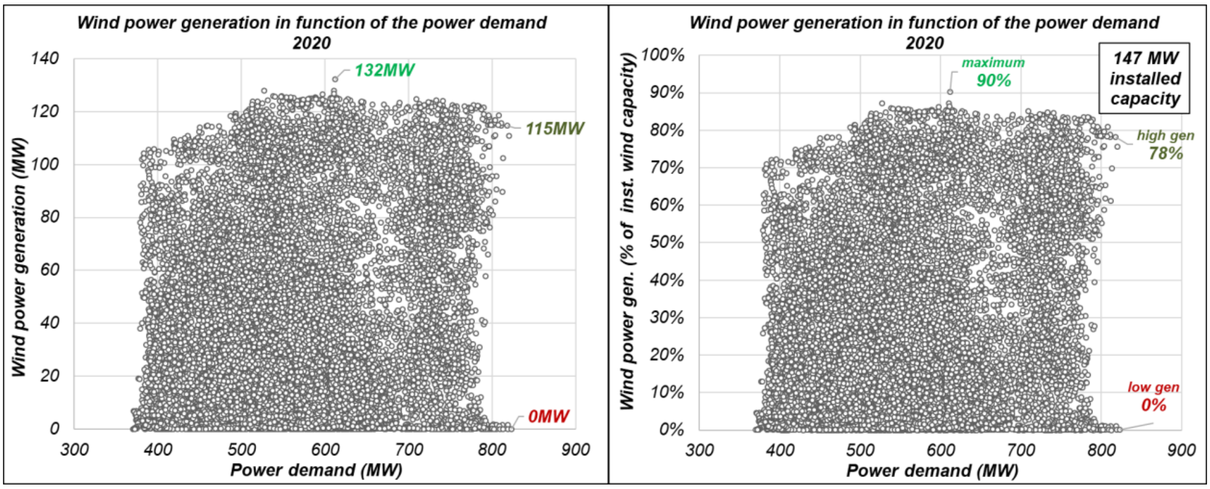
Solar / PV 2020:



Source: Creos Luxembourg

It is apparent that during the periods of high power demands, 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 recognisable that only a maximum of 12% of the installed PV capacity generated power during the periods of high consumptions. It should also be noted that only 70% of the total installed capacity were effectively generated at a maximum during spring and summer, assumably due to the various orientations of the individual installations.

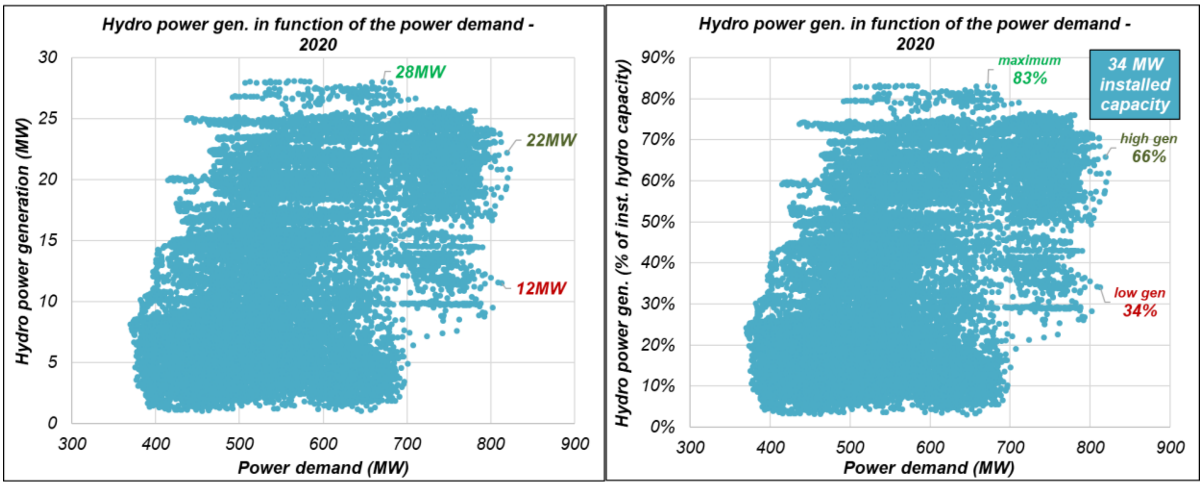
Wind power 2020:



Source: Creos Luxembourg

The maximum delivered power of all the windturbines climbed up to 90% of their installed capacity. However, during peak demand the wind power generation varied widely between 0% and 78% of its installed capacity.

Hydro-electric power 2020:



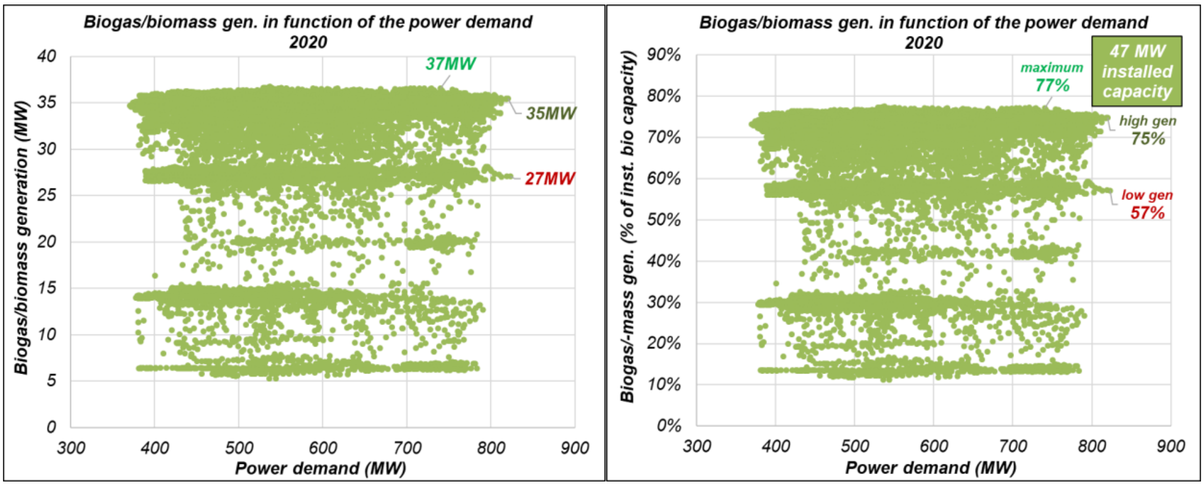
Source: Creos Luxembourg

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

During times of high demand for consumption needs, the hydro electric power varied from 34% to 66% 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.

