VARIABLE 2: Energy Security

12 February 2025 (final version)

A. Definition of the variable

1. What is meant by Energy Security?

Energy security can be defined as the reliable and uninterrupted access to sufficient and affordable energy resources for current and future energy needs. It is a broad subject that encompasses several topics. One aspect are prices that are covered by the global context variable (Variable 1). Other aspects are for example the energy security of supply, cross-border connections capacity, the security of the infrastructure in terms of the durability and suitability of its components in the long term but also its cyber-security. We limit the scope of this variable by exploring the energy needs of passenger cars in Wallonia/Belgium in the context of the energy system of the region/country, the main sources of energy on which it relies, and their origins. For each energy source, or vector, we provide some salient aspects that are relevant in terms of security.

2. Geographical scope

The focus is Wallonia, within the Belgian and European context

3. Link with passenger transport by car in Wallonia

This variable looks at the energy needs of passenger cars as an integral part of the energy system. The availability of the different energy resources to satisfy consumption, the energy mix of electricity generation, and the energy needs of the different sectors, including transport, are strongly interlinked and should therefore be holistically addressed.

B. Indicators

1. Direct indicators

Several indicators are considered to describe the Belgian and Walloon energy system, in particular, in terms of its energy balance. The main definitions that should be kept in mind are:

- **Gross inland consumption**[1]: *[…] measures the total energy demand of a country. It covers the consumption of the energy sector itself, losses during transformation (for example, from gas into electricity) and distribution of energy, and the final consumption by end users. It includes energy used for non-energy purposes (such as petroleum used for producing plastics). It excludes energy provided for international maritime transport* [1].
- **Gross electricity production or generation:** *[…] is the sum of the electrical energy production by all the generating sets concerned (including pumped storage) measured at the output terminals of the main generators* [1].
- **Final energy consumption** i*s the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself. It includes energy used for non-energy purposes. It excludes energy provided to international aviation* [1].

[1] In the original reference this is denoted as 'Primary Energy Consumption'. Numerical values and definition are however consistent to the 'Gross Inland Consumption' as defined by Eurostat. For consistency and clarity, it was decided to report the nomenclature used by Eurostat.

- **Energy dependency rate** *shows the proportion of energy that an economy must import. It is defined as net energy imports divided by gross available energy*[2]*, expressed as a percentage. A negative dependency rate indicates a net exporter of energy while a dependency rate in excess of 100 % indicates that energy products have been stocked. It can be defined for all products total as well as for individual fuels (for example: crude oil, natural gas).* [2].

For Belgium these indicators can be obtained from Eurostat's complete energy balances [3] or from the Service Public Fédéral Économie (SPF)[1]. For the Walloon region, as far as to the authors' knowledge, similar indicators are published by the 'Institut wallon de l'évaluation, de la prospective et de la statistique' (IWEPS) in the 'Bilan énergétique'[4], [5]. The most recent data available however refer to 2020, and therefore display the impact of Covid but not the fast recovery thereafter. These indicators are published in pdf documents and reports, rather than a dataset.

Table 1 Available indicators

Indicator	Source	Period	Comments
Gross Inland Energy Consumption (BE)	SPF	2022	Eurostat makes available data for the 1990-2023 period.
Gross Inland Energy Consumption (WL)	IWEPS	1990-2020	
Gross electricity production or generation (BE)	SPF	2022	Eurostat makes available data for the 1990-2023 period.
Gross electricity production or generation (WL)	IWEPS	1990-2020	
Final energy consumption (BE)	SPF	2022	Eurostat makes available data for the 1990-2023 period.
Final energy consumption (WL)	IWEPS	1990-2020	
Final energy consumption in road transport (BE)	Eurostat	1990-2023	
Final energy consumption in road transport (WL)	IWEPS	2020	
Energy (in)dependency rate (BE)	Eurostat	2022	Could be calculated from Eurostat for the 1990-2023 period.
Energy (in)dependency rate (WL)	IWEPS	1990-2020	

Notes: BE: Belgium, WL: Wallonia. IWEPS: Institut wallon de l'évaluation, de la prospective et de la statistique. SPF: Service Public Fédéral. The indicators ware reported consistently with the most recent data made available by SPF. To note, the same indicators could be calculated, at least for Belgium, using Eurostat data directly. As will be explained later, Energy independence rates for Belgium and Wallonia are calculated using different approaches.

When possible, the information on the energy resources used in Belgium and Wallonia, is complemented with insights relative to their origin. To keep in mind though, that because of international trade in a global market, it can be difficult to identify the ultimate origin of specific products.

[2] To note, gross available energy differs from gross inland consumption as it includes also international bunker fuels. According to Eurostat, Gross Available Energy, *includes overall supply of energy for all activities on the territory of the country. It includes energy needs for energy transformation (including generating electricity from combustible fuels), support operations of the energy sector itself, transmission and distribution losses, final energy consumption (industry, transport, households, services, agriculture, ...) and the use of fossil fuel products for non-energy purposes (e.g. in the chemical industry). It also includes fuel purchased within the country that is used elsewhere (e.g. international aviation, international maritime bunkers and, in the case of road transport "fuel tourism")* [2].

2. *Indirect indicators*

Several indirect indicators, calculated from the data sources outlined above, are proposed showing the contribution of the different energy sources (or vectors) to the main indicators described above.

C. Retrospective analysis

1. *Energy context*

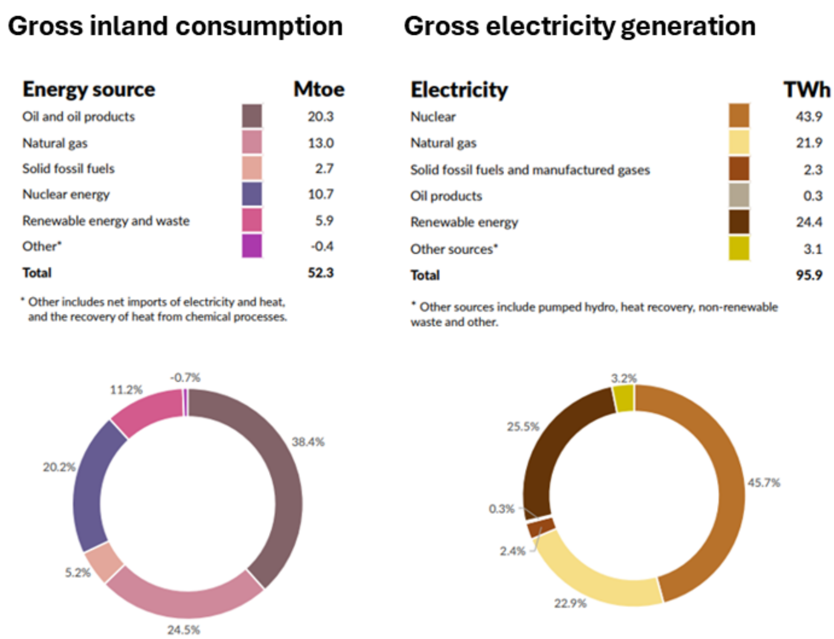
In this section we give a brief overview of the energy context of Belgium through the main indicators that describe its energy system. Further insight on the specific context of Wallonia is provided by reporting the figures as made available in the 'complete energy balance' of the region [5]. To note, the reporting methodology used at national and regional level may not always be consistent and therefore a direct comparison is not always possible.

Gross inland consumption and electricity generation

Figure 1 shows the gross inland consumption per energy source and gross electricity production or generation for Belgium in 2022.

In terms of gross inland consumption, Belgium is mainly reliant on oil and oil products (38.4%), natural gas (24.5%), and nuclear energy (20.2%). In terms of gross electricity production, in 2022, 45.7% of electricity in Belgium originated from nuclear power plants. Renewables are the second largest contributor to electricity production with a share of 25.5%, similar to that of gas with a share of 22.9%.

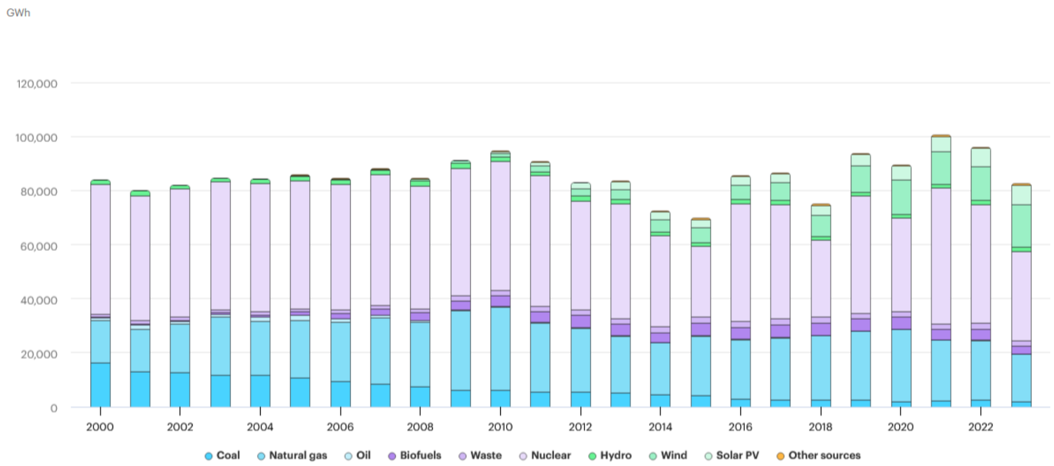
Figure 1: Energy sources for gross inland consumption (Mtoe heat equivalent) and gross electricity generation per fuel (TWh electricity), Belgium, 2022.



