Scenarios for a climate neutral Belgium by 2050

May 2021

FPS Public Health - DG Environment
Climate Change Section

https://climat.be/2050-en
https://klimaat.be/2050-en

Content

Summary

Climate neutrality is the new policy context in which any societal prospective analysis needs to be framed since the adoption of the Paris Agreement and the recent developments at the European level. This work provides new insights on pathways and actions to be deployed for reaching climate neutrality by 2050 in Belgium. As such, the analysis contributes to underpin the development of a broad, quantitative vision on the transition in Belgium, while identifying the necessary transformations. Therefore, it allows us to take more informed strategic decisions.

An innovative methodology

A set of five main scenarios are built on the basis of the Belgian “2050 Pathways Explorer”, which is an energy accounting model extended to materials, products, land and food systems. The model is based on a series of levers that allow for potentially strong technological developments as well as radical changes in societal organisation and behavioural patterns. A key feature of the model consists in outlining all potential decarbonisation options, thereby offering a broad view on the challenges of the transition, in particular on a series of trade-offs between sectors and fields of activity. Given this broad view offered by the model, certain specific aspects of the transition nevertheless need to be explored more thoroughly by complementary, sector-specific modeling analyses.

As Figure 1 on p. 10 shows, besides a “REFERENCE”, business-as-usual scenario, two scenarios shed light on the technological versus behavioural dimensions underpinning climate-neutral scenarios: the “BEHAVIOUR” scenario emphasises transformational changes in mobility, housing and dietary patterns, while the “TECHNOLOGY” scenario relies more heavily on technological developments. A “CORE-95” scenario is defined based on a balanced approach between these two dimensions. A fourth scenario, the “HIGH DEMAND” scenario, is set to explore the implications of a pathway characterized by a significantly higher level of energy demand than in the other climate neutral scenarios and by constant industrial production volumes in 2050 when compared to 2015. Finally, a set of sensitivity analyses are performed on the basis of the CORE-95 scenario in order to analyse impacts from energy mixes focusing either on electrification (“ELEC”), hydrogen (“H_2”), e-fuels (“E-FUELS”) or biomass (“BIO”).

The different pathways described here are not prescriptive in nature. They should be considered as a set of narratives that allow a concrete understanding of possible implications of the transition in Belgium, while inviting everyone to reflect on them and to build their own transition scenario.

Transversal results

Reaching climate neutrality in Belgium by 2050 is technically feasible, even though it is particularly challenging and requires systemic changes. New technologies such as hydrogen, e-fuels, direct air capture or bioenergy with carbon capture (BECCS), as well as new consumption and production patterns are needed in all scenarios. Furthermore, while greenhouse gas (GHG) emissions can be reduced to zero in the buildings, transport and energy production sectors, some hard-to-abate emissions in the industrial and agricultural sectors will remain and will need to be offset by negative emissions through land use, direct air capture and storage or BECCS. In 2050, these negative emissions will need to amount to between 7 and 11 $MtCO_2e$ (8 $MtCO_2e$ in the CORE-95 scenario, of which 4 $MtCO_2e$ in the LULUCF sector – see Figure 2 on page 12).

In all scenarios, energy demand decreases significantly and fossil fuels are gradually phased out through electrification and the use of carbon neutral fuels. The decrease in final energy demand amounts to as much as 57% in 2050 in the CORE-95 scenario w.r.t. the REFERENCE scenario (with 62% in the BEHAVIOUR scenario and 33% in the HIGH DEMAND scenario – see Figure 4 on page 15). Electrification of the demand sectors, combined with a power production system based entirely or almost entirely on renewable energy sources, is the main avenue to gradually phase out the use of fossil fuels. Since electrification is not possible for all energy end-uses, it needs to be complemented with the deployment of climate-neutral fuels. Biomass will be used to some extent but its potential, although significant, remains limited and is strongly linked to land use choices. Hydrogen and e-fuels will be required to close the gap, especially for use as industrial feedstocks. Finally, the small amount of fossil fuels remaining in the industry need to be combined with CCUS.

Material demand is much lower than current levels in all climate neutral scenarios. When expressed in terms of tons of materials, the demand decrease ranges from more than 50% in the BEHAVIOUR scenario to less than 30% in the HIGH DEMAND scenario, with 44% in the CORE-95 scenario (w.r.t. the REFERENCE scenario – see Figure 7 on page 18). This is driven by drastic changes in consumption patterns that are characterized by a strong reliance on the sharing economy and the economy of functionality, as well as behavioural changes with respect to mobility (reduced travel demand, modal shift, …), housing (smaller living spaces), diets and waste. These changes are much more pronounced in the BEHAVIOUR scenario. Changes in production patterns also impact material demand significantly, especially material efficiency (by improving product design, using more efficient materials or reducing material losses) and material switch. Changes in diets also lead to profound changes in the agricultural sector, which in turn has a strong impact on land use through freed up land that can be used to stimulate carbon absorption and, potentially, biodiversity depending on how the freed up land is used.