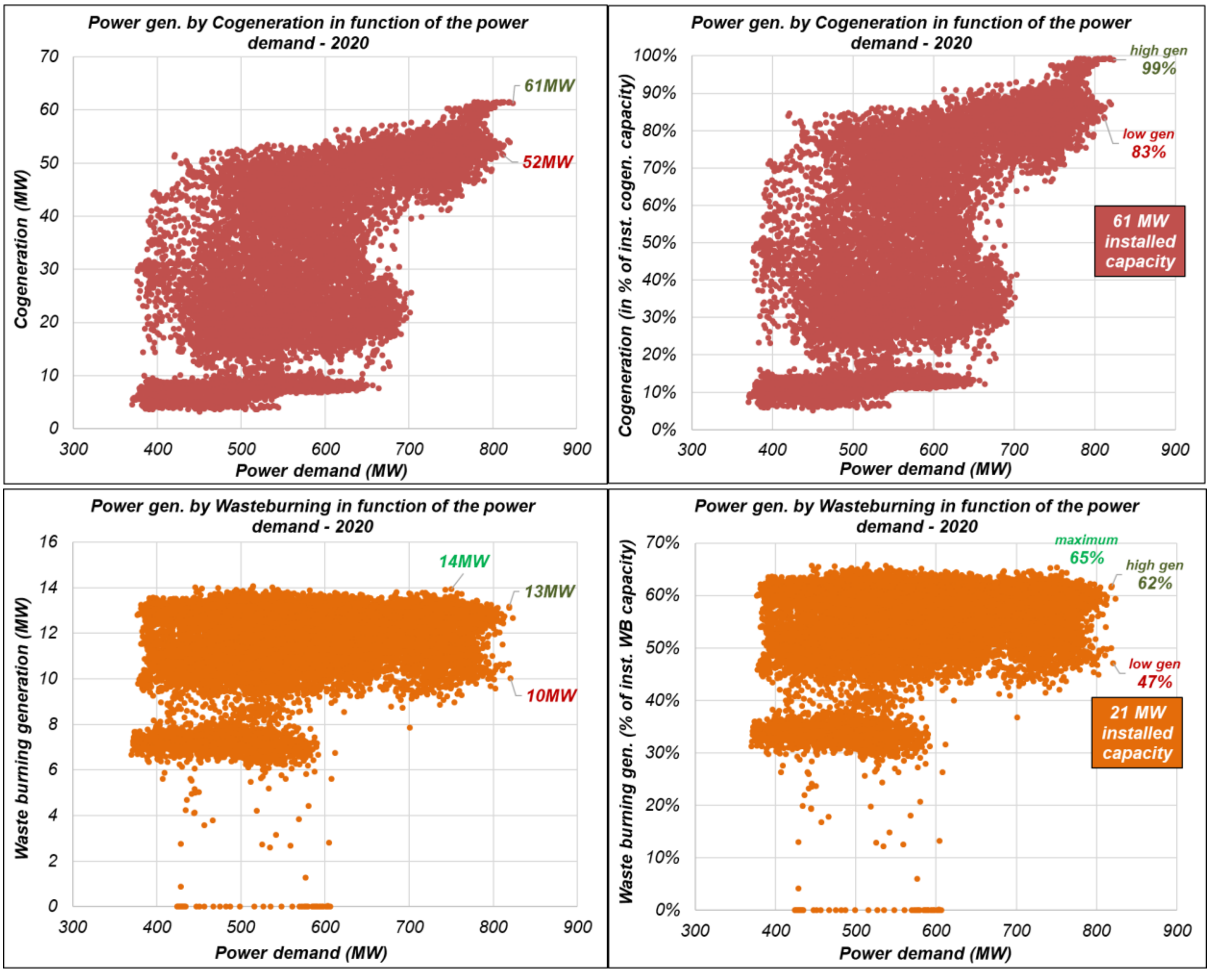
Biogas and biomass power generation 2020:



Source: Creos Luxembourg

Provided that the primary energy requirement is covered, the biomass and biogas power plants can be seen as controllable generation. Their contribution during the peak demand times is more elevated and reliable, it was between 57% and 75% of the installed capacity in the first half of 2020.

Power generated by cogeneration systems *and* ***by the waste burning power plant 2020:***



Source: Creos Luxembourg

The combined heat and electricity generation units are controllable, and those units benefit from special incentives in order to activate them during the times of peak consumption, what explains the very high availability range of 87% and 99% during those times. The waste burning plant was a little bit less available when the consumption needs were high, between 47% and 62% of the installed capacity was injected during these times in 2020.

In order to confirm the prior statements and figures from 2020, all the 15min measurements from 2015 to 2020 have been charted and analysed, 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 not only been determined for the peak demand value, but for a whole high demand range. In fact, for every year, high generation and low generation points situated in the most highest power demand field of about 4% have been identified. For example, for the year 2020, that field has been selected between a power demand of about 795MW and the peak power of 823MW.

