Scenario towards a climate neutral Belgium by 2050

INTRODUCING THE **SHIFT** SCENARIO - A PATHS2050 COMPARISON

A study commissioned by Ecolo-Groen

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Key insights

CO_2 emissions reduce by

90%

by 2040 through early access to clean electrons and system shifts

Electricity generation reduces with almost

20%

in 2050 by implementing system shifts

System shifts can save more than

30B€

in the power system up to 2050

This study can be considered as a sensitivity on the PATHS2050[1] study which came out end of 2022. EnergyVille constructed a Low Energy Demand (LED) scenario for Belgium, using the TIMES-BE model. The **SHIFT scenario** explores the potential of system shifts to ease some of the challenges associated with the energy transition, particularly those arising from upscaling electricity supply. The scenario assesses the impact of the development towards a more resource-efficient society and circular economy, driven by system shifts in production, consumption, mobility and housing patterns towards more sustainable alternatives. These shifts take into account already existing potential societal trends and assume policy measures and investments to facilitate a systemic shift, possibly without sacrificing societal comfort. Societal shifts are already incorporated into national strategies[2] and the EU's Circular Economy Action Plan (CEAP).

Impact of the net-zero target in all scenarios

The following statements are general conclusions valid for the four scenarios considered in this study: the Central scenario, the Central+16GW scenario, the Central+SMR scenario and the SHIFT scenario.

Diverse pathways lead to carbon neutrality.

- Our scenarios demonstrate varied approaches to achieve CO_2 neutrality in Belgium, emphasizing balanced strategies, electrification, and clean molecules as potential solutions.
- The model shows that a purely renewable energy transition is possible[3].

Rapid electrification is key for net-zero emissions.

- Across all scenarios, electrification is pivotal.
- The most cost-optimal pathway for net-zero emissions involves a substantial increase in electrification, with a need for clean electrons, reaching 70 TWh by 2030 and at least 130 TWh by 2040 of renewable electricity generation.
- Space heating, transport and industry are largely electrified.

Timely access to clean electrons lowers the cost of transitioning.

- Having access to clean electrons timely is a crucial factor in achieving the climate goals.
- By 2030, a substantial increase in renewable energy capacity is imperative with factors of 3 for solar PV (compared to 2023) and 2 for onshore and offshore wind compared to 2020. This is equivalent to tripling renewable electricity.
- Access to additional offshore wind emerges as a crucial factor, enabling early electrification of demand sectors and contributing significantly to lowering overall energy system costs, offering a smoother transition.

Shifting away from fossil fuels.

- While fossil fuels constituted over 70% of the final energy demand in 2020, our results show a nearly complete phase-out by 2050.
- By 2050, however, a small demand for fossil oil (around 12 TWh) remains in 2050, used as a feedstock in industry (for which biomass could be an alternative).

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[1] "PATHS2050 | Energy Outlook," accessed December 12, 2023, https://perspective2050.energyville.be/node/9.

[2] France introduced sufficiency as a key aspect of its decarbonization strategy in June 2023, based on a national sufficiency plan that was introduced in October 2022, https://www.ecologie.gouv.fr/sites/default/files/dp-plan-sobriete.pdf

[3] Except for a small quantity of fossil fuel use in some industries and excluding the origin of the imported electricity.

Impact of the SHIFT scenario

The **SHIFT scenario** is an alternative net-zero pathway towards a 90% reduction by 2040 and a carbon-neutral 2050 for our Belgian energy system. These system shifts define a more feasible alternative transition pathway with a 20% reduction of electricity generation by 2050, resulting in total cumulative power system savings of more than 30 B€ from 2020 to 2050.

Researching Low Energy Demand (LED) scenarios is a relevant topic today. The recent EU-impact assessment[4] describes enhanced circularity to entail comparatively lower needs for primary production of materials which results in a lower need for carbon capture. This statement is introduced by the European Scientific Advisory Board on Climate Change (ESABCC) in their 2023 report[5] which proposes that LED scenarios reduce the risk associated with the upscaling of supply-side options that have comparatively higher transition risks, according to the vision of ESABCC, such as nuclear power, carbon capture, utilisation, and storage (CCUS) and bioenergy. The 2023 adequacy and flexibility study by Elia[6] establishes that major changes in the energy system are required to reach net zero by 2050 for Belgium. The study underlines a focus on energy efficiency, sufficiency, and electrification to reduce final energy needs as well as an increase in the share of RES technologies integrated into the system.

Impact on the energy system

The new Low Energy Demand scenario broadens the palette of scenarios on the PATHS2050 platform.

- By including behavioural patterns and materials efficiency, the new SHIFT scenario complements our current palette of scenarios that are mostly based on energy technology solutions.
- The scenario underlines that a transition towards a nearly 100% renewable energy system becomes easier by a LED scenario and access to an additional 9 GW of far offshore wind.

Electricity demand doubles and final energy demand almost halves by 2050.

- Whereas final energy demand reduces by a third in the other PATHS2050 scenarios.
- Starting today, the electricity demand increases with approximately 30 TWh each decade, landing in a 160 TWh electricity demand by 2050 in the SHIFT scenario. This is 34 TWh or almost **20%** lower than the Central+16GW scenario in 2050 (192 TWh).
- The SHIFT scenario reduces fossil energy demand by nearly 20% compared to the Central+16GW scenario throughout the transition period.

The largest impact arises from changes in the industry and transport sector.

- In 2050, final electricity demand is reduced by 18 TWh in the industry sector, 13 TWh in the transport sector and by 3 to 5 TWh in buildings, resulting in a total final electricity demand of around 160 TWh. By 2050, road transport is 100% electrified, requiring 16 TWh of electricity per year. For 2050, we assume a 16% modal share for passenger trains which is equivalent to doubling the train use, similar to the “Spoorvisie 2040” that also formulates a doubling however already by 2040[7].
- The SHIFT scenario assumes a more resource-efficient and circular economy which results in a lower need for primary production of basic products, primarily impacting the production of new high value chemicals (-18%) in the chemical sector and reduced use of new cement (-39%) and ceramics (-33%) in the non-metallic minerals sector.

Covering future electricity needs requires faster deployment of renewables.

- Having access to clean electrons timely is a crucial factor in achieving the climate goals. The amount of new clean electrons can be reduced by down-scaling the demand-side.
- For all scenarios, by 2030, a substantial increase in renewable energy capacity is imperative, mainly with regards to photovoltaic and wind power.
- In the SHIFT scenario, solar PV reaches 20 GW and wind power reaches 13GW by 2030.

Impact on the climate

Up to 60% by 2030 and 90% by 2040 reduction of energy related and process CO_2.

- During the period 2030-2040, the total annual system emissions reduce from 48 MtonCO_2 in 2030 down to below 15 MtonCO_2 in 2040 mostly through additional access to clean electrons.
- With this additional electrification, there is up to **90%** CO_2 emission reduction in the SHIFT scenario in 2040 compared to 1990.

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[4] “Recommendation for 2040 Emissions Reduction Target,” Text, European Commission - European Commission, accessed February 9, 2024, https://ec.europa.eu/commission/presscorner/detail/en/ip_24_588.
[5] “Scientific Advice for the Determination of an EU-Wide 2040 Climate Target and a Greenhouse Gas Budget for 2030–2050,” June 14, 2023, https://climate-advisory-board.europa.eu/reports-and-publications/scientific-advice-for-the-determination-of-an-eu-wide-2040.
[6] “Adequacy Studies,” accessed February 23, 2024, https://www.elia.be/en/electricity-market-and-system/adequacy/adequacy-studies.
[7] In the Spoorvisie 2040, a goal for 2040 is formulated to increase the modal share of passenger transport from 8% to 15%, source: https://mobilit.belgium.be/sites/default/files/publicaties%20en%20statistieken/20220506_spoorvisie_2040_-_lange_versie_nl.pdf

- The largest reduction in annual CO_2 emissions occurs between 2020 and 2030, relying for more than one third on CCS.

A lower energy demand result in a lower dependency on CCS.

- Compared to a scenario without the systemic shift, the SHIFT scenario presents a decarbonization pathway which is 30% less dependent on CCS technology throughout the energy transition, reducing annual CCS volumes from 21 $MtonCO_2$ down to 13 $MtonCO_2$ in 2040.
- After further electrification of the energy system in 2050, all scenarios (except Clean Molecules) reduce their need for CCS down to approximately 8 Mton CO_2, remaining dependant on CCS to fully reach carbon neutrality.

Impact on the transition cost

Power system investment costs scale down proportionally with the final energy demand reduction.

- The SHIFT scenario reduces the size of the power system by 15 GW from 100 GW in the Central+16GW scenario.
- Between today and 2050, the SHIFT scenario can save more than **30 B€** in terms of investment and fixed operational costs for the power sector transformation compared to the Central and Central+16GW scenarios. Compared to the Central+SMR scenario, the SHIFT scenario can save 130 B€ by 2050.

Achieving climate targets incurs no extra energy system costs if demand can be reduced without comfort loss.

- In terms of total energy system costs, achieving climate targets incurs no additional cost if demand reduction can occur without compromising comfort. Negative costs occur mainly due to a reduced number of cars and reduced demand for energy services. Positive costs are mostly related to massive and rapid additional investments in rail infrastructure to realise a doubling of train use (costs covered in this analysis) and in other public infrastructure to more than double active transportation modes such as cycling (costs not covered).

Table 1: Scenario comparison overview

	Central			Central+SMR			Central+16GW			SHIFT		
Period	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Power system capacity GW												
Wind onshore	5	12	20	5	12	13	5	12	12	5	10	12
Wind offshore	3	8	8	5	8	7	8	19	24	8	16	17
PV	25	57	97	24	55	46	21	32	56	20	29	49
Hydrogen	0	1	8	0	0	0	0	0	4	0	0	4
Nuclear/SMR	2	0	0	2	0	14	2	0	0	2	0	0
Climate												
CO2 % reduction	-56%	-80%	-98%	-56%	-80%	-98%	-59%	-88%	-98%	-60%	-90%	-98%
Power system costs												
Power sector [B€ per 10 years]*	45	69	100	45	109	161	48	81	92	47	69	69

(*) Sum of investments and fixed operation and maintenance costs

1. Objective and context

Many scenarios exist which describe a pathway to a net-zero 2050 to limit global warming and comply with the EU Fit-For-55 regulations. These carbon neutral scenarios present major transformations of our energy system which require large investments in new clean energy generation and transport infrastructure. This study proposes an alternative Lower Energy Demand approach to tackle this transformation challenge.

This study aims to improve our understanding of the impact of changes in behavioural patterns and increased material efficiency on the Belgian energy system – on the condition that no personal comfort is sacrificed – to enable a faster and more feasible energy transition.

In this section, we give an explanation on the context of challenging climate goals as well as the need for Low Energy Demand scenarios.

1.1. Project scope

In this report, EnergyVille evaluates the effects of new *behavioural patterns* and increased *materials efficiency* on the Belgian energy system. Increasingly, research emphasizes the importance of sufficiency as a major transformation in the energy system, along with energy efficiency, electrification, and increased integration of renewable energy sources. Industries too must transform towards climate neutrality and circularity. The report primarily analyses the effects on the energy system resulting from shifts in mobility, housing and industry.

The first Low Energy Demand scenario on PATHS2050

Our original PATHS2050[8] scenarios and sensitivities assume a continuation of transportation growth, residential patterns and constant production levels of new materials. Our newest scenario is different and introduces societal behavioural changes and an industrial transformation, challenging the assumption of a status quo of our economy (remaining mainly linear by 2050) and of our ways of transportation. The quote *"the future cannot be predicted, but futures can be invented[9]"* suggests an active role of policymakers as well as innovators, companies, civil society, and end consumers/citizens in shaping the future. By including behavioural patterns and materials efficiency, the new SHIFT scenario complements our current palette of scenarios that are mostly based on energy technology solutions.

How the SHIFT scenario was created

SHIFT is a 'what-if' scenario to gain insights in the possible impact of 'societal behavioural changes and an industrial transformation' on the energy system. We assess the most cost-effective route to serve the energy services for society. The new model run is based on the existing 'Central+16GW' sensitivity of the PATHS2050 study, where we started from the Central scenario adding the option to invest in 16 GW additional offshore wind in the North Sea from 2030 onwards. The ranges of system shifts are selected from several studies that were screened by EnergyVille.

Research scope

This study focuses on the impact on the energy system resulting from decreased demand levels to provide input to the energy debate. Our study analyses the effect of a reduced need for new materials on the "input side" through the circular economy (circular product design, repair, reuse, remanufacturing, recycling…). The impact of system shifts on material demand levels is taken from external studies and is out of scope of this research. This report does not assess the energy use of recycling, the actual level of material use, or business models. At the same time, there is evidence that circular economy leads to a reduction of material and energy use[10]. Also, the role of new emerging industries is not assessed. Whether Belgian energy-intensive industries will be able to compete with other countries is an open question not addressed. Possible changes in comfort level, welfare, wellbeing and GDP are also outside of the scope of this project. The benefits of climate action – such as fewer natural disasters and a positive impact on air quality and health – were not quantified either.
Furthermore, it is to be noted that all numbers regarding costs in this study are expressed in constant €2019 values, in accordance with our other PATHS2050 results.

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[8] PATHS2050 | Energy Outlook https://perspective2050.energyville.be

[9] The full quote is *"The future cannot be predicted, but futures can be invented. It was man's ability to invent which has made human society what it is."* Quote from Dennis Gabor, inventor of holography and recipient of the 1971 Nobel Prize for Physics.

[10] Circular economy approaches could reduce energy use in economic activity by 6%–11%, source: Samuel J.G. Cooper, Jannik Giesekam, Geoffrey P. Hammond, Jonathan B. Norman, Anne Owen, John G. Rogers, Kate Scott, Thermodynamic insights and assessment of the 'circular economy', Journal of Cleaner Production, 2017, https://doi.org/10.1016/j.jclepro.2017.06.169

1.2. Climate Goal for 2040: a new milestone for the EU

In February 2024, the European Commission (EC) proposed legislative changes and compared potential climate goals for 2040, aligning with the target of achieving climate neutrality by 2050. The preferred trajectory suggests a 92% reduction in emissions by 2040 compared to 1990, following recommendations from the European Scientific Advisory Board on Climate Change. This option is deemed the most efficient route to climate neutrality by 2050, with higher net benefits, including avoided climate impact and air pollution, and only slight cost increases compared to less ambitious alternatives. Without adjustment to EU policy, the reduction is already 88% in 2040.

Sectors like industry, buildings, and transport are expected to contribute significantly to achieving these reductions. Emissions from energy use in industry, buildings and transport will each decrease by about 85% compared to 2015. The energy sector (electricity, fuel production, etc.) is projected to emit almost nothing by 2040, with extensive electrification and the rise of renewable energy sources. The share of renewable energy in total electricity generation rises from about 40% in 2021 to 87% in 2040, with wind and solar energy having the largest capacity. The use of innovative fuels, such as hydrogen and electrofuels, is anticipated to reach 20% in the transport sector by 2040, especially shipping and aviation. In buildings, these fuels would be almost unused.

The IPCC Special Report on 1.5℃[11] presents compelling evidence in support of the goal to limit global warming to below 2℃, with efforts to achieve a limit of 1.5℃ as outlined in the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). The report emphasises the critical importance of attaining global CO_2 emissions neutrality by 2050, which is a key objective of the Paris Agreement. This objective forms the core of the European Union's (EU) long-term strategy for climate neutrality, which proposes various pathways to facilitate the necessary economic and societal transformations for achieving carbon neutrality within the EU by 2050. The strategy places particular emphasis on the transition to a resource-efficient and circular economy as a prerequisite for achieving this goal.

1.3. Need for Low Energy Demand (LED) scenarios

By reducing energy demand and material use, we can minimize the exploitation of finite resources, lower emissions of greenhouse gases and other pollutants and improve security of supply. A system with a lower energy demand can be more resilient to external shocks, as it is less dependent on fluctuating energy prices or supply distortions. Furthermore, LED scenarios can support urban planning and infrastructure development, as a smaller energy system reduces the stress on energy transport infrastructure, particularly for a densely populated country as Belgium. System shifts can help address hard-to-abate sectors, where technological decarbonization solutions are limited. LED scenarios can also contribute to social equity and energy poverty by reducing the total system cost and consequently, making energy more affordable and accessible to a larger portion of the population.

The European Scientific Advisory Board on Climate Change states in its report[12] that pathways that reduce energy use reduce risks associated with the upscaling of supply-side options that have comparatively higher transition risks such as nuclear power, carbon capture, utilisation and storage (CCUS) and bioenergy. Furthermore, the recent EU-impact assessment[13] has provided a complementary LED scenario, called LIFE, which evaluates the possible impact of a shift in consumption patterns, leading to more sustainable lifestyles that include sustainable alternatives and more efficient use of natural resources. The LIFE scenario includes prolonged use of products, repairing broken products instead of replacing them, a sharing economy, products as a service, sustainable mobility patterns. Moreover, consumers gradually shift to healthier and more sustainable diets.

Several studies and practices underline that there are ways to organise our mobility, housing, economy in a different way, requiring less energy and materials. These shifts include actions which can be taken to reduce or eliminate unnecessary or wasteful energy and material consumption and natural resource use. The systemic shifts analysed in this research, are assumed to be made possible by policy and investments. According to the IEA, changes are more likely to happen at the level of individual citizens if governments bring about systemic changes related to mobility and consumer awareness through effective policy[14]. In other words, behavioural changes depend on more than the choices made by individual citizens or end-consumer, such as the availability of well-functioning public transport infrastructure or safe bicycle lanes.

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[11] "Global Warming of 1.5 oC —," accessed January 29, 2024, https://www.ipcc.ch/sr15/.

[12] "Scientific Advice for the Determination of an EU-Wide 2040 Climate Target and a Greenhouse Gas Budget for 2030–2050."

[13] "Recommendation for 2040 Emissions Reduction Target."

[14] "Behavioural Changes - Energy System," IEA, accessed January 5, 2024, https://www.iea.org/energy-system/energy-efficiency-and-demand/behavioural-changes.

1.4. SHIFT scenario scope

New transport systems

In the transport sector, the analysis includes the impact of modal shifts, both for passengers and freight, as well as the implications of trip sharing. Introducing new systems that facilitate shared vehicle use can enhance trip sharing and reduce the demand for vehicle kilometres. Active transportation, such as walking and biking, is considered in the sense that it replaces other, more energy demanding modes. We consider road, rail and water transport for passenger as well as freight transport. Emissions reduction from international aviation and navigation is excluded (as this was the case currently in PATHS2050).

The impact of behavioural changes on comfort levels is a nuanced topic and out of scope. Research diverges on whether these changes enhance or diminish individual comfort. Classical economic theory suggests that diminished demand for an energy service, characterized by a high willingness to pay (price inelastic), leads to a decrease in overall welfare. However, it's important to note that this assertion holds true only under the ceteris paribus condition (assuming all other factors remain constant), and this theory may fall short when applied to a completely new system.

Specifically on modal shift and trip sharing, reduced comfort could be linked to reduced flexibility, increased travelling time and personal comfort. On the other hand, potential benefits include improved health, enhanced travel quality, reduced traffic jams, reduced accidents and the avoidance of car maintenance responsibilities. To enhance the use of public and active transport , clean infrastructure, safe environments, and overall service provisions are crucial. To revolutionize our travel habits, it is essential to conceptualize and implement innovative systems that facilitate and encourage behavioural changes, while maintaining or enhancing comfort levels.

Optimizing living spaces for housing

The buildings sector in the model considers a distinction between residential and commercial buildings. The SHIFT scenario focuses on measures regarding space heating and building design such as optimized living spaces and a reduction of the setpoint temperature by one degree. No measures are included with regards to water heating, cooking, or other energy consuming activities in buildings.

