Centre on Regulation in Europe
Improving network and digital industries regulation

Gas and the electrification of heating & transport: scenarios for 2050

A case study for Belgium

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Table of Contents

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1. Introduction

This report presents a 2050 scenario study of the implications of a possible gradual electrification of road transportation and domestic heating and cooking in Belgium. The study is intended to derive the consequences of electrification for the electricity and gas sectors, for the CO_2 emissions associated with the residential, transport and electricity sectors and for the overall social costs.

Specifically, the study explores three possible electrification paths:

1. *Fossil Fuel* scenario: a business-as-usual electrification path, where electrification remains quite limited and in line with current practices, even by 2050;
2. *Full Electrification* scenario: a full electrification path as an extreme benchmark in which the residential sector and the road transport sector (in particular passenger cars and motorbikes), are virtually fully electrified by 2050;
3. *Hybrid Electrification* scenario: a path in which the extent of electrification in 2050 is intermediate.

These scenarios are not forecasts, and which scenario turns out to be closer to reality will depend both on the policy goals of the government and developments in the market. Of course, these may vary over time.

Instead, we provide a framework for analysing the consequences that electrification (to a greater or lesser extent) will have for aggregate electricity demand and therefore for the energy mix needed for power generation. It should be noted that throughout this study, we treat gas as a residual fuel for power generation and Power-to-Gas (PtG) as the first source of flexibility.

This study is a data-driven, quantitative exercise. The starting point for the projections to 2050 is the year 2016, a year for which we can obtain most of the necessary data from public sources. Historical data are used to determine the parameters for the year-to-year projections. The analysis takes into account the policy commitments of the government (where they exist) regarding the expansion of renewable electricity sources (hydro, biomass, wind and solar) and the phasing-out of fossil fuel and nuclear sources of power production. The model also accounts for the effect of innovation by including yearly increases in the energy efficiency of housing and cars, decreases in the losses of battery charging devices and improvements in the efficiency of electricity production technologies.

With the necessary data and policy commitments in place, the study proceeds through a number of logical steps:

1. First, it derives the increase in the power demand resulting from electrification of the residential and transport sectors.

2. It then calculates the energy mix which will be required by the power sector to meet this demand. These calculations take into account government commitments/policy objectives and also take gas as the resource of last resort.
3. We then study the reliability of the electricity sector, using PtG as the primary source of flexibility and gas as the secondary source.
4. Following this, we compute the CO_2 emissions of the three sectors involved in the study (the housing, transport and electricity sectors) and compare them to 1990 levels.
5. Finally, we compute the social costs of electrification. In computing these costs, we include the costs of retrofitting houses, the price premia of heat pumps and electric cars, the costs of quick charging posts, the costs of electricity grid expansion, the costs of gas network expansion (if necessary), the cost of PtG technology, the costs of gas-fired power plant capacity expansion to guarantee reliability of the power sector, the savings in fossil fuels (gas in houses and gasoline and diesel in transport), and the savings in CO_2 emissions (outside the European emission trading system (ETS)) and the costs of CO_2 emissions inside the ETS.

Through these steps, the model derives the consequences of electrification for each scenario.

As is the case with all scenario studies, we model some features of the energy markets and purposely leave some aspects outside the analysis. We do not explicitly model the price dynamics of the energy markets, nor the development of the carbon price within the EU ETS. These two assumptions reflect our objective of placing the focus on the impact of government policy on the electricity supply curve. By doing this, we intentionally put the emphasis on a case in which the merit order for electricity production is primarily determined by policy.

These aspects would not significantly alter the main qualitative results of our study. For example, a higher price of natural gas might lead gas-fired power plants to opt for biogas for power production; this would merely affect our calculations of CO_2 emissions but not the other conclusions in our study. Likewise, an increase in the carbon price within the EU ETS might result in a reduction in government support for renewables, thus the share of renewables would remain primarily determined by policy as we assume in our model. Finally, while we have included PtG and gas as the primary sources of seasonal flexibility, we have not included other potential sources such as demand response.

The results of this report should not be seen as a recommendation for a specific policy option. More modestly, we try to shed light on the challenges and choices policymakers and the energy sector will have to manage depending on the extent to which electrification occurs.

1.1 Background

The transport and housing sectors are among the major contributors to greenhouse gas (GHG) emissions in Europe, and Belgium is no exception. In 2014, the transport sector was responsible for 24.8% of the CO_2 emissions; meanwhile, the residential sector accounted for 15.4% of these emissions.[1] The European Commission is committed to reducing EU GHG emissions by 20% below 1990 levels by 2020, and by 40% below 1990 levels by 2030. It is expected that reaching such targets will pave the way to further reductions; in particular, by 60% below 1990 levels by 2040, and by 80% below 1990 levels by 2050. In transport, rather than reducing emissions, Belgium and many other European countries have emitted more CO_2 in recent years than in 1990. Given this, a complete rethinking is due in this sector because the fuel efficiency gains of the last few years seem to fall too short of European ambitions. The news is better in the residential sector, with less emissions recently than in 1990.[2] In this sector, improvements in the building standards have been fruitful but more effort is needed. Electrification is a clear path towards emissions-free transport and housing sectors. It is this path that this report investigates.

The extent of electrification in the Belgium road transport sector is currently quite limited. Data from the *Belgian and Luxembourg Automobile and Two-wheeler Federation*[3] for the year 2015 reveal that out of the existing 5,587,415 passenger cars only 3,307 (around 0.06%) are fully electric and 34,066 (around 0.6%) are hybrid. We do not possess data on electrification of vans, trucks, buses and motorbikes but, except possibly for motorbikes, it is expected to be rather non-existent. In the housing sector, electrification has a higher penetration, reaching 8% of the building stock in 2016 (around 430,000 houses) (see *Association of Belgium Transport and Distribution Gas Networks*[4]). This is much more than in The Netherlands, but much less than in France where around 33% of the building stock is electrified. Note, however, that these houses are mostly heated by conventional electric radiators.

1.2 Organisation of the report

The organisation of this report is as follows. Section 2 describes briefly the modelling approach and the different scenarios adapted to the Belgium case. The electrification of the road transport sector is discussed in Section 3, while that of the residential buildings sector appears in Section 4. The implications of electrification of road transport and housing for total electricity demand appear in Section 5. Section 6 discusses the energy mix to produce the electricity that meets demand. Section 7 is dedicated to the issue of flexibility, which is an important ingredient in the computation of the system costs. Section 8 derives the impact of electrification on the gas sector, taking into account the decrease in the use of gas in the residential sector and the possible increase in the electricity sector. Section 9 investigates whether the electricity and gas systems (networks and generation capacity) need to be adapted to accommodate the electrification path, which is another important element of the costs of electrifying road

[1] See "*EU Energy in Figures: Statistical Pocketbook 2016*," European Union 2016, pages 164-169.
[2] According to the *Belgium's greenhouse gas inventory (1990-2015)*, submitted to the United Nations Framework Convention on Climate Change, in 2015 the residential sector emitted a total of 15.95 Mton of CO_2, compared to the 20.47 Mtons emitted by this sector in 1990; meanwhile, the road transportation sector released 25.55 Mton on CO_2 in 2015, compared to the 19.49 Mton emitted in 1990.
[3] *Belgische en Luxemburgse Automobiel en Tweewielerfederatie* (*febiac.be*)
[4] *Koninklijke Vereniging van Belgische Gasvaklieden* (*gas.be*).

transport and housing. Section 10 derives the implications of electrification for CO_2 emissions, and assesses the merits of electrification by comparing the 2050 levels of emissions from the transport, residential and electricity sectors to the 1990 emission levels. The total costs of electrification, including the social benefits from emissions cuts, are computed in Section 11. Section 12 offers some concluding remarks.

2. Method and scenarios

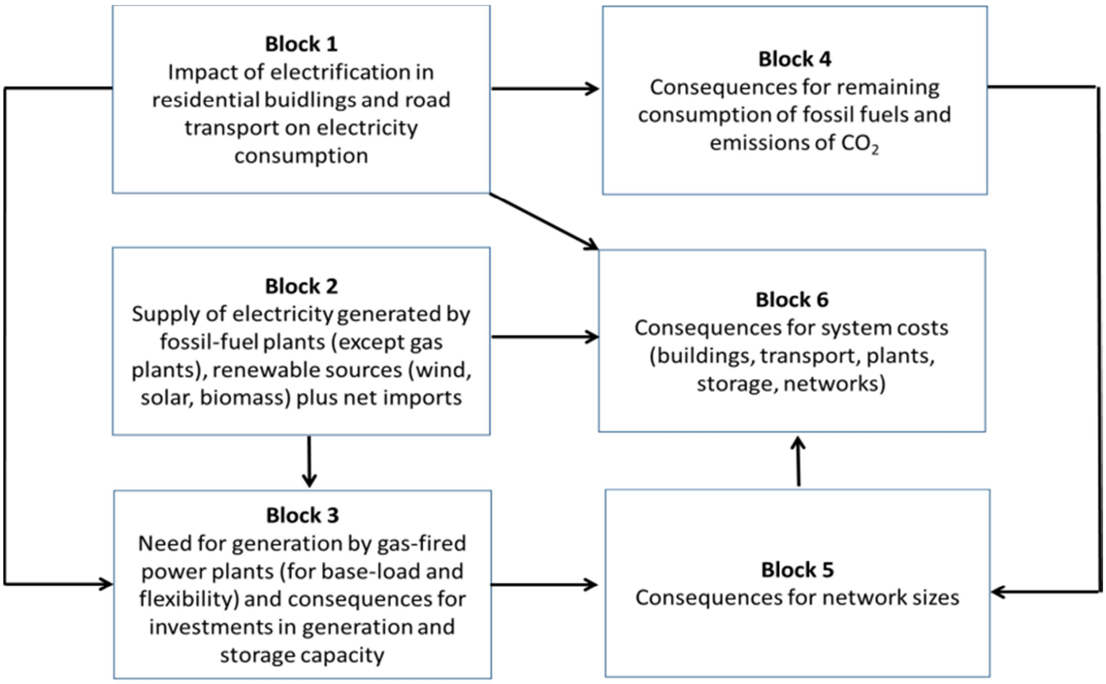
The primary objective of this report is to understand how the gradual electrification of the road transport and residential housing sectors will impact the demand for electricity and, by implication, the demand for gas as an input for electricity generation. The report also derives the effects of electrification on electricity and gas network infrastructure, as well as the impact on CO_2 emissions, which are an important part of the total costs of electrification. The analytical framework is described in more details below in Section 2.1.

Electrification is assumed to be gradual and we model three scenarios. Namely, first, a situation in which electrification occurs at a pace sufficiently high so as to virtually reach a 100% of electrification of passenger cars and housing by 2050; second, a situation in which electrification only reaches 50% of passenger cars and housing; and, finally, a benchmark case or business-as-usual case in which electrification remains rather limited, not much more prominent that it currently is. In these scenarios, light-duty and heavy-duty transport vehicles, buses and motorbikes are also considered to be electrified at different paces. The concrete assumptions behind the three scenarios we model are described below in Section 2.2.

2.1 The framework

The modelling framework is more fully explained in the case study for The Netherlands. The framework can be divided into six blocks, as illustrated in the following figure.

Figure 1: Main building blocks of analytical framework



Source: Moraga and Mulder (2018)

Block 1 of the model calculates the impact of electrification on power demand. The model requires input data on the current stock of vehicles and houses, and their respective energy needs when electrified. Using estimates on the future development of the housing and vehicle stock until 2050, along with the increase in the share of electrified houses and vehicles implied by the various electrification scenarios, the model computes the additional power demand arising from electrification of both sectors.

Block 2 derives electricity supply, taking into account the power demand modelled in the first block. More specifically, the model calculates the resulting generation mix on the supply side used to satisfy future power demand each year. The generation mix for each year is defined based on the assumption that gas-fired power plants act as the residual supplier. Investment and market exit of all other technologies are exogenous and follow policy objectives, e.g. for the discontinuation of nuclear electricity production or the deployment of renewable generation.

Block 3 determines the required generation by gas-fired power plants. The model also derives the gas-fired generation capacity required under extreme weather circumstances, that is, when the renewable sources are not able to produce while the demand for electricity is high. This is a crucial ingredient for the computation of the total system costs of electrification. In addition, this block also determines the possibility to store excess supply of electricity, through power-to-gas, in case of extremely favourable circumstances for renewable production while the demand for electricity is very low.

Block 4 calculates the resulting consumption of fossil fuels (gas and gasoline) and net CO_2 emissions. The higher the degree of electrification, the higher the share of gas demand stemming from the power market, and the lower that from the residential sector. This modelling block thus presents outcomes on the net impact of electrification on gas demand over the years. Cuts in CO_2 emissions represent social benefits and we take them into account in our calculation of the costs of electrification.

Block 5 builds on Block 3 and derives the costs of infrastructure needs for electrification.

Block 6, the last block of the model, aggregates all the benefits and costs of electrification, also providing a net present value approach to electrification.

2.2 Scenario assumptions

The speed of electrification, i.e. the share of electrified houses and vehicles per year, is a crucial element of the analysis. We consider three scenarios with varying degrees of electrification:

- *Fossil Fuel scenario* (henceforth, **FF scenario**): this is a business-as-usual scenario, which serves as a benchmark. Currently the share of houses in Belgium whose main energy source is electricity is 8%. Correspondingly, in this scenario, we assume that 8% of the newly built houses in a given year are electrified. Further, of the existing houses, we assume that 10,000 houses currently using gas as a main energy source are electrified on an annual basis; Furthermore, we assume that 5,000 of the houses using oil (*stookolie*) are electrified. Regarding the road transport sector, in the FF scenario we assume that only 5% of the newly bought passenger cars and motorbikes every year are electric. We assume here that there is no electrification of the light-duty trucks, heavy-duty trucks and buses whatsoever.[5]

- *Hybrid scenario* (henceforth, **HY scenario**): this is meant to capture a moderate amount of electrification in the sectors under study. Here we assume that 50% of the newly built houses every year are fully electric, while 50,000 of the existing houses running on gas and 25,000 of the houses running on oil are electrified on an annual basis. In the road transport sector, we assume that, in a given year, 20% of the newly bought passenger cars are electric, as well as 10% of the vans, 5% of the trucks, 25% of the buses and 40% of the motorbikes and scooters.
- *Full Electrification scenario* (henceforth, **FE scenario**): this is a situation where the road transport and housing sectors are essentially fully electrified by 2050. Here we assume that 100% of the newly built houses every year are electrified, while of the existing gas and oil houses 100,000 and 50,000 are electrified annually, respectively. Regarding the road transport sector, we assume that 40% of the newly bought passenger cars, 25% of the vans, 10% of the trucks and 50% of the buses and 70% of the motorbikes in a given year are fully electric.