Notes: The "Gross Inland consumption" graph is titled "Primary Energy Consumption" in the original reference. We changed it because, the values reported correspond to the gross inland consumption and not to the primary energy consumption as defined by Eurostat. It was decided to title the graph with "Gross final consumption" for consistency with the reporting and the definitions used by Eurostat but one should keep in mind there can be 'nomenclature' inconsistencies when looking at energy statistics.
Source: SPF Economie, PME, Classes moyennes et Energie [1], Eurostat [3]

The evolution of the electricity generation mix, between 2000 and 2023 for Belgium is shown in Figure 2 as reported by the International Energy Agency [6]. In the last 15 years the contribution of renewables has seen a sharp increase and since the 1990s, because of the reduction of related industrial activity, the contribution of coal has seen a sharp decrease.

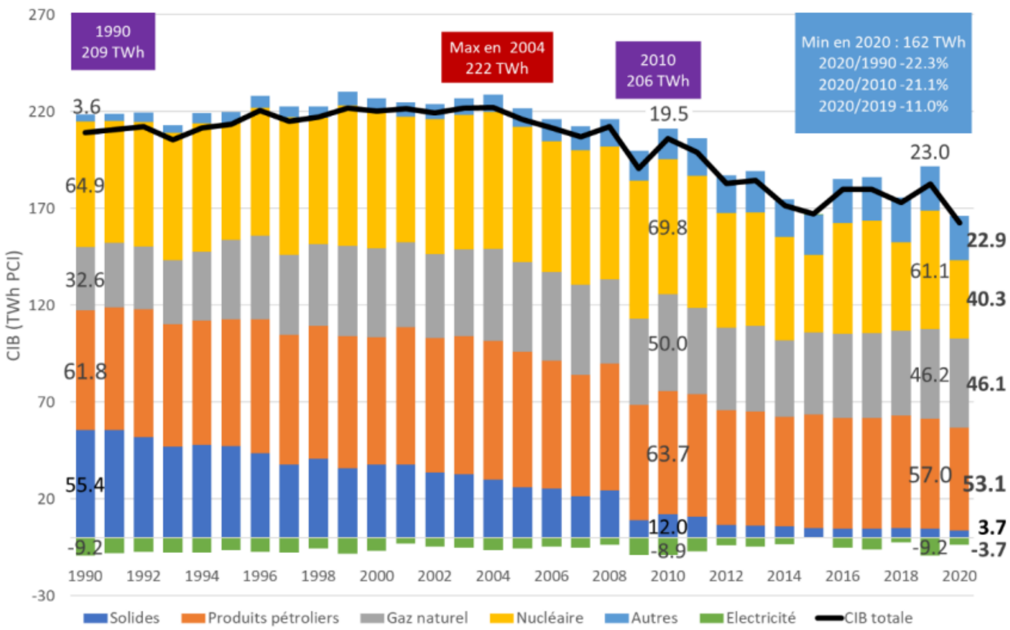
Figure 2: Electricity generation by source, 2000-2023 Belgium.



Notes: IEA - All rights reserved
Source: International Energy Agency (IEA) [6]

Figure 3 reports the evolution of the gross inland energy consumption per energy source or vector specific to Wallonia from 1990 to 2020 [5]. The long time series highlights the decrease of the contribution of coal and the increase of renewables.

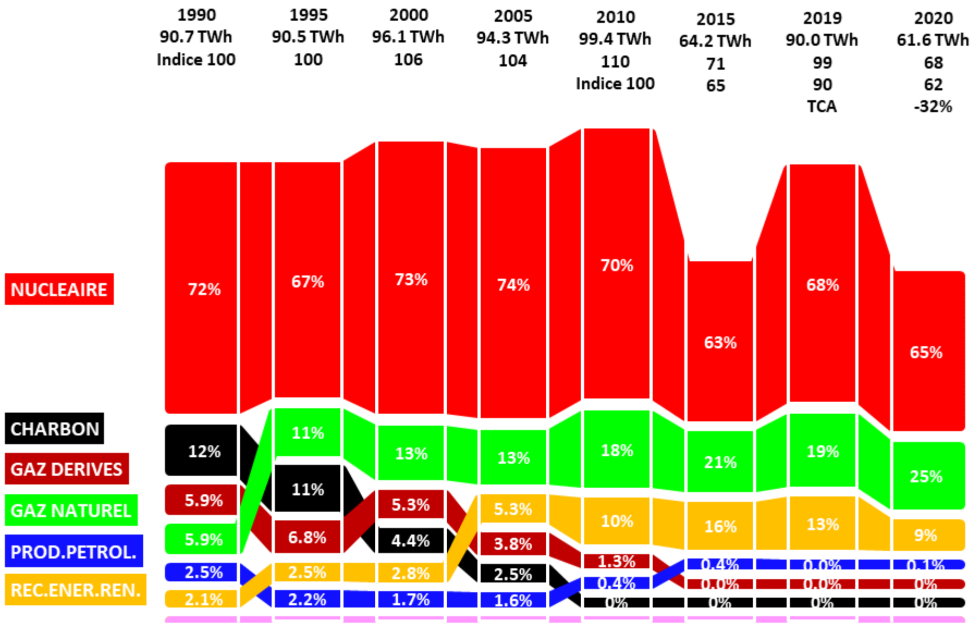
Figure 3: Gross inland energy consumption per energy vector (in TWh, LHV for combustible products, heat for nuclear), Wallonia.



Source: Service public de Wallonie - Institut de Conseil et d'Etudes en Développement Durable [5]

Figure 4, also specific to Wallonia, reports the evolution of electricity production by source from 1990 to 2020. Since 1990, nuclear has always been the most important energy source for electricity generation with a share in the electricity mix ranging from 65% to 72%. In 1995, coal and gas both accounted for 11% of the electricity mix, but by 2020 the contribution of gas had risen to 25% whereas that of coal became negligible. The last coal mines in Belgium were closed in 1992 and remaining coal activities relied on imports. Only small quantities of coal are still recovered from slag heaps, as well as the extraction of colliery gas for the production of electricity and heat [1].

Figure 4: Breakdown of energy sources used for electricity production excluding primary electricity and pump-turbine plants (this is expressed in primary energy, LHV or heat content in the case of Nuclear) in Wallonia.

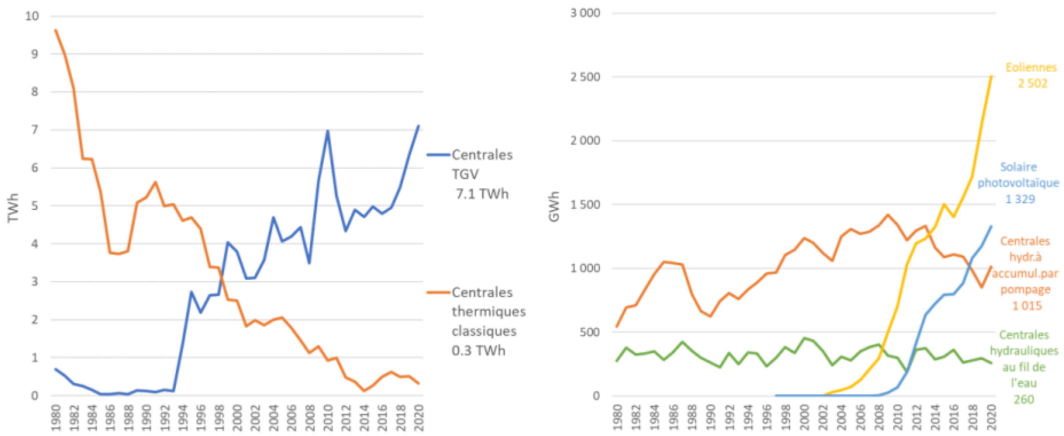


Notes: Primary electricity and pump-turbine are excluded. Primary electricity is defined as follows: Primary electricity = wind, photovoltaic, and run-of-the-river hydroelectric production. TCA = Taux de croissance annuel (Annual Growth Rate)

Source: Service public de Wallonie - Institut de Conseil et d'Etudes en Développement Durable [5]

Figure 5 provides further insight on the evolution of electricity production in Wallonia since 1980 (excluding nuclear power plants). This figure shows that the decrease in electricity production from conventional thermal power plants has been mainly replaced by natural gas combined cycles (TGV: Turbine Gaz Vapeur). It also shows that the contribution of wind and solar has seen a very sharp increase in the last 10-20 years, overtaking the contribution of traditional hydroelectric power plants.

Figure 5: Evolution of the net electricity production of the main types of power plants, excluding nuclear, and evolution of primary electricity production in Wallonia (in TWh, electricity).



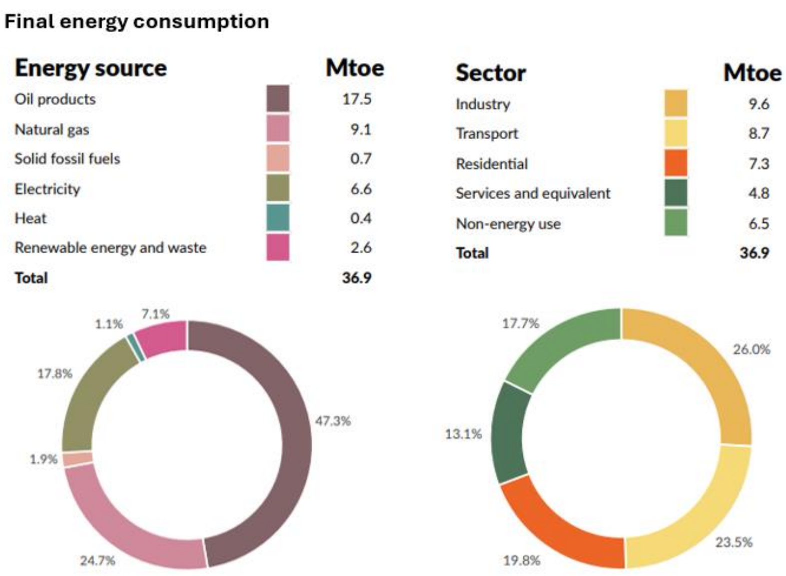
Notes: TGV: turbine gaz vapeur (combined cycles)
Source: Service public de Wallonie - Institut de Conseil et d'Etudes en Développement Durable [5]

Final energy consumption

Figure 6 summarises the final consumption of energy per source and per sector for Belgium.