Additional investments in infrastructure are required but can be limited, depending on the extent to which behaviour changes and the circular economy develops. In all decarbonisation scenarios, additional capital expenditures in climate friendly infrastructure are required in all sectors. Total capital expenditures are nevertheless significantly reduced when demand for energy-consuming activities, products or services decreases as a result of behavioural changes and the transition to a more circular economy. In the BEHAVIOUR scenario, these additional investments are about 12% higher than in the REFERENCE scenario, while this increase amounts to about 26% in the TECHNOLOGY scenario. Fuel cost reductions tend to compensate capital expenditure increases. Although electricity expenditure increases in all sectors, fossil fuel expenditure reaches almost zero in the long run. The price and consumption levels of hydrogen and e-fuels, including for use as feedstock, therefore become a determinant element of total fuel expenditures in the future.

Sectoral results

Buildings

In the buildings sector, the renovation rate and depth need to drastically and quickly increase. The renovation rate needs to move from 1% per year to about 2.5 to 3% per year and the depth of such renovations also needs to evolve from shallow to mainly deep renovations. These renovations go along with an increased need for materials, about 3 times higher than in the REFERENCE scenario. For new constructions, however, the demand for materials can be drastically reduced by limiting the surface in both residential and non-residential buildings, as it is the case in the BEHAVIOUR and the CORE-95 scenarios where material demand for new buildings is divided by around 3, as opposed to a reduction of only about 20-25% in the TECHNOLOGY and HIGH DEMAND scenarios.

Fossil fuels are completely phased out in the buildings sector and electricity becomes the most important energy vector, representing more than 80% of the final energy demand in the CORE-95 scenario. Biomass and H_2/e-fuels complement the energy mix, mainly where electrification is too difficult or costly to implement. Finally, behavioural changes, such as for instance keeping the demand for cooling needs under control, are key in order to keep final energy demand in 2050 at much lower than current levels, i.e. decreases between 46% and 63% in the HIGH DEMAND and BEHAVIOUR scenarios, respectively.

Transport

In the transport sector, total energy demand can be strongly reduced through a set of behavioural levers, such as a lower transport demand per capita, a higher degree of vehicles' occupancy, a higher load factor of trucks, and a strong modal shift towards public transport and active modes (passengers) and towards rail and inland waterways (freight). These behavioural levers together lead to a reduction of more than 50% of final energy demand in the CORE-95 scenario w.r.t. the REFERENCE scenario (from 64% in the BEHAVIOUR scenario to 1% in the HIGH DEMAND scenario). Together with the development of the sharing economy that increases the utilisation rate of vehicles, the total number of registered cars and trucks falls drastically in all decarbonisation scenarios, and especially in the BEHAVIOUR scenario.

Technological switches, in particular electrification, also have a major impact on energy demand and greenhouse gas emissions. Decarbonised electricity and fuels allow to reach a complete decarbonisation of the sector. Even though different energy mixes can be considered for this sector, electrification (batteries) always reaches very high levels in passenger transport, while hydrogen, e-fuels and potentially biofuels will likely need to play a larger role in freight transport.

Industry

Industry is a hard-to-abate sector where remaining energy efficiency gains are lower than in the other sectors, while electrification cannot be pushed to the same extent. Carbon neutral fuels (hydrogen, e-fuels and biomass) will need to be deployed where electrification is not possible, and as industrial feedstocks. Furthermore, end of pipe CCUS will need to be deployed, in combination with BECCS, by an amount ranging from 7 MtCO2e in the BEHAVIOUR scenario in 2050 to 17 MtCO2e in the HIGH DEMAND scenario.

New consumption and production patterns based on a circular economy have the potential to considerably reduce energy demand and use of resources, and thereby greenhouse gas emissions. As stated above, changing consumption patterns, such as reducing packaging, food waste, and adopting more sustainable consumption patterns, as well as changing transport patterns such as sharing cars, extending their lifetime and better organizing travel demand and improving logistics, have a strong impact on material demand. If such changes are implemented on a broad scale, they will likely impact the volumes of domestic production of goods and materials. Furthermore, changing production patterns such as material efficiency through better product design, using more efficient materials, reducing material losses and switching towards less GHG intensive materials, are also reducing resources and energy use, and thereby GHG emissions. While production volumes decrease in most illustrative scenarios, the total value of this production does not necessarily decrease.