Increased materials efficiency and circularity

The materials and chemicals produced by Belgian industries are essential inputs for key value chains, including transportation, infrastructure, construction, consumer goods, agriculture. These same materials will also be crucial for the energy transition itself which will be material intensive in the beginning period of the transition. All previous PATHS2050 scenarios assume an equal output in industry. The new scenario assumes a different future for industry, even though we still assume that the industry structure doesn't change. The new element from this study is the premise that we can optimize the utilization of existing materials, use technology innovation and a higher circularity, thereby diminishing the necessity for producing new materials. We focus on circularity which influences the required output of new materials, for example in the plastics, steel and cement sector, impacting the energy needs. Circularity driven shifts emerge in the industry sector as optimised product design, increased resource efficiency, reuse, and recycling. This is underpinned by the EU Circular Economy Action Plan (CEAP), that focuses on sectors with a high potential for circularity such as vehicles, packaging, plastics, construction and buildings. The impact of system shifts on material demand levels is taken from external studies.

2. PATHS2050 scenarios and modelling framework

2.1. The PATHS2050 platform and three original scenarios

EnergyVille investigated the most optimal way to achieve a climate-neutral Belgium by 2050, and this at the lowest cost. Is it at all possible for Belgium to become climate neutral by 2050? And, if so, will climate policy towards 2050 be affordable for our society? Our results were poured into a platform that allows for these results to be viewed at a glance, and this across different sectors – power, industry, transport, hydrogen and residential & commercial. For the platform, baptised **PATHS2050 – The Power of Perspective**[15], more than 200 EnergyVille researchers collaborated to plot data-driven roadmaps for different scenarios – each of them describing another possible route for our journey towards Belgian carbon neutrality by 2050.

The PATHS2050 platform is an open and living platform which is updated regularly with additional studies and sensitivities. The foundation of the tool is the TIMES-Be model, a model which calculates different net-zero emissions scenarios based on the evolution of technical and economic parameters, and searches for the most cost-effective solution to meet the demand for energy services from today, all the way up to 2050. The results and key conclusions from the new TIMES-Be scenario, developed in this study, are also made available on PATHS2050.

The PATHS2050 platform by Vito/EnergyVille went live end of 2022, presenting three long term scenarios constructed by Vito/EnergyVille which provide a perspective on the Belgian energy transition towards 2050: central, electrification and clean molecules. In all scenarios of the PATHS2050 study, it is assumed that Belgium's energy system will reach net zero emissions by 2050, driven by the cost of CO_2 emissions and climate targets, both at national and EU strategy[16] level. To reach carbon neutrality, the sectors can invest in energy efficiency measures like building renovation, more efficient vehicles, efficiency gains in space heating systems, and so on. Furthermore, new process technologies are modelled: fuel substitution, electrification, the use of synthetic molecules like hydrogen or for the industry and supply sector in 'carbon capture utilisation or storage'. Moreover, the model provides the option to deploy flexibility, such as electric vehicle charging or heat storage in water buffers, which allow the system to react to changing energy prices induced by an increasingly renewable and intermittent power system. When it comes to molecules, import of hydrogen or derivates from outside of Belgium (EU and non-EU) is possible, where the import costs are derived from international studies.

An overview for the three original scenarios presented on the platform is provided below:

The Central scenario envisions a balanced approach to achieving carbon neutrality in Belgium, incorporating various technological options for energy efficiency, fuel substitution, electrification, and carbon removal. Even though Belgium does not have its own storage locations for CO_2, it is assumed that Belgium will have unlimited access to the commercial phase of cross-border carbon storage in the North Sea and Norway. This balanced portfolio of technologies does not allow for investments in new nuclear capacity. Furthermore, the Belgian offshore potential is limited to the Belgian part of the North Sea.

The Electrification scenario creates a net-zero pathway while assuming more access to offshore wind (+16 GW in the North Sea on top of 8 GW of the territorial capacity, including an annual capacity growth limit of 1.5 GW) and the option to invest in new nuclear SMR (Small Modular Reactor) technology by 2045, resulting in a more rapidly electrified outlook.

The Clean Molecules scenario assumes a lower cost for import of synthetic molecules and more limited access to cross-border CO2 storage. These three different scenarios lead to different results for the use of hydrogen, electricity and CCS, for instance. For all three scenarios, the final energy demand decreases by a third while electricity demand more than doubles by 2050.

[15] "PATHS2050 | Energy Outlook."
[16] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

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2.2. Description of important sensitivity scenarios

Following this study, sensitivity results were published, providing insights on the challenges for a fast electrification and on the impact of choices and technology assumptions on costs.

2.2.1 Central+16GW scenario

The Central+16GW sensitivity scenario explores the consequences if we were to acquire additional access to large offshore wind zones in the North Sea as of 2030. This scenario investigates the impacts of adding 16GW of offshore wind power by 2050, on top of the 8 GW in Belgian territorial zone. It is equivalent to adding 800 MW of offshore capacity every year between 2030 and 2050. This setup can also be interpreted as a case in between the Central and the Electrification scenario, as it is also the same as the Electrification scenario but without access to new nuclear capacity. To clarify the dimension of the 16 GW assumption in this scenario, Figure 1 presents the increase in offshore wind capacity for the Central+16GW scenario compared to the Central scenario.

One of the key conclusions of this sensitivity is that additional access to offshore wind is particularly interesting as it is the most effective technology to bring down energy system costs through the replacement of SMR capacity and enable early electrification of demand sectors. This conclusion is in line with one of the key messages of the PATHS2050 study: *it is more* important to have clean electrons timely than to have the optimal mix.

For the availability factor of offshore wind far from the North Sea (i.e., Doggerbank), we used a capacity factor of 60%. For the investment cost assumption, we increased the cost of offshore wind with the cost of a 300 km HVDC cable connection and offshore convertors, amounting to an additional 950 million €/GW.

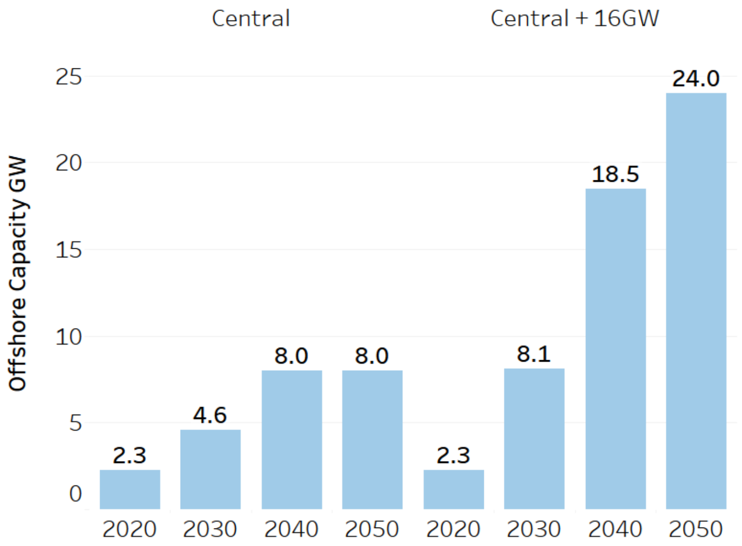

Figure 1: Offshore wind capacity in the Central (left) and Central+16GW scenario (right).
Note: recent publications indicate more ambitious targets to go to 6 GW offshore wind capacity by 2030.

Gradual additional access to 16GW of offshore wind power outside Belgian territorial waters.

An important element is the additional offshore wind to which Belgium could have direct access. We assumed that Belgium would have access to 16 GW of additional offshore potential outside of the Belgian territorial waters. A capacity of 16 GW is 10% of the 150-180 GW planned for in the **Esbjerg Offshore Wind Declaration**[17] of 19 May 2022, where Belgium, Germany, Denmark and the Netherlands signed an agreement to jointly build **at least 150 GW** of offshore wind capacity by 2050. The Netherlands recently increased their target to 70 GW by 2050, Germany to 50 GW and Denmark to 35 GW.

In April 2023, **the Ostend Declaration**[18] was signed by a North Sea coalition of nine countries. It pledges to transform the North Sea into the world's largest green energy power plant. Different from the Esbjerg declaration, also France, Ireland, Luxembourg, Norway and the United Kingdom joined this Ostend declaration. The ministers aim to accelerate the shift to renewable energy and achieve ambitious offshore wind targets of 120 GW by 2030 and **at least 300 GW by 2050**. They emphasize cross-border cooperation, infrastructure development, and support for an integrated offshore network plan, urging Transmission System Operators to collaborate on a meshed offshore grid for sustainable energy resilience in Europe. Within this context, Belgium and the Netherlands will research the feasibility of an additional offshore hybrid interconnector between both countries.

2.2.2 Central+SMR scenario

Research into new nuclear technologies focused on ‘Small Modular Reactors’ is ongoing, which leads to the developing of different types of reactors – with an average size of 300 Mwe – that comply with the EU Taxonomy requirements of ‘passive safety, minimization of long-lived waste and non-proliferation’.

Under the Central+SMR sensitivity, we allow investments in SMR technology to be operational from 2045 onwards (without access to additional offshore wind), that comply with the most stringent EU Taxonomy guidelines: advanced technologies with closed fuel cycle (“Generation IV”) to incentivise research and innovation into future technologies in terms of safety standards and minimising waste (with no sunset clause[19]). At this moment, different reactor concepts are under investigation. We did not differentiate between these different technologies, but we work with a synthesised plant being able to operate flexibly, with an investment cost of 7500 €/kW[19]. This overnight investment cost is taken from a vision document by Tractebel from 2020, for a large Gen III design such as the one in Hinkley Point in the UK. This number is assumed to include waste management steps and partial[20] risk insurance. More recently[21], it was announced that the cost estimations for the Hinkley Point have increased to at least 12500 €/kW.

One of the main conclusions from the sensitivity is that allowing access to SMR in scenarios increases the electricity demand and lowers electricity imports, similar to the Central+16GW scenario. These changes are caused by lower electricity prices and are also observed with increasing access to additional zones for offshore wind power. Furthermore, when no additional access to far offshore wind is available, the SMR technology has proven to bring down total energy system costs. But when additional access to far offshore wind does become available (Electrification scenario), the offshore wind potential is maxed out first before deploying SMR, reducing the total energy system cost even further.

Table 2 provides an overview of the 2050 power system capacities for the different sensitivities per technology, as these capacities are the main distinguishing elements that build up the different sensitivities. In particular, the far offshore wind and SMR capacities are the constraining assumptions which define the storylines, while the other technology capacities are an output of the model resulting from the constraints. For reference and completeness, the three main scenarios are provided in the table as well.

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[17] Andreas Tang, “The Esbjerg Offshore Wind Declaration,” WindEurope, May 19, 2022, https://windeurope.org/policy/joint-statements/the-esbjerg-offshore-wind-declaration/.
[18] admin, “EU Leaders Meet in Ostend to Agree Rapid Build-out of Offshore Wind in the North Seas,” WindEurope, April 24, 2023, https://windeurope.org/newsroom/press-releases/eu-leaders-meet-in-ostend-to-agree-rapid-build-out-of-offshore-wind-in-the-north-seas/.
[19] “Tractebel’s Vision on Small Modular Reactors,” accessed March 8, 2024, https://tractebel-engie.com/en/tractebel-s-vision-on-small-modular-reactors
[20] Nuclear risk liability is complex matter, however in all conventions, the liability is limited in amount and in time. Source: Cross-border nuclear safety, liability and cooperation in the European Union, 2019.
[21] “Hinkley Point C Update | EDF FR,” January 23, 2024, https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/hinkley-point-c-update-1

Table 2: PATHS2050 results for 2050 for the power sector in GW, highlighting the differences between scenarios and sensitivities.

GW	CENTRAL	CENTRAL+16GW	CENTRAL+SMR
Wind onshore	20	12	13
Wind offshore	8	8	7
Wind far offshore	0	16	0
PV	97	56	46
Hydrogen	8	4	0
SMR	0	0	14

2.3. PATHS2050 initial scenarios conclusions

End of 2022, EnergyVille compared different scenarios, including the Central scenario, the Central+16GW scenario and the Central+SMR scenario. Each of those scenarios has its own fundamental approach. What all scenarios do have in common, however, is the fact that we pushed our TIMES-Be model to reach net-zero carbon emissions in Belgium by 2050 for each of them.

Different scenarios can reach CO_2 neutrality

The Central Scenario envisions a balanced approach to achieving carbon neutrality in Belgium, incorporating various technological options for energy efficiency, fuel substitution, electrification, and carbon removal. The Electrification Scenario introduces increased access to offshore wind and the option to invest in new nuclear technology, focusing on adding 16GW of offshore wind power by 2030 and Small Modular Reactors by 2050. The Clean Molecules Scenario explores carbon neutrality with a focus on importing synthetic molecules at lower costs, emphasizing limited cross-border CO2 storage and reliance on offshore locations for storage. In the Central+16GW EnergyVille analysed the impacts of adding 16GW of offshore wind power by 2050, on top of the 8 GW in Belgian territorial zone. It is equivalent to adding 800 MW every year between 2030 and 2050.

Demand reduction and electrification in all scenarios

There are different roads leading to a climate neutral Belgium, but the window of opportunity to walk any of them is narrow. By 2030, in all scenarios -including sensitivities- solar PV capacity needs to increase by a factor 4 and wind onshore and offshore by a factor 2. In all sensitivities, there are 1,5 million residential homes and commercial buildings with heat pumps and 2 million electric cars on the Belgian roads by 2030.

While in 2020, fossil fuels still represent more than 70% of the final energy demand, by 2050, there is no more fossil fuel used except small quantities in some industries. Much of this fossil energy will be imported from nearby sources and in all scenarios, we will import far less energy than we do today.

On the supply side, low carbon electricity is the largest resource for the total energy system. It is important to have clean electrons timely. The most cost optimal net-zero emission scenario is a scenario with a very high level of electrification in which Belgium looks for renewable energy resources beyond its borders. Demand electrification can happen in time only if zero carbon electricity generation reaches 70 TWh by 2030 and 130 TWh by 2040. Starting from currently 22 TWh, electricity production from renewable resources must triple by 2030 and must increase sevenfold by 2040.

Total annual system costs

The total system cost reflects the total cost of transforming the Belgian energy system towards a net-zero solution by 2050. This includes annualised investment costs and all operational costs for the different technologies, but not taxes or subsidies as to present the most-cost efficient pathways from a system perspective or a technology point-of-view. All technologies are included in the system cost, including flexibility solutions required to have a large share of renewable energy. It is up to policy makers and governmental institutes to decide on the best pathway, guiding society towards a societal optimum, which does not necessarily coincide with the techno-economic one. Nevertheless, these scenarios provide valuable insights to support policy makers and long-term investment decisions in sculpting our future energy landscape.

Figure 2 illustrates the total system cost of the Central scenario as well as the two sensitivity scenarios presented on the PATHS2050 platform. From this graph, it becomes clear that access to new SMR nuclear capacity by 2050 can slightly reduce the total system cost. This graph also underlines the much larger cost reduction which could be achieved when access to far offshore wind becomes available. Access to additional offshore wind is the most important factor to lower the energy system cost because it can enable early electrification of demand sectors. In doing so, around 19 GW of offshore is active by 2040 (8 GW in Belgian waters + around 11 GW additional). Based on our assumptions, and taking into account the full technical lifetime, new small modular nuclear power plants (SMR) and offshore wind have a comparable electricity cost however SMR comes too late for guaranteeing a smooth transition in the demand sectors.

For the availability factor of offshore wind far from the North Sea (i.e., Doggerbank), we used a capacity factor of 60%. For the investment cost assumption, we increased the cost of offshore wind with the cost of a 300 km HVDC cable connection and offshore convertors, amounting to an additional 950 million €/GW.

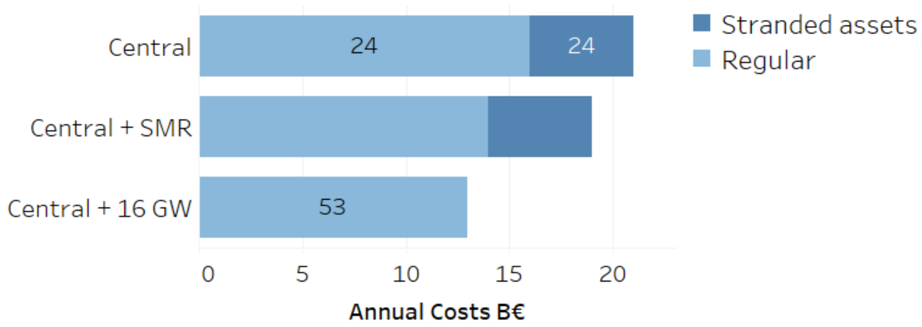

Figure 2: Total annual system cost comparison in billion euros.
Note: more information on stranded assets is on the PATHS2050 website

In the upcoming sections, we define the SHIFT scenario and the assumptions behind and delve into its implications on the energy mix. The SHIFT scenario incorporates a reduced energy demand, leading to an inherently lower total system cost compared to all other scenarios considered in this report.

2.4. The TIMES BE modelling framework

TIMES, as defined on its website[22], is a modelling framework used to model energy systems varying the spatial and temporal resolution (e.g.: regions, countries, hours, seasons, years) which allows the development of both top-down and bottom-up models. The TIMES model is developed as part of the IEA-ETSAP's methodology for energy scenarios to conduct in-depth energy and environmental analyses (Loulou et al., 2004), (Loulou et al., 2005).

TIMES is able to represent the full value chain from the import or mining of energy and material resources up to meeting final demands, either energy or products (e.g.: ammonia, glass, space heating, lighting). The modelling framework uses what is called commodities to represent the flow of energy carriers and materials between processes. These processes can represent transformation processes such as energy transformation processes such as electricity production, coke ovens, transmission and distribution equipment, biofuels production; or final energy-consuming processes such as vehicles, industrial processes, light bulbs, refrigerators, boilers, air-cooling, etc.

[22] https://iea-etsap.org/index.php/etsap-tools/model-generators/times

The processes, commodities and commodities flows are used to build be the mathematical representation of the energy system, the Linear Program (LP), which is then needed to optimize. The optimization includes the constraints defined by physics such as the balance between electricity demand and electricity generation in each period, as well as user-defined constraints such as the maximum capacity of certain technologies, annual growth and emissions targets.

Finally, the results of the model, and the defined scenarios, provide detailed information such as installed capacity, energy and material flows, marginal production cost, CO_2 emissions, investments and O&M cost needed to meet the different demands in a cost-optimal manner. The TIMES-BE model has been developed by VITO - EnergyVille for several years, incorporating insights and good practices from the international TIMES–ETSAP modelling community.

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3. SHIFT scenario definition

This chapter discusses the scenario definitions and assumptions behind the PATHS2050 scenarios and the newly developed scenario 'SHIFT'. Section 3.1 explains the general assumptions within the TIMES-BE model which are present in all scenarios. Section 3.2 introduces the SHIFT scenario. Section 3.3 continues with an outline of the demand evolution for different scenarios (Central and SHIFT) and sectors (transport, buildings, industry) representing exogenous inputs to the TIMES-BE model. Section 3.4 complements this analysis with a benchmarking of the selected demand reductions based on different studies.

3.1. Net-zero pathway general assumptions

The following list summarizes the main assumptions used in the TIMES-BE model.

- All scenarios are designed to reach **net zero CO_2 emissions of the Belgian energy system in 2050**. In addition, there is a CO_2 price increasing from today's levels to 350EUR/ton CO_2 in 2050. This value is in line with fit-for-55 European modelling exercises. The CO_2 price is necessary, as otherwise the model only invests in climate-friendly technologies at the end of the energy transition.

- **Population growth** is driving a slight increase in energy demand in the transport sector as well as an increase in housing need, renovation is modelled as an option in the model (residential and commercial sectors), which will cause a net decrease in heating demand in buildings.