Transport, with a share of 23.5% accounts for an important part of the final energy consumption. Eurostat, for 2022, reports that road transport alone accounted for 8.3 Mtoe of the 8.7 Mtoe used in the transport sector [3].

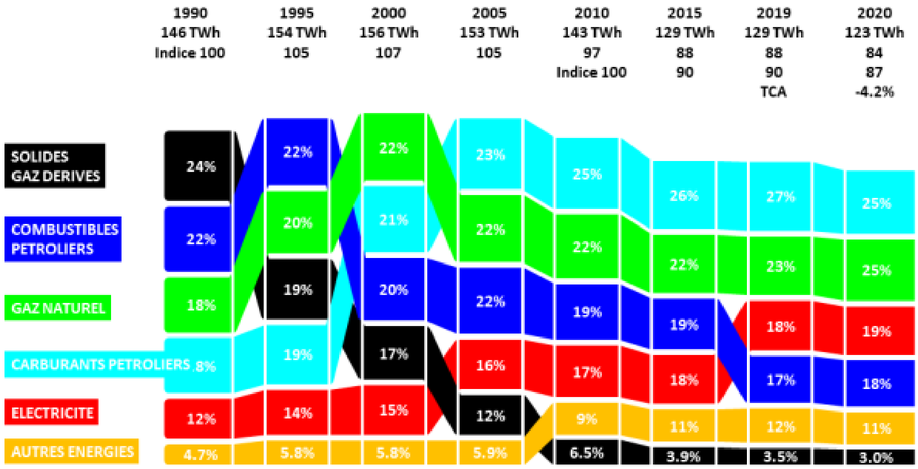
Figure 6: Final energy consumption per source/vector and per sector, Belgium, 2022.



Notes: Cross-checking the numerical values with the ones reported by Eurostat, the final energy consumption reported in this corresponds to the sum of the final energy consumption for energy use and for non-energy uses reported by Eurostat. It is also important to note that the final energy consumption of 'transport' does not include maritime bunkers and international aviation bunkers
Source: SPF Economie, PME, Classes moyennes et Energie [1], Eurostat [3]

Figure 7 and Figure 8 give the corresponding information for Wallonia, in terms of the contribution of sources/vectors and sectors. Figure 7 highlights again the decreasing role of solid fuels and the increasing role of electricity and renewables in the final energy consumption.

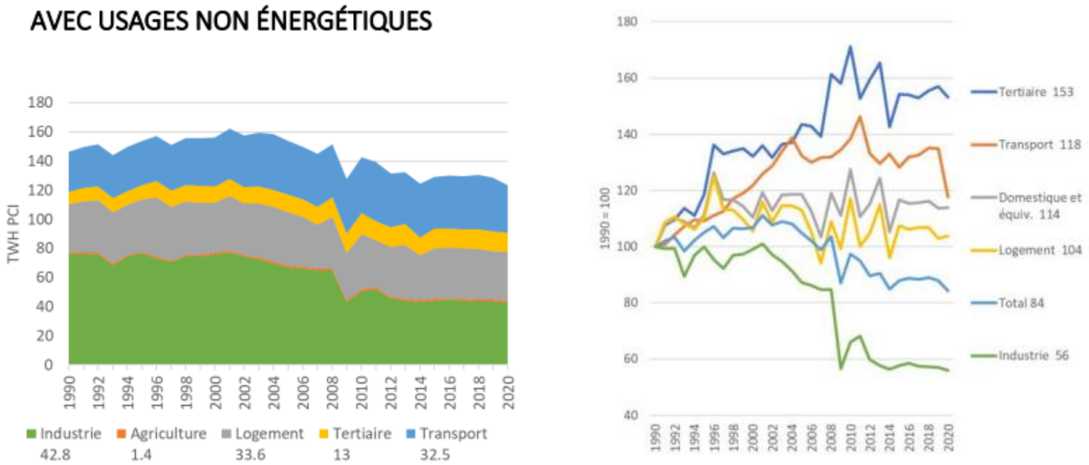
Figure 7: Final energy consumption per vector in Wallonia (in TWh).



Source: Service public de Wallonie - Institut de Conseil et d'Etudes en Développement Durable [5]

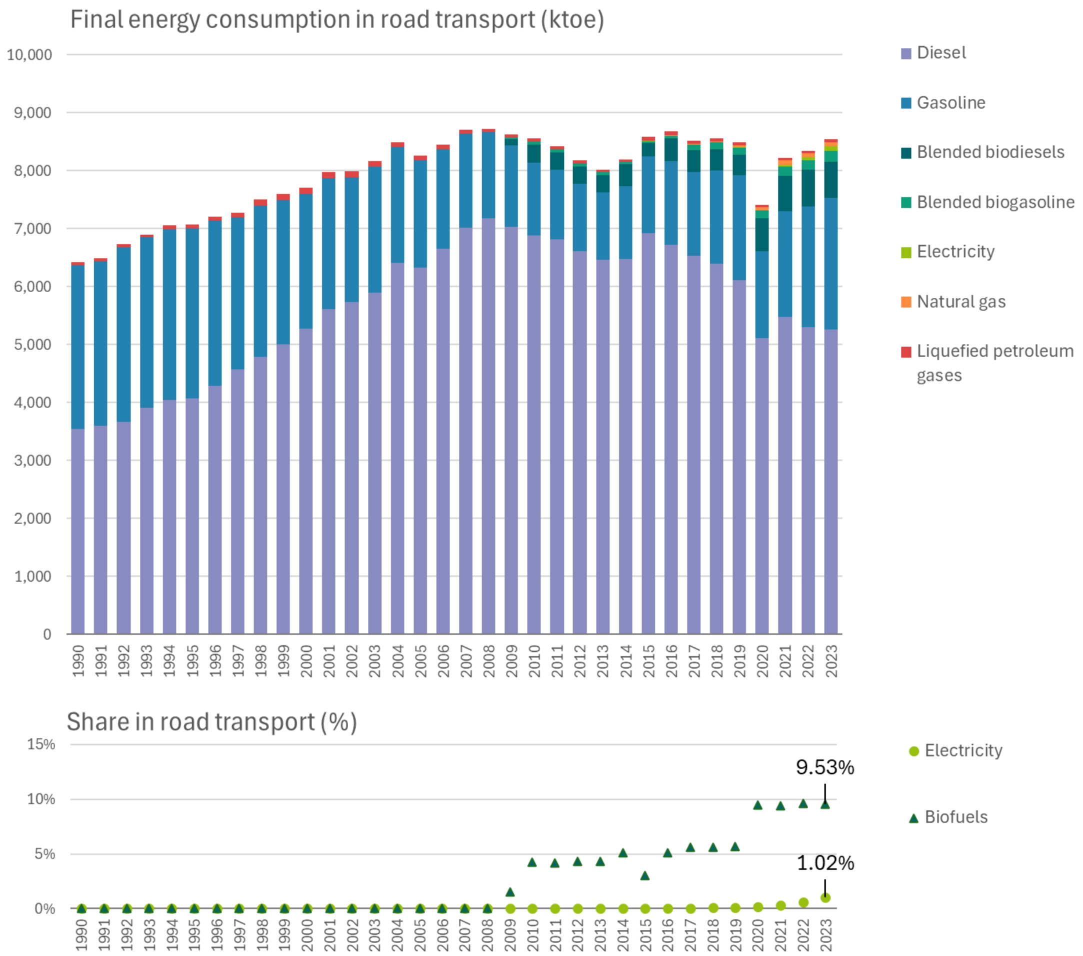
Figure 8 shows that, in Wallonia, the tertiary and transport sectors are the sectors that have seen the greatest increase in final energy consumption since 1990. To note, the strong drop observed in 2020 in energy consumption of transport is a consequence of the global COVID-19 pandemic and has since largely recovered.

Figure 8: Evolution of final energy consumption in Wallonia.



Within road transport, *Figure 9* shows the evolution of the different types of fuels for Belgium. Road transport mainly relies on fossil fuels with an increasing, though still small, role of electricity. In 2023 biofuels account for about 10%, electricity for about 1%.

Figure 9: Fuel use in final energy consumption for road transport and shares of biofuels and electricity, Belgium, 1990 to 2023.



Source: Eurostat [3]

Figure 10 provides further insight on the role of passenger cars within road transport for Wallonia, showing that about 55% of final energy consumption of the road transport sector can be attributed to passenger cars alone.