Table 1 summarises the electrification assumptions used in each scenario. The impact of these assumptions on the extent of electrification of the different components of the road transport and housing sectors are described later in Sections 3 and 4. We estimate the model for the Netherlands using data for Belgium. The model is run separately for each of the three scenarios just described.

Table 1: Assumptions on the speed of electrification, by scenario

	Scenarios		
	Fossil Fuel	**Hybrid**	**Electrification**
Annual degree of electrification			
Housing			
New	8%	50%	100%
Existing stock gas houses	10	50	100
Existing stock oil (*stookolie*) houses (x1000)	5	25	50
Transport (% of new cars)			
Passenger cars	5%	20%	40%
Vans	0%	10%	25%
Trucks	0%	5%	10%
Buses	0%	25%	50%
Motorbikes and scooters	5%	40%	70%

[5] For heavy-duty trucks and intercity bus transportation, solutions based on LNG and/or CNG are better positioned at this moment (EC, 2013). Because of this, we assume that electrification of these vehicles remains limited across the three scenarios we consider.

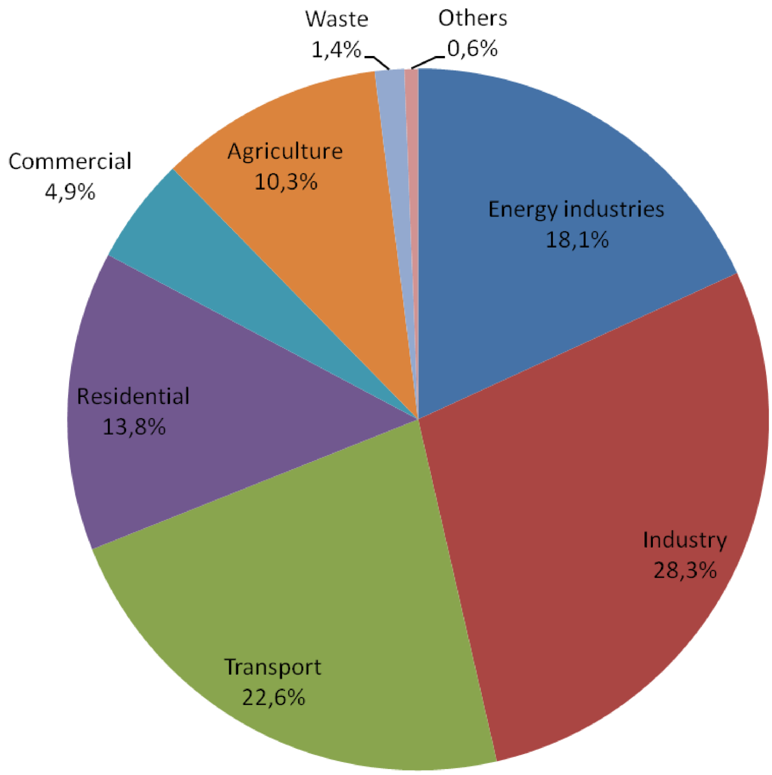
Policy assumptions concerning the deployment of renewable generation (wind and solar) or the shutting down of nuclear plants, or assumptions regarding the exogenous increase of demand for electricity and energy efficiency improvements, all discussed later in the text, are kept *constant* across electrification scenarios.

3. Electrification in road transport

3.1 Policy objectives

The transport sector is the second largest contributor to greenhouse gas emissions, accounting for 22.6% of Belgium's total emissions in 2015 (see Figure 2). Relative to 1990, the CO_2 emissions stemming from the transport sector have increased by approximately 30%. This is no exception in Europe, and therefore, like in other countries, in Belgium rethinking the transport sector has a significant potential to reduce GHG emissions.

Figure 2: Distribution of GHG emissions in Belgium, 2015



Source: Belgium's greenhouse gas inventory (1990-2015), National Inventory Report, United Nations, p 44.

According to the 2016 IEA report on Belgium, emissions from the transport sector are expected to continue to increase if no further policy measures are taken. So far, most of the effort to reduce GHG from the transport sector in Belgium has been in the form of fiscal policy to incentivise the use of public transport and dis-incentivise the use of polluting cars and in particular diesel-powered cars. These policies do not seem to have delivered a lot until now and sharper transport policies directed at reducing CO_2 emissions are necessary. As far as we know, in contrast to the Netherlands where there is a clear policy aimed at stimulating electric mobility, there is no clear policy towards electrification of the car stock in Belgium. However, there are voices within the current government pushing forward an agenda of electrification of the transport sector. According to *Autoweek.nl* (30/01/2017), the Belgium Christian Democratic Party (CD&V) wishes that the whole supply of new cars of leasing companies becomes electric by 2025. Note that because above 40% of the passenger cars in Belgium are leased cars, this is a significant and quick amount of electrification. The Party further advocates for a steady deployment of the necessary charging infrastructure.

3.2 Data and assumptions

All input data for the transport sector are derived from statistics published by the *Federal Public Service of Transports* (*mobilit.belgium.be*). The data relates to the existing stock of vehicles and its yearly increase. The data entail statistics for a range of vehicle types: passenger cars, light-duty trucks (≤ 3.5 tons), buses, heavy-duty trucks (> 3.5 tons), and motorbikes and scooters. It also covers the annual average number of kilometres driven by each type of vehicle. This will be used to evaluate cuts in emissions of CO_2 and savings in gasoline in the various electrification scenarios of the vehicle fleet.

Table 2 below summarises the data on the stock of vehicles for the starting year of our model. In 2015, there were approximately 5.61 million passenger cars registered in Belgium, 680,000 light-duty trucks (including vans), 158,000 heavy-duty trucks, 17,000 buses and 484,000 motorbikes (including scooters, tricycles and quadricycles). Of the passenger cars, around 61% are powered by diesel engines; the rest are mainly gasoline cars. Only around 20,000 cars are electric (this includes full electric vehicles plus half of the hybrid ones) and another 20,000 cars run using LNG or CHG. We ignore bicycles. The available data do not contain information on the shares of electric vans, trucks, buses and motorbikes so we set these shares to zero.

In order to compute the electricity demand stemming from electric vehicles, we also need an estimate of the distance driven by the various vehicles and the performance of electric motors. In Belgium, the average diesel car drives around 19,000 km a year, while the typical gasoline car covers around 9,000 km. On average, vans and trucks drive about 17,000 and 35,000 km a year, respectively, and buses 41,000 km. We do not have data for motorbikes. Based on the figure for The Netherlands, we set the average number of km driven by a motorbike to 2,000.

Table 2: Input data for road transport

Variable	Value
Number of (x million)	
passenger cars	5.610
vans	0.680
trucks	0.158
buses	0.017
motorbikes and scooters	0.484
Of which electric (x 1000)	
passenger cars	20.3
vans	0
trucks	0
buses	0
motorbikes and scooters	0
Average distance per year (km)	
passenger cars (weighted avg.)	15151
vans	16685
trucks	35032
buses	41441
motorbikes and scooters	2000

Table 3 gives data on the expected increase in the number of vehicles for the years to come. We draw these figures from historical data reported by the *Belgische en Luxemburgse Automobiel en Tweewielerfederatie* (*febiac.be*). Since 2010, the number of new passenger car registrations has been oscillating around 500,000. New registrations of light-duty transport vehicles have been around 57,000 a year for the same period. For heavy-duty trucks, we compute 16,700 new registrations a year and for motorbikes, 25,000. We have not found data for buses; drawing from the data for The Netherlands, we set the new bus registrations to 750.

Some vehicles are taken out of circulation due to various reasons including age, accidents and exports. Data from *mobilit.belgium.be* reveals that the stock of passenger cars has increased on average by 1.46% annually from 2007 to 2015. In the same time, the stock of light-duty trucks has increased by 3% on average, the stock of heavy-duty trucks by 0.26% and the stock of buses by 1.25%. Because we expect people to share cars more often in the future and perhaps rely more on public transport, we set the net increase in the stock of vehicles to 1.25% per year. The distance driven by the vehicles is assumed to remain constant over time.

Data on the efficiency of electric vehicles and on losses while charging car batteries are drawn from information published by the *US Department of Energy*.[6] The average performance of electric passenger cars in 2017 was 20kWh/100km. For the case of vans, trucks and buses we have less reliable data. Using the consumption of electricity for cars, we impute vans, trucks and buses consumption levels that are in proportion to what they consume of fossil fuels. For the case of vans, we factor an electricity consumption of 35 kWh/100km, for trucks 70 kWh/100km, for buses 100kWh/100km, and for motorbikes and scooters of 5 kWh/100km.

In our simulations, we also take into account electricity losses that occur while charging batteries of about 16% (see also *fueleconomy.gov)*. Finally, to account for cars becoming more energy efficient, we assume their energy consumption decreases by 1% per year. In a similar vein, we assume that there will be an annual improvement in battery charging efficiency of 0.5%.[7]

Table 3: Assumptions on new vehicles

Variable	Value
Passenger cars	
Annual number of new cars (x 1000)	500
Performance - electric (kWh/100km)	20
Vans	
Annual number of new vans (x 1000)	57
Performance - electric (kWh/100km)	35
Trucks	
Annual number of new trucks (x 1000)	16.7
Performance - electric (kWh/100km)	70
Buses	
Annual number of new buses (x 1000)	0.75
Performance - electric (kWh/100km)	100
Motorbikes and scooters	
Annual number of new M&S (x 1000)	25
Performance - electric (kWh/100km)	5
All vehicles	
Annual increase in number (%)	1.25%
Battery charging units	
Annual improvement in charging efficiency	0.5%

[6] See *fueleconomy.gov.*

[7] Throughout the projections we model energy efficiency gains over time, for example for the performance of electric motors, for battery charging efficiency, or for the performance of heat pumps. In all cases, we apply the formula $x_{t+1}=x_t*(1-g/100)$ where *x* is the variable of interest and *g* is the annual change in efficiency. For example, if battery charging improves by 1% a year, after 10 years battery charging losses go down to 16*(1-0.01)^9=14.62 percent.

Using the data just presented and the assumptions made, we first project the overall share of electrified vehicles for each year until 2050 and then derive the amount of electricity needed to power them.

3.3 Results

Figure 3 illustrates the shares of electric vehicles in each scenario by 2050. The amount of passenger cars, the most important subsector in transport when it comes to electrification, reaches 8.6 million by 2050. In the FE scenario, the share of electric passenger cars reaches 100% by construction. The total electricity necessary to power these cars is 29.01 TWh. The number of light-duty vehicles (vans and trucks) increases to 1 million by 2050, with almost 50% degree of electrification in the FE scenario. The power needed for these vehicles is 2.3 TWh. Regarding heavy-duty trucks, the amount of these vehicles goes up to 240,000. In the FE scenario, the degree of electrification of heavy-duty trucks is 24% by 2050, and the necessary electricity to power them is 1.12 TWh. The number of buses increases to 26,000. In the FE scenario the share of electric ones is almost 50%. The energy necessary to power them is 0.43 TWh. Finally, the amount of motorbikes reaches 740,000 by 2050. In the FE scenario, around 80% of the motorbikes are electric. This signifies an additional demand for electricity of 0.05 TWh.

In the HY scenario, the extent of electrification is around 50% of that under the FE scenario by construction, with the corresponding demands for electricity divided by 2 approximately. In the FF scenario, there is little penetration of the electric vehicles in the transport sector.

Figure 3: Shares of electrified vehicles in 2050

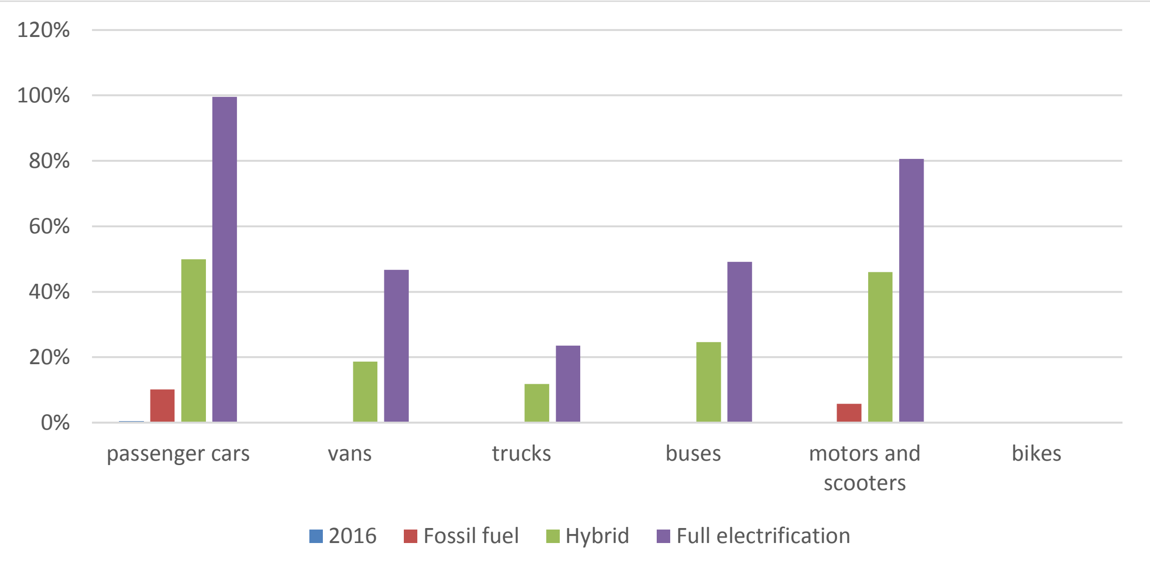
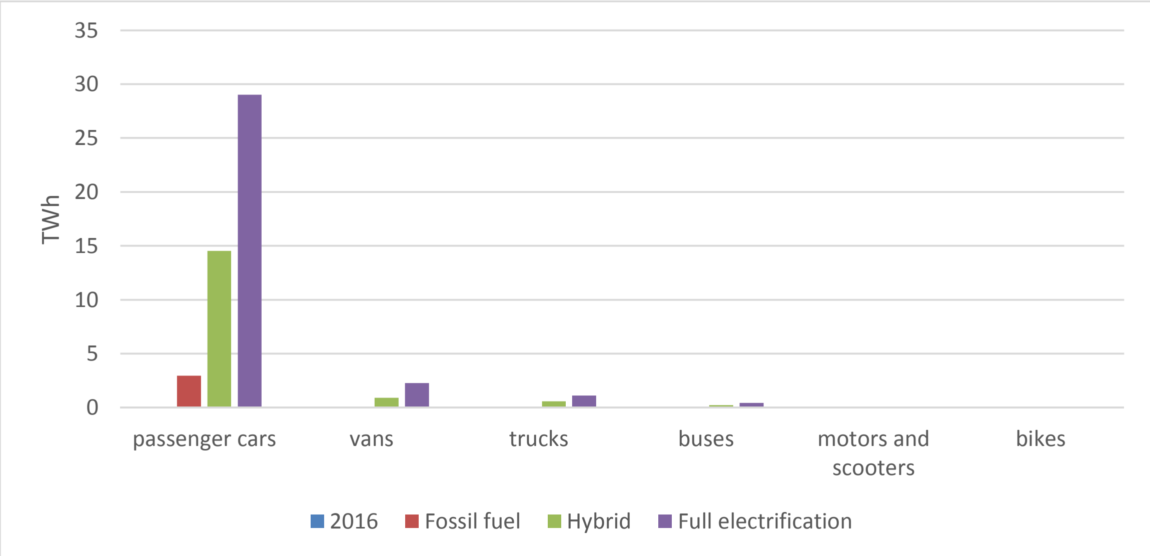


Figure 4 complements Figure 3 by reporting the additional electricity demand originating from electrification of the road transport sector, by scenario. The total amount of additional electricity needed to power the road transport sector by 2050 is 33 TWh, which amounts to approximately 39% of today's total electricity load in Belgium of 85 TWh.