- In all scenarios, the lifetime of 2 GW of existing nuclear capacity (Doel 4 and Tihange 3) is extended by 10 years from 2025 until 2035[23-24]. It was assumed that the investments in nuclear lifetime extension are completed by 2025.

- Renewables take an important role in the power sector as demand for electrification is expected to increase. In this context, **Belgium can invest in renewables up to its technical potential (see Table 3).** For offshore wind and district heating, the renewable potentials increase gradually due to the need for grid infrastructure development, while for onshore wind and PV, the grid infrastructure is assumed not to be a bottleneck.

- **Power interconnection capacity increases from 6.5 GW in 2020 to 13 GW by 2040**, in line with the Ten-Year Network Development Plan (TYNDP) scenarios by ENTSO-e. The transmission capacity increase is included as an exogenous assumption for all scenarios without a cost allocation.

- **International shipping and aviation are not included in the results**. Also, non-CO_2 emissions, such as methane and N_2O in the agriculture sector, are not included.

- Electricity distribution grid upgrade costs are taken into account in a rudimentary way. Transmission grid extensions within Belgium are not included, however the transmission costs for additional offshore wind from outside the North Sea are taken into account at 950 million €/GW, on top of the investment cost of the windmills.

- The **hydrogen infrastructure costs** are taken based on the definition of the **Hydrogen Backbone for Belgium**[25] and a given investment cost, while for the distribution level, a tariff approach was defined. For CO_2 grid costs, these were taken into account via an estimation of shipping from the main ports (Antwerp and Ghent), and a transport tariff. In this way, the last-mile delivery cost of CCS is taken into account for sites not in proximity to the backbone.

- For the availability factor of **offshore wind far from the North Sea** (i.e., Doggerbank), we used a capacity factor of 60%. For the investment cost assumption, we increased the cost of offshore wind with the cost of a 300 km HVDC cable connection and offshore convertors, amounting to an additional 950 million €/GW.

TIMES discounts all costs of the energy system to a user-selected year. Additionally, the model uses the discount rate to calculate the annualized payment of the investment cost of each process. TIMES offers the possibility to define different discount rates for each process, or sector (e.g.: industry, residential). TIMES-BE works with a discount rate of 3%. Additionally, there is the alternative to use sector-specific rates. Nonetheless, in this exercise, and aligned with analysis on discount rates in energy system

[23] https://www.premier.be/fr/declaration-du-premier-ministre-et-de-la-ministre-de-l-energie
[24] https://www.belgium.be/sites/default/files/Accord_de_gouvernement_2020.pdf
[25] European Hydrogen Backbone, EHB, 2020. https://ehb.eu/files/downloads/2020_European-Hydrogen-Backbone_Report.pdf

studies[26], a discount rate of 3% over all sectors is chosen for consistency reasons, avoiding the individual investor perspective and opting for a more social or macro-economic one.

BE-TIMES considers only the underlying techno-economic costs of the system and does not take into account taxes, subsidies etc. For instance, the costs of electricity and distribution grids are taken into account, but non-technical costs such as green certificates, and social tariffs are not. This is an explicit choice made in the model, as this allows a view of the energy system which is unbiased by politically inspired taxes and subsidies.

Table 3: Maximum availability of selected resources in TIMES-BE.

COMMODITY	UNIT	2020	2025	2030	2035	2040	2045	2050	SOURCE
Biomass	TWh	13.89	13.89	13.89	13.89	13.89	13.89	13.89	Eurostat average
Municipal Solid Waste	TWh	3.67	3.67	3.67	3.67	3.67	3.67	3.67	Eurostat average
District Heating	TWh	1.21	5.20	9.20	13.54	17.87	20.89	23.91	EnergyVille own assumption
Rooftop PV	GW	104.1	104.1	104.1	104.1	104.1	104.1	104.1	BREGILAB study by EnergyVille[27]
Onshore wind	GW	20.0	20.0	20.0	20.0	20.0	20.0	20.0	BREGILAB study by EnergyVille
Territorial offshore wind	GW	2.26	2.26	4.60[28]	4.60[28]	8.00	8.00	8.00	Belgian offshore platform[29] – Maximum potential in the Belgian part of the North Sea
Extraterritorial offshore wind allocated to Belgium (North Sea)	GW			3.50 (120)	7.00	10.50	14.00	16.00 (300)	*Ostend declaration[30] - Maximum potential combined for 9 countries: Belgium, Denmark, Germany, France, Ireland, Luxembourg, the Netherlands,* *Norway and the UK*

[26] Steinbach J, Staniaszek D. Discount rates in energy system analysis Discussion Paper. https://www.bpie.eu/wp-content/uploads/2015/10/Discount_rates_in_energy_system-discussion_paper_2015_ISI_BPIE.pdf
[27] Expliciet, "BREGILAB-project stelt technisch potentieel wind en zon binnen België beschikbaar," EnergyVille, December 5, 2022, https://energyville.be/blogs/bregilab-project-stelt-technisch-potentieel-wind-en-zon-binnen-belgie-beschikbaar/.
[28] Recent publications indicate higher ambitions of 5.7 GW by 2030.
[29] https://www.belgianoffshoreplatform.be/en/
[30] admin, "EU Leaders Meet in Ostend to Agree Rapid Build-out of Offshore Wind in the North Seas."

3.2. Introducing the SHIFT scenario

In this report, we present the newly developed SHIFT scenario as an alternative net-zero pathway towards 2050 under new Low Energy Demand (LED) assumptions, induced by system shifts. These shifts include actions which can be taken to reduce or eliminate unnecessary or wasteful energy and material consumption and natural resource use. The SHIFT Scenario is defined a LED variant of the Central+16GW scenario. The scenario fixes imports of electrons and molecules to the quantities achieved by the Central+16GW scenario and imposes a systemic shift which lowers the final energy demand. Due to the lower energy demand, a new optimal power mix equilibrium can be found by balancing the offshore wind capacity with solar and onshore wind capacity. Therefore, the far offshore wind capacity in this scenario is constrained to 9 GW additional to the existing maximum of 8 GW territorial offshore wind. The 9 GW of extraterritorial offshore wind is well within the limits of the total technical potential of 300 GW by 2050 in total for the nine countries of the North Sea coalition who signed the Ostend declaration.

The proposed system shifts in this scenario refer to three different sectors: the transport sector, the buildings (residential and commercial) sector and the industry sector. For the transport sector, a modal shift towards more sustainable transport options is included as well as increased trip sharing. In the buildings sector, the smaller housing trend is taken into account in the space heating demand and a lowering of the setpoint temperature by one degree is included. Lastly, the production output of new materials in the industry sector is lowered by allowing for a more circular economy, reducing the need for new materials such as virgin steel, aluminium, cement and plastics. The aspect of circularity covers recycling, reuse and circular building as well as circular product design, leading to reduced packaging and reduced single-use products, minimising waste and maximising resource efficiency. The measures and their corresponding assumptions on demand are described in more detail in chapter 3.

This leads to a resource-efficient scenario, driven by centrally organized systemic shifts which results in smarter societal energy decisions leading to a more circular economy and more sustainable lifestyles resulting in a lower final energy demand. This scenario partially relieves the pressure on energy infrastructure development that comes with the upscaling of the supply-side, by proposing a more feasible solution resulting from a down-scaling of the demand-side.

3.3. Demand trajectories in the initial scenarios

The evolution of the demand is exogenous input to the TIMES model, which means that substantiated and reasonable assumptions are required to construct the scenarios. The future energy landscape will be driven by changes in final energy demand and consumption patterns across all sectors (i.e.: industry, residential, transport). Therefore, demand projections are a crucial input for any energy system model. Before outlining the assumption used in the SHIFT scenario, we first analyse the assumptions regarding demand in the existing PATHS2050 scenarios. Note that all demand assumptions in the Central scenario are identical in all other PATHS2050 scenarios and sensitivities.

General trends in the reference scenario

This section presents a list of PATHS2050 scenario trends covering behavioural and circularity aspects influencing energy demand within the energy system. TIMES-BE differentiates between service demands (i.e.: space heating, passenger transportation), product output (i.e.: steel, ammonia, bricks) and energy demands (i.e.: annual energy consumption in PJ or TWh). The original PATHS2050 scenarios and sensitivities are referred to as the 'reference' scenario in the remainder of this chapter.

Main assumptions used for future sector demands:

- **Industry:** In 2050, the throughput of products is assumed to have the same level as in 2020. Already planned new investments, such as the investments in the blast furnaces in Arcelor Mittal, are taken into account.

- **Transport:** Annual demand of passenger-km, tonne-km, and energy demand are taken from the results of the TREMOVE model developed by Transport and Mobility Leuven (TML)[31].

- **Residential:** Final energy services demand is driven by population growth according to the Federal Planning Bureau. The population is assumed to increase from 11.5 million in 2020 to 12.4 million by 2050 [32].

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[31] Projections done within the Energy Transition Found project EPOC. https://www.tmleuven.be/en/navigation/TREMOVE
[32] Demografische vooruitzichten 2020-2070, Federal Planning Bureau, 2021. (pg.3) https://www.plan.be/uploaded/documents/202103310840330.FOR_POP2070_12389_N.pdf

- **Commercial:** Final energy services demand is driven by economic growth projections according to the Federal Planning Bureau[33].
- **Agriculture:** Energy demand is assumed to remain at the same level as today. Agriculture energy consumption, although with yearly variations, has been rather stable during the last 20 years. Greenhouse gas emissions from non-CO_2 sources (methane, N_2O) are not considered.
- **Transformation:** The transformation sector, which includes refineries and the power sector, reflects the changes in demand sectors. Nonetheless, as Belgium exports a large volume of petroleum products, refineries are set to follow the downward trend in crude intake expected by CONCAWE as a low boundary of their activity[34].

3.4. Demand trajectories in the SHIFT scenario

The difference in the assumptions of the demand trajectories is the main driver for the SHIFT scenario differentiating itself from the other PATHS2050 scenarios and sensitivities. Aside from the general trends which are present in all scenarios, the evolution of the demand in the SHIFT scenario is superposed with drivers which represent the systemic and behavioural shifts. The remainder of this section therefore quantifies these additional drivers that are used to define the SHIFT scenario. We broadly cover aspects that remain unchanged, gradual development trends, and aspects that imply a more fundamental behavioural shift.

The different measures and their impacts on the final energy demand are presented in the following tables. The demand levels in the original PATHS2050 scenarios and sensitivities are referred to as the 'reference' scenario in the tables. The ranges of system shifts are selected from several studies that were screened by EnergyVille.

3.4.1 Transport trends

summarizes the demand evolution assumptions for passenger transport for the Central scenario as well as the new SHIFT scenario. These values are reflected in Figure 3 which presents the evolution of the demand trajectories. All trajectory multiplicators are provided relative to the 2015 demand values.

For passenger cars, for instance, a total reduction of 21% of passenger kilometres compared to 2015 is assumed in the SHIFT scenario with an overall reduction of vehicle kilometres of 48%. This number is a combination of multiple effects. The first influencing factor is a general growth of 7% in passenger kilometres, as proposed by the Climact/Vito study. Whereas the reference scenario assumes a general growth of 14%. Furthermore, the systemic shift leads to an increase of the modal share of public and active transport, whilst decreasing the modal share of cars, as well as an increase in trip sharing. Similar measures are implemented for the rail and bus demand, where a general societal increase in travelled kilometres is combined with a shift in modal shares. Combining these effects results in more than doubling of rail passenger transport and active transport, a 39% increase of passenger travel by bus and a reduction of 48% in car kilometres. Rail infrastructure is included in the model with a fixed annual operation cost that is proportional to the passenger kilometer and freight demand.

[33] Economische vooruitzichten 2021-2026 (Table 7), , Federal Planning Bureau, 2021. https://www.plan.be/uploaded/documents/202102260904210.Rapport_feb2021_12364_N.pdf

[34] A demand reduction of all refinery products of 43% compared with 2014 levels from Refinery 2050: Conceptual Assessment (Table3.3-2), CONCAWE, 2019. https://www.concawe.eu/wp-content/uploads/Rpt_19-9-1.pdf

Table 4: Demand evolution in transport sector for passenger travel for reference and SHIFT scenario and subsector. (2050 evolution compared to 2015) SHIFT evolution by 2050 taken from Climact/Vito CORE-95 scenario.

MEASURE	REFERENCE	SHIFT	DESCRIPTION	SOURCE FOR SHIFT
Evolution passenger travel (2015-2050)	+16%	+7%	A 7% growth for the total passenger km, combining population growth and a 6% reduction of km/capita	Climact/Vito Core-95 scenario
Modal share cars in 2050	71%	55%	55% modal share in 2050 for cars	Climact/Vito Core-95 scenario
Trip sharing (person per car) in 2050	1.5	2.3	The average number of people in a car increases to 2.3	Climact/Vito Core-95 scenario
Car (vehicle km)	+14%	-48%	Combined impact of all measures above	
Car (Pkm)	**+14%**	**-21%**	**Combined impact of evolution Pkm and modal share**	
Evolution passenger travel (2015-2050)	+16%	+7%	idem	Climact/Vito Core-95 scenario
Modal share in 2050	7%	16%	16% modal share in 2050 for passenger trains	Climact/Vito Core-95 scenario
Rail (Pkm)	**+14%**	**+114%**	**Combined impact**	
Evolution passenger travel (2015-2050)	+16%	+7%	Idem	Climact/Vito Core-95 scenario
Modal share in 2050	11%	13%	13% modal share in 2050 for busses	Climact/Vito Core-95 scenario
Bus (Pkm)	**+12%**	**+39%**	**Combined impact**	
Evolution passenger travel (2015-2050)	+16%	+7%	Idem	Climact/Vito Core-95 scenario
Modal share in 2050	9%	16%	16% modal share in 2050 using the bicycle or walking	Climact/Vito Core-95 scenario
Active (bicycle and walk, Pkm)*	/	**+145%**	**Combined impact**	

Different measures are implemented for freight transport in the SHIFT scenario. A general increase in transported tonnes of freight of 10% is assumed for all transportation modes, as suggested by the Climact/Vito Core-95 scenario (see Figure 17 in the Climact/VITO report). Moreover, a modal shift reduces the share of trucks down from 64% in the reference scenario to 54% in the SHIFT scenario by 2050. A 12.5% loading efficiency increase of trucks allows for more tonnes to be transported per vehicle, reducing the required kilometres per tonne of freight. This optimization and reorganization of freight transport leads to a combined impact of 29% reduction in vehicle kilometres.

For inland water navigation, the general increase of 10% is combined with a modal share of 28% by 20250, resulting in a combined impact of a 93% increase in demand in 2050. This is a much larger increase in demand compared to the reference scenario, which estimate an increase of 35% for inland navigation. For rail freight, the existing assumption in the reference scenario, based on a dataset obtained from TML[35] (Transport Mobility Leuven), is used in the SHIFT scenario as well: a demand increase of 84% by 2050 compared to 2015 values. These numbers indicate that the reference scenario is assumed to already be relatively ambitious regarding rail freight transport, while the SHIFT scenario assumes even greater ambitions to partially replace trucks with more efficient inland navigation transport. This trend is reflected clearly on the left side of Figure 3 which shows a diverging evolution between the truck and inland navigation curves, while both curves were running in parallel in the reference scenario.

Table 5: Demand reductions in transport sector for freight for reference and SHIFT scenario and subsector. (2050 evolution compared to 2015)
SHIFT evolution by 2050 taken from Climact/Vito CORE-95 scenario[36].

MEASURE	REFERENCE	SHIFT	DESCRIPTION	SOURCE FOR SHIFT
Evolution Tonne kilometers	+39%	+10%	A 10% growth for the total tonne km	Climact/Vito Core-95 scenario
Modal share in 2050	64%	54%	54% modal share in 2050 for trucks	Climact/Vito Core-95 scenario
Load factor vans and trucks (tkm/vkm)	0%	+12.5%	A 12.5% increase of the load in vans and trucks (tkm/vkm)	Climact/Vito Core-95 scenario
Truck (vehicle km)	+29%	-29%	Combined impact of all measures above	
Truck (Tkm)	**+29%**	**-19%**	**Combined impact of evolution total Tkm and modal share**	
Evolution Tonne kilometers	+39%	+10%	Idem	Climact/Vito Core-95 scenario
Modal share in 2050	22%	18%	18% modal share in 2050 for freight trains	Climact/Vito Core-95 scenario
Rail (Tkm)	**+84%**	**+84%**	**Combined impact**	
Evolution Tonne kilometers	+39%	+10%	Idem	Climact/Vito Core-95 scenario
Modal share in 2050	14%	28%	28% modal share in 2050 for inland waters	Climact/Vito Core-95 scenario
Inland water (Tkm)	**+35%**	**+93%**	**Combined impact**	

[35] "Transport & Mobility Leuven," accessed February 23, 2024, https://www.tmleuven.be/en/.
[36] See Figure 19 in https://climat.be/doc/climate-neutral-belgium-by-2050-report.pdf

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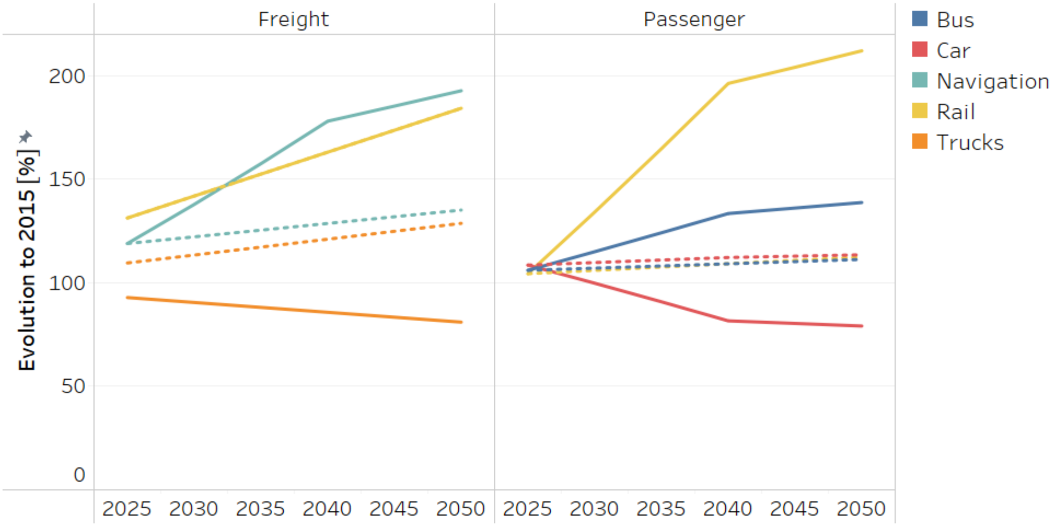

Figure 3: Evolution of freight and passenger transport demand for reference (dotted) and SHIFT (solid) scenario. Note trajectory for freight – rail overlaps for both scenarios.

3.4.2 Building trends

The building sector covers both residential and commercial buildings, as illustrated in Figure 4 which shows the evolution of the final energy demand for space heating in buildings compared to 2015 values. The TIMES-Be model implements a general growth in heating demand residential (19%) and commercial (14%) buildings due to population and economic growth respectively. These factors are transferred to the SHIFT scenario and combined with two extra assumptions.

The first assumption is optimized heating and cooling temperature settings, by lowering the setpoint temperature in our housing by one degree. EnergyVille data point out that this results in a 7% reduction in the final energy demand for heating[37]. The second measure is to further optimize living spaces which is an emerging trend as of today already[38]. This refers to a reorganization of living spaces to optimize the use of surface area and reduce redundant areas to lower the required heated surface area per capita. As prices of building land become more and more expensive, the compact living trend turns this difficulty into an opportunity to live in more compact, but also higher quality buildings which are better suited for each stage of life. The two measures are implemented in both building types, resulting in a final demand reduction of 7% for residential housing and 11% for commercial buildings. The speed of implementation of these measures is illustrated in the trajectories in Figure 4. The first measure of lowering the setpoint temperature is implemented from 2025 onwards, as this measure does not require a break-in time. The second measure is implemented more gradually as optimizing living spaces takes more time to realize.