Figure 10: Final energy consumption of road transport in Wallonia (in GWh, Lower Heating Value (LHV))

Véhicule	Diesel	Bio diesel	Diesel + bio diesel	Essence	Bio éthanol	Essence + bio éthanol	Bio éthanol pur	GPL	GNC	Électricité	Total	% du Total
Bus et cars	478,9	53,6	532,4				0,55			1,0	534,0	2,1%
Camionnettes	2 764,7	309,4	3 074,1	90,9	7,9	98,9				0,7	3 173,6	12,7%
Camions	6 542,0	732,1	7 274,1	0,1	0,01	0,1				0,002	7 274,2	29,0%
Motos vélos	3,3	0,4	3,6	166,1	14,5	180,6				3,1	187,3	0,7%
Voitures	7 698,4	861,5	8 559,8	4 604,9	402,1	5 007,0		178,4	107,3	49,3	13 901,9	55,4%
Autres										0,0	0,0	0,0%
Total	17 487,2	1 956,8	19 444,1	4 862,0	424,6	5 286,6	0,55	178,4	107,3	54,2	25 071,1	100,0%
% du Total	69,8%	7,8%	77,6%	19,4%	1,7%	21,1%	0,0%	0,7%	0,4%	0,2%	100%	

Sources: SPW Mobilité et Transports (enquêtes sur les carburants pétroliers dans les stations publiques et privées et ventes CNG),
AWAC IRCELINE (répartition de la consommation par type de véhicules),
ICEDD (estimation de la consommation d'électricité)
TEC (bio-éthanol pur)

Source: Service Publique de Wallonie [4]

The figures reported in this section show that road transport is an important and integral part of the energy system. The energy security of the Belgian energy system, as a whole, has therefore direct impacts on the security of the energy needs of the transport sector. In the following section, after a brief discussion on energy independence, we give more detail on the main energy sources and vectors on which the system relies, their role in the energy system, how their contribution has evolved and salient aspects that are relevant in terms of security with, when possible, specific information for Wallonia.

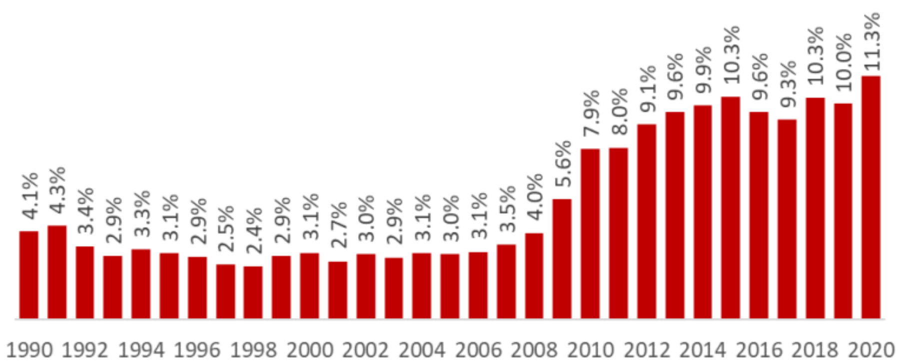
2. *Energy independence and energy security*

In response to Russia's war of aggression and invasion of Ukraine, the *Direction Générale de l'Energie du SPF Economie* [7] conducted a study analysing the energy security of Belgium with respect to both natural gas and its energy mix. The reader is also referred to the International Energy Agency's report 'Belgium 2022 – Energy Policy Review' for a detailed overview about the energy security of the country for the main energy sources and vectors [8].

According to Eurostat [9] and SPF [7], Belgium, with 78.1% of its Gross Inland Energy Consumption coming from abroad, is the 5th most energy dependent country in Europe, after Malta, Cyprus, Luxembourg and Greece. The diversification of the countries of supply and the management of the strategic stocks are therefore of fundamental importance to ensure energy security of the country [7].

Looking at Wallonia's "complete energy balance" [5], the region's energy dependence in 2020 was 88.7% (or 11.3% energy independence) as shown in Figure 11. To note, in the estimate for Belgium mentioned above, nuclear energy is accounted for as domestic production regardless of the actual source of the fuel. In contrast, in the estimate for Wallonia, nuclear energy is accounted for as imported as the nuclear fuel and raw materials are nor produced nor extracted in Belgium. SPF, like Eurostat, considers nuclear energy as part of Belgium's Primary Energy Production (with a contribution for 2022 of 67.4%, as reported in the latest Belgian Energy Data Overview [1]). The differences in accounting of nuclear energy should be kept in mind when looking at the overall energy picture of Belgium and Wallonia as the different approaches inevitably result in a different picture[3].

Figure 11: Evolution of energy independence in Wallonia, with nuclear energy accounted for as an import.



Source: Service public de Wallonie - Institut de Conseil et d'Etudes en Développement Durable [5]

The increase of the energy independence of Wallonia, shown in *Figure 11*, can be explained considering two main trends. First, the increase of the contribution of renewables and heat recovery. Second, the decline in activity of Wallonia's industry, and particularly the steel industry, which until recent years was a major consumer of imported coal (for which prior to the war, Belgium had turned to Russia).

[3] Furthermore, it is not clear if the calculation approach for Wallonia is the same as the one used in Eurostat. Eurostat calculated dependency (or independency) considering at the denominator the gross available energy (which includes bunkers), the numbers for Wallonia refer to the gross inland consumption ("consommation intérieure brute") (which according to Eurostat excludes international bunkers).

The analysis of the import dependencies of Wallonia, Belgium and Europe with respect to Russia and other countries with complex geopolitical contexts is an important aspect to consider when looking at energy security. Even if an in-depth study is beyond the scope of this short report, a brief discussion limited to some of the salient aspects is provided.

Nuclear energy

In 2022, in Belgium, **nuclear energy** contributed to:

- 20.2% of gross inland energy consumption
- 45.7% of gross electricity production

Belgium imports nuclear fuel that is manufactured in France, with the Uranium itself coming from elsewhere. Data for 2020 show that Uranium used in Europe was mainly imported from Niger, Russia, Kazakhstan and Canada, with each country accounting for about 20% of supply [7]. Around 40% of the uranium used at the Doel and Tihange nuclear power plants (NPP) was in fact linked to Russia prior to the war but, since the end of 2021, uranium used in Belgium is no longer imported or refined in Russia [10].

Nuclear power represents an important share of the Belgian electricity mix with, in 2022, over 45% of electricity generation but its future has been long debated. According to the law passed by Parliament in 2003, nuclear fission energy was to be phased out between 2015 and 2025. Successive Governments have amended the law to ensure the security of supply of electricity and extended the operating licences of the three oldest reactors while maintaining the phase out deadline for all nuclear reactors by 2025. On 18th March 2022, after Russia's invasion of Ukraine, the Federal Government extended the operational life of the two youngest nuclear power reactors, Doel 4 and Tihange 3, that entered in operation in 1985, by ten years, until 2035.

Oil and oil products

In 2022, in Belgium, **oil and oil products** contributed to:

- 38.4% of gross inland energy consumption

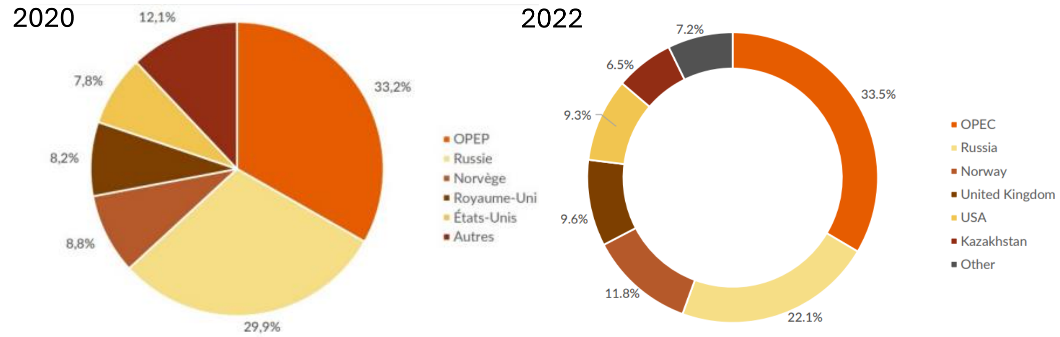
In 2022 in Belgium, **oil products** contributed to:

- 0.3% of gross electricity production
- 47.4% of final energy consumption
- 89% of final energy consumption in road transport

Despite Belgium not being a crude oil producing country, Belgian refineries transform crude oil into **products** that exceed the domestic demand. Belgium is therefore a net oil products exporter, with 8.7% of its total oil products production exported in 2023. In refineries, crude oil is transformed into fuels used in the transport sector (in 2023, 43.6% of oil products), heating oil used in the residential sector (in 2023, 12.5% of oil products), and other chemicals and products with a wide range of industrial and commercial uses, notably plastics.

However, Belgium is completely reliant on other countries for its **crude oil** consumption. In 2020, it imported 33.2 % of its crude oil from the Organization of the Petroleum Exporting Countries (OPEC) and 29.9% from Russia alone [7]. As shown in Figure 12, though the share of crude oil imports from Russia decreased to 22% by 2022, Russia remained the second most important crude oil source.