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

Solar / PV	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Average*
Installed gen. capacity	*119MW*	*125MW*	*130MW*	*135MW*	*155MW*	*167MW*	*/*
*High generation**	*14%*	*13%*	*19%*	*10%*	*5%*	*12%*	***12,2%***
*Low generation**	*1%*	*2%*	*0%*	*0%*	*1%*	*3%*	***1,2%***
Wind power	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Average*
Installed gen. capacity	*64MW*	*121MW*	*121MW*	*123MW*	*133MW*	*147MW*	*/*
*High generation**	*71%*	*55%*	*48%*	*60%*	*45%*	*78%*	***59,5%***
*Low generation**	*1%*	*0%*	*0%*	*9%*	*1%*	*0%*	***1,8%***
Hydro power	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Average*
Installed gen. capacity	*38MW*	*38MW*	*38MW*	*34MW*	*34MW*	*34MW*	*/*
*High generation**	*66%*	*73%*	*32%*	*72%*	*73%*	*66%*	***63,6%***
*Low generation**	*25%*	*13%*	*8%*	*35%*	*39%*	*34%*	***25,6%***
Biogas / -mass	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Average*
Installed gen. capacity	*14MW*	*15MW*	*26MW*	*27MW*	*47MW*	*47MW*	*/*
*High generation**	*56%*	*60%*	*35%*	*53%*	*75%*	*75%*	***59%***
*Low generation**	*46%*	*48%*	*30%*	*36%*	*31%*	*57%*	***41%***
Cogeneration	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Average*
Installed gen. capacity	*92MW*	*86MW*	*72MW*	*63MW*	*62MW*	*61MW*	*/*
*High generation**	*81%*	*85%*	*96%*	*98%*	*98%*	*99%*	***93%***
*Low generation**	*73%*	*77%*	*87%*	*87%*	*81%*	*83%*	***81%***
Waste burning	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Average*
Installed gen. capacity	*21MW*	*21MW*	*21MW*	*21MW*	*21MW*	*21MW*	*/*
*High generation**	*56%*	*64%*	*65%*	*64%*	*100%*	*62%*	***69%***
*Low generation**	*42%*	*5%*	*55%*	*0%*	*49%*	*47%*	***33%***

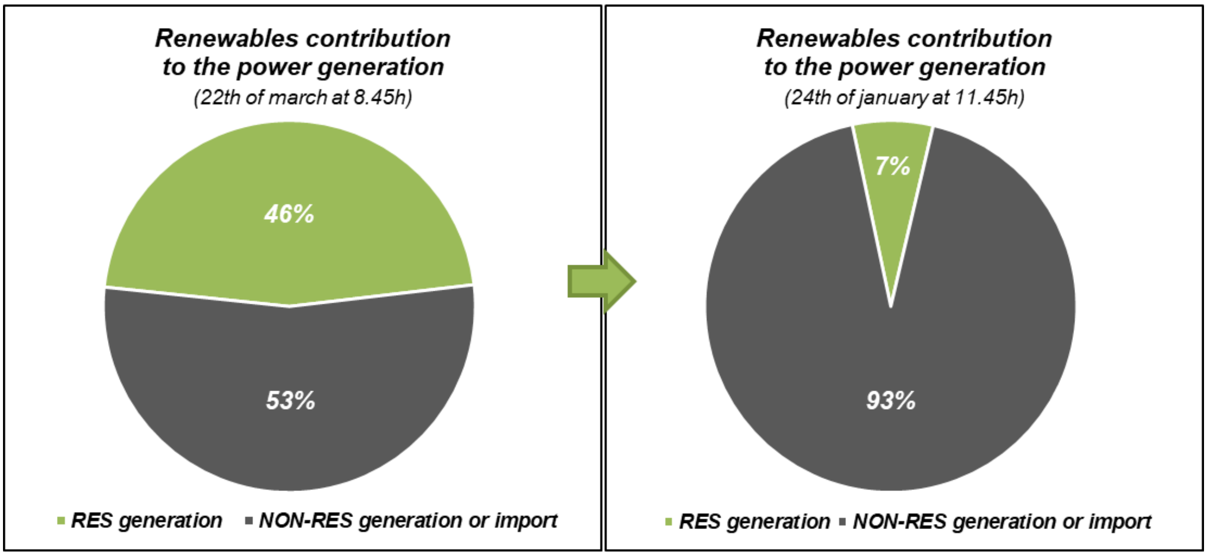
Source: Creos Luxembourg (in % of respective installed capacity, during high power demands)*

With those average figures applied to the installed capacity of 2020, the total generation could theoretically vary between 89MW (low generation case) and 229MW (high generation case) during the times of highest power demand.

During the peak demand at the 24th of January 2020 at midday, a total generation of 134MW was measured (33% of the average variation). The 5-year average figures should have a good validity for the further use, but it is important to note that the power generation can even be less than the low generation average. (see spreadsheet here before)

It is obvious that the power produced by the 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 some of those installations can vary widely during the consumption peak.

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



The 22nd of March 2020 at 8.45h, 46% of the electricity consumed on the Creos grid was generated by inland renewable energy sources, 53% were generated by non-renewable energy sources or had to be imported.

During peak consumption the 24th of January at 11.45h, only 7% of the consumption was generated by RES units and 93% were generated by Non-Res units or had to be imported.

It should be clear that the expansion of renewable energy sources is not preventing grid reinforcements but could make them even necessary on all voltage levels. The generation varies strongly throughout the year, and is generally greatest during spring and summer months, at times when the power demand or electricity consumption is not at its peak. If the power generated during those times grows higher than the consumption, the power generation must be considered for the grid dimensioning. The generation could surpass the grid capacities for consumption needs.