Table 6: Demand evolution for space heating in the buildings sector for reference and SHIFT scenario. (2050 evolution compared to 2015)

MEASURE	REFERENCE	SHIFT	DESCRIPTION	SOURCE FOR SHIFT
Population growth	+19%	+19%	19% population growth assumption	Population growth driven according to the Federal Planning Bureau database “Energy Outlook for Belgium towards 2050”[39]
Optimised living spaces	**0%**	**-16%**	16% reduction of living space per person (m2/capita)	Climact/Vito

[37] EnergyVille calculations for De Standaard, as an average for different building types, https://energyville.be/blogs/energyville-berekent-voor-de-standaard-hoe-u-honderden-euros-op-energie-kunt-besparen-zonder-kou-te-lijden/
[38] “Iedereen wint bij kleiner wonen,” De Tijd, March 26, 2018, https://www.tijd.be/partnercontent/vastgoed/nieuwbouw-en-reconversie/iedereen-wint-bij-kleiner-wonen/9995829.html.
[39] “Federal Planning Bureau - Databases - Energy Outlook for Belgium towards 2050 (October 2017 Edition) - Statistical Annex,” accessed February 13, 2024, https://www.plan.be/databases/data-36-en-energy_outlook_for_belgium_towards_2050_october_2017_edition_statistical_annex.

				CORE-95 scenario[40]
Minus one degree setpoint	0%	-7%	Setpoint temperature lowered by 1 degree, impacting the average temperature in the building.	EnergyVille data
Residential space heating	**+ 19%**	**-7%**	**Combined impact of measures**	
Optimised work spaces	0%	-16%	16% reduction of work space per person (m2/capita)	Same as for residential space heating
Activity level	+14%	+14%	14% activity increase assumption	Data from study by Federal Planning Bureau "Towards 100% renewable energy in Belgium by 2050"[41]
Minus one degree setpoint	0%	-7%	Setpoint temperature lowered by 1 degree, impacting the average temperature in the building. The reduction percentage is obtained from EnergyVille data.	EnergyVille data
Commercial space heating	**+14%**	**-11%**	**Combined impact of measures**	

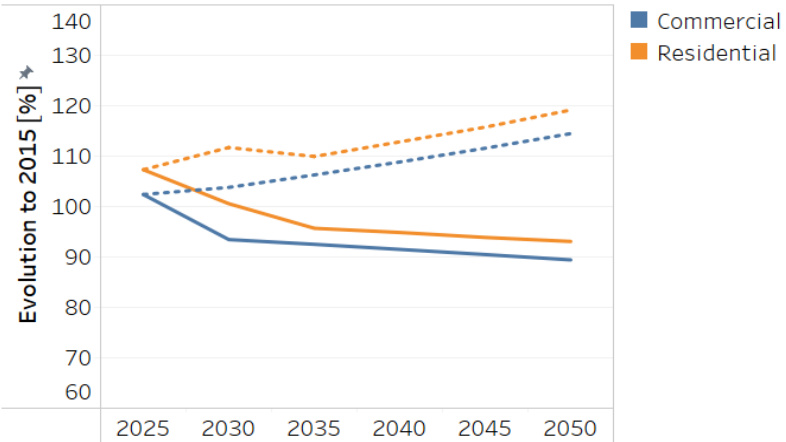

Figure 4: Demand evolution of space heating in buildings for reference scenario (dotted) vs SHIFT scenario (solid).

3.4.3 Industry trends

Figure 5 and Table 7 present the evolution of the demand in the industry sector for the Central and SHIFT scenario. In the Central scenario, we assume that industrial activity in Belgium will stay mostly constant in the coming decades, with only some changes due to planned investments. This, in other words, means that the current production of materials such as steel, plastics, ammonia or cement is considered to have similar levels by 2050.

The SHIFT scenario, however, challenges this perspective by evaluating the possibility of a more resource-efficient and circular economy, leading to a lower need for primary production of materials. Moreover, improved design of product can lead to less

[40] See Table 1 in Appendix 1 in https://climat.be/doc/climate-neutral-belgium-by-2050-report.pdf
[41] "Federaal Planbureau - Publicatie - Towards 100% renewable energy in Belgium by 2050," accessed February 13, 2024, https://www.plan.be/publications/publication-1191-nl-towards_100_renewable_energy_in_belgium_by_2050.

material needs or to higher quality product with a prolonged lifetime which can be repaired more easily or assure better recyclability of the product at its end-of-life. To this end, the BBL/Climact study[42] and the Material Economics[43] study are used as a reference for the demand reductions in the different subsectors. Optimisation of concrete recipes, reduced waste, reconstruction and re-use instead of demolition and optimisation of concrete elements all lead to a demand reduction of 39% for new virgin cement production, as proposed by the Material Economics study[44]. Optimised product design, resource efficiency, reuse and recycling lead to a 10% reduction in demand for virgin iron and steel production. For ammonia, a reduction potential of at least 15% is possible and 18% for the production of virgin high value chemicals (HVC), due to increased recycling of plastics and a reduction in demand. Furthermore, oil refineries are assumed to phase out completely by 2050 in the SHIFT scenario while a 43% reduction was implemented in the Central scenario. Figure 5 shows the resulting trajectories of the demand reduction. The largest share of the reduction efforts is performed early on in the transition as 90% of the reduction is achieved by 2040 already, aligning with the recent EU-impact assessment[45] recommendation of a 90% emission reduction target by 2040.

Table 7: Product output evolution in industry for reference and SHIFT scenario. (2050 evolution compared to 2015)

MEASURE	REFERENCE	SHIFT	SOURCE FOR SHIFT
Cement production	0%	-39%	Material Economics, Circular Economy scenario
Ceramics	0%	-33%	BBL/Climact
Steel production (total)	0%	-10%	BBL/Climact
Ammonia production	0%	-15%	BBL/Climact
HVC production	0%	-18%	BBL/Climact: combination of -13% demand reduction and +22% recycling rate[46]
Non-ferrous	0%	-11%	BBL/Climact
Oil refineries	-43%	-100%	BBL/Climact

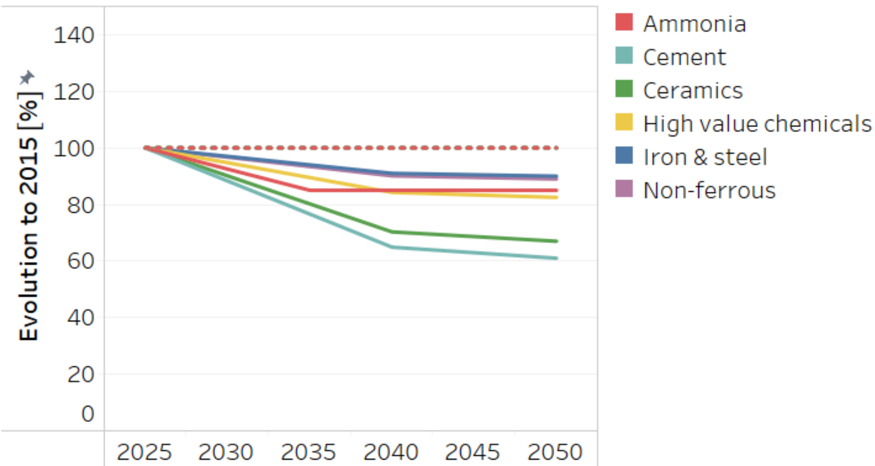

Figure 5: Industry product output evolution for reference (dotted) and SHIFT (solid) scenario reflecting a more resource-efficient and circular economy.

[42] https://www.bondbeterleefmilieu.be/artikel/bbl-berekent-zo-wordt-vlaamse-industrie-sneller-klimaatneutraal
[43] "Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry - Material Economics," accessed February 13, 2024, https://materialeconomics.com/s//s/s.com/s/s.com///s//s/s.com/s/s.com/s//s/s.com/s/s.com/s//s/s.com/s/s.com/latest-updates/industrial-transformation-2050.
[44] "Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry - Material Economics."
[45] "Recommendation for 2040 Emissions Reduction Target."
[46] "Exploratory Study on Chemical Recycling. Update 2019," CE Delft - EN, accessed February 13, 2024, https://cedelft.eu/publications/exploratory-study-on-chemical-recycling-update-2019/.

3.5. Benchmarking of demand assumptions

In this section, we provide a benchmarking of the selected demand reductions based on different studies including but not limited to, the sources used for the SHIFT scenario assumptions. The emphasis lies on the so-called Low Energy Demand (LED) scenario studies that explore the potential for energy demand reduction through changes in behaviour and increasing end-use efficiency. These studies show how sectors and their end use energy service demands can be influenced by system shifts and circularity, and which plausible assumptions could underpin these trends. From a broader literature review, six main studies were selected to provide a benchmarking of the different assumptions in the SHIFT scenario. The six studies are shortly described below.and the benchmarking of assumptions is provided in Annex 1.

BBL/Climact 2021 - A green industrial revolution

This study[47] on decarbonizing the Flemish industry was executed by the independent study bureau Climact, assigned by Bond Beter Leefmilieu (BBL). The study follows up on a previous study[48] performed by the Vlaamse Agentschap Innoveren & Ondernemen (Vlaio) in 2020 which presents different scenarios tackling the challenges of decarbonizing the Flemish industry. None of these scenarios, however, reach carbon neutrality by 2050 and they present high levels of carbon capture and less electrification solutions.

BBL/Climact therefore proposed a new set of scenarios that include a strong manufacturing industry combined with a growing circular economy and material efficiency, increased electrification trends and circular technologies, a weaker dependency on carbon capture and biomass and a phase out of oil refineries by 2040. For comparability, this second study uses the same energy system model as the one used in the initial Vlaio study. The BBL/Climact scenario reaches an emission reduction of 95.2% by 2050, comparing to 2005, which is a larger reduction than the Vlaio scenario which presented a reduction of 86%. The BBL scenario lowers the final energy demand with 48% by combining new technology options with measures on the demand side, such as an increased circular economy. Moreover, carbon capture quantities were lower from 12 Mton to 2.5 Mton. The BBL/Climact study presents measures impacting the final energy demand in industry. This study is therefore selected as a main source in this study for the industry sector assumptions, providing production output reduction percentages by 2050 compared to 2020.

Climact/Vito 2021 – Scenarios for a climate neutral Belgium by 2050

The second study, a collaboration between Climact and Vito, presents the scenarios from the 2050 Pathways Explorer[49]. The study is a follow-up on the 2013 'Scenarios for a low carbon Belgium by 2050' published by the Climate Change Service of the federal administration. The scenarios have been developed using a model that combines energy, land, materials, product and food systems. The model provides a bottom-up, driver and lever-based approach to address system dynamics and non-linear behaviour.

Climact/Vito presents a REFERENCE scenario (business-as-usual) and two alternative scenarios (BEHAVIOUR and TECHNOLOGY) to evaluate technological and behavioural aspects in the energy transition. The BEHAVIOUR scenario includes shifts in mobility, housing and dietary patterns, while the TECHNOLOGY scenario relies more heavily on technological developments. By balancing both behavioural and technological approaches, the CORE-95 scenario is defined. The CORE-95 scenario is a further development on the CORE-80 scenario which was included in the 2013 study. This new scenario aims to realize a 95% emission reduction by 2050 compared to 1990. The CORE-95 scenario was selected as a main data source for the systemic shifts this study for transport and buildings, as it is most in line with the essence behind the SHIFT scenario and proposes a less extreme perspective than the other Climact/Vito scenarios.

CLEVER – Climate neutrality, energy security and sustainability

The CLEVER study[50] (a Collaborative Low Energy Vision for the European Region) proposes an ambitious decarbonisation pathway for Europe through a bottom-up modelling approach. The CLEVER scenario focusses on evaluating the potential of energy demand reduction (sufficiency and efficiency) and renewables to reach carbon neutrality within Europe by 2050. Assumptions are made explicit on the level of individual EU countries, including Belgium. The study shows that, for example in the buildings sector, efficiency alone is insufficient to off-set the growth of living space areas, and that in addition sufficiency measures are needed. The scenario reports an overall final energy reduction due to sufficiency of -20 to -30% for France, Germany

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47 "PUB 2021-10 Studie Hoe Creëren We Een Klimaatneutrale Vlaamse Industrie?.Pdf," Google Docs, accessed December 13, 2023, https://drive.google.com/file/d/1VcL9kANMMDu_qiydzFk0YI-QSSe1bLgZ/view?usp=sharing&usp=embed_facebook.
48 https://www.vlaio.be/nl/publicaties/naar-een-koolstofcirculaire-en-co2-arme-vlaamse-industrie
49 https://climat.be/doc/climate-neutral-belgium-by-2050-report.pdf
50 "CLEVER energy scenario -," accessed December 13, 2023, https://clever-energy-scenario.eu/.

and the United Kingdom. For the buildings sector, this number equals -13 to -25%, for transport -20 to -39% and for industry -13 to -36%.

Material Economics – Industrial Transformation 2050

The study by Material economics[51] - Industrial Transformation 2050: Pathways to Net-Zero emissions from EU Heavy Industry – addresses technological and economic aspects surrounding the decarbonization of heavy industry by 2050. The study analyses three different pathways to net-zero: the Circular Economy scenario, the New Processes scenario and the Carbon Capture scenario. The study builds on the conclusion of the European Commission's 'A Clean Planet for All' report which confirms that it is possible to achieve net-zero emissions in industry if one considers a wider range of solution strategies, besides carbon capture, mainly driven by a more circular economy and new business models but also including technical innovations in industrial processes and renewable energy.

For this study, the Circular Economy scenario was selected as a data source for the SHIFT scenario evolution in cement production by 2050 compared to the reference year (2015), complementing the BBL/Climact study that given its regional scope of Flanders did not consider cement.

TML MVK 2018

The background study 'Solution directions for the mobility system' for the Flemish Environmental Outlook 2018[52] analyses a set of potential measures to reduce the environmental impact of mobility. Different demand side measures in transport are analyzed, such as increased home office, trip sharing, and modal shift. This analysis provided useful reflection on the potential and feasibility of demand reduction measures in transport, including on the role of rebound effects.

TNO TRANSFORM

The scenario report 'Towards a sustainable energy system for the Netherlands in 2050' by TNO applies an energy system modelling methodology similar to TIMES-BE. Two scenarios are developed: ADAPT and TRANSFORM. The ADAPT scenario meets 2030 and 2050 emissions targets through a technology-oriented approach involving, for example, a relatively high reliance on CCS. The TRANSFORM scenario, on the contrary, assumes more transformative developments, including replacement of energy intensive industry (i.e. lower industrial production and energy use) to some extent compensated by an increase of service sector output. As the geographical scope (Netherlands versus Belgium) is relatively similar, the TRANSFORM scenario assumptions provide relevant comparison to the SHIFT scenario assumptions, mainly for industry.

[51] "Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry - Material Economics."
[52] "Milieuverkenning 2018: Achtergronddocument Oplossingsrichtingen Voor Het Mobiliteitssysteem," accessed February 27, 2024, https://archief.algemeen.omgeving.vlaanderen.be/xmlui/handle/acd/761922.

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4. SHIFT scenario results

This chapter outlines a vision for the net-zero pathway developed in this study, the SHIFT scenario, to highlight the potential for systemic shifts leading to a more circular, sustainable and resource-efficient society as a tool to support the energy transition. The assumptions behind this scenario are described in more detail in chapter 4. We will present the future of our Belgian energy system by describing the evolution in the final energy demand, the power sector, the buildings sector, the transport sector and the annual emissions towards 2050.

4.1. Final energy demand

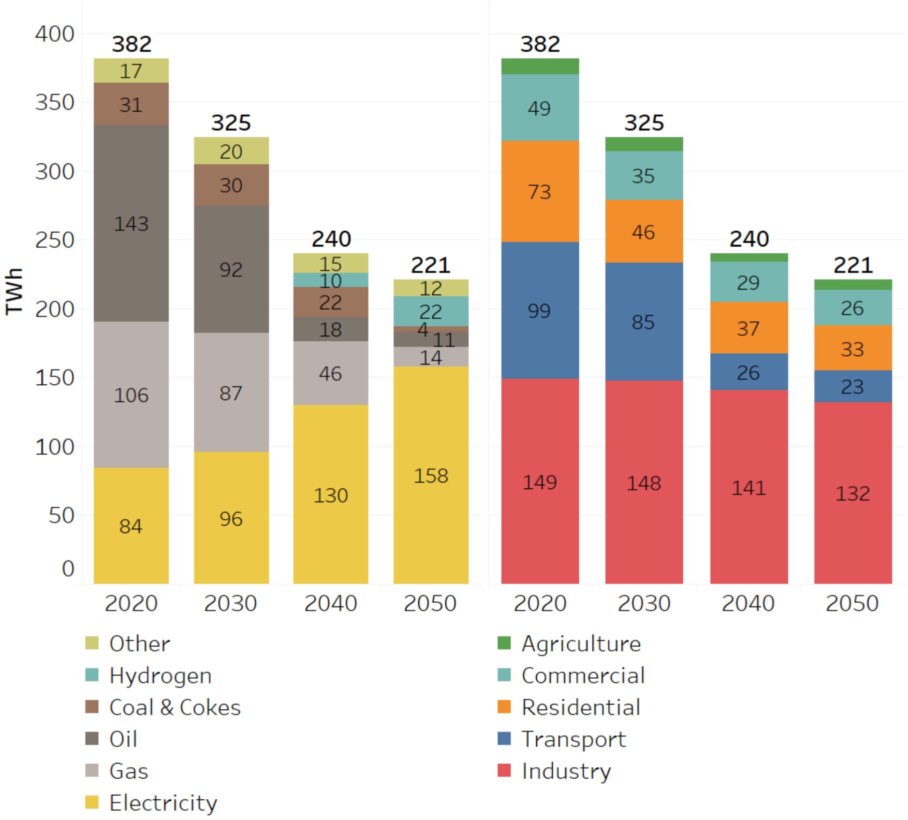

Figure 6: Final energy demand by source (left) and by sector (right).

The evolution of the final energy demand in the SHIFT scenario for the Belgian energy system is presented in Figure 6 by energy source and by sector. Two main trends emerge. Firstly, the final energy demand for electricity doubles by 2050 due to electrification trend in all sectors. The increase in electricity demand is accompanied by a decrease in fossil sources of energy. Consumption of oil in particular experiences a sharp decline of 80% from 2030 to 2040. By 2050, however, a very limited demand for fossil oil remains present in 2050, mainly used as a feedstock in industry. Secondly, the overall final energy demand decreases with approximately 40% by 2040 and 45% by 2050.

This evolution is mainly driven by the electrification trend due to rising carbon prices and the increased availability of far offshore wind, which allows the solution to electrify earlier on in the energy transition. The electrification trend is distinctly visible in the transport sector for the period of 2040, which can avoid 25 TWh of fossil energy by electrifying its road transportation. Aside from the electrification trend, the system shifts further lower the final energy demand with 53 TWh annually compared to the Central scenario by 2040 already, as will be discussed in more detail in section 5.1.