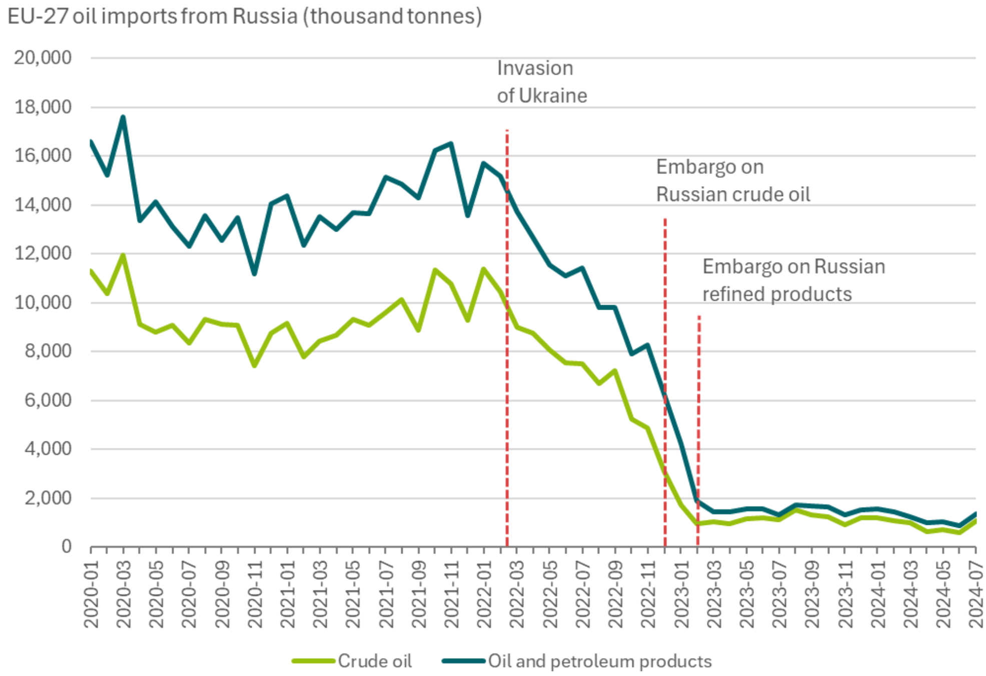
Figure 12: Origin of crude oil imports to Belgium in 2020 and 2022.



Source: SPF Economie, PME, Classes moyennes et Energie for 2020 [7] and for 2022 [1]

In June 2022 the European Council adopted a sixth package of sanctions which, among other things, prohibits the purchase, import and transfer of seaborne crude oil and certain petroleum products from Russia to the EU. The restrictions apply from 5 December 2022 for crude oil and from 5 February 2023 for other refined petroleum products [11]. As shown in Figure 13, since Russian invasion of Ukraine, Russian oil exports to the EU27 have significantly declined. The 'Europe's new oil map' report from Transport and Environment warns however that Russian oil imported in the form of products refined in other countries is still allowed in the EU, which is increasingly importing from India and China [12].

Figure 13: Russian oil exports to the EU27.

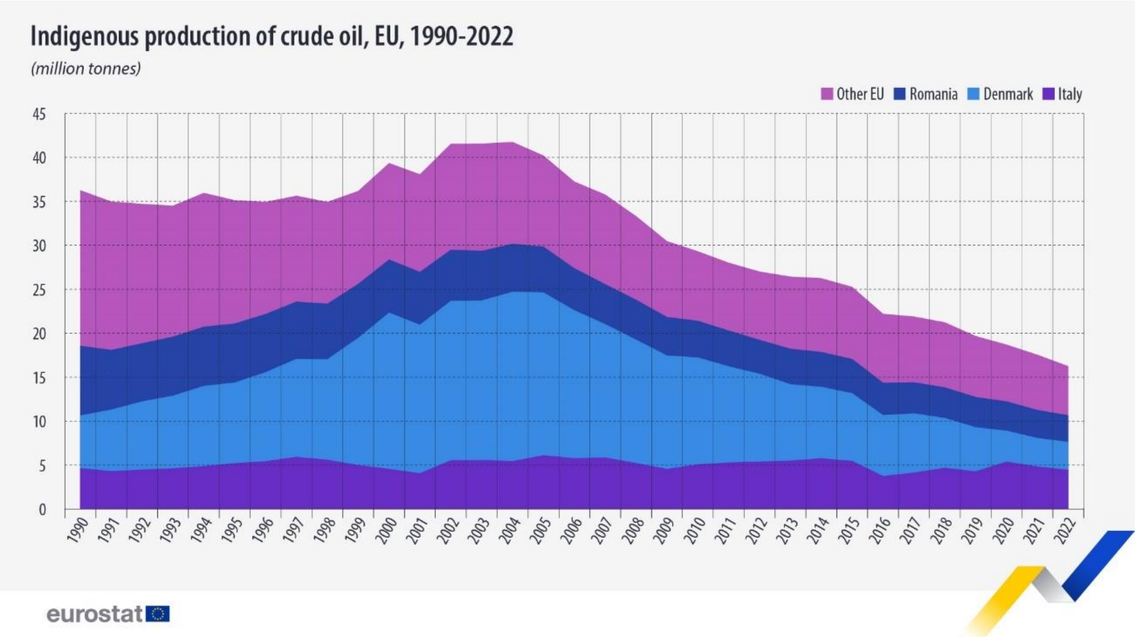


Notes: Adapted from the report 'Europe's new oil map' from Transport and Environment [12] with more recent Eurostat data.
Source: Eurostat [13], Transport and Environment [12]

At the same time, as shown in Figure 14, the EU indigenous production of crude oil continues to decline, despite a significant increase in crude oil prices caused by the Russian aggression against

Ukraine [14]. Denmark, in particular, around 2004 was the major European crude oil producer with oil production peaking at roughly 22,700 m^3. But, since 2005, Danish oil production has been decreasing with the business case for continuing oil production becoming less promising [15]. The Danish parliament decided in December 2020 to terminate all oil and gas extraction by the end of 2050 [16]. In 2022, the EU's import dependency for crude oil and petroleum products surged to a new record high of 97.7% [14].

Figure 14: Indigenous production of crude oil.



Source: Eurostat [14]

Oil products still make-up the largest part for the final energy consumption of road transport, their security is therefore of utmost importance for the security of the sector.

Natural gas

In 2022, in Belgium, **natural gas** contributed to:

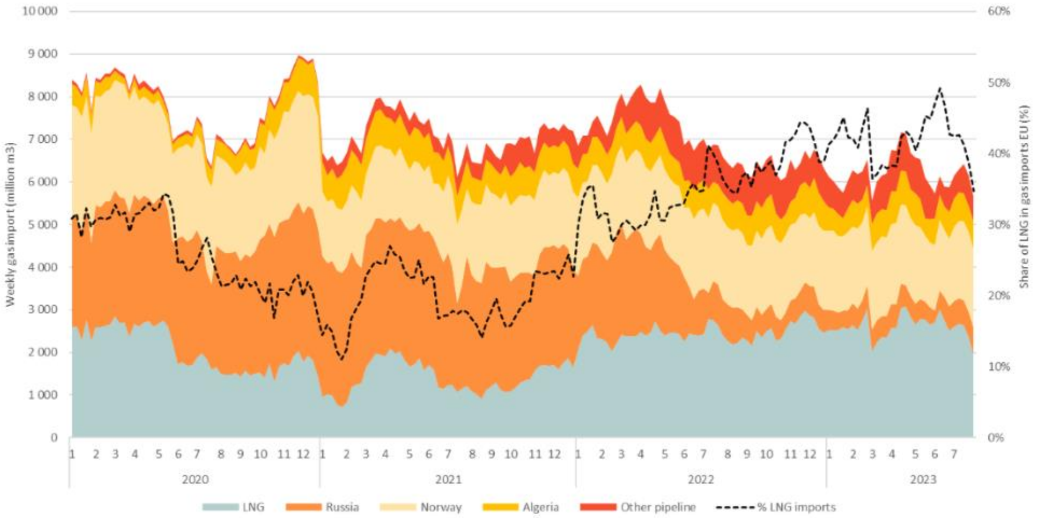
- 24.5% of gross inland energy consumption
- 22.9% of gross electricity production
- 24.7% of final energy consumption

Like for crude-oil, Belgium is completely dependent on imports also for its **Natural Gas** (NG) consumption, except for a small production of bio-methane. Natural gas is mainly imported through pipelines (82% of the NG consumed in 2022 in Belgium) but also via Liquefied Natural Gas (LNG) tankers, namely via the port of Zeebrugge. Figure 15, shows how LNG imports, for the whole of Europe, increased after Russia's invasion of Ukraine and the consequent reduction of imports through pipelines. Starting from the 1st of January 2025, as a five-year pre-war deal expired, Russian gas can no longer transits through Ukraine to be delivered to its final destinations in the EU [17].

Belgium is located at an important crossroad for natural gas, and apart from diversified source and access to LNG, it can also rely on a gas network capable of transporting more than twice the country's consumption volume to neighbouring countries, and NG storage. In Belgium, as in

Europe, NG has seen an increase in use for power generation thanks to its flexibility and lower CO_2 emissions with respect to coal and oil, but it has also exposed its energy security risks, as demonstrated by the global energy crisis following Russia's invasion of Ukraine on the 24th of February 2022 [18], and the fragility of the infrastructure with the sabotage of the Nord Stream 2 pipeline. In 2022, after the sharp decrease of Russian gas imports to Europe, the direction of gas flows through Belgium changed: from a North-South orientation to a West-East orientation and the proportion of gas entering Belgium that transited to a neighbouring country increased from 50% in 2021 to 73% in 2022.

Figure 15: EU imports of natural gas.