'Smart grids' could help smooth out the discrepancy between highest generation and highest demand with the help of intelligent communication and energy storage capabilities but cannot prevent it completely.

Different technical solutions for the storage of electrical energy are beginning to come up and they may be of importance in the future. Smaller, decentralized battery storages or bigger seasonal "Power to X" storages may emerge in order to accumulate a surplus of generated electricity and to provide it when there is a consumption need. Electrical storage methods could indeed help reduce import peak demands.

Still, it is a fact that, today, those solutions are not yet fully developed and not cost-effective. It would be highly speculative to consider them presently in the context of this study.

Future installed electricity generation capacity

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

Besides a steady increase of biomass generation, especially the wind power and solar PV generation are expected to have a continuing strong growth in the reference scenario. And in order to meet the requirements of the target scenario, the photovoltaic generation capacity has to rise even more steeply.

The detail of the installed generation capacity per type has 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 detail is listed hereafter:

Reference scenario (NECP LU – pages 163 & 169) – Installed generation (MW)			
Future generation capacity	***Jul. 2020***	***2030***	***2040***
RES generation capacity	*395*	*1125*	***1500***
NON-RES gen. capacity	*82*	*90*	***100***
Total generation capacity	***478***	***1215***	***1600***
PV	*167*	*608*	*857*
Wind	*147*	*400*	*500*
Hydro	*34*	*42*	*43*
Biogas / Biomass	*47*	*75*	*100*
Cogeneration	*61*	*69*	*79*
Waste burning	*21*	*21*	*21*

Target scenario (NECP LU – page 201) – Installed generation (MW)			
Future generation capacity	***Jul.2020***	***2030***	***2040***
RES generation capacity	*395*	*1496*	***2500***
NON-RES gen. capacity	*82*	*50*	***35***
Total generation capacity	***478***	***1546***	***2535***
PV	*167*	*984*	***1800***
Wind	*147*	*400*	***550***
Hydro	*34*	*37*	*40*
Biogas / Biomass	*47*	*75*	*110*
Cogeneration	*61*	*29*	*14*
Waste burning	*21*	*21*	*21*

(jul. 2020 : actual situation ; 2040: figures from NECP LU ; 2030 extrapolated values)
Source: NECP Luxembourg & Creos Luxembourg

For the reference scenario, the total Non-RES generation is supposed to be about 100MW in 2040. Today, the 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 those units for the target scenario.

In addition to the preceding scenarios, we would like to add our own assumption scenario for the 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 that we named it accordingly.

Assumed was a growth of 15MWp per year for the solar PV installations and the completion of 75% of the projects for wind farms or wind turbines that are known today. The biomass / biogas generation is also supposed to increase.

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

TIR / Rifkin - Fraunhofer ISE scenario – Installed generation (MW)			
Future generation capacity	***Jul. 2020***	***2030***	***2040***
RES generation capacity	*395*	*730*	***1055***
NON-RES gen. capacity	*82*	*65*	***45***
Total generation capacity	***478***	***795***	***1100***
PV	*167*	*318*	*470*
Wind	*147*	*303*	*450*
Hydro	*34*	*35*	*35*
Biogas / Biomass	*47*	*74*	*100*
Cogeneration	*61*	*44*	*24*
Waste burning	*21*	*21*	*21*

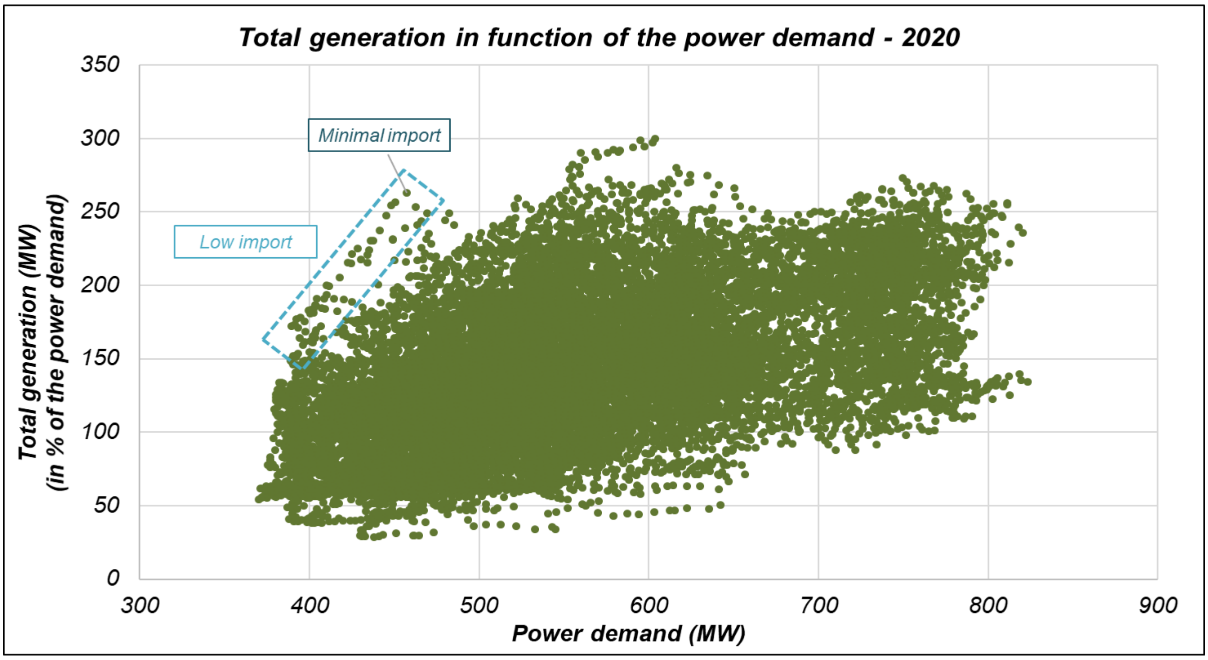
(jul. 2020 : actual situation)
Source: Creos Luxembourg

With these installed generation scenarios paired with the past 5-year average variation of the generation during high demands, the future generation range to expect during the peak demands can be assessed. The result can be viewed in the resuming chart in the chapter “Future electricity generation during peak demand”.