4.2. Power sector

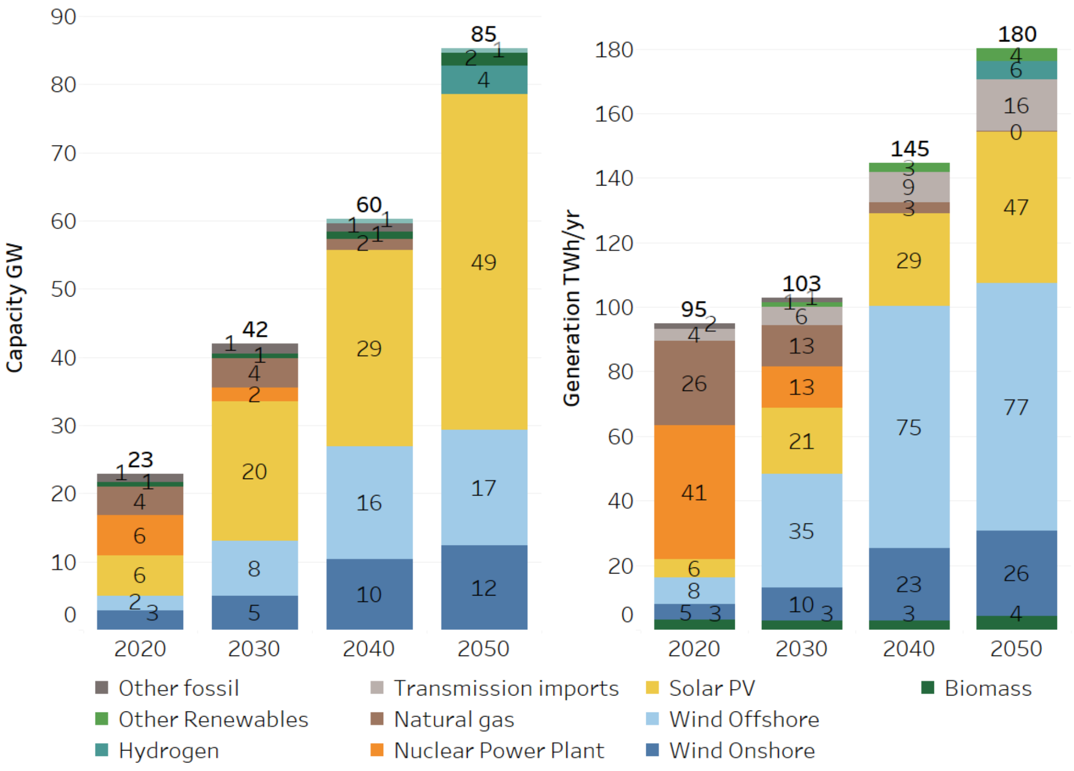

Figure 7: Power sector in SHIFT scenario: generation (right) and capacity (left).

The previous section indicated a doubling of the electricity demand by 2050. Consequently, the power system is transformed to accommodate the increasing electricity demand and comply with the net-zero target. Figure 7 shows an overview of the evolution in the power sector generation and installed capacity by energy source. Note that the total electricity generation in this graph is slightly larger than the final demand for electricity. This is partially due to grid losses, but also due to the scope of what is included in the final energy demand. Converting electricity into hydrogen for final consumption, for instance, is excluded from the final electricity demand. The energy mix in 2020 is made up by fossil sources (4.3 GW natural gas and 1.3 GW other fossil), 5.9 GW nuclear, 6.5 GW transmission capacity and a substantial capacity of solar (5.8 GW) with smaller additions from wind offshore (2 GW) and onshore (3GW). This installed capacity translates to a generation mix which is dominated by electricity of nuclear (41.5 TWh) and fossil (26.2 TWh) origin.

By 2030, solar capacity increases to 20.5 GW, onshore wind to 5 GW and offshore wind to 8 GW. Throughout the transition periods 2030 and 2040, the SHIFT scenario indicates substantial investments in additional wind (both onshore and offshore) and solar capacity, reaching 10 GW onshore wind, 16 GW offshore wind and 29 GW of solar capacity by 2040. These capacities translate to 22 TWh onshore, 76 TWh offshore and 30 TWh of solar electricity by 2040. Identical to the Central+16GW scenario, the SHIFT scenario benefits from the early access to clean electrons which enables a rapid launch for the energy transition.

In general, the scenario indicates a strong push for offshore wind, as the model decides to invest in offshore capacity as soon and as much as possible indicting it can bring down system costs. The scenario assumes an offshore potential of 17 GW (8 GW on Belgian territorial waters and 9 GW extraterritorial), which is almost fully developed by 2040 already. The 9 GW of extraterritorial offshore wind is well within the limits of the total technical potential of 300 GW by 2050 in total for the nine countries of the North Sea coalition who signed the Ostend declaration. This assumption of 9 GW of extraterritorial far offshore wind is a more conservative assumption compared to the Central+16GW and the electrification scenarios, both of which assume an availability of 16 GW of far offshore wind capacity. Moreover, nuclear is phased out completely by 2035 and transmission capacity increases up to 13 GW by 2040, while contributions from hydro, biomass and other renewables remain limited.

As the offshore potential is almost fully used up by 2040, the model invests in an additional 20 GW of solar capacity to bridge the transition towards 2050 resulting in 49 GW of installed capacity or 47 TWh of annual generation. Moreover, onshore wind capacity increases up to 12 GW and transmission import volumes reach 16 TWh These import quantities are in line with the other PATHS2050 scenarios which have shown that early access to clean electrons, such as the SHIFT scenario, can half the import need for electricity in 2050, reducing from roughly 30 TWh down to 15 TWh. By 2050, approximately 80% of the generation mix is made up by local renewable energy sources. The remaining part is largely based on electricity imports and a growing share of hydrogen which generates 5.8 TWh on an annual basis, similar to the other PATHS2050 scenarios.

4.3. Buildings sector

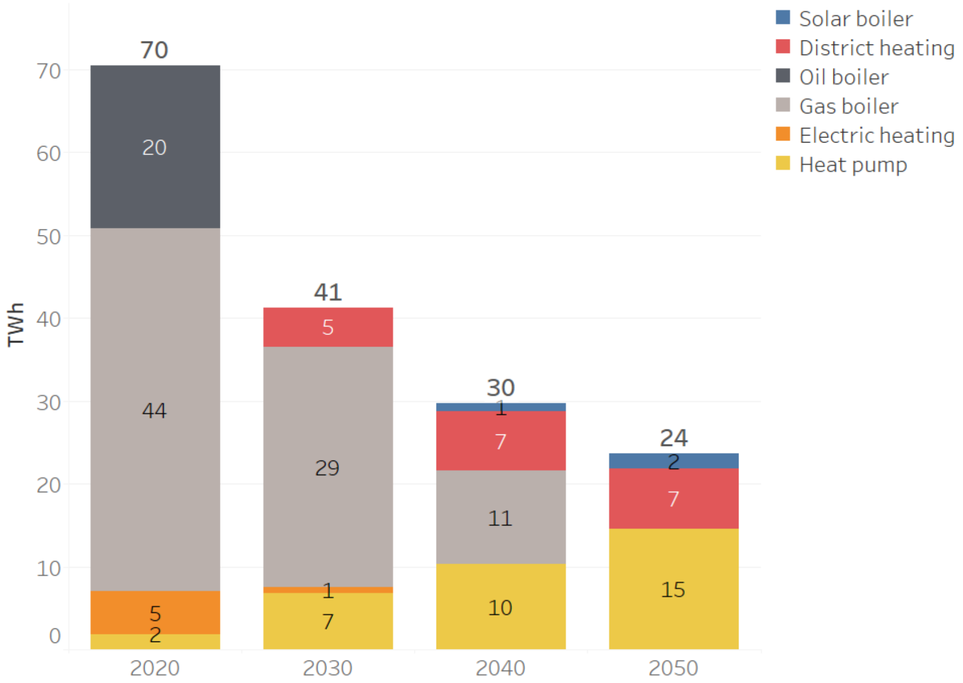

Figure 8: Space heating in buildings (residential and commercial) by technology.
Note: electric heating is any form of electric resistance heating

The buildings sector is directly linked to behavioural and systemic shifts by its end-consumers. Therefore, the measures implemented in the SHIFT scenario have a direct impact on the final energy demand. The effects of the measures are superposed on top of the effects of population growth, which increases the demand for heated areas if no optimized living measures would be implemented. These measures include lowering the thermostat by one degree and optimizing living space or housing to reduce surface area per inhabitant. Other measures related to efficiency gains, such as electrification (heat pumps) and insulation, are included in the model by default in all scenarios.

Figure 8 presents the evolution in the final energy consumption by buildings for space heating, which represents the largest share of energy consumption in buildings. Note that the figure does not present other energy demands in buildings such as water heating, cooking or lighting. These other demands are not altered compared to the other PATHS2050 scenario, where general efficiency or flexibility measures are included by default. The SHIFT scenario presents a 7% reduction in space heating demand for households and an 11% reduction in space heating for commercial buildings, while the other PATHS2050 scenarios all present an increasing demand, scaling with population growth (+19%) and activity increase (+14%) by 2050 for the residential and commercial sector respectively.

In 2020, the energy mix is predominantly fossil, including 64 TWh of gas or oil-based heating technologies. By 2030, the share of oil-based heating disappears completely while gas-based heating reduces to 29 TWh. These shares of fossil heating are replaced by heat pumps, increasing their electricity consumption up to 7 TWh, but reducing the final energy consumption due to the high efficiency of heat pumps and other efficiency measures in buildings, such as insulation. Furthermore, district heating – from geothermal sources and waste heat – starts to play a more significant role from 2030 onwards, covering more than 5 TWh of the final space heating energy demand. The share of gas-based heating diminishes towards 2050, resulting in a space heating demand which is more than 60% electrified. The remaining share is covered by district heating and solar boilers.

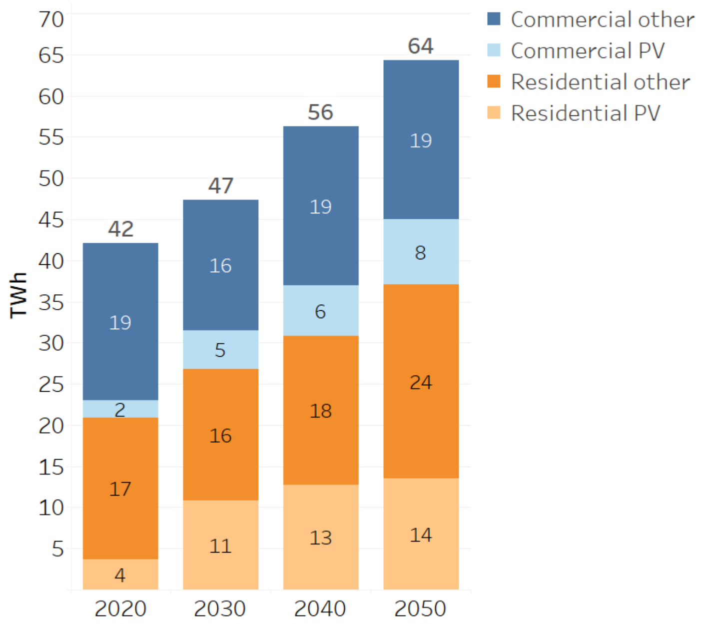

Figure 9: Buildings sector electricity consumption and PV self-consumption
Note: this includes EV charging.

The electrification trend in the buildings sector is inherently linked with the growing PV capacity, as discussed in the previous section. Figure 9 therefore illustrates the total electricity consumption in the buildings sector (including residential and commercial buildings). Note that the additional electricity required for lightning, cooking, electric vehicle smart charging etc. the total electricity consumption is larger in this figure compared to the share of electricity in the previous graph.

The figure presents the division of electricity consumption between residential and commercial buildings as well as the self-consumption of PV generation. By 2030 and on a cumulative sectoral level, residential buildings can cover 40% of their electricity demand using their own installed capacity of PV panels, while this percentage remains lower in the commercial sector which can cover approximately 25% with self-consumption. As the demand for electricity increases throughout the energy transition, these self-consumption shares converge to 35% and 30% for residential and commercial buildings, resulting in 14 TWh of PV self-consumption for residential buildings by 2050 and 8 TWh for commercial buildings. On top of the solar production, the buildings require a total of 43 TWh additional electricity in 2050.

It is important to note that these values of PV self-consumption represent theoretical sectoral cumulative quantities, as TIMES-BE is an aggregated national model which does not include details on a household level. This means that the self-consumption values should be interpreted as a theoretical maximum where rooftop solar electricity generated anywhere in the country can be consumed by any building in Belgium, no matter its location. In other words, the TIMES-BE buildings sector is representing a sector-wide energy community, implementing the energy sharing principle.

4.4. Transport sector

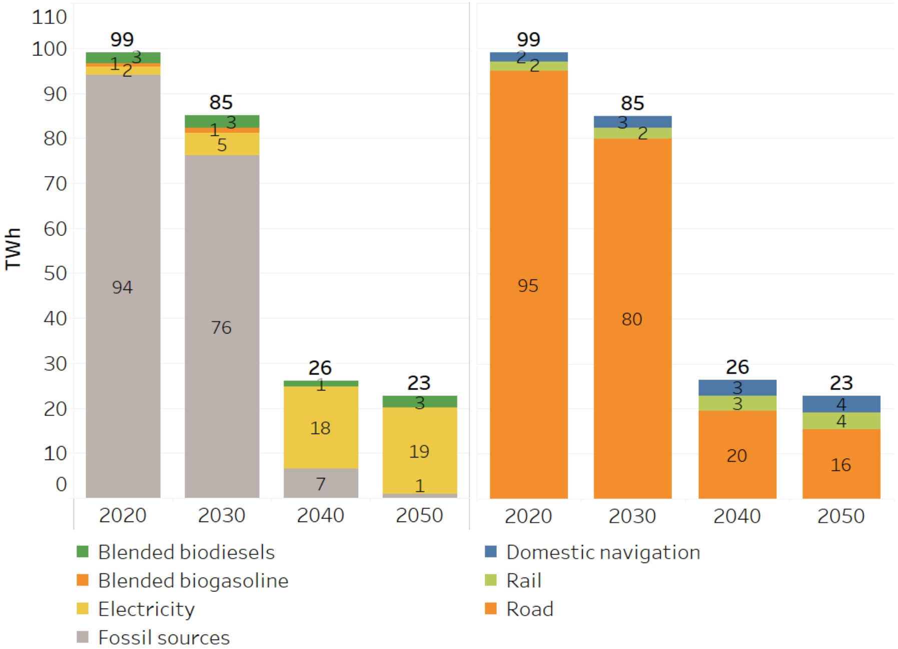

Figure 10: Transport sector SHIFT scenario: final energy consumption by energy source (left) and by modus (right).

The transport sector is responsible for approximately 25% of the total system emissions. Furthermore, the sector is highly sensitive to behavioural and systemic shifts due to the direct link with the end-consumers. We therefore analyse this sector in more detail by looking at the final energy demand by energy source in Figure 10. In 2020, the figure indicates a large dependency on fossil sources, representing approximately 75% of the energy mix. By 2030, this dependency decreases as electric vehicles are introduced and the share of electricity consumption increases in the transport sector. Furthermore, the final energy demand decreases due to efficiency gains from technology development and different technology decisions by 2030.

The largest difference, however, is observed in the transition period from 2030 to 2040. Increasing carbon prices, modal shifts, increased car sharing, reduced travel, improved truck loading etc. all contribute to a final energy demand decreases from 100 TWh today, down to 30 TWh by 2040 and 27 TWh in 2050. The main driver for this final energy demand reduction, however, is the electrification trend, enabled by the additional far offshore wind capacity as perceived in some of the other PATHS2050 scenarios. Furthermore, the systemic shifts support this trend to decarbonize the energy system earlier on in the transition, reducing the dependency on gas, oil and diesel oil to 25%. By 2050, the transport sector is 85% electrified, relying mostly on blended biofuels (approximately 10%) for the remaining demand and only limited amounts of gas and diesel oil. This remaining part of fossil is expected to be replaced by renewable options in future version of TIMES-BE.

The right side of Figure 10 presents the final energy consumption by the different transport modes. This figure shows that road transport remains the dominant mode of transportation for both passenger and freight transport in terms of final energy demand. The scenario presents a modal share of 54% for trucks in freight transport, 68% for cars and busses in passenger transport. These shares in terms of ton and person kilometres translate to a 70% share in the final energy demand, due to the lower efficiency compared to the rail and navigation transport, representing 30% of the final energy demand while covering a larger share of the ton and person kilometres.

Figure 11 zooms in on the previous figure by illustrating the energy mix for the different transport modes. Due to the large share of road transport, the results are similar to the general findings for the transport sector. By 2050, however, road transport is approximately 100% electrified, requiring 16 TWh of electricity per year to charge approximately 3 million electric vehicles. Furthermore, rail transport requires an additional 4 TWh by 2050. The blended biodiesels go to inland navigation as well as 1 TWh of remaining fossil gas and diesel oils.

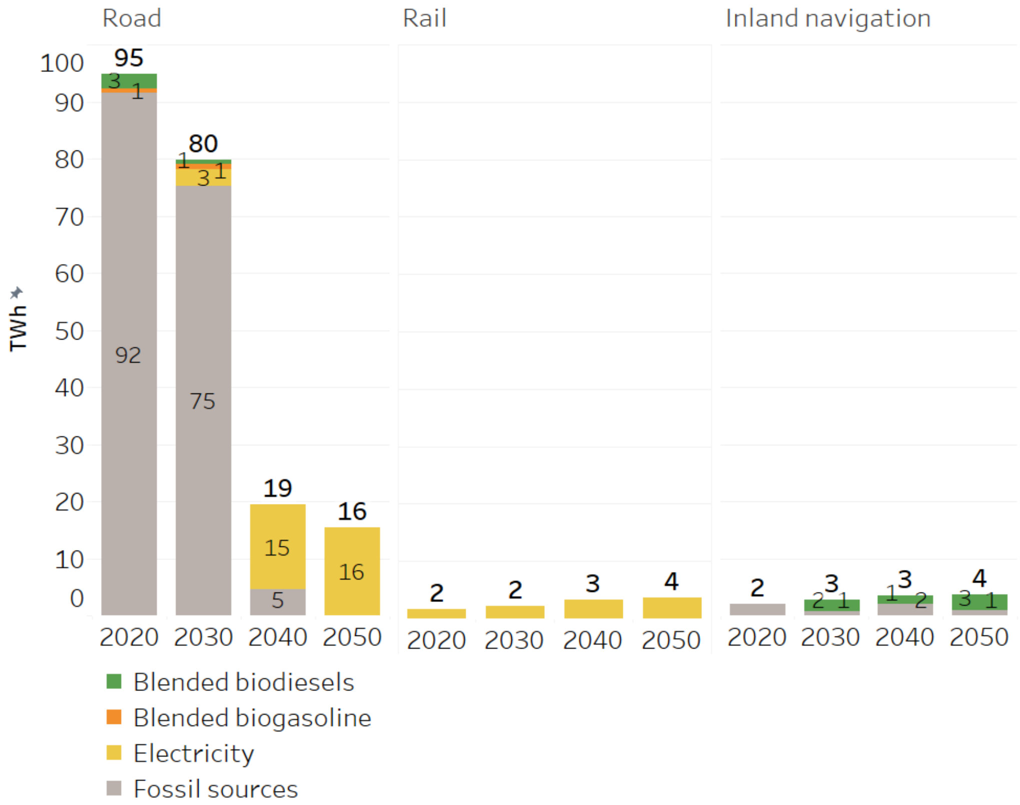

Figure 11: Road transport final energy demand in TWh by energy type.