Figure 5: Power demand from electrified transport in 2050



4. Electrification in residential buildings

This Section focuses on the additional demand for power arising from electrification of the residential housing sector.

4.1 Data and assumptions

The approach is similar to that in Section 3 on the electrification of the transport sector. The additional demand for power stemming from electrification of the residential housing sector is estimated taking into account the characteristics of the houses in Belgium (current energy carrier (mainly oil vs. gas), current consumption, etc.), the net increase of the housing stock, the assumptions on the pace at which electrification unfolds for newly built and old houses (see Table 1) and assumptions about the performance of heat pumps.

We have collected data about the housing sector in Belgium from the *Belgium Statistics Bureau* (*statbel.fgov.be*) and from the *Association of Belgium Transport and Distribution Gas Networks* (*gas.be*). In 2016, there were 5.36 million houses in Belgium. 57% of these houses use gas as a main energy source, 33% use oil (*stookolie*), 8% use electricity and the rest use wood, coal and perhaps other energy sources. The average size of a house in Belgium is unknown to us; basing on the idea that Belgium and Dutch houses are probably quite similar in size, we set it to 119m^2, which is the figure for The Netherlands. Further, in 2015, the average consumption of a gas-house for space and water heating and cooking was 17,500 KWh per year in Flanders (57% of the population in Belgium), 17,800 KWh per year in Wallonia (32% of the population) and 14,100 KWh per year in Brussels (11% of the population). The population-weighted average is 17,222 KWh per year, which we transform into 1,590 m^3 of gas per year.[8] About 20% of this consumption is for water heating and cooking. We do not know the exact breakdown and assume it is similar to the Dutch case, with 15% of total gas consumption being for heating water and 5% being for cooking. Note that this distinction between the different gas usages is relevant for deriving the extra power demand stemming from the different gas applications.

We also lack data about the energy consumption of the oil-fired houses. We make the assumption that they consume similarly as the gas-fired houses. These input data on the stock of houses and the corresponding energy usage are summarised in Table 4.

[8] 1 m^3 gas = 10.83 KWh.

Table 4: Input data on residential buildings

Variable	Value
Number of houses (x million)	5.36
Number of houses electrified (x million)	0.472
Average size of houses in m^2	119
Average gas consumption per house (m3)	1590
% of gas used for cooking	5%
% of gas used for hot water	15%
CO_2 emissions by households in 1990 (Mton)	20.47
% houses connected to district heating	n/a

To determine how the stock of houses develops up to 2050, we rely on historical trends. In the last few years (from 2013 to 2017), data from *statbel.fgov.be* reveals that the stock of houses has grown on average around 0.85% per year. Because some houses replace old houses, we assume that each year 50,000 new houses are built. This, together with the assumptions on the pace of electrification in the different scenarios (see Table 1), gives us the path of electrification of the housing sector up to 2050.

The energy usage (measured in m^3 gas) of an electrified newly built, or renovated, house is set to 1000 m^3. The coefficients of performance for heat pumps are set to 3 and 1 for space heating and warm water, respectively, and we assume that these devices will become more efficient over time, specifically at a rate of 1% per year. In addition, we assume an autonomous increase in electricity usage of 0.25% in the housing sector; this increase stems, for instance, from an increased use in electric appliances but it could also stem from other sectors in the economy.[9]

Table 5: Parameters for residential buildings

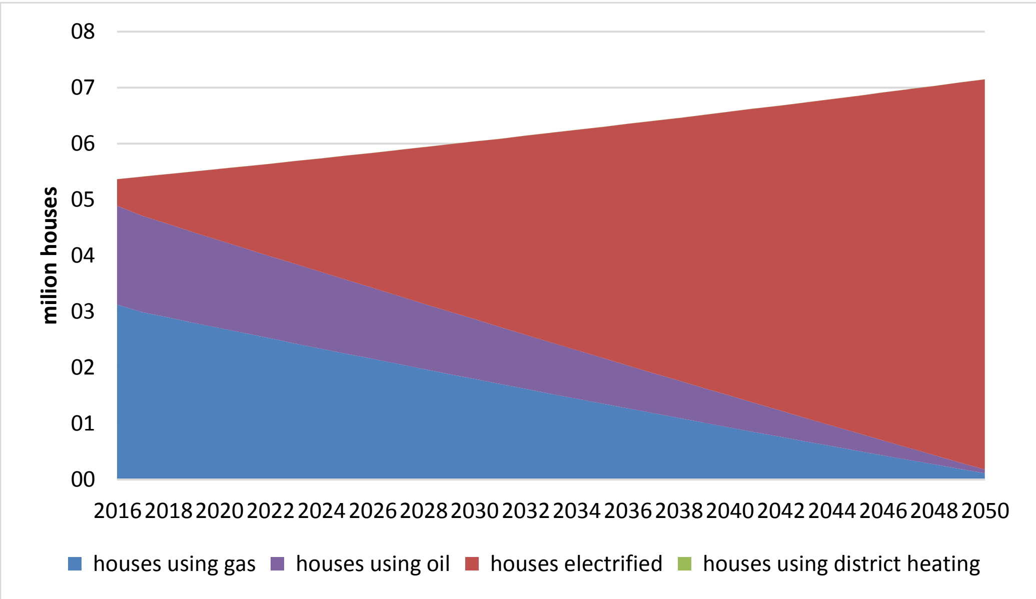
Variable	Value
Annual increase in number of houses (%)	0.85%
Annual number of new houses (x 1000)	50
Energy use for heating a new house (in m3 gas)	1000
Annual increase in efficiency houses	1%
Coefficient of performance (COP) of heat pumps	
Space heating	3
Warm water	1
Annual increase in efficiency of heat pumps	1%
Autonomous increase in electricity use	0.25%

[9] According to data published but the *Federatie van de Belgische Elektriciteits- en Gasbedrijven* (see *febeg.be*), total consumption of electricity in Belgium has oscillated around 90 TWh from 2007 to 2013, but in the last couple of years it has started to decrease towards 86 TWh in 2016. We nevertheless model a slight increase of 0.25% per year.

4.2 Results

The additional demand for electricity is constructed by aggregating the power needed for space heating, water and cooking by the newly built houses that are electric and by the renovated/electrified old gas- and oil-houses. Figure 5 shows the composition of the housing sector as time evolves in the FE scenario. The graph shows a steady decline in the number of houses using gas and oil as main energy source and by 2050 virtually all houses use only electricity for space heating, water and cooking.

Figure 5: Distribution of houses in the FE scenario, 2016 to 2050



In the FF scenario, the share of electrified houses increases very slowly from the current 8% to 10 % by 2050. This is by design, assuming that only 8% of the newly built houses are electric and very few of the old houses are electrified. In the HY scenario, the share of electrified houses increases up to 51% and in the FE scenario this share reaches 97%. This can be seen in Figure 6.

Figure 6: Share of electrified houses by scenario, 2016 to 2050

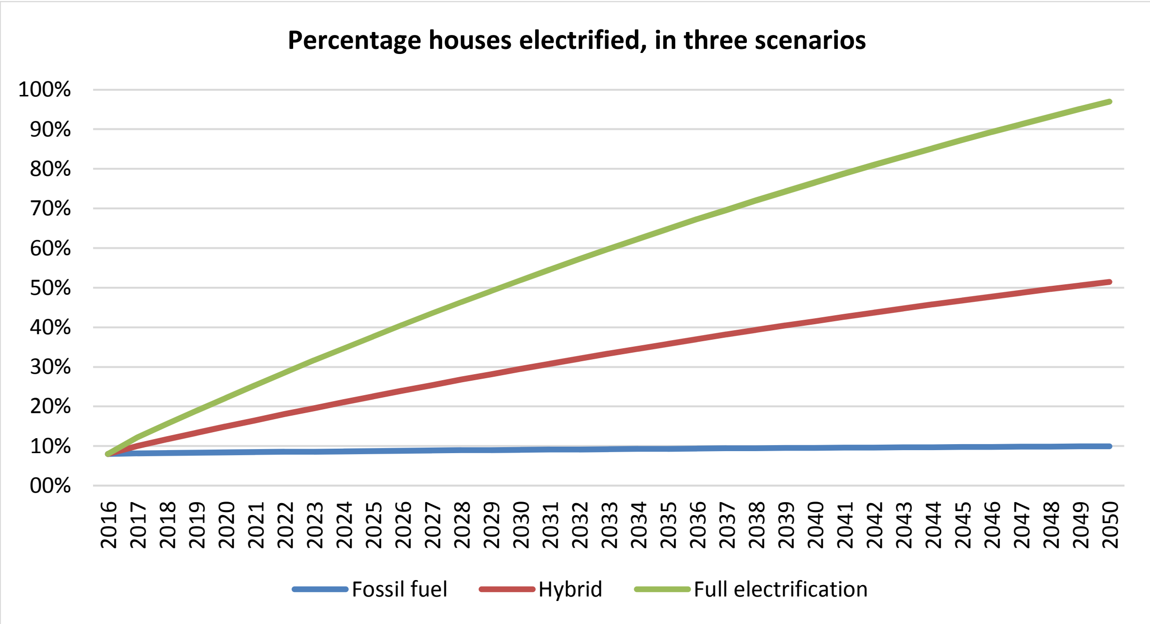
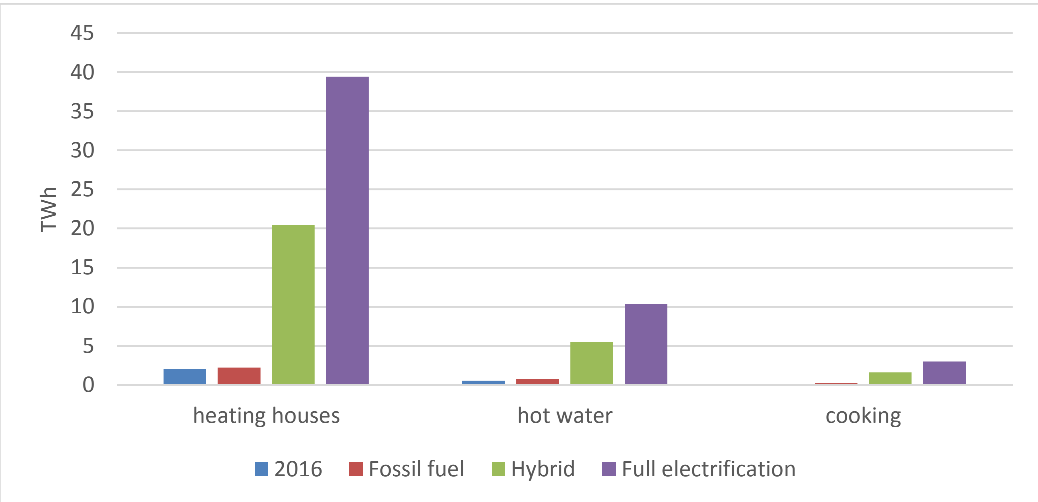


Figure 7 shows the projected electricity consumption by the housing sector in 2050. Most strikingly, in the full electrification FE scenario, the total amount of electricity consumed by the housing sector increases to nearly 40 TWh, which is close to 50% of the current consumption. The increase is roughly halved in the HY scenario, and is insignificant in the business as usual FF scenario. The bulk of this new electricity is needed for heating houses, but the amount needed for heating water is also relevant.

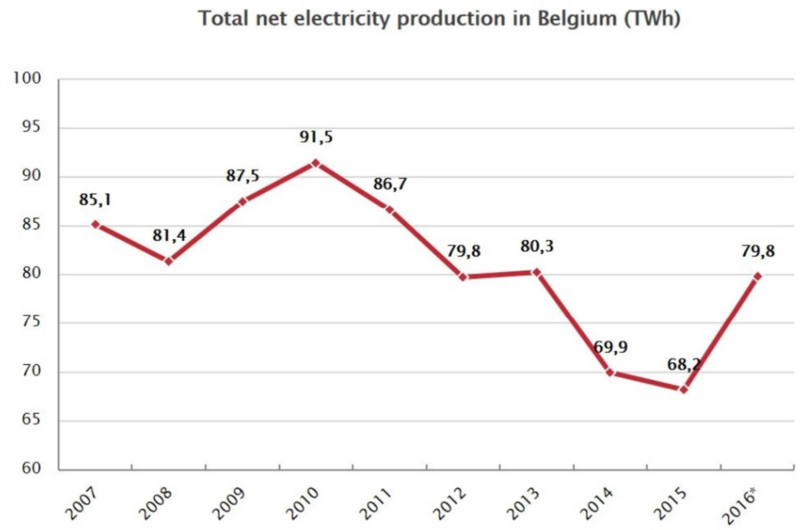
Figure 7: Household electricity demand by scenario in 2050



5. Total electricity consumption

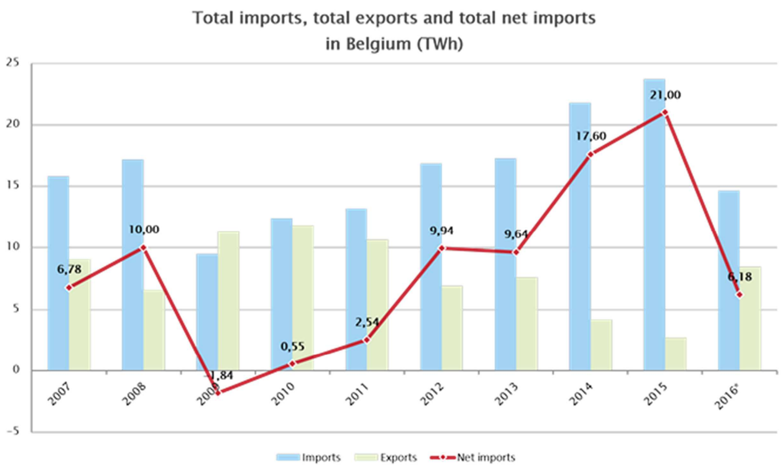
As mentioned above, the total electricity consumption in Belgium has been around 90 TWh and has gone down in the last couple of years. Figure 8a shows the indigenous production in Belgium for the period 2007-2016; to this we have to add the net imports, which can be seen in Figure 8b.