Future electricity generation during low demand

As the future installed generation capacity is expected to rise over the actual total transport capacity of the high voltage grid of about 1000MW, it is worthwhile to analyse the grid situation which might occur, when there is a high generation and a low demand at the same time.

The lowest import is not necessarily achieved when the power demand is lowest. Until this day, the lowest total demand in 2020 was about 370MW, but at that time the generation was low too, so that the resulting import was still quite important. In fact, the smallest import of 194MW was at a power demand of 457MW, at that time a total power of 263MW was generated, reducing the import to a minimum.



Source: Creos Luxembourg

At the moment of minimal import, the generation was about 55% of the total installed generation capacity. Generally, the generation did not exceed 63% of total installed generation capacity.

It is assumed 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 2500MW of installed generation would lead to a power generation of 1500MW to 1900MW. Even if there would be minimal consumption during that time, most of the generated power would have to be transported and exported over the existing 220kV high voltage transport grid.

The minimal power consumption, which never falls under a certain minimum on the high voltage transport grid, will not get smaller in the future and should be at least about 400MW. The remaining, generated power 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. It could range between 1100MW to 1500MW on the 220kV transport grid.

Nonetheless, as the forecast of the future peak power demand shows, the total projected peak power is expected to rise up even more than the generated power.

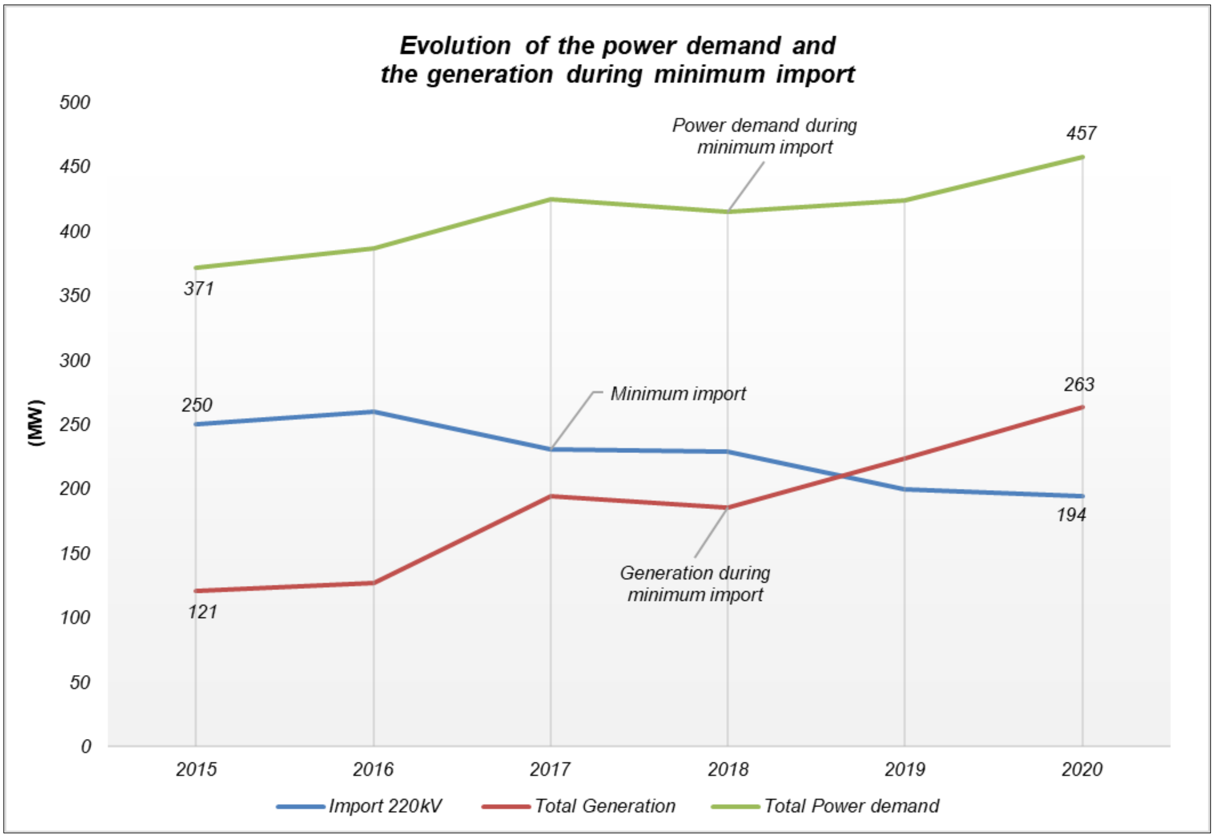
With the assumptions made in this report, the future peak power for consumption needs will be the determining value for the dimensioning of the future high voltage transport grid.

It should be noted that although the future generated “surplus” power will likely not be the decisive factor for the dimensioning of the **high voltage transport grid (220/380kV)**, it could be the **determining factor for grid reinforcements on the high voltage distribution grid (65/110kV), the medium voltage (20kV) and low voltage (400V) distribution grids**. Here consumptions could temporarily fall back to nearly zero, and all the generated power would have to be conveyed to the super ordinated grids.

As the future installed generation units are planned on all the voltage levels, it should be obvious that all the grids implied may need necessary reinforcements.