4.5. Industry sector

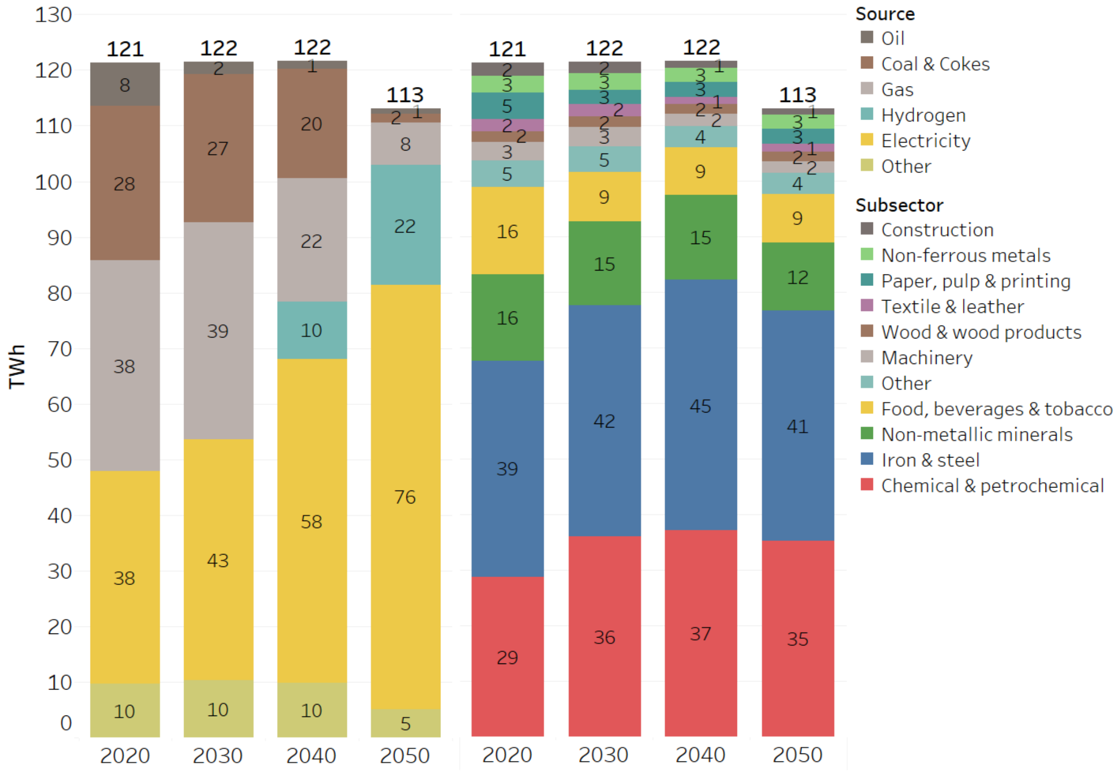

Figure 12: SHIFT scenario industry overview: final energy demand by source (left) and by subsector (right) in TWh. Note: Feedstock for industry is excluded in this graph.

The high temperatures, which are often required in industrial processes, form an additional challenge to decarbonize the industry sector, exploring the limits of electrification options. For this reason, systemic shifts which lead to increased resource-efficiency and circularity could be particularly important for this sector. Figure 12 presents an overview of the evolution of the energy demand of the industry sector in the SHIFT scenario. The left figure illustrates the final energy consumption in industry by fuel type and the right provides an overview of the energy demand by subsector.

All PATHS2050 scenarios present an increasing final energy demand in industry throughout the transition which lowers back down to 2020 levels by 2050. In the SHIFT scenario, however, the final energy demand remains stable throughout 2030 and 2040, replacing some of the fossil energy demand with electricity and hydrogen. By 2050, the SHIFT scenario achieves a 10% reduction in final energy demand. These total industry savings are therefore a direct result of the systemic shifts imposed by the SHIFT scenario. Figure 13 zooms in on the three most energy-intensive sectors for Belgium: the iron & steel sector, the chemical & petrochemical sector and the non-metallic minerals sector.

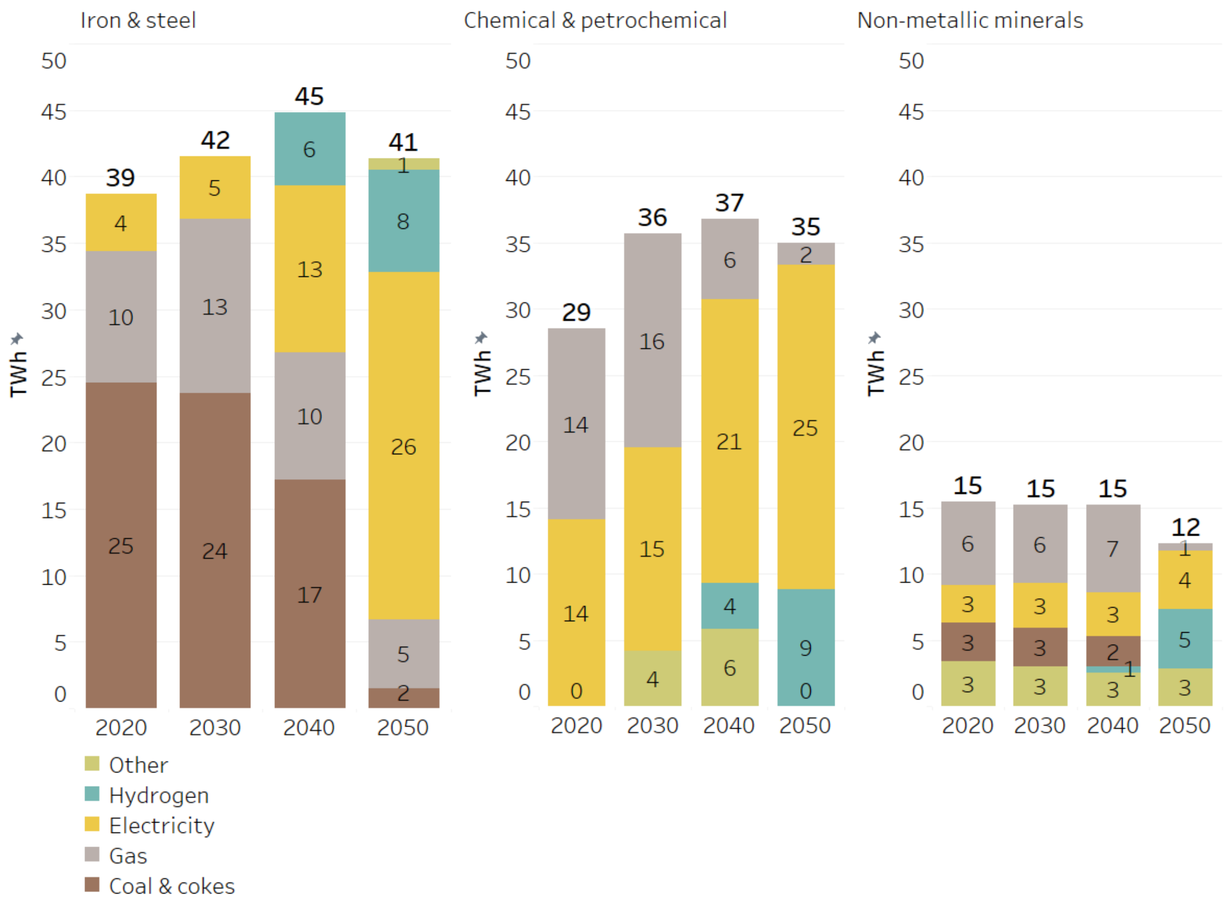

Figure 13: SHIFT scenario iron & steel (left) and chemical & petrochemical (middle) and non-metallic minerals (right) annual final energy demand sector breakdown by fuel in TWh.

Iron & steel subsector

The iron & steel subsector is responsible for a large part of the industry emissions as the sector is 90% fossil-based and represents 30% of the industrial energy consumption in the reference period.

Two main effects are driving the evolution of the final energy demand in this sector. Firstly, the graph shows an increasing and subsequential decreasing trend in the final energy demand. This general pattern is driven by the carbon price which is pushing the model to invest first in CCS technology and later on in cleaner technologies, once the existing assets have reached their end-of-life. Secondly, the systemic shifts are lowering this bumpy profile by slowing down the increase in the final energy demand during the transition period and by further reducing the final energy demand after 2040.

The general electrification in the sector results in 26 TWh of electricity consumption in 2050 which covers 60% of the total energy demand. Aside from the electricity consumption, the iron & steel sector partially relies on hydrogen in 2040 and 2050 as the Direct Reduced Iron (DRI) technology emerges. The remaining demand is covered by fossil sources and a smaller share of solid biofuels.

Chemical & petrochemical subsector

In the chemical and petrochemical subsector, the presented final energy demand profile is, again, a result of the combined impact of the carbon tax and system shifts. The carbon tax is inducing a general electrification trend, while the systemic shifts are able to flatten out the final energy demand towards 2040 and even induce a decreasing trend towards 2050, whereas the alternative PATHS2050 scenarios present a continuously increasing final energy demand.

The final energy demand in 2020 is split equally between electricity and gas. The largest part of the increase in energy demand by 2030 is covered with additional gas and solid biofuels. After 2030, the SHIFT scenario slows down the energy demand increase while the carbon price is driving fossil-based technologies to be replaced with new investments in electrified options as well as hydrogen consuming technologies. This results in an electricity demand of 21 TWh by 2040 and 25 TWh by 2050 and a hydrogen demand of 3 TWh in 2040 and 9 TWh by 2050. The share of solid biofuels in the chemical sector increases up to 16% by 2040 with 6 TWh while this share diminishes to nearly zero by 2050. This indicates the temporary character of biofuels in the chemical sector, as they are used in the transition period to manage high carbon prices with the remaining fossil-based capacity that is yet to be electrified. It is notable to mention that the decrease in the final energy demand, induced by the systemic shifts, does not alter these volumes of biofuels and hydrogen consumption. Instead, the demand reduction only reduces the electricity consumption. Similar to the iron and steel sector, the chemical and petrochemical sector is left with a limited share (2 TWh) of gas-based processes, to be tackled with investments in CCS capacity.

Non-metallic mineral subsector

The non-metallic mineral subsector contains different products such as cement, bricks and glass. Cement production reduces with 39% because of increased circularity and optimized building and construction which lead to a more resource-efficient non-metallic mineral subsector. For the same reason, the production of bricks reduces with 33%, following the industrial assumptions for ceramics in section 3.4.3.

The final energy consumption of this sector is relatively small compared to the other two sectors discussed above. However, the sector realizes a final energy demand reduction of 4 TWh by 2050 which is approximately a third of its final energy demand in the reference year. As the alternative PATHS2050 scenarios present a final energy demand by 2050 which is approximately equal to the 2020 value, this final energy demand reduction is a direct result of the system shifts, while the carbon tax is driving the investments in new technologies which are consuming electricity and hydrogen instead of fossil sources of energy.

4.6. CO_2 emissions

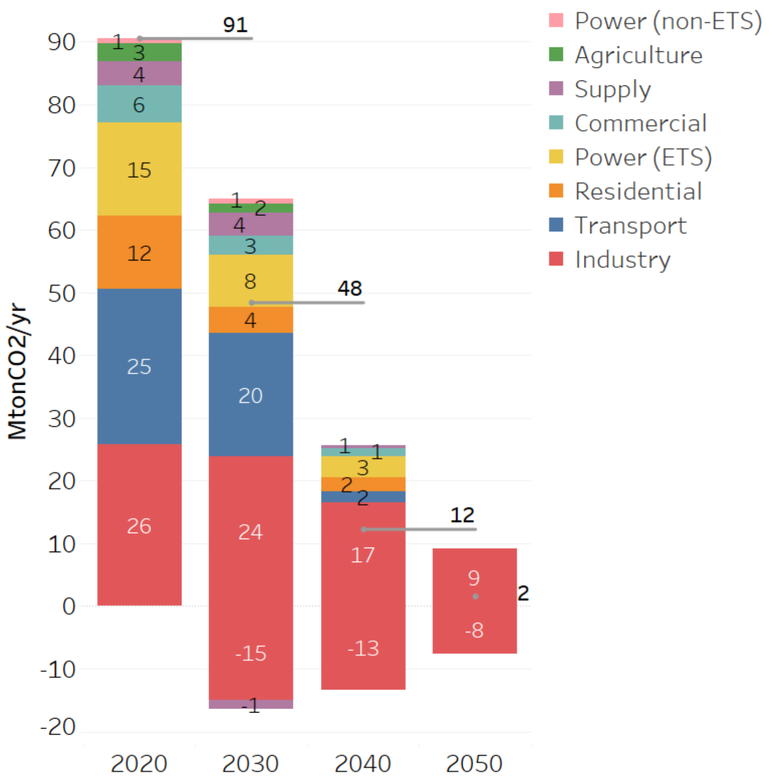

Figure 14: Annual CO_2 energy and process emissions in $MtonCO_2$ per year for SHIFT scenario. Net emissions indicated by lines. Note that the oil refineries are represented by the supply sector.

The SHIFT scenario presents a possible pathway to a carbon-neutral 2050, reducing CO_2 emissions on an annual basis through the implementation of an increasing carbon price combined with systemic shifts. The systemic shifts that define the SHIFT scenario result in a more resource-efficient and more rapidly decarbonizing energy system, induced by increased circularity, sustainable lifestyles, optimised mobility and housing etc.

The largest efforts in annual emission abatement is present in the transition period 2030-2040, where an increasing carbon price as well as systemic shifts reduce the net annual system emissions from 48 MtonCO_2/yr in 2030 down to 12 MtonCO_2/yr. The SHIFT scenario thereby achieves a 90% CO_2 (energy and process) emission reduction by 2040, aligning with the recent EU-impact assessment[53] recommendation of a 90% reduction target by 2040. The Central+16GW scenario achieves a similar reduction of 88% by 2040, while the Central scenario, for instance, reaches a 80% reduction by 2040. This emphasizes that having access to clean electrons timely, either by upscaling the supply-side or by down-scaling the demand-side, is a crucial factor to achieve the 2040 ambitions.

The CCS capacity is indicated by the negative segments in the graph. The resulting net emissions are therefore indicated by the grey line. The SHIFT scenario lands in a net-zero 2050 where some hard-to-abate industries, like steel and cement, remain dependant on CCS capacity to become carbon neutral, similar to the other PATHS2050 scenarios. The largest CCS capacity of 16 MtonCO_2/yr is deployed in 2030, where all sectors battle a high carbon price with existing carbon-based facilities. This pushes the model to electrify towards 2050, thereby reducing the need for CCS to 8 MtonCO_2/yr.

The first sector to electrify is the residential sector, which more than halves its annual emissions from 2020 to 2030 due to the deployment of heat pumps. In the transport sector, the largest efforts occur in the transition between 2030 and 2040, where a shift to electric vehicles is largely driving the reduction in emissions. The power sector (ETS) emissions decrease gradually (annually to 8 MtonCO_2/yr by 2030, 3 MtonCO_2/yr by 2040) as the share of renewable sources increases, completely decarbonizing the sector by 2050.

53 "Recommendation for 2040 Emissions Reduction Target."

5. Comparing Net-zero pathways

In this chapter, we challenge the SHIFT scenario by comparing it against three alternative net-zero pathways. The first alternative pathway is the Central scenario which is used as a reference scenario for this comparison. The other two scenarios are the Offshore Scenario (Central+16GW), which proved to be the most cost-efficient scenario, and the SMR Scenario (Central+SMR), both of which were selected from the sensitivity scenarios of the PATHS 2050 study. A comparison of the SHIFT scenario with the Central scenario and the two sensitivity scenarios (+ 16 GW and + SMR) can provide valuable insights to determine the strengths and opportunities of the systemic shifts within a broader context. The scope of the comparison will be limited to the selected indicators: the final energy demand, the power system, CO2 emissions and cost indicators.

5.1. Final energy demand

5.1.1 Overview

The first indicator, the final energy demand, is illustrated in Figure 15. From the top figure, the final energy demand by energy source can be derived. The Central scenario includes a decreasing trend in the final energy demand, accompanied by an increasing demand for electricity and a decreasing demand for fossil-based energy sources. The decarbonization rate of the demand in the Central scenario is similar to the Central+SMR scenario, while the Central+16GW and the SHIFT scenario both indicate a more rapid decrease in demand for fossil energy by 2040. This suggests that enabling clean electrons from far offshore wind early on in the energy transition is crucial for a more rapid decarbonization of the final energy demand.

The Central+16GW scenario results in an increased final energy demand for electricity by 2040 (9 TWh) due to the access to additional offshore wind, while significantly reducing the consumption of oil with 21 TWh. By 2050, the Central+16GW scenario lands on a larger final energy demand compared to the Central scenario due an additional 6 TWh of electricity demand, enabled by the more rapid electrification. This trend is even more pronounced in the Central+SMR scenario which requires an additional 12 TWh of electricity in 2050, while showing similar data for all other categories. The difference compared to the Central scenario indicates that the access to nuclear capacity results in almost no replacement of fossil sources, but rather increases the final energy demand with electricity by 2050.

Compared to the Central scenario, the SHIFT scenario results in a decrease in the (mainly fossil) final energy demand of approximately 20% by 2040 already. This final energy demand reduction consists of a reduction of 27 TWh of oil and 11 TWh of gas in 2040. Compared to the Central+16GW scenario, the SHIFT scenario has a lower final energy demand, mostly reducing the demand for electricity with 15 TWh in 2040 and 34 TWh in 2050, requiring less power capacity. Consequently, the SHIFT scenario results in a more rapidly decarbonized final energy demand, leading to an accelerated electrification of technologies and overall, a cleaner energy system earlier on in the transition. These trends are driven by the carbon price as well as the system shifts which reduce the final energy demand, supported by earlier access to clean electrons coming from 9 GW of additional far offshore wind.

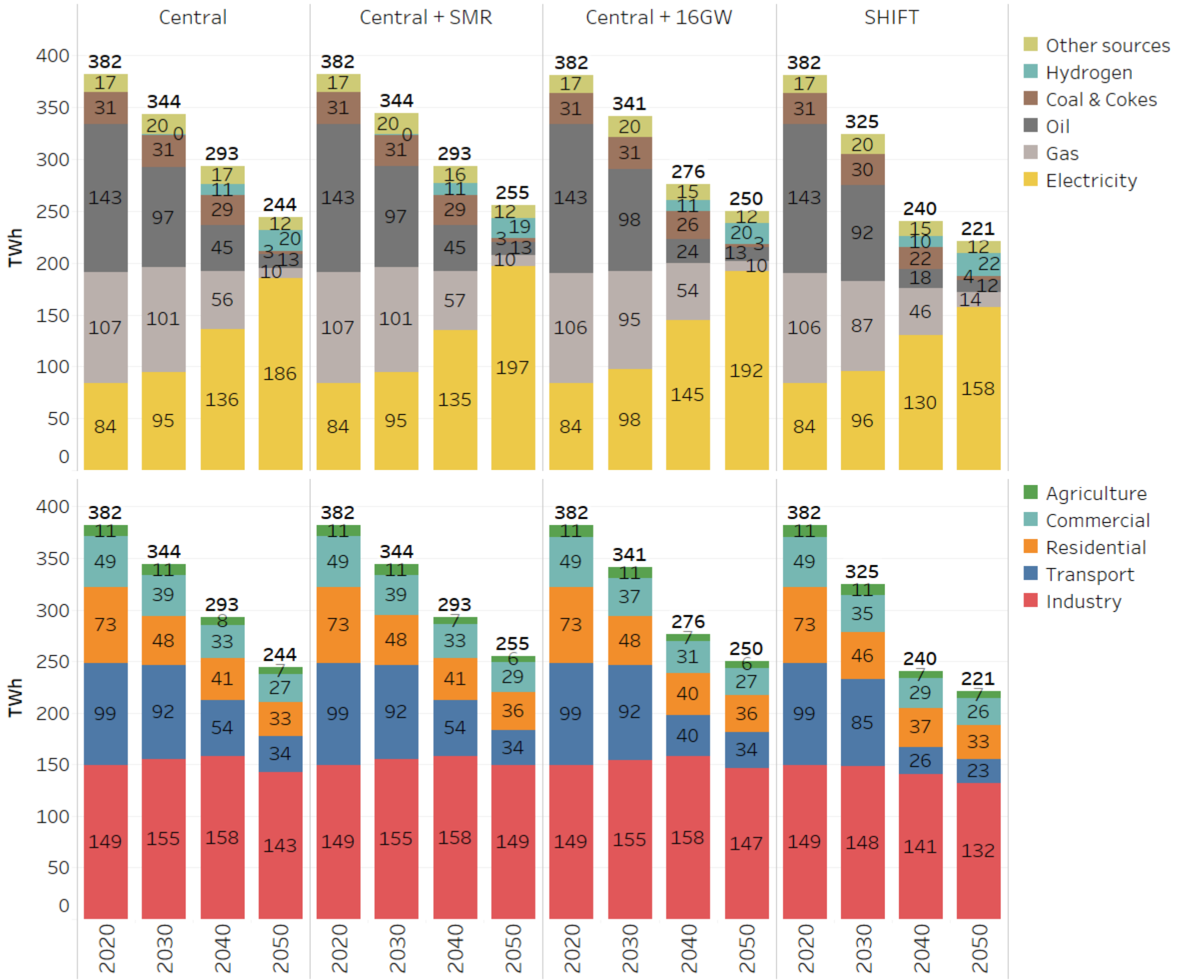

Figure 15: Final energy demand comparison by source (top) and by sector (bottom). Note: different scaling in both axes.