Power

Total electricity demand will be significantly higher than current levels, with an increase by about 25% in the BEHAVIOUR scenario to 90% in the HIGH DEMAND scenario (38% - reaching 121 TWh in the CORE-95 scenario) by 2050, assuming that about 20% of the domestic hydrogen and e-fuels demand is produced domestically. Raising this share of domestic production increases total electricity demand considerably.

Producing 100% renewable electricity is achievable, even in high electricity demand scenarios, provided that intermittency is adequately managed. We assume a level of electricity imports between 20 and 30% by 2050 in our main scenarios, acknowledging that higher or lower levels could be set. Under this assumption, the renewable energy potential is sufficient to fully cover the electricity demand in all scenarios, mainly through an installed capacity in solar PV of between 30 and 46 GW, an onshore capacity up to between 8 to 9 GW (11 GW in the HIGH DEMAND scenario) and an offshore capacity up to 6 GW in Belgian waters, to be increased by up to 2 to 6 additional GW elsewhere in the North Sea.

Agriculture

In the agricultural sector, gradual but transformative changes of consumption patterns and agricultural practices are required to reach climate neutrality by 2050. On the demand side, a series of levers need to be deployed to reduce GHG emissions such as strong changes in total calories consumption (-34% and -15% w.r.t. current levels in the BEHAVIOUR and TECHNOLOGY scenarios, respectively), the type of diets and food waste. On the supply side, some trade-offs need to be made regarding changes in agricultural practices (towards a lower use or no use of synthetic fertilisers and (chemical) pesticides), climate-smart livestock and land management in order to further reduce emissions.

Remaining emissions can be compensated by increased natural absorption. The transformation of agricultural practices and consumption patterns, and the related reduction of livestock allow to free up a significant part of land that can be converted in natural prairies, forests or non-food cropland. Such a gradual reallocation of land leads to an absorption of between 3.7 MtCO2e (BEHAVIOUR scenario) and 4.9 MtCO2e (TECHNOLOGY scenario) in 2050, thereby contributing to reaching climate neutrality in this time horizon.

1. Introduction: climate neutrality context

At international level, in order to formulate a solution to the climate urgency, 195 Parties to the UN Framework Convention on Climate Change (UNFCCC) agreed in Paris in December 2015 to jointly take actions to combat climate change under the so-called Paris Agreement. Under this agreement, Parties committed to holding the increase in the global average temperature to well below 2°C above preindustrial levels and to pursuing efforts to limit the temperature increase to 1.5°C. In order to be able to reach this objective, global greenhouse gas emissions need to decrease as soon as possible, and a balance between anthropogenic emissions and removals (i.e. climate neutrality) must be achieved in the second half of this century. Furthermore, Parties committed to developing long-term low GHG emissions development strategies.

At EU level, taking into account the then recently published 'Special Report on Global Warming of 1.5 °C' by the IPCC, the European Commission presented several pathways to respect the commitments taken under the Paris Agreement[1] in November of 2018. Some of these pathways assess how Europe is to transition towards net-zero emissions by 2050. Following discussions at the level of the European Council, the EU adopted the objective of a climate-neutral EU by 2050. This objective will be anchored in the "European climate law", a cornerstone of the European Commission's Green Deal that intends to provide predictability for investors and other economic actors and to create a system for monitoring progress, as well as to ensure that all policies and measures are aligned with the EU's long-term objective. In December 2020, the European Council also aligned the EU's 2030 climate objective with its 2050 objective by increasing it to a net reduction of greenhouse gas emissions of 55% by 2030 compared to 1990. In the context of the current crisis related to Covid-19, the Green Deal is perceived as an opportunity to accelerate the transition while simultaneously boosting the economic recovery.

Belgium approved its long-term strategy in the course of February 2020 and subsequently submitted it to the EU in accordance with the Governance Regulation, as well as to the UNFCCC[2]. The four governments within Belgium, nevertheless, agreed to review the submitted strategy as it is currently seen as a 'minimum' engagement and does not currently include the objective of climate neutrality by 2050. In the context of the development of Belgium's long-term strategy, the federal administration prepared a vision document in which it sets out the objective of climate neutrality by 2050 for the country as a whole, while presenting the main levers that need to be activated in each sector in order to reach this objective and identifying the crucial areas or workstreams where further work and interaction with stakeholders is needed to make the transition happen.