Source: European Commission [19]

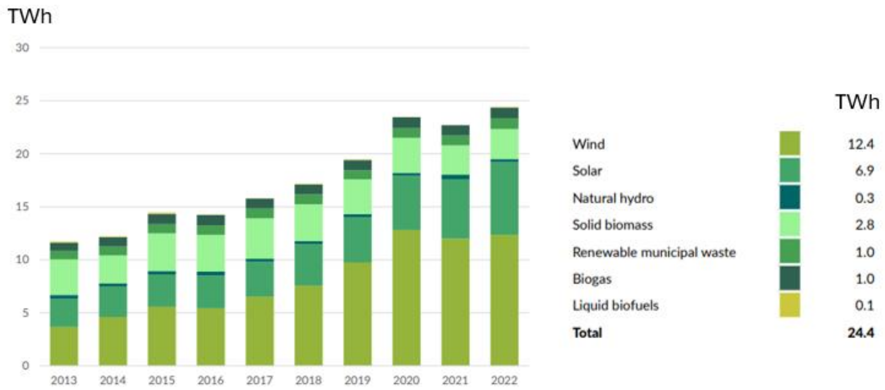
Renewables

In 2022, in Belgium, **renewables** contributed to:

- 11.2% of gross inland energy consumption (renewable energy and waste)
- 25.5% of gross electricity production (renewable energy)
- 7.1% of final energy consumption (renewable energy and waste)
- 9.53% of final energy consumption in road transport (biofuels only), 2023 value reported in Figure 9

As mentioned before, an important element that contributed to the reduction of energy dependence is the penetration of renewables which has seen a sharp rise in the last 20 years. In part because of offshore wind farms, wind energy is the main source of renewable electricity production. In 2022, offshore wind farms produced 6.7 TWh of electricity. Solar, with 6.9 TWh of electricity production, is the next largest contributor to renewable electricity. Photovoltaic installations under 30 kW, primarily situated in households, play an important role as they represent approximately 65.9% of the solar capacity.

Figure 16: Evolution gross electricity production from renewables in Belgium.

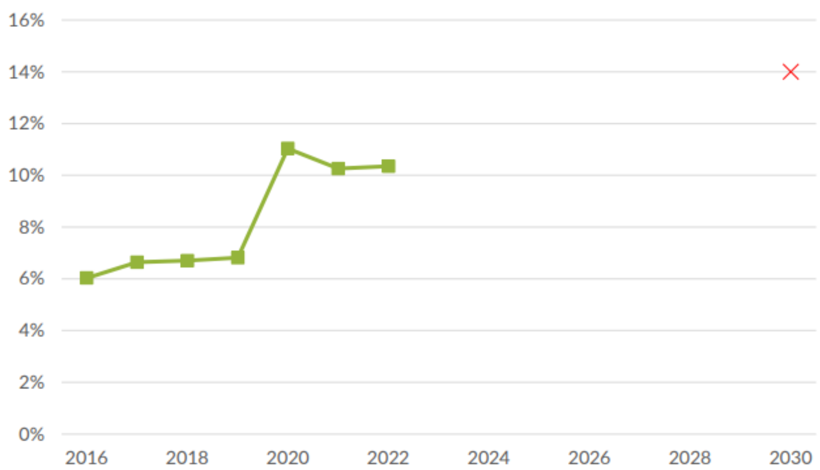


Source: SPF Economie, PME, Classes moyennes et Energie [1]

Figure 17 shows the renewable energy share in transport in Belgium. The renewable energy share (RES) in transport reported in the figure is calculated up to and including 2020 considering the calculation rules imposed by Directive 2009/28. Starting from 2021, the calculation follows the guidelines of Directive 2018/2001, which also sets a target of 14% for 2030. This directive was however amended in 2023 with Directive EU/2023/2413. This directive sets new targets to 2030, with, for transport a share of 29% of renewable energy, or a reduction of the emissions intensity of transport fuels by 14.5%, as well as a combined sub-target for renewable hydrogen and advanced biofuels of 5.5%. The amended directive also sets more stringent requirements for sustainability [20].

Considering the data reported in *Figure 9*, in 2022, biodiesel accounted for 0.63 Mtoe and bio-gasoline for 0.17 Mtoe of the final energy consumption in road transport. In 2020, 59% of these liquid biofuels were imported, mainly from Switzerland and the Netherlands [21].

Figure 17: Renewable energy share in transport in Belgium.



Source: SPF Economie, PME, Classes moyennes et Energie [1]

Electricity

In 2022, in Belgium, **electricity** contributed to:

- 17.8 % of final energy consumption
- 1.03 % of final energy consumption in road transport , 2023 value reported in Figure 9

- Given the increasing role of renewable energy in the electricity mix and the importance of electrification to decarbonize transport and other sectors, the Belgian electricity sector is expected to undergo major changes in the next decade. The federal government is focused on increasing cross-border interconnection capacity, ensuring security of electricity supply, lowering electricity costs and increasing the competitiveness of electricity markets. Regional policies focus on distribution system flexibility and the participation of consumers through smart meters, demand response measures, energy storage and distributed renewables (including self-consumption). The reader is referred to the IEA report 'Belgium Security Policy' for more information on Belgian electricity grid infrastructure and related security policies [6].

As shown earlier, electricity is starting to play a role in the final energy consumption of the passenger car fleet. This additional electricity consumption is delivered by the private and public charging points that are being integrated to the network. According to the European Alternative Fuel Observatory (EAFO), the Belgian electric car fleet can rely on 66.9 thousand AC and 4.2 thousand DC publicly available charging points [22]. On top of public charging points, home charging has also become a popular and cost-effective choice for many electric vehicle owners. Since 2024, private charging points must be registered to help grid operators better understand the electricity grid and enable them to make timely adjustments and reduce the risk of breakdowns [23]. The increase of small private solar installation, apart from creating a more decentralized energy systems, is turning consumers into prosumers, who both produce and consume electricity and exchange it with the electricity grid. Furthermore, the rise of new technologies, such as vehicle-to-grid with bi-directional smart charging will allow to shift battery charging away from periods with higher residual load and use the batteries as energy storage devices connected to the network which can inject energy back to the grid [24].

3. *Emerging factors of change*

The following emerging factors can be listed:

- **Role of renewables**: the increase in the contribution of renewables to the electricity mix, namely solar and wind, with the reduction of the use of coal, allowed Belgium and Wallonia to rely for a greater share of their consumption on primary resources and reduce their degree of dependence.
- **Nuclear power**: The expected shutdown and phase out of the last operating Nuclear power plants by 2035 will put additional pressure on the resources needed for electricity generation.
- **Electrification**: Electricity is starting to play a small but increasing role in the final energy consumption of the passenger car fleet. To note, transport is not the only sector that is expected to electrify as also the residential and industrial sectors are expected to decarbonize, at least in part, through electrification.
- **Distributed energy system**: a more distributed energy system is emerging both in terms of electricity generation with the rise of small photovoltaic installations and, relevant for passenger cars, electricity consumption with the increase of availability of private and public charging points.

D. Dynamics of change

This section builds on the retrospective analysis presented in the previous section, taking into account the trends expected in the Belgian National Energy and Climate Plan (NEKP) [25] and the regional plan for Wallonia, the Plan Air Climat Énergie (PACE) [26], which were recently updated (November and March 2023 respectively).

1. *Strong trends – the increasing role of renewable energy*

One of the objectives of the PACE, as a means to **decarbonisation**, is to end our dependence on fossil fuels and massively deploy renewable energies. The emergence of **renewable energy** and its increasing role in the energy system is one of the strong trends that can be observed in the last 20 years, with, in particular the rise in solar and wind power. According to the PACE the objective is to increase renewable electricity generation in the Walloon region from 5.4 TWh in 2019 to 13.6 TWh by 2030. Maintaining the electricity system in balance with a high integration of renewables, which are intermittent in nature, is a challenge. Elia, the Belgian Transmission System Operator (TSO), reported a record number of hours with negative day-ahead prices of electricity for the summer of 2024 [27]. During last summer in fact, 23 warnings were issued. Emergency measures were avoided thanks to market parties adapting their behaviour, coupled with weather conditions which reduced renewable electricity generation, and higher consumption levels. To accommodate for the increase share of renewables, further development of flexibility is urgently needed both in terms of how the market works and technical mechanisms [27].

2. *Uncertainties and inflection factors – the phase-out of nuclear power?*

The phase-out of **nuclear power**, which has long been debated in Belgium, is a major factor of uncertainty in the energy system. A capacity remuneration mechanism (CRM) is in place which aims to ensure security of electricity supply as nuclear generation is reduced. This mechanism, through auctions, awards payments for availability of capacity to drive deployment of additional capacity, demand-side response (DSR), storage and retention of existing capacity [8]. In the recent past, natural gas combined cycle gas powered plant made up most of the reduction in electricity generation from conventional thermal power plants in Wallonia, as shown in the retrospective analysis. Russia's war of aggression in Ukraine, however, highlighted the natural gas related energy security risks. By the end of August 2022, unprecedented month-ahead gas prices reached 320 EUR/MWh, compared to 25 EUR/MWh or less nominal prices before the Covid-19 pandemic and the invasion[19]. The phase-out of nuclear power plants by 2035 will drastically change the energy landscape for both Belgium and Wallonia, especially for what concerns electricity. The blue print for the Belgian electricity system [24], recently published by Elia, warns that due to the rising demand for electricity, if policies remain unchanged, in 10 years' time, the foreseen increase in low-carbon electricity generation will no longer be sufficient, and dependence on electricity imports will steadily increase.

3. *Weak signals and emerging trends – electrification and efficiency improvements, but beware of rebounds effects*

According to the PACE objectives, final energy consumption will be reduced by 2030 through both energy efficiencies improvement driven by electrification, and behavioural changes that will lead to a more rational use of energy.

As shown, in retrospective analysis, **electrification** in road transport is starting to play a role. Electricity consumption in road transport was negligible before 2020 but, by 2023, represented about 1% of final energy use in road transport. As the share of electric vehicles in the new fleet increases [28], driven by EU policies, the role of electricity in final energy use will increase accordingly. PACE, foresees 25% of private passenger cars to be battery electric by 2030 and 10% to be plug-in hybrid electric vehicles. These vehicles will replace in large part diesel vehicles. Electric cars are more efficient than their conventional internal combustion engine counter parts and therefore offer higher vehicle utility without the need for more fuel, and increase resilience to volatile oil prices [29].