Figure 8a: Electricity consumption in Belgium



Source: Federatie van de Belgische Elektriciteits- en Gasbedrijven (febeg.be, accessed 12/04/2018)

Figure 8b: Import, export and net imports of electricity in Belgium

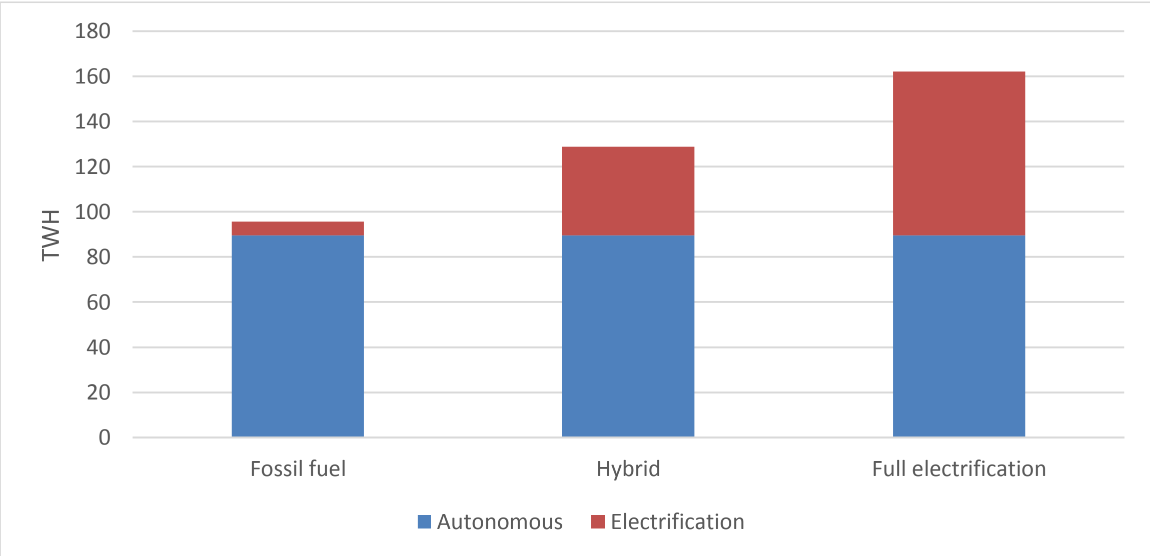


Source: Federatie van de Belgische Elektriciteits- en Gasbedrijven (febeg.be, accessed 12/04/2018)

Because we nevertheless expect that people will use more electric appliances in the future -- think for example of electric bicycles, grass cutting machines, air conditioning, robots and drones--, we have assumed a slight increase in the autonomous demand for electricity over time of 0.25% (see Table 5). As a result, the impact of electrification is the major factor that leads to an overall rise in consumption of electricity. Figure 9 displays the absolute demand levels in 2050 broken down in autonomous growth and the growth due to electrification of the housing and road transport sectors, in the three scenarios of analysis.

In the FF scenario, the autonomous growth leads to an insignificant increase in consumption as compared to the 85 TWh in Belgium in 2016. The impact of electrification is also relatively small in this scenario, 6.12 TWh. By contrast, in the FE scenario, the absolute consumption reaches more than 160 TWh, almost doubling current consumption, of which electrification accounts for about 72 TWh. The latter splits up into roughly 40% of additional demand stemming from electric cars (around 30 TWh) and 54% from electrified buildings (around 40 TWh).

Figure 9: Electricity consumption in 2050, broken down to autonomous growth and electrification



6. Generation of electricity

After having determined the demand arising from electrifying the housing and road transport sectors in Section 5, we move to examine the composition of the fuel mix in the electricity sector necessary to meet demand. In doing so, we need to take into account the policy objectives of the Belgium government regarding the phasing out of some generation technologies as well as the deployment of renewable generation capacity.

6.1 Policy objectives

The main policy objectives known to us at the time of writing can be summarised as follows:

- Nuclear production of electricity will be phased-out gradually starting in 2022 and finishing in 2025. Specifically, the first shutdown will be that of Doel 3 on October 1, 2022 and it will concern a capacity of 1006 MW; Tihange 2, with a capacity of 1008 MW, is expected to close down on February 1, 2023; Doel 1, with a capacity of 433 MW is expected to discontinue production by Feb 15, 2005; Doel 4, with a capacity of 1038 MW will shut down by July 1, 2025; Tihange 3, which has a production capacity of 1046 MW will stop by September 1, 2025; finally, Tihange 1, with a production capacity of 962 will close operations by October 1, 2025.
- According to the *Belgium Federal Planbureau*[10]*,* the ambition of the Belgium government when it comes to wind generation capacity is to have an installed capacity of 5.7 GW by 2030, and reach 9 GW by 2050.
- Regarding electricity production by solar panels, the same institution reports a target of 4 GW installed capacity by 2030, increasing to 5.1 GW by 2050.

We implement these targets in our simulation model as follows. Despite the fact that the phasing-out of nuclear production is clearly stepwise, we implement it as a linear reduction in generation of 11% per year from now till 2025 so that by 2025 nuclear plants no longer produce electricity. Admittedly, the linear implementation is a simplification but because our objective is the generation mix and the associated emissions in the long run (2030 and 2050), this simplification does not have a fundamental bearing on our results.

For wind, we have an increase in electricity production of 0.69 TWh yearly up to 2030, and of 0.43 TWh annually from 2030 to 2050. For this calculation we use a capacity factor for wind turbines of 30% (see *European Network of Transmission System Operators for Electricity* (*entsoe.eu*)). Regarding solar, we model an annual increase in solar generation of 0.03 TWh per year up to 2030, and of 0.05 TWh yearly for the period from 2030 to 2050. For this calculation the capacity factor for solar panels is assumed to be 10% (see *entsoe.eu*).

[10] See *Het Belgische energie-landschap tegen 2050*, Figure 27, page 52.

Moreover, coal-fired power plants have already been phased-out on the transmission grid since 2015. There remain some coal-fired power plants dedicated to industry. We assume these will gradually disappear by 2050. The reduction is 3% annually. There are also some power plants using other fossil fuels (excluding gas). For these generation units we also assume that they will no longer be functioning by 2050.

The amount of power production using biomass is assumed to remain constant over time. Imports are taken to increase by 2% per year, on the basis that cross-border capacity is expected to increase in the years to come. Generation based on other energy sources is assumed to increase by 1% per year.

Table 6 gives an overview on the implications of the modelling of the policy objectives.[11]

Table 6: Modelling choices for market exit and entry of different generation technologies (based on policy objectives)

Variable	Assumption	Background		
coal-fired plants	-3%	phasing out in	2050	
other fossil fuel plants	-3%	phasing out in	2050	
nuclear plants	-11%	phasing out in	2025	
hydro plants	0%	remains constant		
wind (annual increase in TWh)	0.69	policy target in 2030 is	5700	MW
wind in period after policy target (increase in TWh)	0.43	policy target in 2050	9000	MW
solar (annual increase in TWh)	0.03	policy target in 2030 is	4000	MW
solar in period after policy target (annual increase in TWh)	0.05	policy target in 2050	5100	MW
biomass	0%			
other	1%	gradual increase based on past		
net import (if negative, this refers to export)	2%	increase in cross-border capacity		

6.2 Data and assumptions

We assume that in the short run demand will be covered according to marginal cost, i.e. we use a merit-order approach to determine the supply mix year by year. However, market entry and exit of capacity is driven by the policy targets outlined above in Section 6.1.

The starting point for the projection of the generation mix (until 2050) is the mix of the year 2016. Table 7 summarises the generation mix for this year.

[11] Further modelling details are discussed in the Netherlands case study.

Table 7: Generation mix in 2016

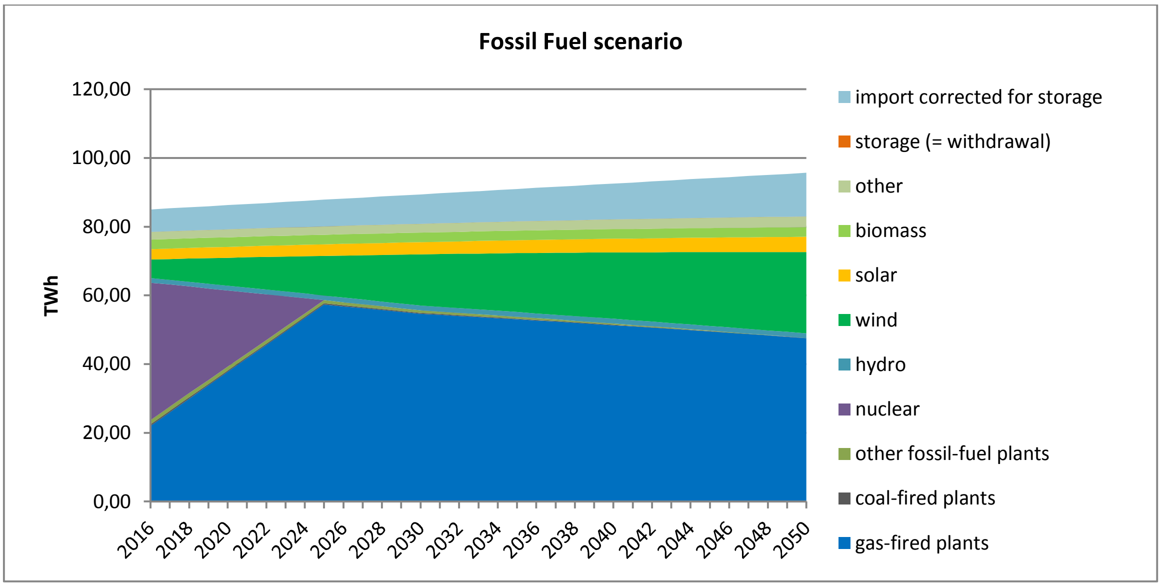
Variable	Value (TWh)
gas-fired plants	22
coal-fired plants	0.47
other fossil fuel plants	1.23
nuclear	40
hydro	1.37
wind	5.28
solar	3.04
biomass	2.79
other	2.22
net import	6.50
total load	85

Source: ENTSOE

6.3 Results

Results for the supply mix are, of course, strongly driven by the assumptions mentioned earlier in connection with the policy objectives. In Figure 10a, we observe the generation mix per scenario, from 2016 to 2050. Gas is assumed to be the input of last resort, that is, gas-fired plants are only dispatched when other technologies are all running at full capacity. In the business-as-usual FF scenario the amount of gas used for power generation increases up to 2025 due to the decline in nuclear; thereafter it decreases due to the deployment of renewables. In the HY and FE scenarios, the deployment of renewables is too small to be able to deal with the additional demand for power stemming from electrification. As a result, the amount of gas used in the system continues to increase up to 2050, though at a slower pace compared to the period in which the production of nuclear electricity is progressively discontinued.