The past evolution shows that the minimum import decreased due to the growth of the generation during the periods of lower consumption, even if the power demand itself increased during these moments. If the installed generation capacity is constantly raised such as planned, the actual generation will surely surpass the power demand at times of low consumption in the future. As a result, the generated power at that time will be exported for the first time from the Creos grid.

Depending on the expansion speed of the additional generation capacity, this could happen in 5 to 10 years.

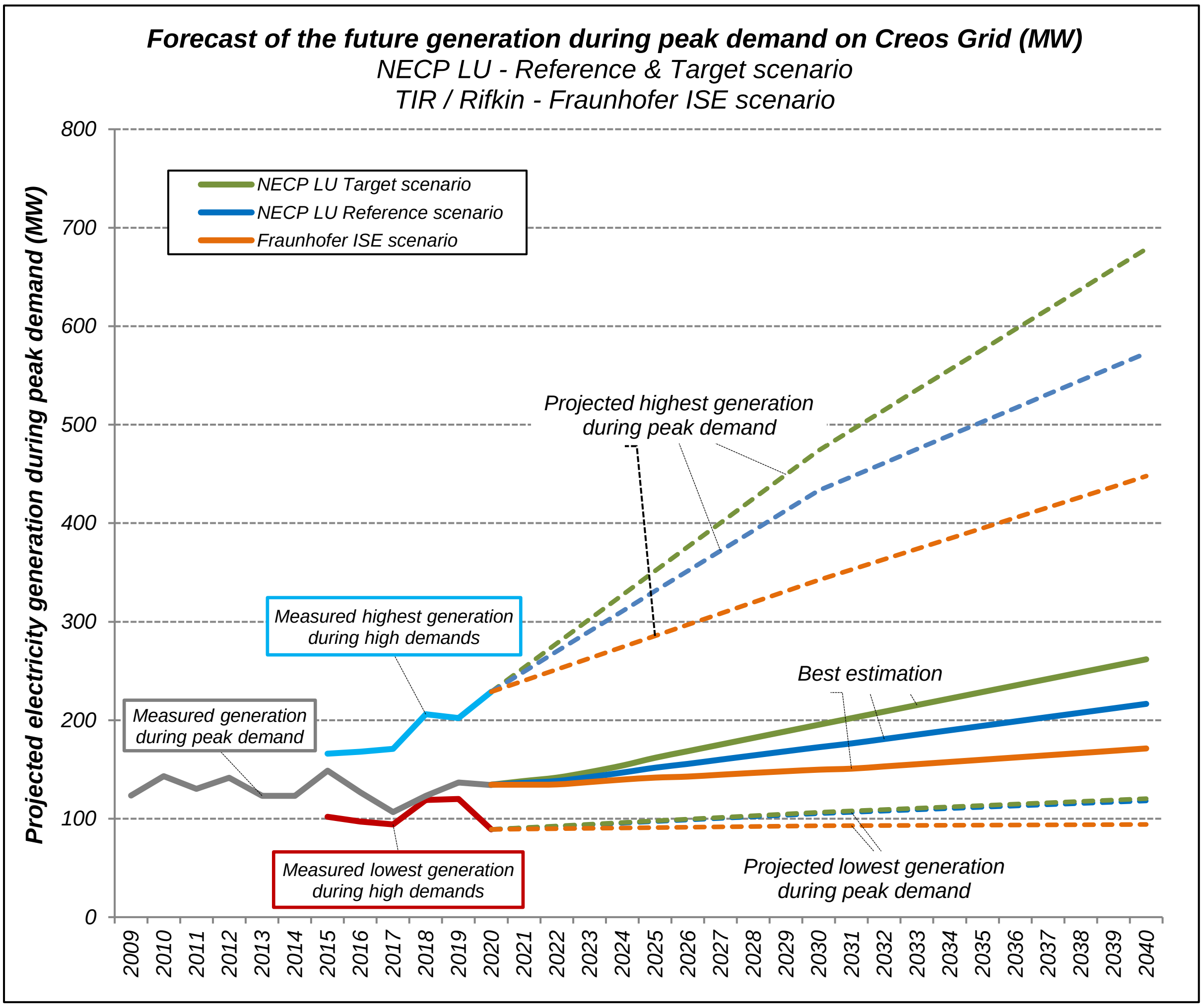


Source: Creos Luxembourg

Future electricity generation during peak demand

As shown previously, the future generation will probably vary between a low generation and a high generation during the peak demand. Additionally to those projections, a “best estimation” for the forecast of the generation during peak demand has been established as well. Furthermore, the real, measured values of the generation during peak demand from the past has been added to the chart, just as the measured highest and lowest generation variation from the last few years.