This vision document, that intends to guide further work, was partially based on preliminary results from the modelling exercise of which this document will present the main outcomes, namely possible pathways and/or requirements for reaching climate neutrality in Belgium by 2050. The different pathways described here are not prescriptive in nature. They should be considered as a set of narratives that allow a concrete understanding of the implications of the transition in Belgium while inviting everyone to discuss them by formulating their own transition scenario on the basis of the simulation tool available online.

[1] In its communication "A Clean Planet for all: A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy".
[2] The submitted strategy can be found on https://unfccc.int/process/the-paris-agreement/long-term-strategies.

The following section briefly presents the methodology followed and the exploratory scenarios modelled. A series of 20 messages are then formulated and analysed. The third section presents the main cross-cutting issues, while the fourth section details the messages by emission sector. Finally, conclusions and perspectives are presented in the last section.

2. An innovative methodology linking emissions, energy, resources and land

In 2013, the Climate Change Service of the federal administration published its “Scenarios for a low carbon Belgium by 2050” together with the online model underpinning the analysis. This work has led to a series of accompanying studies, among which the analysis of the macroeconomic impact of low carbon scenarios in Belgium. However, in the meantime, this work faced several shortcomings and needed to be updated for several reasons. First, new data are available and trajectories need to be analysed from a more recent starting point. Second, the initial analysis looked at the 80 to 95% GHG reduction range while the context described in the introduction has evolved towards the need to explore climate neutrality by 2050. Third, more and more attention must be paid at policy level on the interactions between energy-GHG emissions and other dimensions, such as natural resources and biodiversity.

2.1 The “2050 Pathways Explorer”: a transparent, levers-based model

A new modelling tool, the “2050 Pathways Explorer”, was developed by Climact[3] on the basis of the EU funded Horizon2020 project “EUCalc”. The “2050 Pathways Explorer” is a model of energy, land, materials, product and food systems that can be applied for delineating emission and sustainable transformation pathways. While optimisation models are often used in climate policy analysis (e.g. economic optimisation), the massive uncertainties arising from taking a long-term horizon as 2050 or beyond mean that optimizing on certain factors like costs is at the least extremely challenging, meaning these models should be complemented with other approaches to defining possible long-term trajectories, particularly if one wants to include the potential of breakthroughs or non-linear changes. Addressing these system dynamics with a bottom-up, driver and lever-based model provides a very powerful and complementary alternative.

The Pathways Explorer has these two concepts at its core: first, it defines calculation sequences based on material, energy, land and emissions drivers and, second, it offers the user a range of ambition levels for each of these drivers. These drivers are called levers and they are at the centre of the scenario creation logic. Estimates of the end-use service demand (e.g. buildings heating, appliances usage, car road travel, freight demand, etc.), of the demographic evolution, and of the techno-economic trends are defined by the user and mapped by so-called levers representing various ambition levels for policy making.

Based on the lever ambitions that the user sets, the model supplies the energy to fulfill the resulting demand. The calculation of GHG emissions is therefore based on the amount and the type of energy used as well as the selected agricultural and industrial practices. Rather than calculating optimal pathways, the model allows the user to choose the ambition level of each individual lever (from a reference level up to maximum technical ambition) and thereby explores different scenarios or pathways to 2050. The investment costs of each pathway are estimated by adding the annual capital expenditures (e.g. for new infrastructures or assets), operational costs (e.g. maintenance) and fuel costs. Air pollution emissions are also available. As mentioned above, the tool therefore complements

[3] With the support of VITO and Espaces-Mobilités.

other modelling approaches focused on specific sectors or issues[4], in such a way that it allows for a systemic transition perspective.