Figure 10a: Generation mix, per scenario, 2016 to 2050, TWh



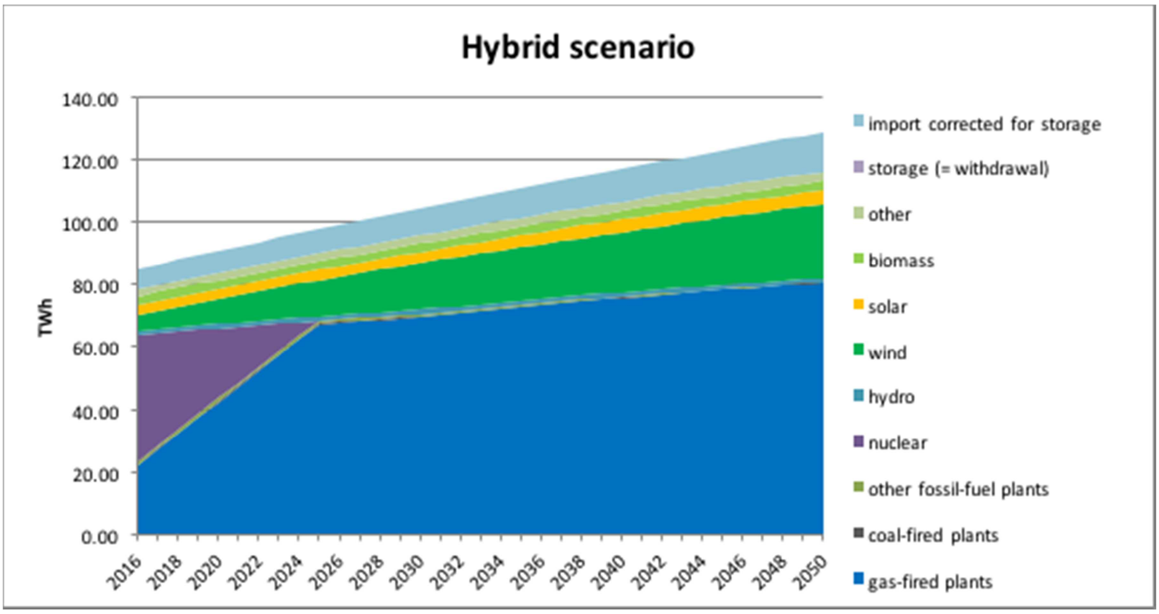
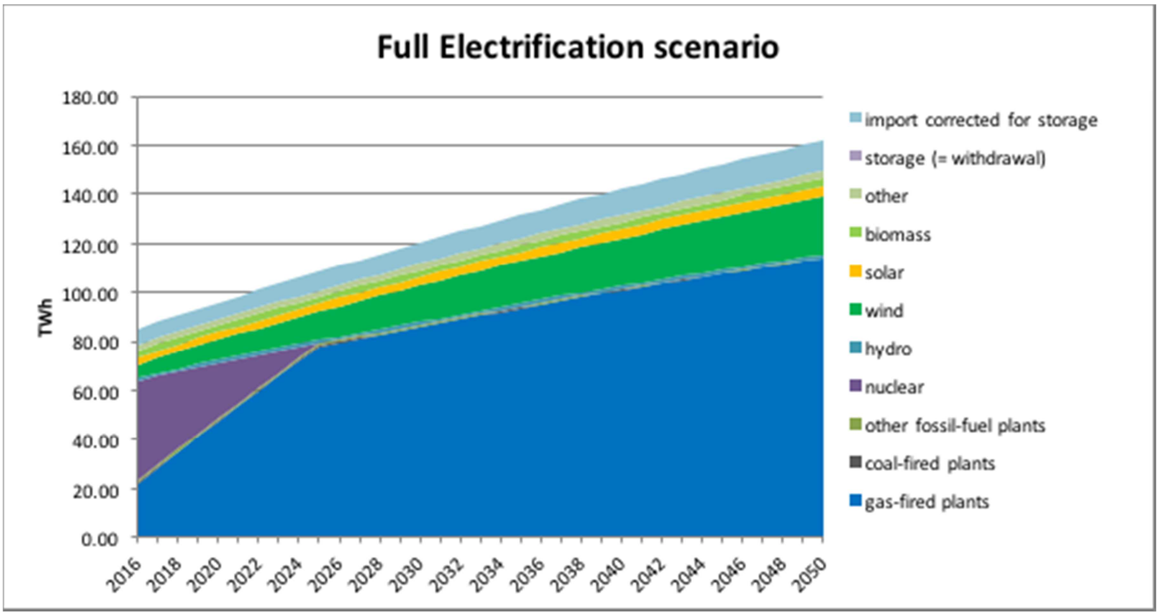
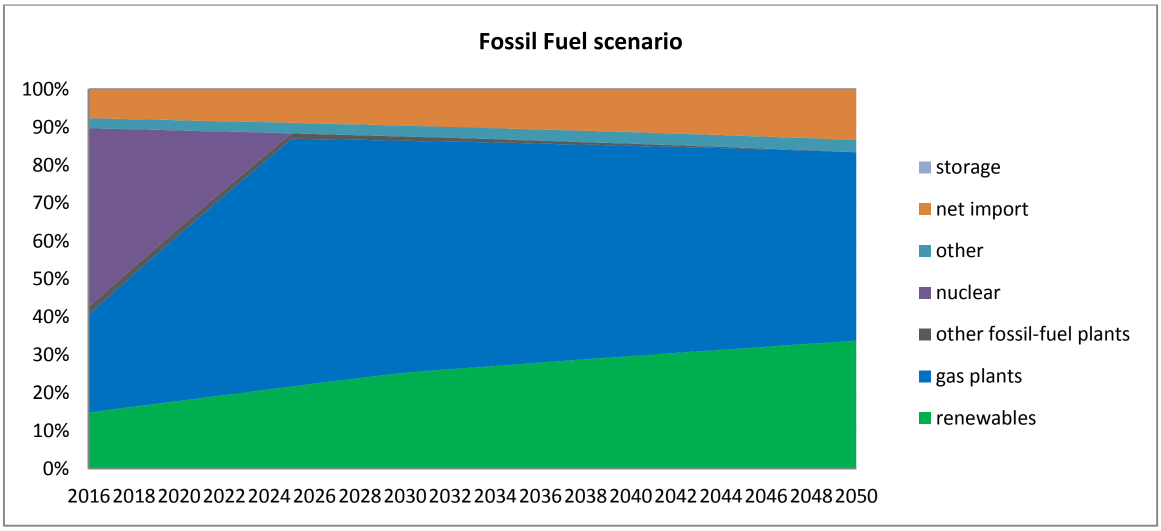


Figure 10a (cont.): Generation mix, per scenario, 2016 to 2050, TWh



In Figure 10b, we provide the shares of the various technologies in the generation mix per scenario, from 2016 to 2050. The share of renewable generation (wind, solar, biomass) across the three electrification scenarios is, by assumption, constant. In all scenarios, the targets regarding the phasing out of nuclear and other fossil fuels are also taken into account. As a result, we observe that the share of gas in electricity production increases with the extent of electrification. In the FF scenario, RES generation reaches 33.7% in 2050, and gas-fired power plants supply 75% of the total 96 TWh demanded. In the FE scenario, RES generation is only around 20% and gas-fired plants serve 70% of the total 162 TWh of demand. If electrification of road transport and housing kicks in seriously, the current objectives of the Belgium government regarding the deployment or RES generation are far too low.

Figure 10b: Generation mix shares, per scenario, 2016 to 2050, TWh



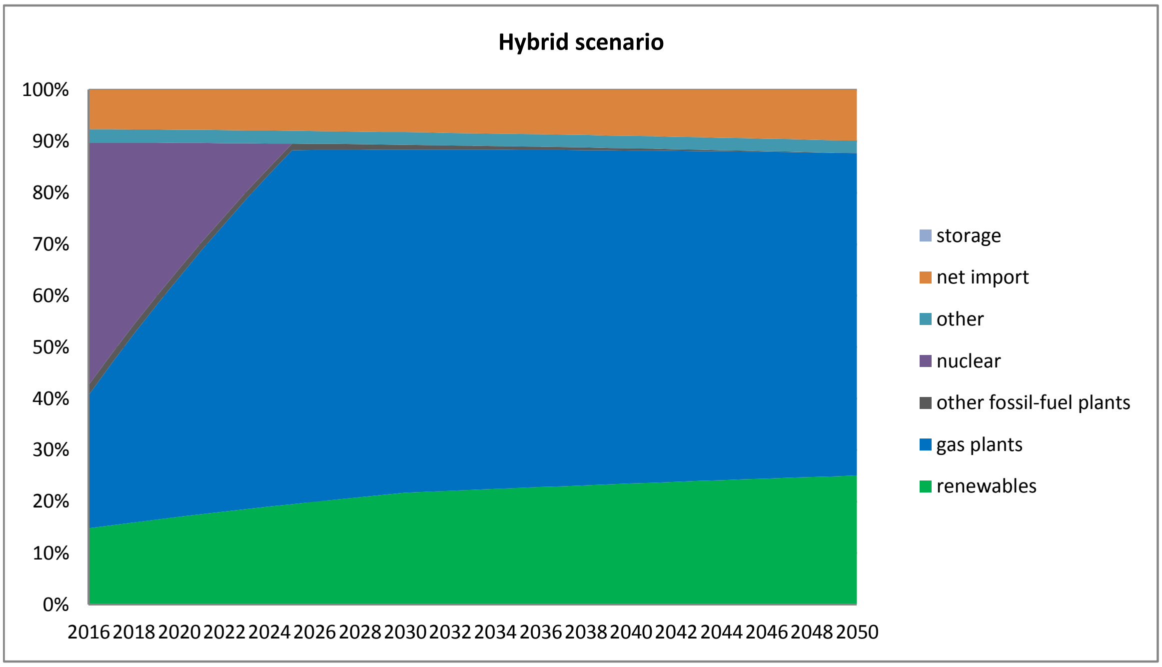
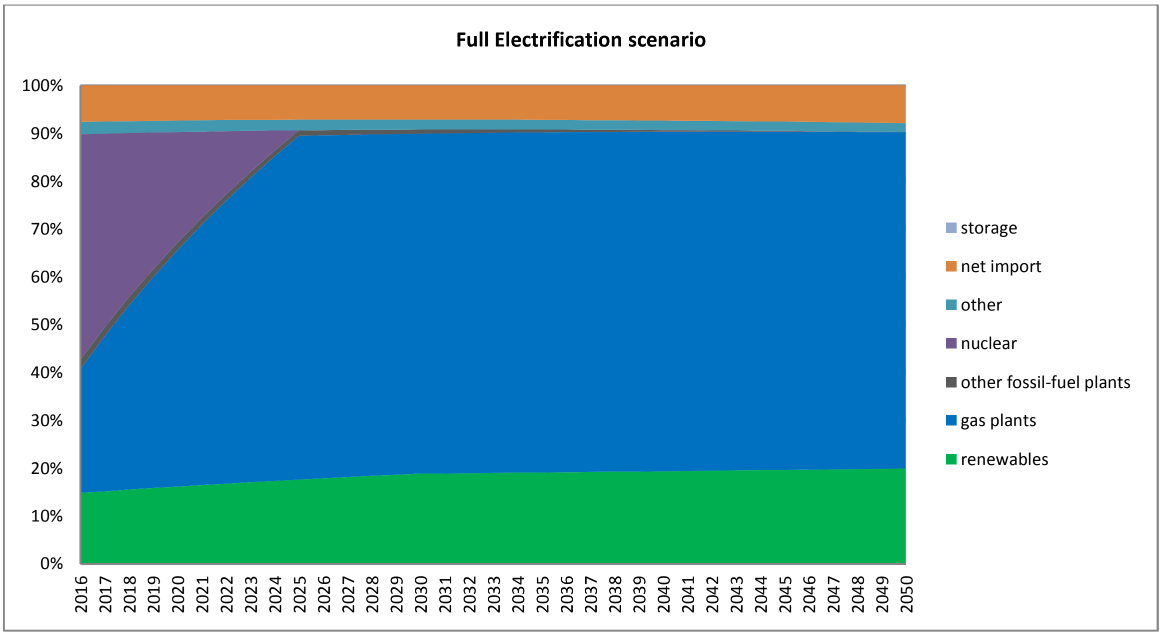


Figure 10b (cont.): Generation mix shares, per scenario, 2016 to 2050, TWh



7. Demand and Supply of Flexibility

The generation mix estimated in Section 6 is based on average capacity factors for wind and solar. This approach is relevant for a full-year analysis but does not take into account the volatility of renewable generation as well as the volatility of demand. The volatility issue is very important for the computation of the system costs because the electricity supply needs to be permanently equal to the total load in order to keep the system working. Therefore, the networks and the generation capacities of the input of last resort, in this case gas, have to be optimised to satisfy peak demands. To do this, this Section analyses how extreme weather and demand conditions impact the flexibility of the system.

7.1 Data and assumptions

Notion of "Best" and "Worst" days

To analyse system needs to satisfy peak demands, we follow the method in the Netherlands case study. We first characterise representative "best" and "worst" days (from the point of view of demand and supply of energy). A day among the "best" days is typically a warm summer day with low demand but high solar and wind power production. In contrast, a day among the "worst" is often a very cold winter day with high demand and low renewable generation.

According to ENTSOG data, in 2017 peak daily gas demand for Belgium was 1,207 GWh. The yearly demand for gas was 167,559 GWh, which implies that on a typical day the demand was 459.06 GWh. This means that peak gas demand was 163% higher than on a normal day. In our definition of "worst" day we then assume that demand is 263% that of a normal day. Regarding electricity demand, according to data published by the Belgian transmission operator *ELIA*,[12] the peak was around 324 GWh per day (13.5 GW) in 2016. The yearly demand in Belgium is around 85,000 GWh (see Table 7), which signifies that in a typical day the demand is 232.9 GWh per day. Therefore, the peak electricity consumption is about 40% higher than average. In our definition of "worst" day we then assume that electricity demand is 140% that of an average day. Regarding wind and solar conditions, we do not have precise data. We then proceed by implementing what was found for The Netherlands using weather data, which is reasonable because daylight and wind conditions are probably not that different between Belgium and The Netherlands. For The Netherlands, wind availability on such a "worst" day is 17% of the normal, and solar supply is 24% of the average supply. To summarise, a "worst" day has 263% the demand for gas, 140% the demand for electricity, 17% of wind generation and 24% of PV of an average day. The next step is to derive the energy mix necessary to meet demand for electricity on such a "worst" day. This computation indicates what the available capacity of non-renewable generation should be in order to meet demand, which serves to measure the system costs associated to supply security of electricity.

[12] See ELIA: *Electricity Scenarios for Belgium towards 2050*, November 2017, p.36.

For "Best" days we do not have data so we define them also on the basis of the Dutch case. PV output is about 189% of the daily average, wind output reaches 194% of the daily average, load is around 92% of that of a normal day, and heating demand is 26% of the daily average. We also derive the supply of electricity on such "best" days. The notion of "best" day is used to see whether the entire demand can be met using renewable generation, in which case the excess supply is stored for seasonal flexibility.[13]

Seasonal storage

The volatility of the generation by renewable sources can be managed in different ways: change in electricity export level, seasonal storage and gas-fired power plants. The potential of seasonal storage is calculated by assuming that oversupply during "best" days is first converted into hydrogen, then stored and finally used on "worst" days (see Table 8 for the efficiency of the power-to-gas technology). Once again, the gas-fired power plants are considered here as the technology of last resort (i.e. only dispatched if additional supply from hydrogen is still insufficient to satisfy demand).

Table 8: Assumptions on efficiency of Power-to-Gas, seasonal storage

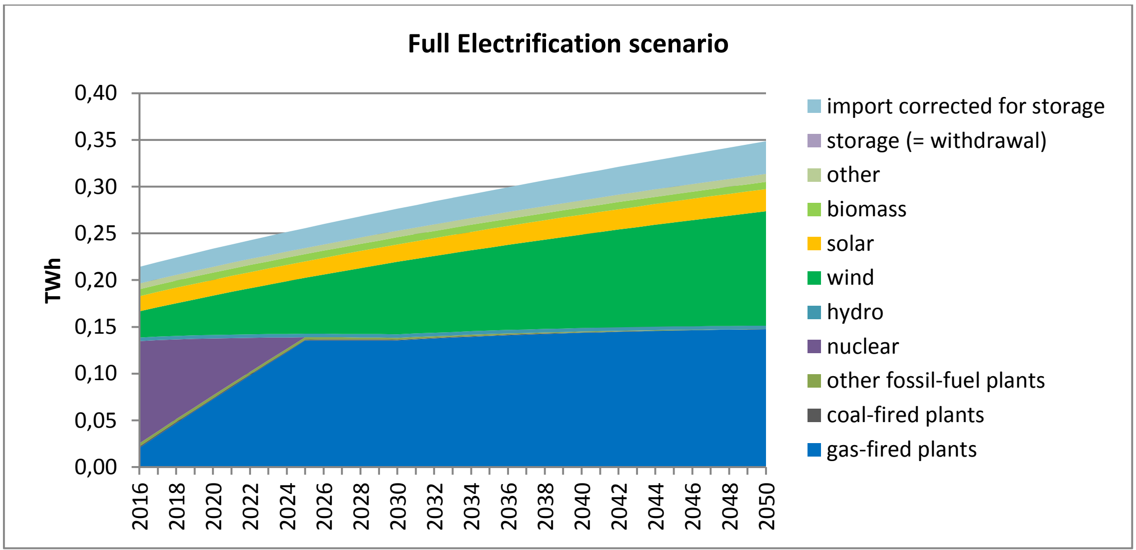
Variable	Value (%)
Efficiency electrolyser	75%
Efficiency power plants	50%
Resulting efficiency PtG	38%

7.2 Results

During "best" days with extreme levels of solar PV, wind, high temperatures and resulting low heating demand, as well as low load levels, in the FE scenario demand cannot be fully met by renewable sources of generation. This is illustrated in Figure 11a, where, note, generation on the y-axis indicates TWh per day. This implies that gas has to be utilised for generation even under such good weather conditions. In the FF and HY scenarios, the situation is similar, though less gas has to be utilised to produce electricity on such good weather days.