5.1.2 Sectoral difference

The bottom part of Figure 15 shows the final energy demand by sector. Two visible observations can be made, which were already touched upon in more detail in section 4.5. Firstly, the final energy demand in the transport sector reduces more rapidly in the SHIFT scenario compared to all other scenarios, mostly due to the modal shift which is steering the solution towards more sustainable transport options, as well as increased trip sharing in passenger car travel. Secondly, all scenarios present an increasing final energy demand in industry throughout the transition which lowers back down to 2020 levels by 2050. In the SHIFT scenario, however, the final energy demand remains stable throughout 2030 and 2040, replacing some of the fossil energy demand with electricity and hydrogen. By 2050, the SHIFT scenario achieves a 10% reduction in final energy demand in industry. These total industry savings are therefore a direct result of the systemic shifts introduced by the SHIFT scenario.

Figure 16 zooms in on the difference in final energy demand by sector between the SHIFT scenario and the Central+16GW scenario, to isolate the impact of the system shifts from the electrification trend. The largest impact arises in the industry sector, lowering the final energy demand with 18 TWh in 2040 and 15 TWh in 2050. These reductions are primarily caused by the reduced use of virgin high value chemicals or plastics (-18%) in the chemical sector and the reduced use of virgin cement (-39%) and ceramics (-33%) in the non-metallic minerals sector. The transport sector also presents a significant final energy demand reduction of 13 TWh in 2040 and 11 TWh in 2050. These reductions are primarily induced by the modal shift towards more sustainable transport options and increased trip sharing in passenger cars. Moreover, the reductions are a result of the doubling of train traveling and a more than doubling of active transportation such as cycling. The impact of the measures in the buildings sector (residential and commercial buildings) is more limited, resulting in a final energy demand reduction of 3-5 TWh and is mainly driven by the optimized living spaces.

In terms of electricity demand, a slightly larger reduction is present by 2050, consisting of 18 TWh in industry, 13 TWh in transport and 3 to 5 TWh in buildings. In total, this is more than 34 TWh or almost 20% lower than the Central+16GW scenario in 2050 (192 TWh).

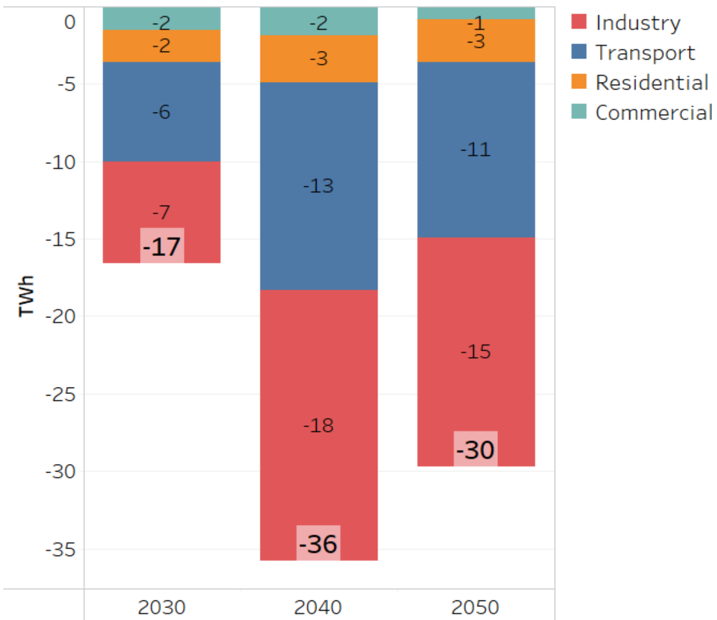

Figure 16: Sectoral difference in final energy demand - SHIFT scenario compared to the Central+16GW scenario.

5.2. Power system

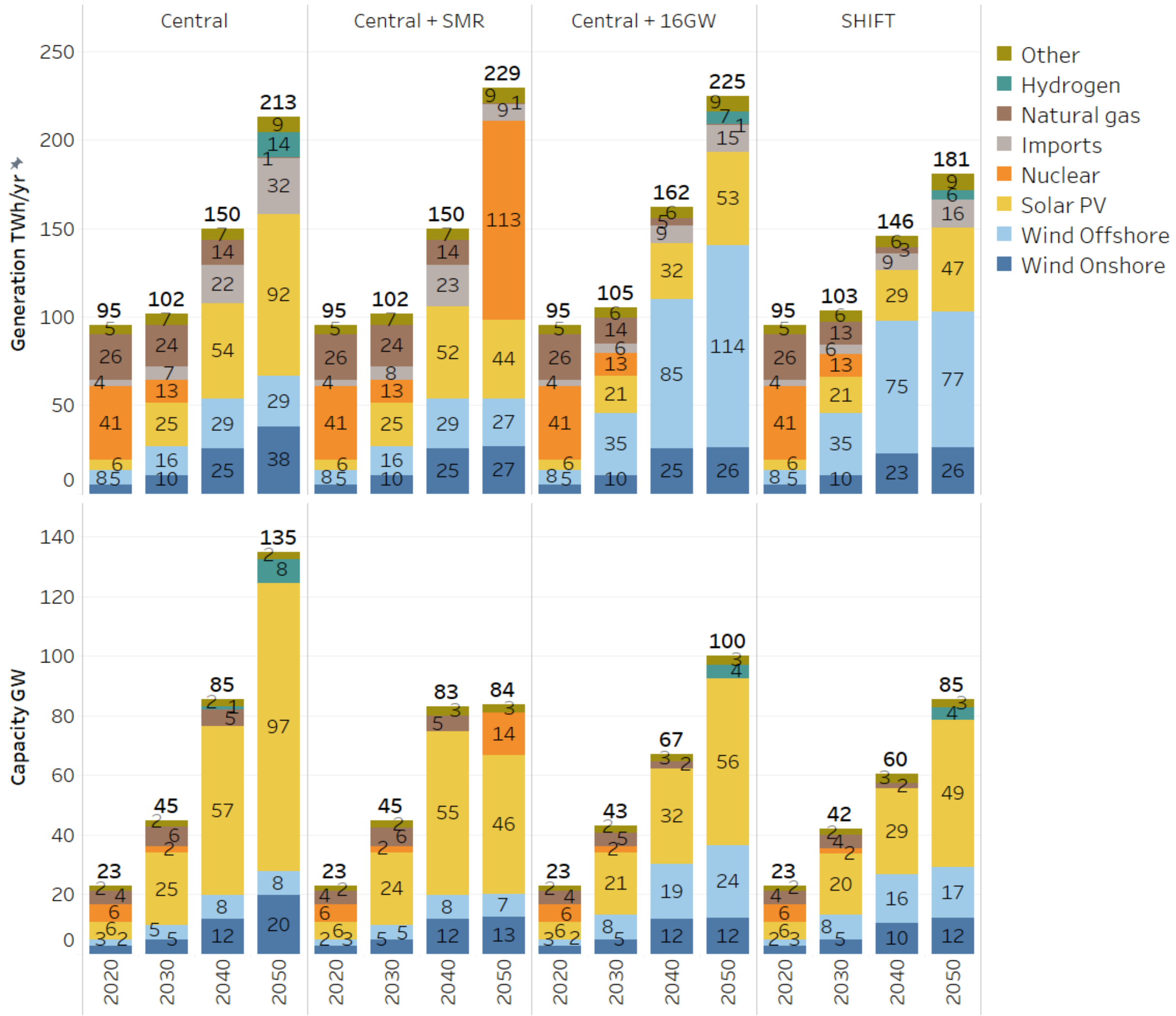

Figure 17: Power system comparison for capacity (bottom) and generation (top). Note: different scaling in both axes.

The composition of the energy mix is the second indicator to compare and situate the different scenarios. We therefore assess the 2050 energy mix based on five varying energy sources provided in Table 8: wind onshore and offshore, solar PV, hydrogen, and nuclear small modular reactors (SMR). The wind offshore is split up between offshore wind on Belgian territory (wind offshore) and outside of the Belgian territory (wind far offshore), such as the Dogger Bank. The other sources, such as imports, biomass, and fossil, are not considered in this table because these values remain relatively stable over all scenarios. A full overview, however, of installed capacity as well as generation is provided in Figure 17.

Table 8: Power system overview for selected scenarios in 2050

GW	CENTRAL	CENTRAL+SMR	CENTRAL+16GW	SHIFT
Wind onshore	20	13	12	12
Wind offshore	8	7	8	8
Wind far offshore	0	0	16	9
PV	97	46	56	49
Hydrogen	8	0	4	4
SMR	0	14	0	0

The Central Scenario does not consider this additional far offshore wind or SMR capacity as an option and therefore invests in 20 GW of onshore wind by 2050, on top of the maximum potential of 8GW of offshore wind. Due to the nuclear phase-out and the absence of the far offshore wind, the scenario invests in large amounts of solar PV capacity, nearly reaching the Belgian maximum potential of rooftop PV with 97 GW. This solar capacity is roughly twice as large as the capacities proposed by the other scenarios. This is a known outcome of the model: as soon as additional offshore wind becomes available, solar PV gets replaced by offshore wind capacity.

The Central+SMR scenario enables the option to invest in new SMR nuclear capacity by 2050, which results in 14 GW of SMR in 2050 which corresponds to approximately 45 small reactors. This nuclear capacity replaces the far offshore wind of the SHIFT scenario while all other sources remain approximately the same. Rooftop PV capacity decreases down to 47 GW and the hydrogen capacity disappears completely.

In the Central+16GW Scenario, where new nuclear (SMR) is also not allowed, the results indicate that when additional offshore wind capacity becomes available, it replaces solar PV, thereby reducing the total system cost. The model decides to max out the far offshore wind potential and invest in 16 GW, reducing the PV capacity down to 56 GW in 2050. Furthermore, electricity production from hydrogen decreases from 8 to 4 GW and onshore wind capacity lands on 12 GW.

Analogous to the sensitivity scenario described above, the SHIFT scenario - with a reduced final energy demand - reacts by reducing solar PV capacity when far offshore wind becomes available. Due to the lower energy demand, however, a new and smaller power mix equilibrium can be found, landing on a far offshore wind capacity of 9 GW combined with 49 GW of solar PV. This results in a more balanced portfolio of wind and solar capacity, compared to a case with LED and 16 GW of far offshore wind. Moreover, sensitivity runs indicate that enabling increased industrial flexibility could further reduce PV capacity with approximately 4 GW. We refer to industrial flexibility as the ability of a production plant to shift its production output as a response to changing energy prices. However, the impact of industrial flexibility is not analysed in more detail in this report.

This comparison indicates that a nearly 100% renewable energy transition is possible and that a LED scenario and additional access to 9 GW of offshore wind capacity, can support a more feasible energy transition. The SHIFT scenario thereby presents itself as a resource-efficient net-zero pathway towards 2050 which balances the need for offshore wind and solar capacity.

5.3. CO_2 emissions

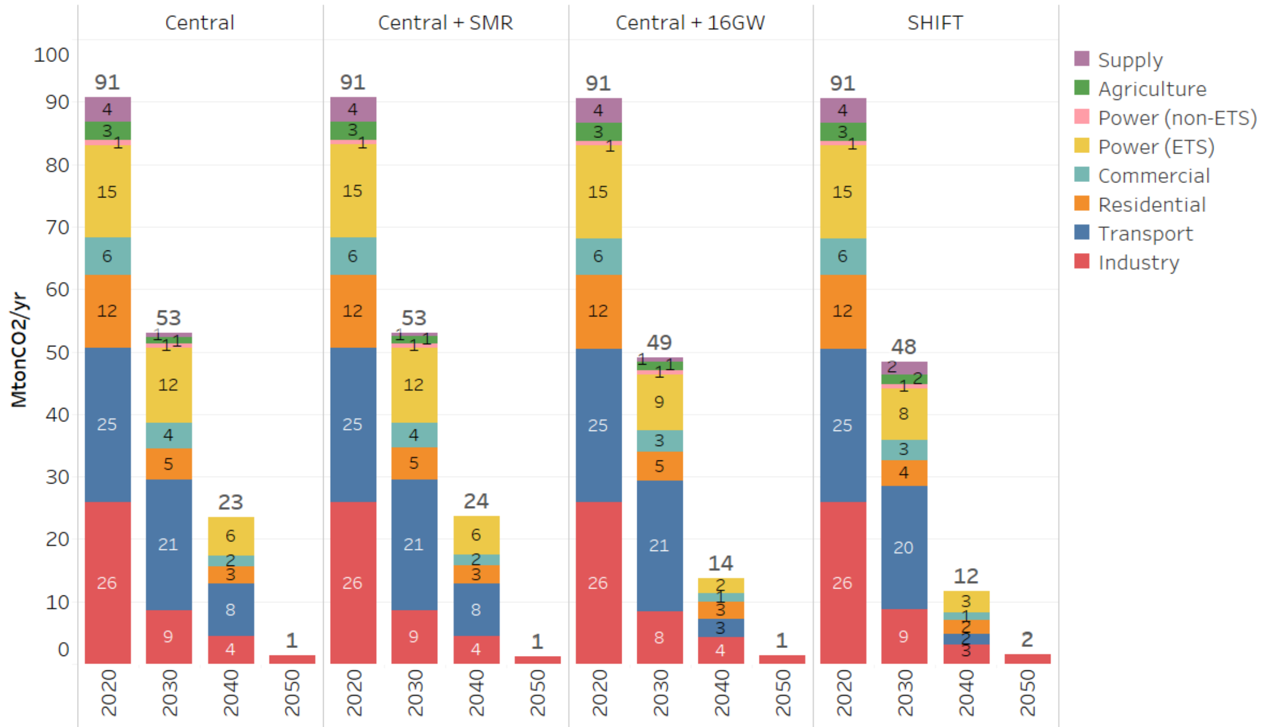

Figure 18: Net annual energy and process CO_2 emissions comparison in MtonCO_2 by sector. Note 1: refineries are represented by the supply sector. Note 2: different scaling in both axes.

Figure 18 presents the net annual CO_2 emissions for each scenario by sector. The figure indicates a similar evolution of the annual emissions for all scenarios in 2030 and 2050. For 2040, however, more diverging trends are present.

In 2040, the Central scenario includes 8 MtonCO_2/yr of transport emissions and 23 MtonCO_2/yr of industry emissions which are partially compensated with 19 MtonCO_2/yr of carbon capture in industry. In the Central+16GW scenario, which includes additional access to far offshore wind, the industry emissions and carbon capture volumes remain the same, while the transport emissions reduce to only 3 MtonCO_2/yr due to the more rapid electrification of the sector in 2040, supported by early access to clean electrons which encourage a faster introduction of electric vehicles.

In the SHIFT scenario, a reduced final energy demand combined with additional access to far offshore wind (9 GW), cause a decrease in the annual emissions compared to the Central scenario in the transition period 2030 and 2040. Similar trends are observed for the power sector and transport sector emission reductions as in the Central+16GW scenario. In the industry sector however, a new trend emerges in the SHIFT scenario. Due to the lower energy demand, industry emissions reduce (from 23 to 17 MtonCO_2/yr in 2040). Consequently, the industry sector becomes less reliant on carbon capture technology. Due to this decrease in CCS capacity, the effects of the lower energy demand are not visible in Figure 18 which illustrates the net annual emissions. Figure 19 does reflect these differences in captured emissions, underlining the main difference in emissions with the Central+16GW scenario.

All scenarios present a remaining 2 MtonCO_2/yr of emissions in oil refineries which are compensated with CCS technology, except the SHIFT scenario which aims to phase-out the oil refineries and eliminate these emissions as well. In total, the SHIFT scenario reduces the annual CCS volumes from 20 MtonCO_2/yr down to 16 MtonCO_2/yr in 2030 and from 21 MtonCO_2/yr down to 13 MtonCO_2/yr in 2040. The SHIFT scenario therefore presents a decarbonization pathway which is approximately 30% less dependent on CCS technology throughout the energy transition. By 2050, the model indicates a robust CCS capacity of approximately 8 MtonCO_2/yr for all scenarios, replacing 2 MtonCO_2/yr of CCS in the supply sector with 2 MtonCO_2/yr in industry in the SHIFT scenario.

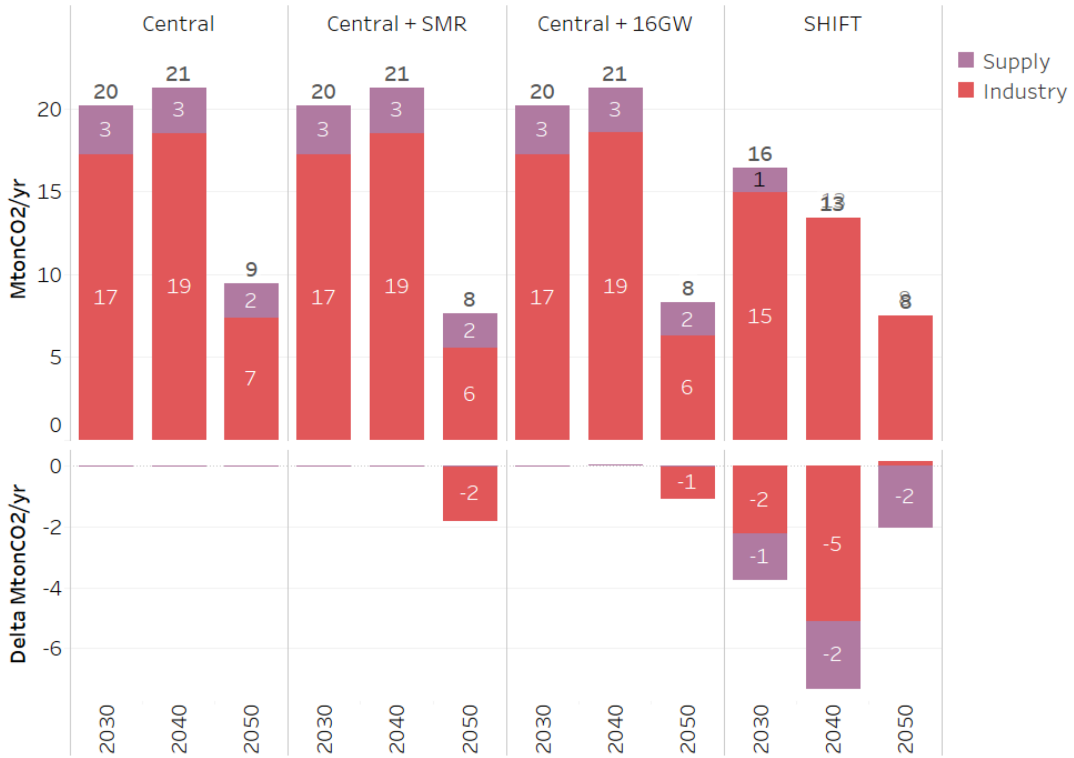

Figure 19: Annual CCS volumes in MtonCO₂ per year: real values (top) and difference to central scenario (bottom). Note: different scaling in both axes.