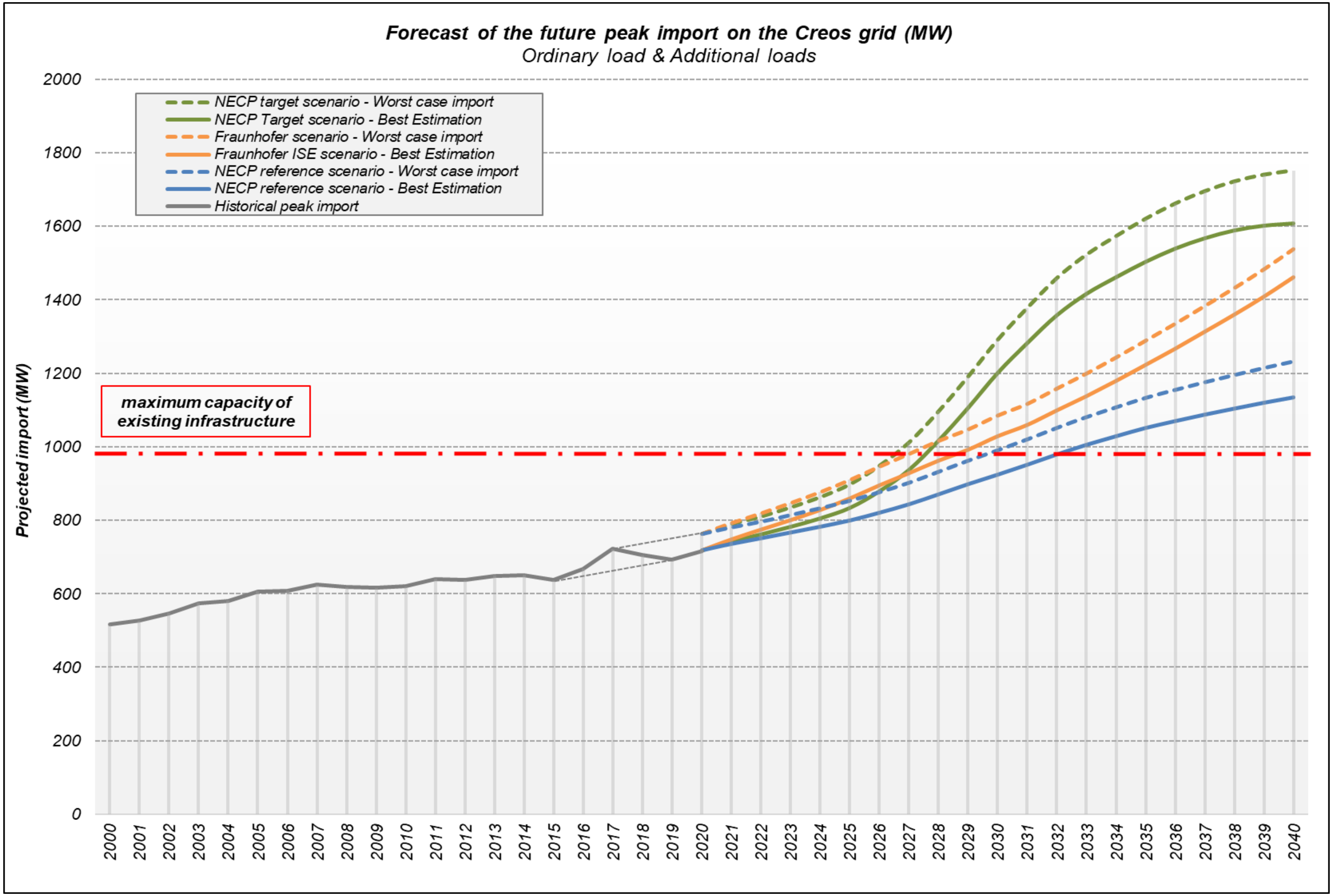
Import will be highest when the consumption will be highest and the domestic generation will be lowest; That would be the worst case. However, a “best estimation” scenario of the generation during peak demand was added in order to give a more optimistic assessment.