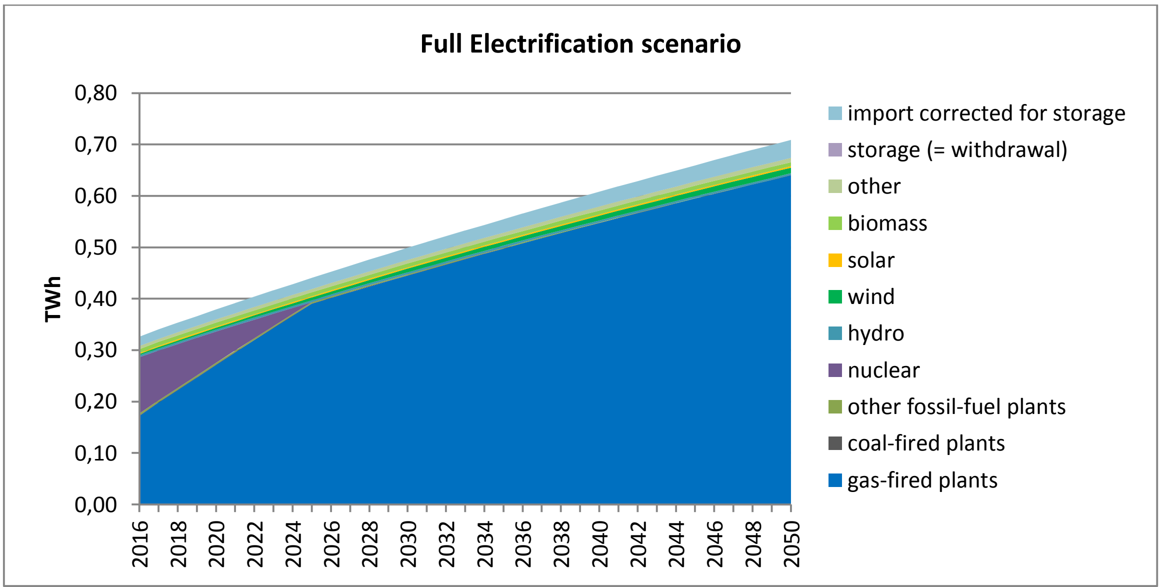
[13] Note that the analysis excludes a range of flexibility sources such as pooling effects of cross-border trade or demand response.

Figure 11a: Power supply on a hypothetical "best" day under full electrification



The picture is very different in a winter day with extremely low levels of renewable generation, low temperature, and extremely high demand. In this case, gas-fired plants will have to supply most of the electricity no matter the scenario (see Figure 11b). As pointed out above, because other flexibility sources are excluded, the shares of gas-fired generation should be interpreted as an upper bound and would be lower if trade and demand response would be included in the model.

Figure 11b: Power supply on a hypothetical "worst" day under full electrification



A clear picture emerges from this analysis: because we do not have excess supply under the best possible weather and demand conditions, there is no role of power-to-gas in the case of Belgium. This is different from the case of France for example. It should be noted, however, that at a higher level of granularity, say at the hour level, there may be much more volatility and power-to-gas may have a role.[14]

A second observation is that a lot of gas-fired generation will be needed to make the electricity system reliable. We compute that 27 GW of capacity will be necessary by 2050 in the FE scenario. This is almost 4 times as much as the current generation capacity to deal with peak demand. We will take this into account in our computation of the costs associated with electrification.

[14] Note also that power-to-gas may also be used as an alternative to grid expansion in order to deal with transmission congestion. This possibility has not been investigated in this project.

8. Consumption of natural gas

This Section presents the impact of electrification of the road transport and residential housing sectors on gas consumption in Belgium. The net impact on gas consumption is obtained from putting together, on the one hand, the reduction in the use of gas in the residential buildings (see Figure 5), and, on the other hand, the increase in the use of gas in the power sector (see Figure 7).

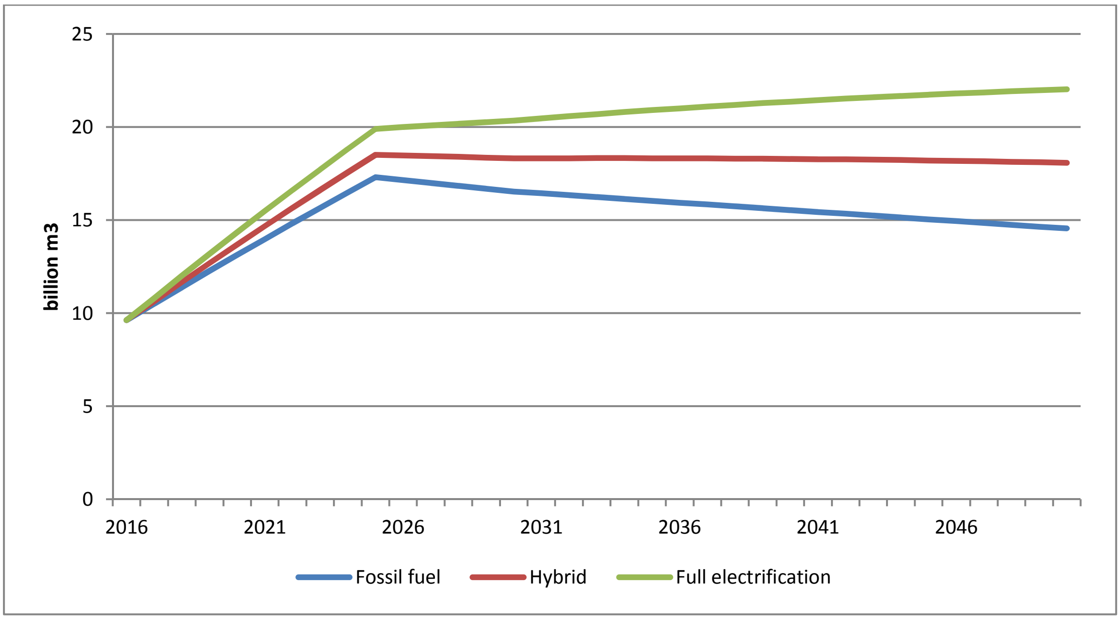
8.1 Data and assumptions

For calculating the demand for gas as an input for the gas-fired power plants, we assume an efficiency of the gas-fired power plants of 50%, and an annual increase in this efficiency of 0.5% so that by 2050 the efficiency is 60%. The assumptions made to calculate the remaining gas consumption in residential buildings have been discussed above (see Tables 4 and 5).

8.2 Results

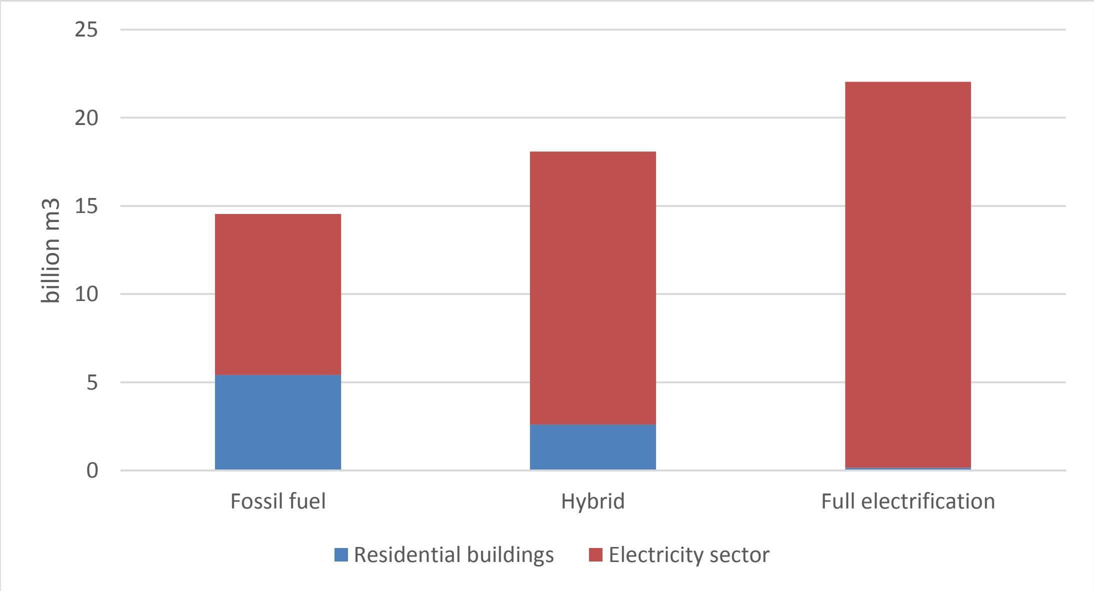
The net impact of electrification on gas demand for the different scenarios is shown in Figure 12.

Figure 12: Gas demand from residential and power sectors, 2016-2050, by scenario



The pattern is similar in the three scenarios up until 2025. The gradual phasing out of nuclear generation increases the needs for gas as an input for electricity production. This effect is stronger than the reduction in the use of gas in the residential sector. On net, thus, gas consumption increases substantially from 11 bcm in 2016 to 17-20 bcm in 2025 depending on the scenario. After this, the decrease in the consumption of gas in the housing sector has a dominating influence in the FF and HY scenarios. By contrast, in the FE scenario it is the increase in the power sector that dominates. In general, there is a shift of gas usage from the residential sector to the power market, and this shift is stronger the higher the extent of electrification. This can be seen in Figure 13.

Figure 13: Gas demand in 2050, by origin



Later in Section 10 where we calculate the emissions associated to the housing, transport and electricity sectors we take into account that part of the gas consumed by households and gas-fired power plants is biogas. Drawing from the case in the Netherlands, we assume that 0.08 bcm of green gas enter the gas system in 2016. The yearly increase in biogas is assumed to be 2%.

9. Electricity and gas distribution networks

Both electricity and gas provision rely on the use of distribution and transmission networks. These networks have been developed over time in order to facilitate the shipping of the commodities at all times. Electrification implies a higher use of electricity and of gas and thus transmission and distribution network capacities have to be adapted to accommodate the upcoming increases in power generation as well as in gas consumption. Below, we highlight the changes in load that the power grid, and the changes in gas demand that the gas network, have to accommodate.

9.1 Data and assumptions

To derive the system needs for the gas network, we look at the gas demand during the so-called "worst" days, as defined above in Section 7. During the "worst" days, the use of gas will be the highest not only because the residential sector will demand much for space heating purposes but also because there will be a high demand for electricity that cannot be produced with renewable generation. The gas networks have to be able to accommodate such volumes of gas. For the electricity networks, it is the opposite. Electricity networks need to be adapted to deal with the maximal level of load within a year. We therefore compute the amount of power generated under the most favourable weather conditions for electricity production, which we defined as the "best" days in Section 7. Departing from the assumption that the present networks in Belgium are optimised to deal with current volumes of usage, we express the network needs for the HY and FE scenario in percentages of the needs in the baseline FF scenario.

9.2 Results

Figures 14a and 14b illustrate how the peak demand that the power and gas networks have to transport change in percentage as compared to the business-as-usual scenario. The electricity grid capacity has to increase greatly (by 70% in 2050) to ensure the extra demand generated by full electrification of the road transport and residential sectors can be satisfied (see Figure 14a). In the HY scenario, the transport capacity should also increase, but by only around 35% in 2050 relative to the case of no electrification. The gas network capacity also has to be extended in the case of full electrification, by more than 50% in 2050 (see Figure 14b), while in the case of the HY scenario by 25% in 2050.[15]

[15] Note that the model does not take network topology into account. That is, as gas demand shifts to gas-fired plants, network requirements may change locally, with more capacity needed to deliver spots of gas-fired generation, and less capacity for vast residential areas.