5.4. Cost

Within this project, we compare the costs of electricity generation as well as the total energy system cost.

- Section 5.4.1: **The cost of electricity generation** refers to the cost for the power sector, covering the investment and fixed operational cost of the generation units and grid infrastructure[54]. We report the total investment and fixed operational costs needs for the reported periods, not the difference compared to a more 'business-as-usual' situation with only limited climate ambition.
- Section 5.4.2: **The total energy system cost** refers to the whole system cost, covering all sectors (including the power sector), such as costs related to the deployment of electric vehicles or heating technologies for buildings. The importance of electricity generation costs is large because of the pivotal role of this sector and its role in attracting investments. The total costs are an important indicator for how much more costly the energy system is compared to a more 'business-as-usual' situation with only limited climate ambition.

The Central+16GW scenario highlights the importance of having access to clean electrons timely, which can drastically bring down the total system cost compared to alternative scenarios that do not include early access to clean electrons, as is illustrated in Figure 20. To reduce the risk associated with the upscaling of supply-side options, the SHIFT scenario presents a more technically feasible alternative which lowers the energy demand through system optimization and more sustainable lifestyles. As a consequence of the lower energy demand, the SHIFT scenario is able to further bring down system costs.

[54] Interconnection expansions are considered as a given. Additional HVDC grid to connect direct far offshore as well as distribution grid costs are included.

5.4.1 Investment and fixed costs of the power system

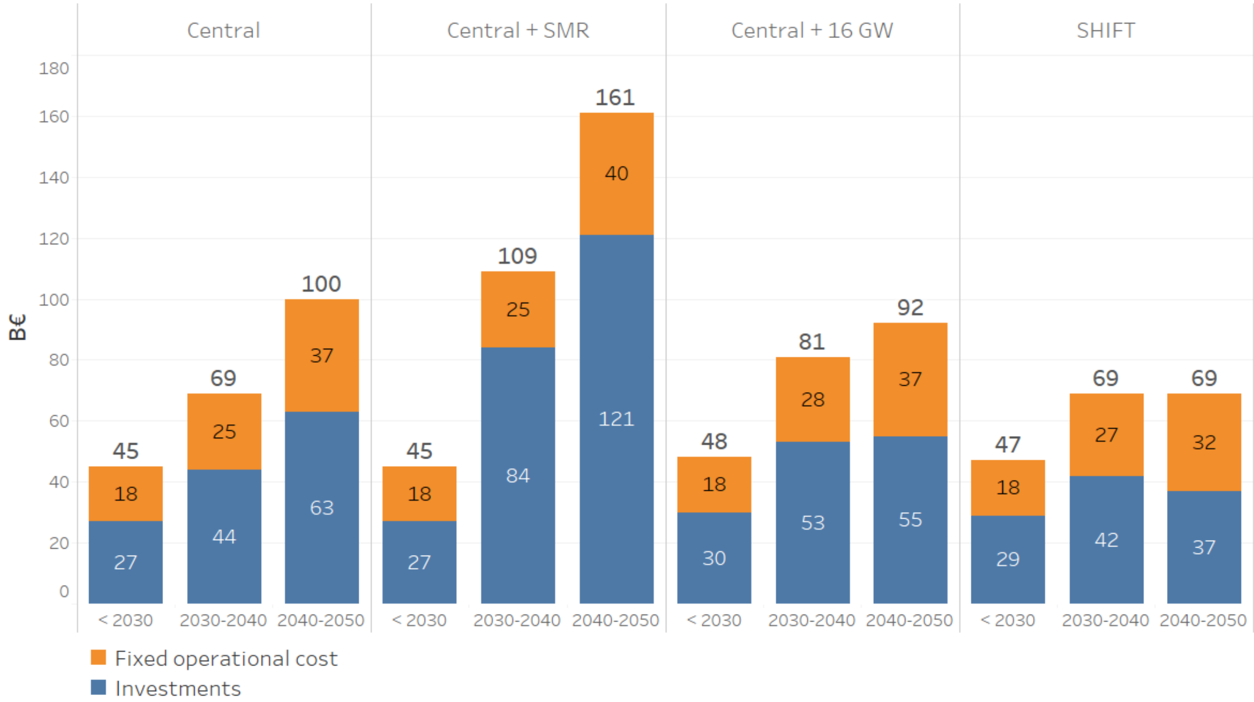

Figure 20: Cumulative power system investment and fixed operational cost expressed in billion euros. Note: 1/3rd of the investment costs for SMR is assumed to occur in the period 2030-2040.

Figure 20 presents the cumulative investment and fixed operational costs for the power system required to accommodate a successful energy transition for Belgium in the coming decades. As a first observation, the Central+SMR scenario shows significantly higher power system costs, mostly related to the investments in nuclear capacity throughout the last two decades, requiring 109 B€ and 161 B€ respectively. This is roughly twice as much as is required according to the other scenarios presented in this graph. The investment cost of nuclear power plants is higher also due to their longer technical lifespan compared to other types of power plants. The total power system cost of the different scenarios over the entire period are: 215 B€ for central; 221 B€ for Central+16GW ; 315 B€ for Central+SMR and 185 B€ for SHIFT.

All scenarios require substantial short-term investments of approximately 45 B€ to happen before 2030. In the following decade (2030-2040), the SHIFT scenario is in line with the Central scenario (also 69 B€), but tempers the costs compared to the 81 B€ in the Central+16GW scenario, and to 109 B€ in the Central+SMR scenario. This cost reduction becomes more pronounced throughout the last decade (2040-2050) where the SHIFT scenario requires 69 B€ compared to more than 92 B€ in all other scenarios, with the Central+SMR scenario reaching 161 B€. In total, the SHIFT scenario can save more than 30 B€ for the power sector transformation by 2050 compared to the other scenarios. Compared to the Central+SMR scenario, the SHIFT scenario can save 130 B€ by 2050. Up to 2050, nuclear requires substantially more investments compared to the other technologies available, however it has a long technical lifetime. Nevertheless, based on our assumptions, nuclear remains more costly than wind offshore. Our model takes into account technical lifespans when optimizing and selecting technologies.

5.4.2 Total additional cost

Different from the previous section, in which the cumulative costs per decade were presented, this section analyses the additional annual costs that are required to realize the energy transition towards a carbon neutral energy system by 2050, compared to a BAU (business as usual) scenario. This BAU scenario presents the unlikely situation of limited climate ambition, assuming a constant carbon price of 50 €/ton CO_2 for all sectors (ETS and non-ETS). Only system costs, such as technology costs and import costs are considered, while taking into account the technical lifespan of each technology (using annualised investments). Costs related to the damage from carbon dioxide or the prevention of those are not included.

Key aspects:

- **The SHIFT scenario demonstrates comparable or lower costs when contrasted with the BAU scenario** that has limited climate ambition and lacks systemic changes on the demand side. Put differently, achieving climate targets incurs no additional cost, on the condition that demand reduction can occur without compromising comfort. Negative costs occur mainly due to a reduced number of cars and reduced output of the production of new materials in industry.
- **In 2050, the SHIFT scenario can save more than 20 B€** in terms of annual total energy system costs compared to the Central and Central+SMR scenarios. Compared to the Central+16GW scenario, the SHIFT scenario can save more than 15 B€ by 2050.
- **The central scenarios have an additional cost to support the energy transition.** Around 2040, the yearly energy system expenses increase by 3 to 5 billion euros compared to the BAU scenario. This sum accounts for approximately 1% of Belgium's 2021 GDP. As we approach 2050, the disparities in annual costs between the different central scenarios to achieve nearly carbon-neutral Belgium grow.
- **Access to additional clean electrons is the most important factor to lower the energy system cost** because it can enable early electrification of demand sectors, especially the transport sector. Not only the cars get electrified but also the trucks. The 'Central+16GW' scenario has more than 18 GW offshore wind power by 2040 which therefore allows the costs to be lower in the long run.
- **The Central scenario and Central+SMR scenario include stranded costs**. These scenarios increase the likelihood of stranded assets, such as replacing an existing diesel truck with a new one that becomes obsolete before reaching its intended lifespan. Insufficient low-carbon electricity in the next decades (up to 2040) in this scenario poses a challenge for certain sectors to transition to electrification, leading them to reinvest in fossil-based technologies that become stranded by 2050.

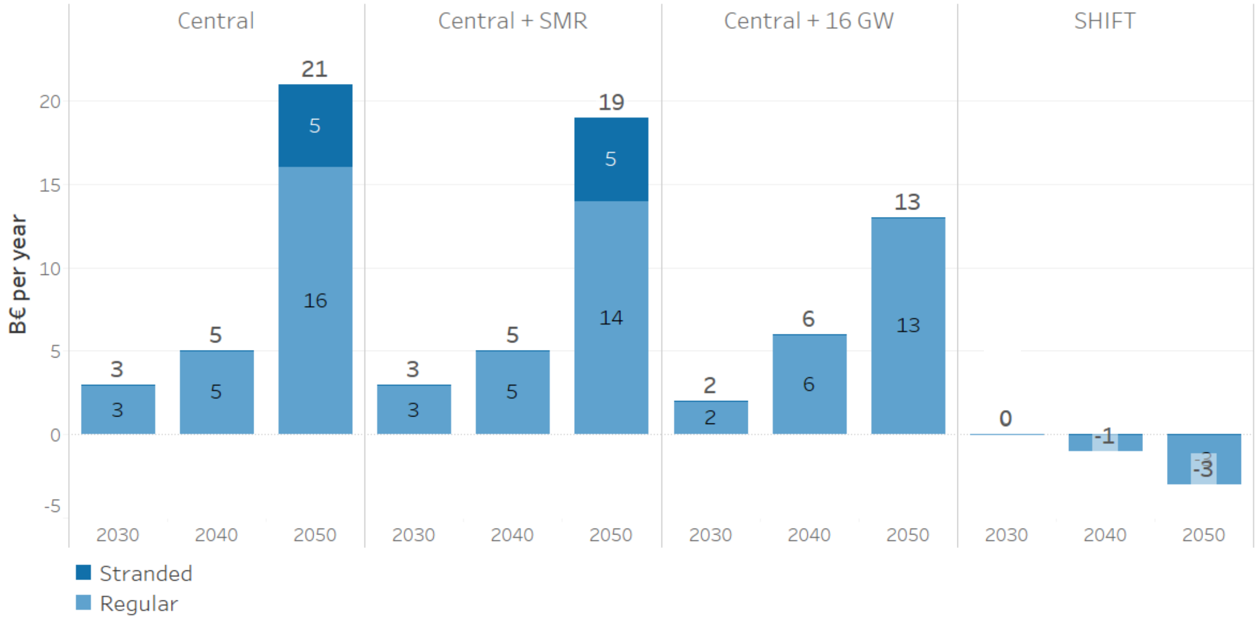

Figure 21: Cumulative total energy system cost expressed in billion euros.

6. Annexes

Annex 1 - Overview and benchmarking of assumptions

This section presents an overview of different possible assumptions regarding energy service demand reduction included in the studies described in Section 3.3. The aim is to provide a benchmarking, reflecting on the assumptions behind the newly developed SHIFT scenario in comparison with alternative sources.

Table 9 lists and characterises each study in the benchmarking, including its geographical scope (from Flanders to EU), reference year, and sectoral scope for benchmarking. The latter lists the sectors for which from this study data was extracted for the bechmarking tables, distinguishing the three sectors: transport, buildings, and industry. Relevant and comparable assumptions were extracted from those studies and reported in Tables 1.2-4. Empty fields indicate that a comparable assumption was not readily available. In the following we summarise main observations per sector.

Transport (Table 10):

- Assumptions for passenger total vehicle kms are roughly in line with alternative studies, however with different underlying assumptions. The CLEVER study, for example assumes a stronger reduction of vehicle kms of road transport, but a less ambitious assumption for trip sharing.
- The TML MVK study looks in more detail to specific measures. Although it doesn't offer a general comparability, it does point to the importance of acknowledging rebound effects, for example in in the estimate of home office impact on passenger kilometers.
- For freight transport, studies consistently assume a reduction of vehicle kms by trucks as the results of modal shift and logistical improvements, not due to a reduction of transported freight as such.

Buildings (Table 11):

- Floor area reduction assumptions can be considered relatively ambitious compared to other studies. The CLEVER study, for example, assumes a minor increase of per capita floor area considering building stock evolution inertia and an expected decrease in the number of people per household.
- Setpoint reductions are commonly assumed, except for TNO TRANSFORM. Contrary to CLEVER and CLIMACT/VITO, in the SHIFT scenario setpoint reduction is only expressed in relative terms.
- For commercial space heating, floor area demand reduction is minor compared to CLIMAT/VITO CORE 95, with the setpoint decrease being additionally included. An important point of reflection is that a shift from production to services could equally entail an increase floor area in the service sector as in TNO TRANSFORM.

Industry (Table 12):

- For industry demand, assumptions for SHIFT are mostly adopted from the BBL/CLIMACT study, extrapolating Flanders to Belgium. These estimates are generally conservative compared to other studies. Crude steel production, for example, in CLEVER decrease twice as much as in SHIFT.
- As an exception, the decrease of cement production adopted from MATERIAL ECONOMICS is relatively strong compared to CLEVER.
- Oil refinery is assumed to be phased out to negligible levels in other studies as well, however somewhat later, by 2050.
- As a methodological side note: comparison to MATERIAL ECONOMICS and TNO TRANSFORM figures has to be done with care considering the difference in geographical scope (EU and Netherlands respectively).

Table 9: Overview of studies included in benchmarking.

Short name	Title	Geographical scope	Sectoral scope for benchmarking	Reference year
BBL/CLIMACT[55]	Een groene industriële revolutie: Hoe creëren we een klimaatneutrale Vlaamse industrie?	Flanders	Industry	2020
CLIMACT/VITO[56] **CORE-95**	Scenarios for a climate neutral Belgium by 2050	Belgium	Transport, Buildings	2015
CLEVER[57]	Climate neutrality, Energy security and Sustainability: A pathway to bridge the gap through Sufficiency, Efficiency and Renewables	EU including details for Belgium	All sectors	2015
MATERIAL ECONOMICS[58]	Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry	EU	Industry	2015
TNO TRANSFORM[59]	Towards a sustainable energy system for the Netherlands in 2050	Netherlands	Buildings, Industry	2020
TML MVK 2018[60]	Milieuverkenning 2018: Achtergronddocument Oplossingsrichtingen voor het mobiliteitssysteem	Flanders	Transport	n.a.

55 https://www.bondbeterleefmilieu.be/artikel/bbl-berekent-zo-wordt-vlaamse-industrie-sneller-klimaatneutraal
56 https://climat.be/doc/climate-neutral-belgium-by-2050-report.pdf

57 https://clever-energy-scenario.eu/

58 https://materialeconomics.com/s//s/s.com/s/s.com///s//s/s.com/s/s.com/s//s/s.com/s/s.com/s//s/s.com/s/s.com/ latest-updates/industrial-transformation-2050
59 https://repository.tno.nl/islandora/object/uuid%3A5c7f19fb-9e6d-4830-9ad6-1e83d1355ece
60 https://archief.algemeen.omgeving.vlaanderen.be/xmlui/handle/acd/761922

Table 10: benchmarking assumptions – transport sector

TRANSPORT	Source for SHIFT	CLIMACT/VITO CORE-95	CLEVER	TML MVK
Passenger	Climact/Vito Core-95 scenario	-6% passenger kilometers per capita (excl. aviation) -21% passenger kilometers by car Average 2.3 persons/car	-30% passenger-kilometers travelled by road (cars, buses, motorcycles) Average 2.0 persons/car	-2.6% to -9.7% passenger. kms (resp. with and without rebound) due to home office (2 days per week for 80 % of employees -29% of vehicle kms resulting from shifts to Light Electric Vehicles, electric bikes and train. -3.9% vehicle kms based on increased commuting occupancy from 1.06 to 1.25
Freight	CLIMACT/VITO CORE-95	+10% freight transport (tonne km) 54% modal share trucks and vans +12.5% load factor	-28% tonne kms travelled by trucks	-15% vehicle kms of trucks and vans due to better logistical processes (rough estimate / expert judgement)

Table 11: benchmarking assumptions – buildings sector

BUILDINGS	SHIFT	CLIMACT/VITO CORE-95	CLEVER	TNO TRANSFORM[61]
Floor area	CLIMACT/VITO CORE-95	-16% per capita floor area	+2% per capita floor area	+2% number of residential buildings
Space heating temperature set point	Setpoint temperature lowered by 1 degree	18 degrees setpoint temperature	19 degrees setpoint temperature	No change
Commercial space heating	-16% per capita work space 14% activity increase Setpoint temperature -1 degree	-7.5% non-residential floor area demand.		+16% gross floor area services sector*

[61] Relative change TRANSFORM 2050 relative to ADAPT 2030 (2020 data not available)

Table 11: benchmarking assumptions – industry sector

INDUSTRY	SHIFT	BBL/CLIMACT	CLEVER	MATERIAL ECONOMICS	TNO TRANSFORM[47]
Iron & steel	BBL/CLIMACT	**-10%** Production of both primary and recycled steel (shares remain)	-21% (-49% / +56%) Production of crude steel (primary / recycled)	-18%	-25%
High value chemicals	BBL/CLIMACT	-18%: combination of -13% demand reduction and +22% recycling rate		-28%	-11% Based on ethylene production
Ammonia	BBL/CLIMACT	**-15%**		-48%	-53%
Non-ferrous	BBL/CLIMACT	**-11%**			-92% Based on primary aluminium production
Cement	MATERIAL ECONOMICS		-31%	**-39%**	
Ceramics	BBL/CLIMACT	**-33%**			-21%
Oil refineries	Own assumption: -90% by 2040 and -100% by 2050	**-100%** Phased out by 2040	Minor to negligible role for oil refinery in 2030 and 2050 resp. (see Sankey diagrams in Annex 1-3)		Near phase out of oil based fuel production by 2050 (see Sankey diagrams Figure 4.19)

Annex 2 – Data tables

	Central			Central+SMR			Central+16GW			SHIFT		
Period	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Power system capacity GW												
Wind onshore	5	12	20	5	12	13	5	12	12	5	10	12
Wind offshore	3	8	8	5	8	7	8	8	8	8	8	8
Extraterritorial wind offshore	0	0	0	0	0	0	0	11	16	0	8	9
PV	25	57	97	24	55	46	21	32	56	20	29	49
Hydrogen	0	1	8	0	0	0	0	0	4	0	0	4
SMR	2	0	0	2	0	14	2	0	0	2	0	0
Imports TWh												
Electricity	7	22	32	8	23	9	6	9	15	6	9	16
Hydrogen or derived	0	2	36	0	1	3	0	1	19	0	1	19
Climate												
CO_2 % reduction	-56%	-80%	-98%	-56%	-78%	-98%	-59%	-88%	-98%	-60%	-90%	-98%
CCS [MtonCO_2/yr]	20	21	9	20	21	8	20	21	8	16	13	8
Costs												
Power sector [B€ per 10 years]*	45	69	100	45	109	161	48	81	92	47	69	69
*Annual additional costs** [B€ per year]*	3	5	21	3	5	19	2	6	13	0	-1	-3

(*) Sum of investments and fixed operation and maintenance costs
(**) Negative costs occur mainly due to a reduced number of cars and reduced demand for energy services