However, energy efficiency improvements and electrification may not lead to the expected decrease in energy consumption and related greenhouse gas emissions as, as Jevons argued over 100 years ago in the context of coal, technological improvements can actually lead to increase consumption [30], also referred to as **rebound effects**. PACE, in fact, combines the objectives for electrification with a series of **behavioural change**s that would reduce private passenger car use, such as modal shift towards public and active modes of transport and higher occupancy rates with car sharing. This is addressed in Variable 3.

To note, looking at the retrospective analysis, final energy consumption in the road transport sector has increased since 1990 and has not shown significant signs of an inversion trend ever since. Between 1990 and 2007 the increase was steady. After the consumption drops in 2008 due to the 2007/2008 global financial crisis and in 2020 due to the Covid-19 pandemic, energy use in road transport has largely recovered. In 2023 the values were again similar to the peak ones of 2007. Transport, which is still largely dependent on fossil fuels, is in fact the only sector where greenhouse gas emissions have increased in the past three decades [31].

4. Interaction with other system variables (past and future)

The following table summarizes the main interactions with the other system variables.

Table 2 Interaction with other system variables

Variable (and fiche number)	Interaction
Fiche 1: Global context	Fiche 1 discusses the uncertainty of global energy market and access to resources which will have an important role on the future energy mix.
Fiche 3: Mobility practices	The mobility choices of people determine the energy required to satisfy their needs
Fiche 4: Vehicle types	The type vehicles determine the energy mix and the energy efficiency of passenger road transport

E. Hypotheses for the future

The European climate law writes into law the goal set out in the European Green Deal for Europe's economy and society to become climate-neutral by 2050. This is supported at European level by several policies, namely the 'Fit for 55' legislation which is now fully adopted and sets the EU on a path to reach 55% emission reduction by 2030 (compared to 1990 levels). The Belgian National Energy and Climate Plan (NEKP) [25] and the regional plan for Wallonia, the Plan Air Climat Énergie (PACE) [26], cited earlier, are in line with the European ambition. In this context, recent studies have explored the possible energy futures of Belgium with a time horizon to 2050. Namely, the blueprint for the Belgian electricity system published by Elia [24] and the PATHS2050 SHIFT Scenario towards a climate-neutral Belgium, developed by EnergyVille (VITO) [32]. While the reader is referred to the full reports for a detailed overview and the results of the different scenarios, some of the elements are used here to summarise some possible hypotheses for the future, keeping the main focus on the transport sector.

1. Trend hypotheses – increase in renewable electricity generation, electrification and interconnections with Europe.

Trend hypothesis mainly look at developments that are already underway and that are expected to continue given the current European, National and regional policy context and ambition, which aim at climate neutrality by 2050. These trends should therefore not be considered as a simple continuation of the trends observed in the past, but as the trends given the current decarbonisation ambition.

In this context, the scenarios proposed by Elia[24] and VITO[32] agree on an expected decline in overall final energy demand with a rise of electricity demand. Final energy demand is expected to decrease from about 370-400 TWh in 2020-2022 to about 240-300 TWh in 2050[4]. Electricity demand however is expected to more than double from about 84 TWh in 2020 to about 180-200 TWh in 2050.

- **Increase renewable electricity generation**: Belgium continues its push towards reducing carbon emissions leveraging renewable electricity generation through especially wind and solar whereas hydropower and biomass remain stable. In the SHIFT scenarios, renewable electricity generation from these sources, ranges from 148 TWh to 179 TWh in 2050, compared to about 20 TWh in 2020.

- **Increased Electrification**: Sectors like heating, transport, and industry steadily shift to electricity-driven solutions. In the SHIFT scenarios, final energy demand for transport is reduced by 76%, from 100 TWh to 34 TWh in 2050 thanks to electrification whereas the use of clean molecules for road transport is not considered cost effective to reach net-zero by 2050. Clean molecules are considered only for the very small energy share of inland shipping and aviation with biofuels and hydrogen with more clean molecules needed to decarbonize international aviation and shipping. To note, this is quite different from the Elia scenarios, which consider a rather important role of Hydrogen and "other" energy carriers in the decarbonization of road transport.

- **Increased interconnection with Europe**: Belgium deepens its integration into the European energy grid, with more cross-border exchanges ensuring supply stability.

2. *Incremental hypotheses – Hydrogen and synthetic fuels for the hard to decarbonise sectors, Behavioural changes reduce energy consumption and limit rebound effects.*

Incremental hypotheses focus on developments that, while subject to considerable uncertainty, are generally included in the analysis of future scenarios and have roots in the current system. These hypotheses result in an incremental change of the system without a 'major' transformation (which will be the subject of the next point)

- **Moderate hydrogen and other synthetic fuels integration**. Hydrogen and other molecules (synthetic fuels) start to play a role in the reduction of emissions in hard to decarbonise sectors as a complementary energy carrier to electricity. The use of hydrogen is considered in applications like heavy transport and industrial processes but does not fully replace natural gas. Whereas the SHIFT scenarios, from VITO, mainly consider electrification for the transport sector, Elia, on the contrary considers also scenarios where hydrogen, methane and other molecules (like synthetic of biofuels) have an important role for both passenger cars (34% of final energy consumption in 2050) and trucks (72% of final energy consumption in 2050). In an intermediate scenario Elia considers electrification of light weight road transport with some hydrogen and liquids remaining for

[4] To note, as a word of caution, the decrease in final energy consumption is in part driven by electrification and by the use of molecules (such as H_2 and synthetic fuels). Depending on the scenario, a large share of these energy vectors is imported. Therefore, the energy requirements to generate electricity and to synthetically produce these molecules is not accounted for in the final energy consumption.

heavy-duty transport. In the scenario where 'electrification' is most prominent, as much as 20% of the final energy demand for trucks is estimated to be supplied by 'other' energy vectors and methane. Looking at current trends electric vehicles dominate the alternative fuel market for both passenger cars and trucks. However, hydrogen could be considered as a complementary solution to electric vehicles for heavy-duty vehicles in difficult to decarbonize long-haul use cases. Several hydrogen truck models, relying on both of Fuel Cell technology and Internal Combustion engines, are in fact coming to the market in the near future[33]. However, the drivetrain efficiencies of hydrogen fuelled vehicles are lower than the efficiencies of their electric counter parts (depending on the type of vehicle, use case and payload) and that the production of hydrogen, as well as other energy carriers, is an energy intensive process. This aspect reduces the source-to-wheels energy efficiency of hydrogen vehicles with respect to electric ones. To note, that in most SHIFT scenarios, and in all of Elia's scenarios hydrogen is mainly supplied through imports rather than produced, and may therefore become a concern in terms of security.

- **Behavioural changes reducing final energy consumption of passenger transport**. Energy needs can be avoided through efficiency or through sufficiency. In the blueprint for the Belgian electricity system published by Elia [24], the difference between efficiency and sufficiency is explained as follows: "*Efficiency implies reducing the energy used in inputs, while delivering the same quantity in outputs. Sufficiency is about redefining the means to deliver the service, or reconsidering the outputs needed. […]. Both reduce energy needs, but in different ways*". Sufficiency in the contest of passenger road transport therefore mainly points to behavioural changes that could reduce the reliance on private vehicles with a shift to public, shared and active mobility or reduce energy requirements for example with the adoption of smaller vehicles. To note, however, that the number of private vehicles in the Wallon region has increased in the 1990-2023 time-period, as shown in Variable 4. Elia's explores a 'sufficiency' scenario where final energy consumption in road transport in 2050 could be reduced by as much as 25% with an increase in the modal shares of rail, public transport, active mobility at the expense of the modal share of passenger cars combined with a higher occupancy rate.

3. *Hypotheses with major transformation – Strong modal shift to public and share mobility with a large penetration of renewables and a smart, optimally integrated energy system.*

Major transformations refer to changes in passenger transport that would move the sector away from the current mobility model centred on private vehicle ownership and fossil fuel dependence. These transformations should not be considered as likely changes, or developments that can be extrapolated from current trends, but rather as major changes that could lead to a complete shift of the current paradigm of mobility. Of course, these changes are linked to the ones reported in other Variables.

A strong reduction of the final energy needs in the passenger road transport sector with a complete independence of its energy sources by 2050, could mean:

- For longer trips, there is a major shift from private to public transport modes and, in particular, to rail in combination with other transport modes for shorter trips.
- For shorter trips, there is a major shift to active transport modes such as cycling and walking and shared vehicles.
- High penetration of shared vehicles which include e-bikes, e-cargo-bikes as well as light electric passenger cars.

- There is a major shift from private car ownership to car sharing.
- There is a complete electrification of the car park with a shift to smaller, lighter and more energy efficient vehicles.
- The full potential of electric bikes is exploited. Because of the reduce effort with respect to their traditional counter parts, electric bikes are used by a wider share of the population, cover longer trips, carry heavier payloads (e.g. with cargo bikes), and are used hilly terrain.
- There is a major penetration of renewables in the electricity systems that completely covers the final electricity demand of road passenger transport.
- Batteries used in the road transport sector become an integral part of the energy system as energy storage devices with smart and bi-directional charging.

4. *Hypotheses with deterioration – Political shifts an instability halt and reverse decarbonisation trends and ambitions.*

Deterioration hypotheses refer to changes that increase the final energy consumption of the road passenger sector and reduce its security. Again, these are linked to the hypothesis explored in other Variables.