Figure 14a: Increase in electricity network usage, as compared to FF

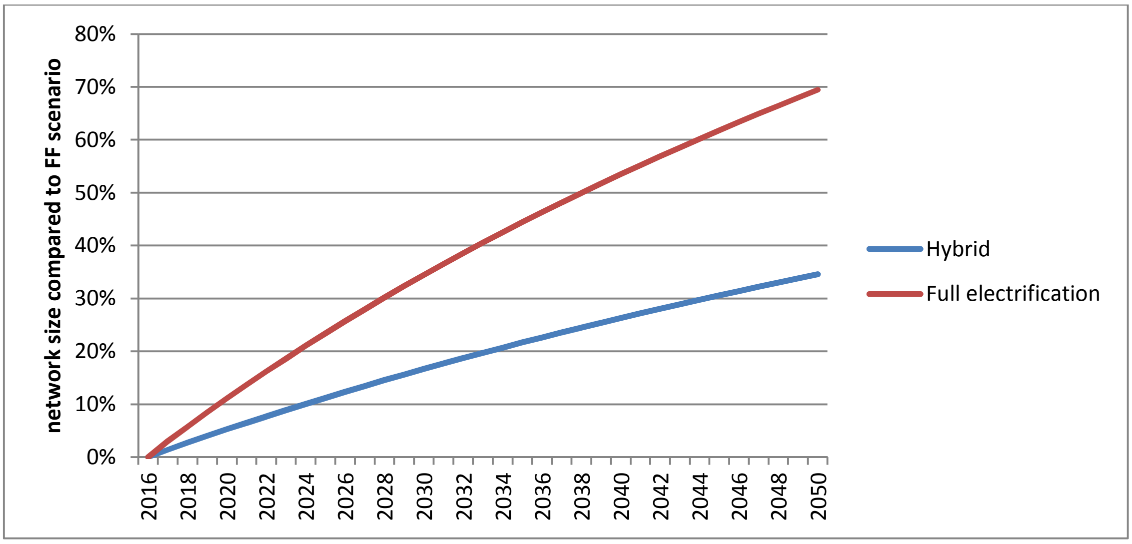
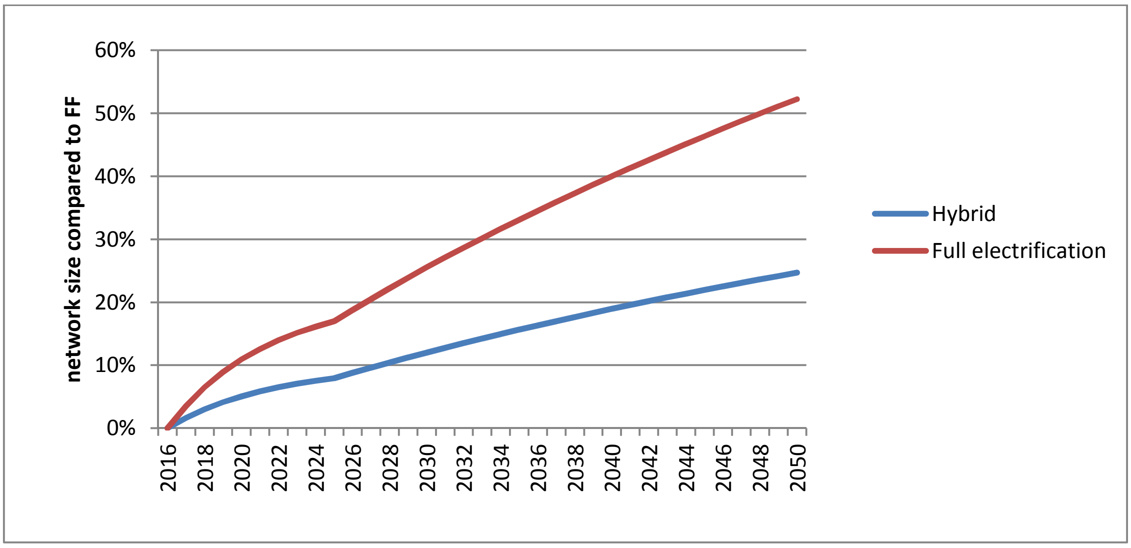


Figure 14b: Size of gas grid compared to the FF scenario (in %), 2016-2050



10. Carbon Emissions

The ultimate objective of electrification of the road transport and residential sectors is to reduce carbon emissions. In this Section we compute the effect of electrification on carbon emissions. We pay special attention to the shift from emissions from the road transport and residential sectors to the electricity sector.

10.1 Assumptions

Table 9 summarises the Belgium data on emissions from transport and buildings in 1990.[16] The road transport sector emitted around 19.5 million tons in 1990; the bulk of these emissions stem from the use of diesel to power cars, vans, trucks and buses (56%). The rest is mainly from the gasoline used by passenger cars (42%). Unfortunately, we do not have the breakdown of these emissions across types of vehicles (cars, vans, trucks and buses) for 1990. We however can compute emissions for the current year, since we have the necessary data. Departing from the 2016 emissions levels, we proceed by calibrating the 1990 emissions levels at the vehicle type using the same proportions as in The Netherlands. For passenger cars, the level of CO_2 emissions in 1990 was 82% of the current level in The Netherlands; we use the same percentage for Belgium. This is also done for the rest of the vehicles types.

For the residential sector, we do have the necessary data at our disposal. The sector emitted a total of 20.47 Mton of CO_2 in 1990. The bulk was from oil-fired houses (62%), followed by the gas-fired houses (29%).

The electricity sector emitted a total of 23.52 Mton on CO_2 in 1990.

Table 9: Emissions by sector in 1990, in million tons of CO_2 equivalent

Variable	Value
CO_2 emissions in 1990 (x Mton)	
residential buildings	20.47
road transport	
- passenger cars	12.76
- vans	1.59
- trucks	3.03
- buses	0.66
- motors	0.07
electricity sector	23.5

[16] The data are extracted from the *Belgium's greenhouse gas inventory (1990-2015)*, submitted to the United Nations Framework Convention on Climate Change (page 294).

The calculation of the carbon emissions for each scenario proceeds as follows. We determine the consumption of fossil energy per sector (transport, housing and electricity) and multiply this consumption with the carbon intensity per unit of fossil energy, i.e. natural gas, oil, and coal in electricity and housing, oil (*stookolie*) in housing, and diesel and gasoline in transport. For the case of road transportation, two factors are relevant: the quantity of fuel used per unit of distance and the carbon intensity of the fuel. Table 10 gives the assumptions made regarding these factors.[17]

Table 10: Assumptions on fuel efficiency and carbon intensity of vehicles

Variable	**Fuel efficiency (lt/100 km)**	**Carbon intensity (ton/lt fuel)**
Passenger cars (diesel)	6.7	0.0027
Passenger cars (gasoline)	8	0.0024
Vans	10	0.0027
Trucks	22	0.0027
Buses	29	0.0027
Motorbikes	5	0.0024

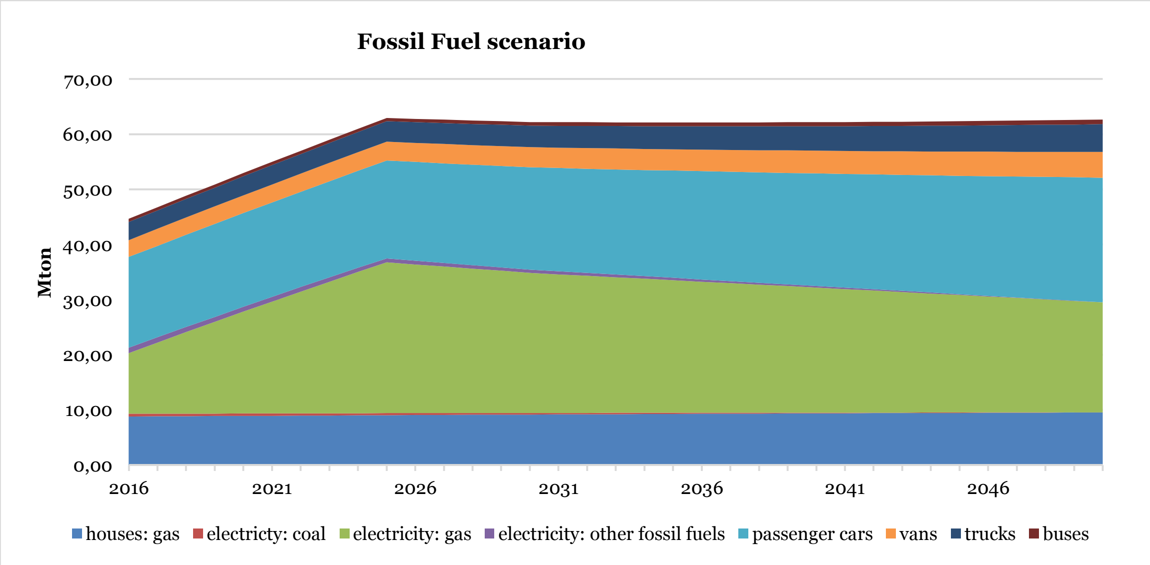
To obtain emissions from gas consumption by (non-electrified) residential households, the model multiplies the total gas consumption in residential buildings in m^3 by the CO_2 content per m^3. The CO_2 emissions per m^3 of natural gas are taken to be 2.2 kg (see *Wikipedia*). We do the same for the oil-fired houses. The CO_2 emissions per m^3 of *stookolie* are taken to be 3.74 kg (see *milieubarometer.nl*). Last, for the electricity sector, the analysis considers the sum of CO_2 emissions stemming from the fossil fuel power plants. For coal-fired plants, CO_2 emissions per ton of coal are assumed to be 3.66 tons. For gas-fired plants, the model applies 0.4 tons of CO_2 emissions per MWh. Of course, in this computation we assume that green gasses are emission-neutral.

10.2 Results

In the FF scenario, we observe an increase in the emissions from the three sectors under consideration up to 2025 and thereafter a very small, almost imperceptible, decline (see Figure 15a). Electrification does not play much of a role here so the increase in the emissions is due to the phasing out of nuclear and its replacement by natural gas. After 2025, we observe the effect of the penetration of renewable generation, with gas losing importance and thereby the electricity sector reducing its contribution to CO_2 emissions. With little electrification, the passenger car sector increases its emissions over time so on aggregate emissions remain on the same level, more or less.

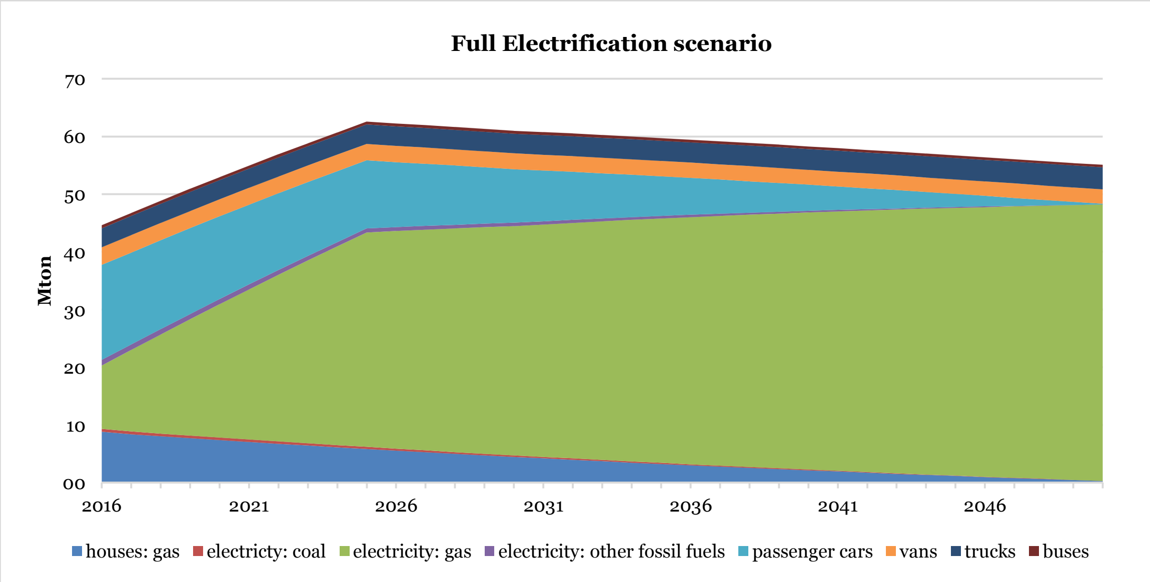
[17] Further, we assume that two-wheelers use gasoline, while vans, trucks and buses use diesel. Regarding cars, 61% of the non-electric cars are diesel and the rest mainly gasoline.

Figure 15a: CO_2 emissions over time, fossil fuel scenario



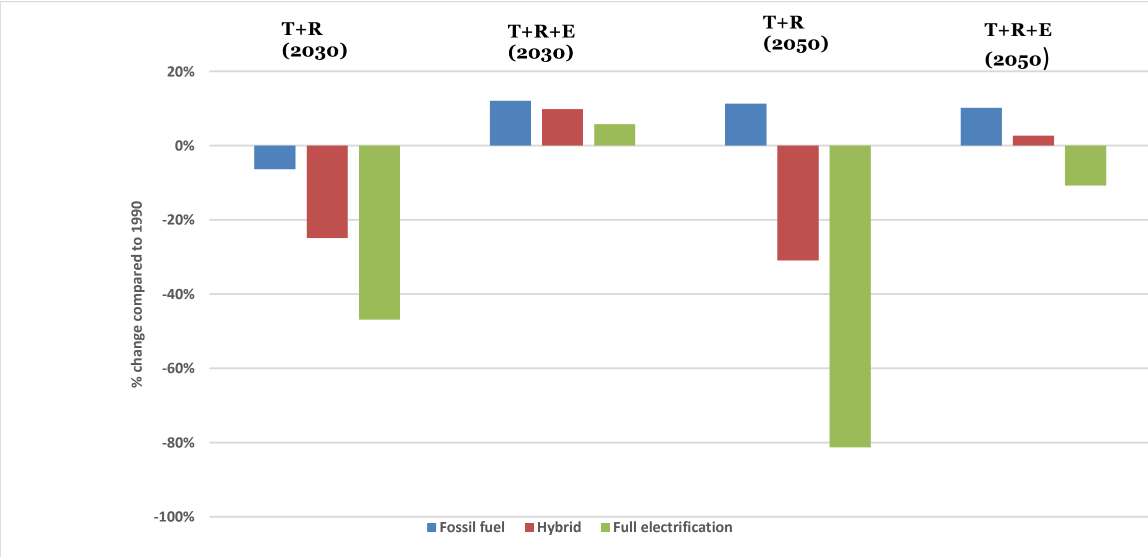
In the FE scenario, the picture is quite different, with CO_2 emissions linearly decreasing from 2025 to 2050 (see Figure 15b). Emissions from houses fully disappear by 2050 due to electrification and the same holds for passenger cars. For vans, trucks and buses emissions remain similar over time. The increase in the use of gas for electricity generation does not offset the cuts in CO_2 emissions originating from electrification due to the penetration of renewables and therefore aggregate CO_2 emissions decrease.

Figure 15b: CO_2 emissions over time, full electrification scenario



Finally, Figure 16 illustrates the projected CO_2 emissions reduction compared to 1990 levels. The first two sets of entries relate to projected reductions in 2030, first transport and buildings only (labelled T+R (2030)), and second, for all sectors (labelled T+R+E (2030)). The second set of entries relates to 2050, again first for transport and buildings only and then for the three sectors.

Figure 16: Carbon emission reduction per group of sectors, per scenario, in 2030 and 2050 (in % of 1990)



In the FF scenario, when we consider the road transport and housing sectors only, we observe that emissions are lower than in 2030 but, because of the increase in the number of houses and number of vehicles, emissions continue to increase so that by 2050 they are above 1990 levels. When we also consider the electricity sector, in 2030 emissions are above the 1990 levels, which clearly comes from the electricity sector being non-nuclear. In 2050, emissions remain above 1990 levels but because of the penetration of renewables, at levels below those in 2030.

The results are quite different when looking at the FE scenario. As expected, because of full electrification of the transport and residential sectors, the carbon emissions are significantly reduced, almost by 50% in 2030 and by more than 80% in 2050. However, because the electricity sector becomes much more polluting, the net effect is much worse, with a 6% increase in 2030 and a relatively low reduction of 11% by 2050.