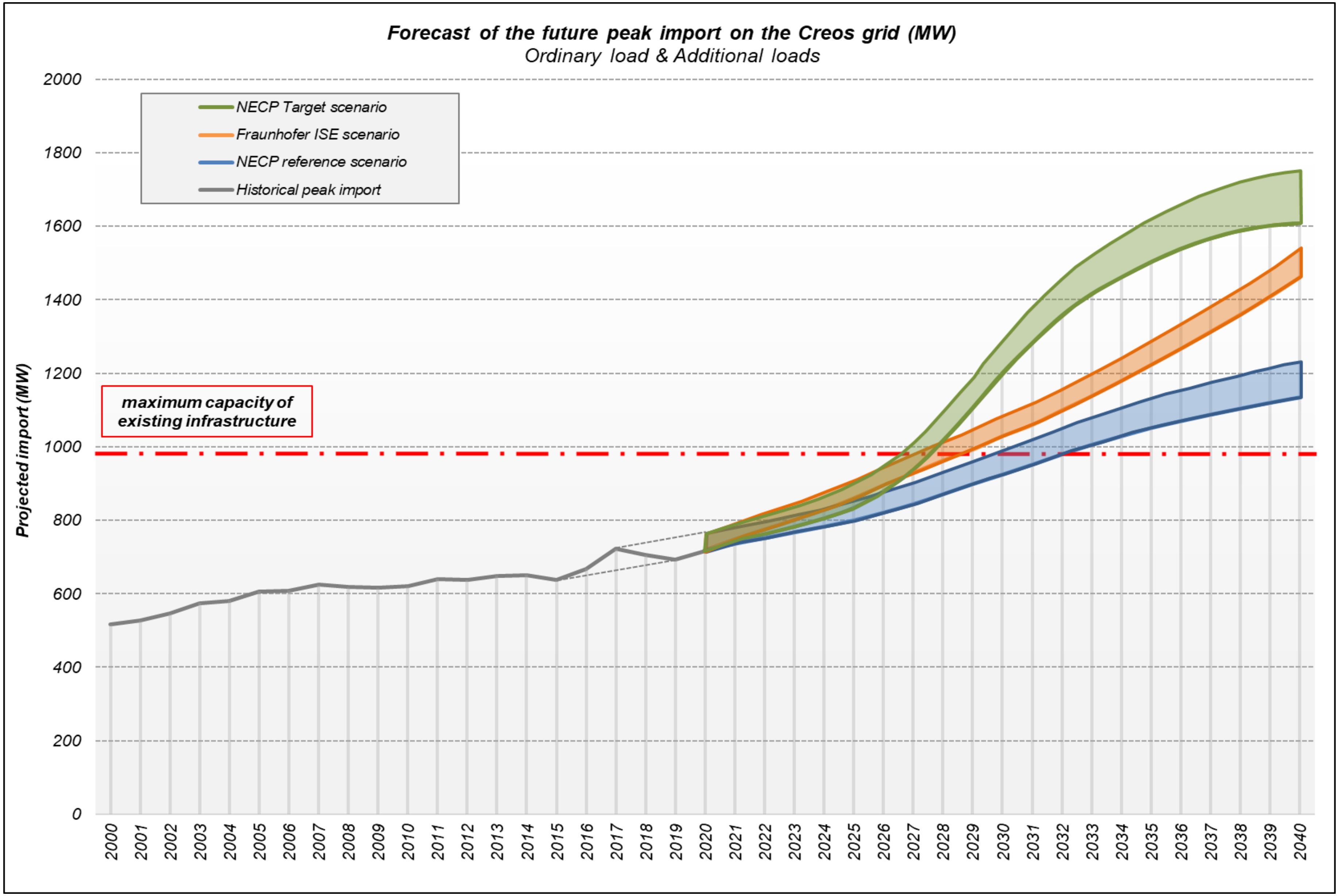
Source: Creos Luxembourg

Finally, the projections of the future import up to the year 2040 have been completed with the estimated contribution of the generation during peak demand (see next pages). The peak import curves have been calculated by subtracting the values of the future generation from the peak power forecasts. Only the values of the lowest and the best estimation generation have been used because that resulted in the highest import curves, which are the most relevant for the dimensioning of the electrical grid.

Forecast curves – peak import



Forecast curves – peak import



Conclusion and Recommendations

The European Network of Transmission System Operators for Electricity (ENTSO-E), and Creos as part of it, set the timely implementation of the Clean Energy Package as a priority, as it is an important milestone for Europe's green energy transition. ENTSO-E calls for stronger cross-border cooperation, in order to distribute and resorb the highly variable electricity flows from the renewables and to avoid congestion. To avoid possible constraints, it is therefore appropriate to increase the cross-border transmission capacities, where needed.

The secured import and transmission capacity of the existing supply lines coming from Bauler and Trier / Quint in Germany is currently 980MW. Worth mentioning is that the existing supply lines were constructed about more than 50 years ago. At that time 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.

Creos has privileged to reinforce the lines with Germany since Luxembourg is part of the German bidding zone (electricity market area). A bidding zone is defined as the largest geographical area in which market players can trade electricity without any restriction due to internal bottlenecks. Transmission capacity is therefore assumed to be unlimited within each bidding zone resulting in an uniform electricity price. Historically in Europe, bidding zones have been mainly defined according to national borders and that means that the electricity prices tend to be defined on a national level.

Interconnections with other neighbouring countries (Belgium and France) are not to be considered since they would only offer a limited transmission capacity for energy trades purposes between different bidding zones (Germany – Belgium or Germany – France) and the energy availability could therefore not be guaranteed for any timestamp.

This means that the interconnection with Belgium via the phase shift transformer cannot not be considered as an additional permanent infeed for Luxembourg since the full availability of the electrical energy cannot be ensured at any time. Controllable by the phase shift transformer, the grid connection with Belgium is a support connection increasing the overall security of supply of Luxembourg and it is mostly useful in case of a major unplanned unavailability on the German side.

Through resolute and extensive energy efficiency measures, it may be possible to slow out or reduce the electricity needs of the industrial, tertiary and residential sector in the future, despite the growth of the economy and of the population. But besides the economic and demographic growth of the country, the switch from heating with fossil fuels to using electric heat pumps and especially the development of the electrical transportation will inevitably lead to a higher electricity consumption and imply a substantial increase of the peak power demand in the future. According to our forecasts, with a medium e-mobility acceptance, the peak load on the high voltage grid could double, a high acceptance could triple the peak load on the high voltage grid. This increase of the maximum peak power has also been stated as such in the NECP report.

In that context, the use of smart-charging solutions for electric vehicles would certainly facilitate the integration of the electric vehicles and would help improve the utilization of the existing electric infrastructure.

Increased investments in renewable energies will surely reduce the total yearly electricity import amount but will not result in relevant reductions of the peak loads on the electrical grids. It is a fact that the relative contribution of the generation during the peak demands has not grown over the last ten years, despite of the doubling of the installed power of renewable energies. The power generated by those installations is subject to fluctuations and often, does not contribute enough during the peak demands. It is clearly shown in the report that the projected increase of renewable domestic power generation will not be enough to guarantee the security of supply in Luxembourg. The import capacities have to be increased in order to ensure the security of supply.

Electrical storage solutions like smaller, decentralized battery storages or bigger seasonal "Power to X" storages might emerge in the future in order to accumulate a surplus of generated electricity and to provide it when there is a consumption need. Electrical storage methods could indeed help reduce import peak demands and might be of importance then. But as those solutions are not yet fully developed and not cost-effective today, their in-depth consideration in the context of this study has been deemed as too speculative.

An additional load due to an interconnection between the Creos high voltage grid and the industrial electrical grid of Sotel has not been integrated in the forecast curves. This interconnection will only be possible after the increase of the import capacities.

Referring to the preceding considerations, it should be noted that all the analysed forecast scenarios are exceeding the current maximum transmission and import capacity. With or without the data center projects, with more or lesser projected electric vehicles, the projected import of every analysed scenario lies well above the current maximum transmission and import capacities. Even without the additional load of the data center project of Google, the increase of the import capacity is a necessity.

The future economic and demographic development and the necessary decarbonisation will lead to an increasing importance of electricity in the mix of energy end uses. Moreover, the design of the existing infrastructure dates from 50 years ago. Therefore, a modernisation is needed.

It is clearly necessary to increase the electrical energy import capacity and transmission capacities of the Creos high voltage grid.

Additionally, it is recommended to promote and support all technical or incentive means, like smart-charging solutions for electric vehicles, load-shifting or peak-shaving measures, which could help to optimize the utilization of the entire electrical infrastructure.

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