- Because of political instability in Europe decarbonisation ambition and targets are scrapped.
- The confusion in the market halts, reduces or even reverses the deployment of renewables and the uptake of zero-emission vehicles.
- Private car ownership relying on fossil fuels remains the dominant transport mode and increases its mode share at the expense of public and active modes of transport.
- Severe whether events, such as draughts, floods and storms, fuelled by the effects of climate change, imperil the energy generation and transmission infrastructure.
- Nuclear power plants are decommissioned without the introduction of zero-emission alternatives further increasing reliance on imports and/or fossil fuels.
- Reliance on imports increases drastically for what concerns both electricity and fossil fuels.
- Political instabilities in the rest of the world initiate new drastic energy crises requiring continuous adaptations to secure the supply of energy.

F. References

[1] SPF Economie, PME, Classes moyennes et Energie, “Belgian Energy Data Overview - January 2024,” Jan. 2024. Accessed: Dec. 12, 2024. [Online]. Available: https://economie.fgov.be/en/publication/belgian-energy-data-overview

[2] Eurostat, “Glossary.” Accessed: Jan. 02, 2025. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Eurostat

[3] Eurostat, “Complete energy balances.” 2024. doi: https://doi.org/10.2908/NRG_BAL_C.

[4] Institut de Conseil et d’Etudes en Développement Durable, “Bilan transport 2020, Service public de Wallonie,” Site énergie du Service public de Wallonie. Accessed: Jan. 02, 2025. [Online]. Available: https://energie.wallonie.be/fr/bilan-transport-2020.html?IDC=6288&IDD=171503

[5] Institut de Conseil et d’Etudes en Développement Durable, “Bilan énergétique global 2020, Service public de Wallonie,” Site énergie du Service public de Wallonie. Accessed: Dec. 12, 2024. [Online]. Available: https://energie.wallonie.be/fr/bilan-energetique-global-2020.html?IDC=6288&IDD=171577

[6] International Energy Agency (IEA), “Belgium Electricity Security Policy – Analysis.” Accessed: Dec. 14, 2024. [Online]. Available: https://www.iea.org/articles/belgium-electricity-security-policy

[7] Direction Générale de l'Energie du SPF Economie, "Analyse : Dépendance énergétique de la Belgique (gaz naturel et mix énergétique)," May 2022. Accessed: Dec. 12, 2024. [Online]. Available: https://economie.fgov.be/fr/publications/analyse-dependance-energetique?utm_source=chatgpt.com
[8] International Energy Agency (IEA), "Belgium 2022 – Energy Policy Review," IEA. Accessed: Dec. 18, 2024. [Online]. Available: https://www.iea.org/reports/belgium-2022/executive-summary
[9] Eurostat, "EU energy mix and import dependency," 2023. Accessed: Dec. 12, 2024. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/104551.pdf
[10] VRT, "Belgian nuclear plants to no longer use uranium from Russia," vrtnws.be. Accessed: Dec. 12, 2024. [Online]. Available: https://www.vrt.be/vrtnws/en/2024/06/07/belgian-nuclear-plants-to-no-longer-use-uranium-from-russia/
[11] Consilium, "EU sanctions against Russia explained," Consilium. Accessed: Dec. 18, 2024. [Online]. Available: https://www.consilium.europa.eu/en/policies/sanctions-against-russia-explained/
[12] Transport and Environment, "Europe's new oil map," Dec. 2024. Accessed: Dec. 18, 2024. [Online]. Available: https://www.transportenvironment.org/articles/europes-new-oil-map
[13] Eurostat, "Imports of oil and petroleum products by partner country - monthly data." 2024. doi: https://doi.org/10.2908/NRG_BAL_C.
[14] Eurostat, "Oil import dependency at its highest in 2022." Accessed: Dec. 18, 2024. [Online]. Available: https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240415-1
[15] Sperling, K., Thøis Madsen, P., Gorroño-Albizu, L., Vad Mathiesen, B., "Denmark without Oil and Gas Production: Opportunities and Challenges," Aalborg University, 2021. Accessed: Dec. 18, 2024. [Online]. Available: https://oilandgastransitions.org/wp-content/uploads/2021/11/Denmark-Oil-and-Gas-Report.pdf
[16] P. T. Madsen, D. S. Hansen, K. Sperling, C. Houeland, and K. E. H. Jenkins, "Abandoning fossil fuel production: What can be learned from the Danish phase-out of oil and gas?," *Energy Research & Social Science*, vol. 103, p. 103211, Sep. 2023, doi: 10.1016/j.erss.2023.103211.
[17] euronews, "Moscow to end gas exports to Europe via Kyiv as transit deal expires," euronews. Accessed: Jan. 02, 2025. [Online]. Available: https://www.euronews.com/my-europe/2025/01/01/russia-to-end-gas-supply-to-europe-via-ukraine-as-five-year-transit-deal-expires
[18] International Energy Agency (IEA), "Belgium - Countries & Regions." Accessed: Dec. 12, 2024. [Online]. Available: https://www.iea.org/countries/belgium
[19] European Commission, "REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Report on energy prices and costs in Europe," 2024. Accessed: Dec. 19, 2024. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2024%3A136%3AFIN&qid=1711266005450
[20] European Commission, "Biofuels." Accessed: Dec. 16, 2024. [Online]. Available: https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biofuels_en
[21] IEA Bioenergy, "Biofuels to decarbonize transport , Bioenergy-Task-39-Newsletter-Issue-59," 2022. Accessed: Dec. 16, 2024. [Online]. Available: https://task39.sites.olt.ubc.ca/files/2022/07/Draft-IEA-Bioenergy-Task-39-Newsletter-Issue-59.pdf
[22] European Alternative Fuels Observatory (EAFO), "Infrastructure." Accessed: Dec. 16, 2024. [Online]. Available: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/belgium/infrastructure
[23] J. Brams, "Home charging points in Belgium: mandatory registration as from 2024," Mobiflow. Accessed: Dec. 17, 2024. [Online]. Available: https://www.mobiflow.be/home-charging-points-in-belgium-mandatory-registration-as-from-2024/

[24] Elia, “Elia publishes blueprint for the Belgian electricity system as a stepping stone towards a long-term strategy for a sustainable and competitive energy policy in the lead-up to 2050,” 2024. Accessed: Dec. 20, 2024. [Online]. Available: https://www.elia.be/en/press/2024/09/20240924_elia-publishes-blueprint-for-the-belgian-electricity-system-2035-2050
[25] Belgian Federal Government, “National Energy and Climate Plan 2021-2030, Conciliation Committee of 22 November 2023,” National Energy and Climate Plan. Accessed: Jan. 02, 2025. [Online]. Available: https://www.nationalenergyclimateplan.be/en
[26] Gouvernement Wallon, “Plan Air Climat Énergie 2030,” 2023. Accessed: Jan. 02, 2025. [Online]. Available: https://energie.wallonie.be/fr/21-03-2023-plan-air-climat-energie-2030.html?IDD=168395&IDC=8187
[27] Elia, “Emergency measures on the Belgian power grid during the summer avoided due to market parties adapting their behaviour, coupled with weather conditions and higher consumption levels.” Accessed: Dec. 19, 2024. [Online]. Available: https://www.elia.be/en/press/2024/10/20241007_emergency-measures-on-the-belgian-power-grid-during-the-summer-avoided
[28] IWEPS, “Parc automobile et immatriculations en Wallonie,” Iweps. Accessed: Feb. 10, 2025. [Online]. Available: https://www.iweps.be/indicateur-statistique/parc-automobile-immatriculations/
[29] M. Weiss, L. Irrgang, A. T. Kiefer, J. R. Roth, and E. Helmers, “Mass- and power-related efficiency trade-offs and CO2 emissions of compact passenger cars,” *Journal of Cleaner Production*, vol. 243, p. 118326, Jan. 2020, doi: 10.1016/j.jclepro.2019.118326.
[30] B. Alcott, “Jevons’ paradox,” *Ecological Economics*, vol. 54, no. 1, pp. 9–21, Jul. 2005, doi: 10.1016/j.ecolecon.2005.03.020.
[31] European Parliament, “CO2 emissions from cars: facts and figures (infographics),” Topics | European Parliament. Accessed: Dec. 20, 2024. [Online]. Available: https://www.europarl.europa.eu/topics/en/article/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics
[32] VITO, “A PATHS2050 SHIFT Scenario towards a climate-neutral 2050 for Belgium: What role can Low Energy Demand play? | VITO.” Accessed: Dec. 20, 2024. [Online]. Available: https://vito.be/en/news/paths2050-shift-scenario-towards-climate-neutral-2050-belgium-what-role-can-low-energy-demand
[33] ACEA, “Truck and bus manufacturers’ contribution to climate-neutral road transport,” ACEA - European Automobile Manufacturers’ Association. Accessed: Jan. 02, 2025. [Online]. Available: https://www.acea.auto/news/truck-and-bus-manufacturers-contribution-to-climate-neutral-road-transport/
[34] Interreg North-West Europe, “Energy storage in Belgium.” Accessed: Jan. 02, 2025. [Online]. Available: https://vb.nweurope.eu/media/20375/energy-storage-in-belgium.pdf

G. Identification of actors relevant for the variable

- **All levels of government from the EU, the federal government, the regional government and local administrations.**
- **Energy providers**
- **Transmission-System Operator (TSO):** Elia manages the entire national electricity grid of 70kV and higher. It is responsible for balancing the grid, frequency control, interconnections and security of supply [34].
- **Distribution System Operators (DSO’s):** 4 regional organizations operate in Belgium. They maintain and develop the distribution grids and manage public service obligations. In Wallonia they are ORES and RESA. Grid operators in Wallonia include ORES, which covers 75% of the area, and RESA, the grid operator in the province of Liège. Other grid operators in the Walloon region include AIEG, AIESH and REW [23].