11. System costs

In the final step of our analysis, we compute the total costs of electrification of road transport and housing. By costs of electrification we mean the investments (net of the savings, if any) necessary to realise the electrification targets laid down in the scenarios HY and FE. These investments relate to the three sectors that are affected by electrification: the housing sector and the mobility sector, which are affected directly, and the electricity sector, which is affected indirectly (additional transport and generation capacity, if any). We compare the benefits from reducing carbon emissions with the costs from switching to electrified housing and road transport sectors.

11.1 Assumptions

The model accounts for the costs of insulating old houses, and the excess costs of installing heat pumps relative to gas boilers. As for road transport, the model accounts for the excess price of electric cars relative to conventional ones, and the costs of deploying the necessary battery charging infrastructure. The model also includes savings of conventional fuels due to electrification. These savings also produce reductions in emissions that fall outside the ETS. We assume a social cost of carbon of €50 per ton. Increases in emissions from the electricity sector fall within the ETS system and are therefore priced at €10 per ton. Parameters for this net-present value approach are depicted in Table 11. For additional details see the Netherlands case study.

The calculation of system costs also uses data on the value of the network assets installed by the electricity and gas companies. Unfortunately, we do not have data on the asset bases of the electricity distribution networks. We proceed by calibrating the asset base of these companies on the basis of the Dutch study. In The Netherlands the current total load is 120 TWh and the corresponding asset base is €19 billion. In Belgium the total load is 85 TWh, so, in proportion, we assume an asset base of €13.6 billion for Belgium. This calibration ignores scale effects but according to Yatchew (2000) these economies seem to be exhausted after a relatively small scale.

Regarding the gas networks, we know that the transmission operator has an asset base of €2.3 billion (see *fluxys.com*). We do not have data for the distribution networks. We calibrate the asset base of the distribution networks again relying on the Dutch study. In The Netherlands the distribution networks have an asset base 30% higher (so €2.99 billion). In total, then, the gas asset base is set to €5.29 billion.

Table 11: Assumptions on fuel efficiency and carbon intensity of vehicles

Variable	Value
Weighted Average Costs of Capital (WACC)	5%
Discount rate (for NPV calculations)	3%
Depreciation periods (years)	
- grid	20
- power plants	20
- house equipment	40
- cars	10
Investments costs:	
- gas-fired power plants (mln euro/MW)	0.75
- electrolyser (mln euro/MW)	0.5
- storage (caverne)	30
Asset value electricity grid (billion euro)	13.6
Asset value gas network (billion euro)	5.29
Investment costs residential buildings	
- heat pump (euro / house)	6000
- renovating house (euro/m2/house)	105
Investments costs road transport	
- quick charging stations (per unit)	35000
- ratio charging stations / cars	0.08
- extra costs of electric cars (euro/car)	7500
Gas price (Euro/MWh)	20
annual change in gas price	0%
Price motor fuels (Euro/lt, excl taxes)	0.5
annual change in price motor fuels	0%
shadow price of CO_2 (euro/ton)	50
CO_2 price in ETS (euro/ton)	10

11.2 Results

Costs of electrification are reported by comparing total system costs across each scenario. Note that the degree of electrification is the only difference across scenarios, so any difference in costs can be fully attributed to differences in the degree of electrification.

The fixed costs associated with the electrification of houses (including the renovation of old houses) and the purchase of electric vehicles are the main cost drivers (see Figures 17a and 17b). The main benefits come from savings in gasoline and diesel consumption, as well as in reduced damages from CO_2 emissions, given the assumed social cost of carbon of €50 per ton. There are some non-negligible costs due to the necessary expansions of the gas-fired generation capacity and the electricity network infrastructure. The expansion of the gas network adds very little to the costs and these costs are probably avoidable because gas network capacity will *de facto* increase when converting low- to high-calorific gas.

Figure 17a: Contribution of different cost drivers (negative costs represent benefits)

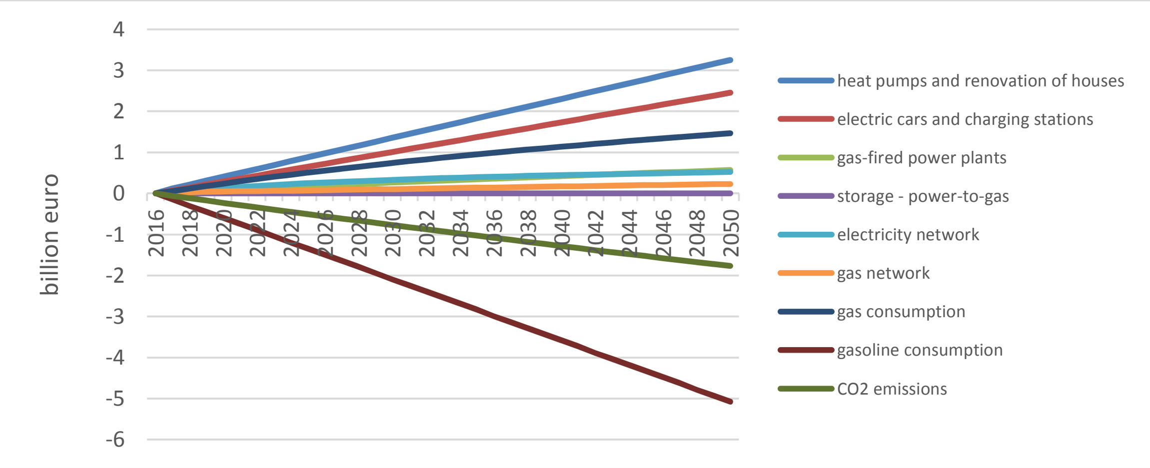


Figure 17b: Contribution of different cost drivers in the year 2050 (negative costs represent benefits)

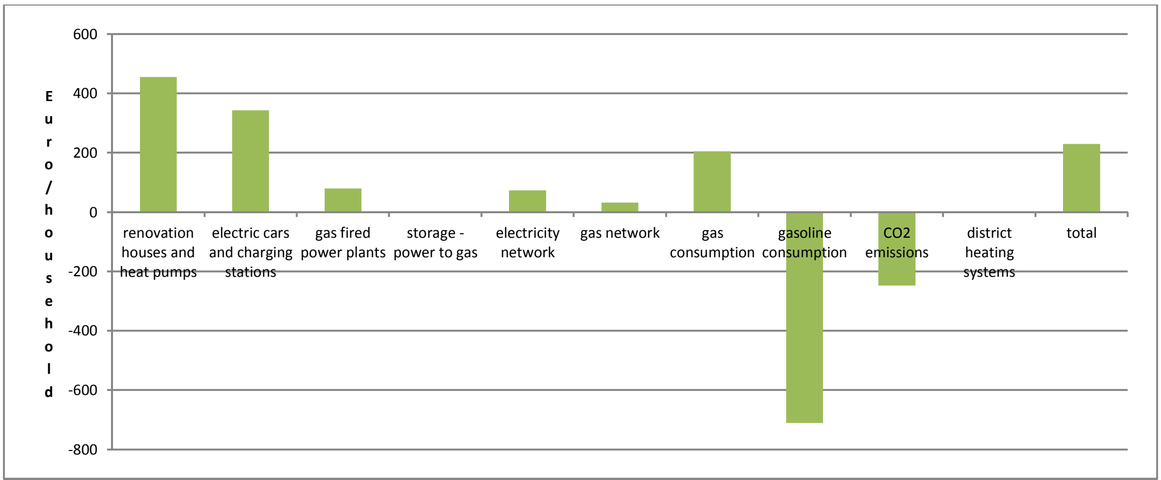
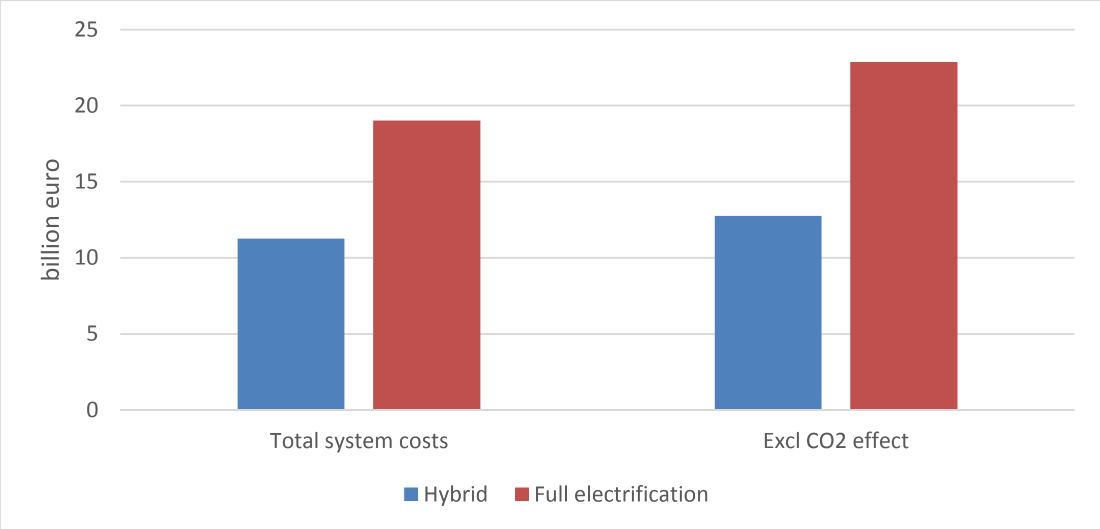


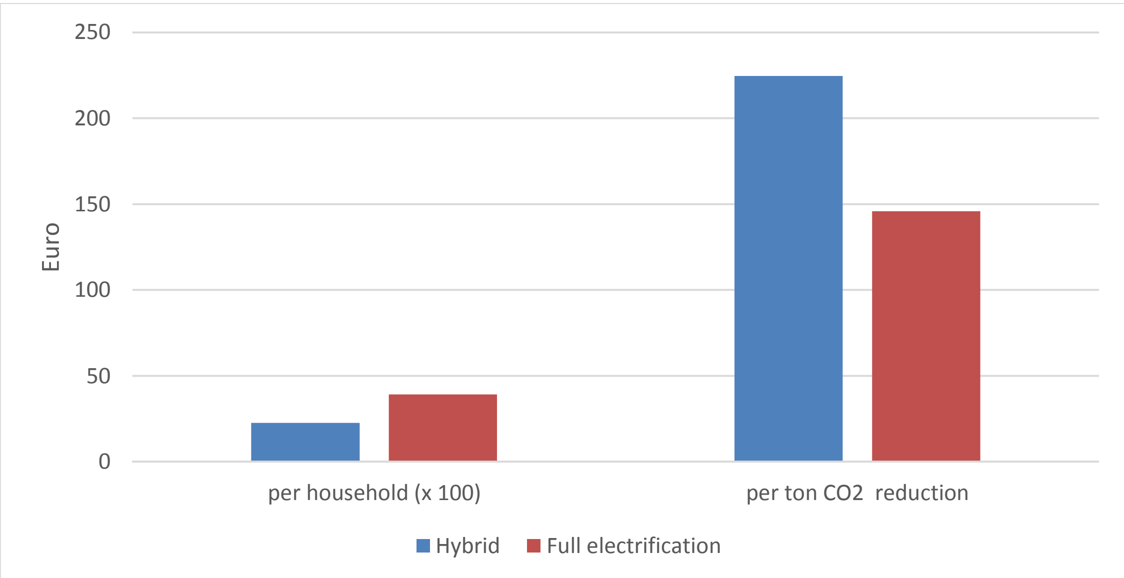
Figure 18 shows the net-present value of the total system costs for both the HY and FE scenarios. These costs include all investments in the residential buildings, road transport and energy sectors needed for electrification, net of all savings in the consumption of fossil fuels and reductions of carbon emissions. In the FE scenario, these costs are estimated to be €19 billion, which amounts to around 4-5% of current GDP. In the HY scenario, the costs are €11 billion. Emissions reductions are relevant: excluding the cuts in emissions, the costs are higher in both scenarios.

Figure 18: Net-present value of total system costs for Hybrid and Full Electrification scenario



These costs are expressed in other metrics in Figure 19. Per-household, the total system costs represent around €2,300 per household in the HY scenario, and in the FE scenario about €3,900 per household. Per ton of CO_2 reduction, the HY total system costs amount to €225, while the FE total system costs are €146.

Figure 19: Net-present system cost for Hybrid and Full Electrification scenario, today's investment cost



12. Conclusion

The primary objective of this report has been to understand how electrification of the residential housing and road transport sectors may impact electricity and gas demand and supply, system needs, and CO_2 emissions in Belgium. We have also computed the total costs of electrification. To address this issue, we have used the model developed for the Netherlands case study, which studies three different electrification path scenarios towards 2050 – fossil fuel (or business as usual), hybrid, and full electrification. The model's results depend on a number of parameters – such as the annual share of new electrified houses and cars, and the government's policy ambitions regarding the energy mix for electricity generation. The parameters used in this report are all derived from historical data, estimates from the existing literature, and documents from the Belgium government, United Nations and the companies or institutions involved in the market such as *ELIA*, *Fluxys*, or *ENTSOE*. When data were not available, we have used the Dutch data to calibrate for the missing Belgian data.

The estimated additional electricity demand due to electrification is met, on the supply side, by renewable energies and gas-fired plants. Because investments in renewables are limited in Belgium, higher levels of electrification automatically translate into higher gas-fired generation. In the case of full electrification, this share is estimated to be 70% in 2050 and is significantly higher than the share of renewables (20%).

In the full electrification scenario, carbon emissions initially increase due to the phasing-out of nuclear generation, but after 2025 they are decreasing linearly until 2050 due to a lower energy usage from fossil fuel intensive traditional heating and transport. The study shows that the target of reducing GHG emissions by 80% compared to the 1990 levels is very unlikely to be reached even with full electrification, given the rest of the government targets. It is necessary to increase renewable generation quite a lot when targeting full electrification of the economy.

Finally, it is important to mention some limitations of the current framework. First, the modelling does not include demand flexibility which would reduce the role of gas. Second, the report does not explicitly take into account targets related to energy consumption reductions, though it incorporates efficiency gains. Third, electricity supply is likely to be more decentralised in the future as it relies more heavily on renewable energy. This in turn will likely require a new network architecture. Because these features are excluded from our analysis, the shares of gas-fired generation may be interpreted as an upper bound. The consequences of allowing trade and demand responses could in fact be an interesting avenue for future research.

References

Adonis Yatchew, "Scale Economies in Electricity Distribution: A Semiparametric Analysis", *Journal of Applied Econometrics* 15 (2000), 187–210.