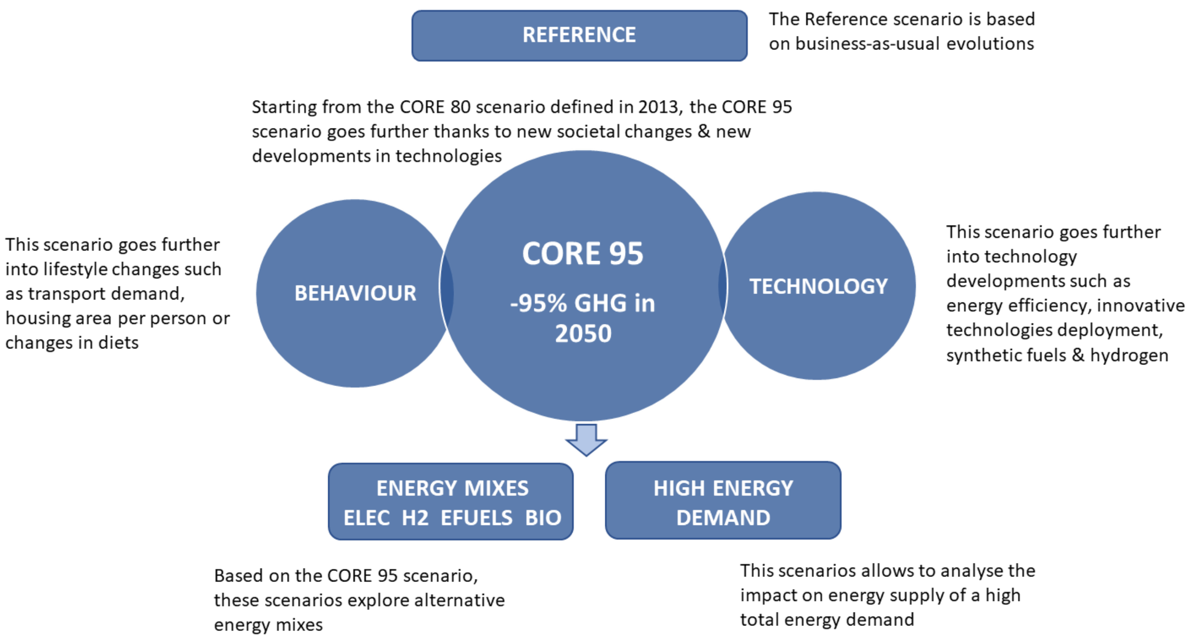
The "2050 Pathways Explorer" is available online at https://climatechange.be/2050. The detailed description of each lever, of its predefined ambition levels and of the sources from which the analyses are performed, is available on the tool itself. Complementary documents that allow a better understanding of the overall and sector-specific modelling logics are also available on the website.

2.2 A set of illustrative climate neutral scenarios

A series of scenarios leading to climate neutrality have been developed and predefined in the online calculator. The degree of ambition of each lever and detailed results are available online. They are briefly summarised in Appendix 1.

As stated above, the purpose is not to be prescriptive but rather to quantitatively illustrate key issues, trade-offs and potential implications of the transition at the system and at the sectoral levels. These scenarios are an invitation to everyone to define its own transition scenario. They are illustrated in Figure 1.

Figure 1: Illustrative scenarios



[4] See for instance the recent analyses by the Federal Planning Bureau on the energy production sector: D. Devogelaer (2020), "Fuel for the future – More molecules or deep electrification of Belgium's energy system by 2050" , *Working Paper 04-20,* Federal Planning Bureau, as well as these by VLAIO on the key industrial sectors in Flanders: Deloitte (2020), "*Naar een koolstofcirculaire en* CO_2*-arme Vlaamse industrie*", Report for the Flanders Innovation and Entrepreneurship Agency (VLAIO), November.

A “Reference” scenario is built based on business-as-usual evolutions and lead to a stabilisation of GHG emissions at a level similar to the current level. It is against this scenario that climate neutral scenarios can be assessed.

The main climate neutral scenario is called the “CORE 95” scenario and leads to a reduction in GHG emissions of about 95% in 2050 w.r.t. 1990 and to so-called negative emissions of about 5% of 1990 GHG emissions, thereby leading to climate neutrality by 2050.

The CORE 95 scenario is a balanced scenario in the middle of an axis between either a series of profound changes in behaviour, lifestyle and marked societal changes in the way people move, house, feed themselves and consume, and more marked technological changes. This axis contrasts the CORE 95 scenario from the "BEHAVIOUR" and "TECHNOLOGY" scenarios.

A second axis of analysis around the CORE 95 scenario concerns more specifically the energy mix. Here, decarbonation trajectories are tested that rely more heavily on electrification ("ELEC"), hydrogen ("H2"), e-fuels ("EFUELS") or biomass ("BIO"). Almost all parameters other than the energy mix are similar to those defining the CORE 95 scenario.

A third axis of analysis concerns the absolute level of energy demand. Starting from the observation that it is very strongly reduced in the scenarios given above, in particular when major changes in behaviour are assumed to take place, the idea is to study the implications of a lower reduction in energy consumption in a scenario called "HIGH ENERGY DEMAND". In particular, unlike the other scenarios, this scenario assumes that industrial production volumes are not related to the national demand for products and materials but are constant over time.

In the next section, we draw and illustrate six key transversal messages that can be derived from the analysis of this set of scenarios.

3. Transversal results

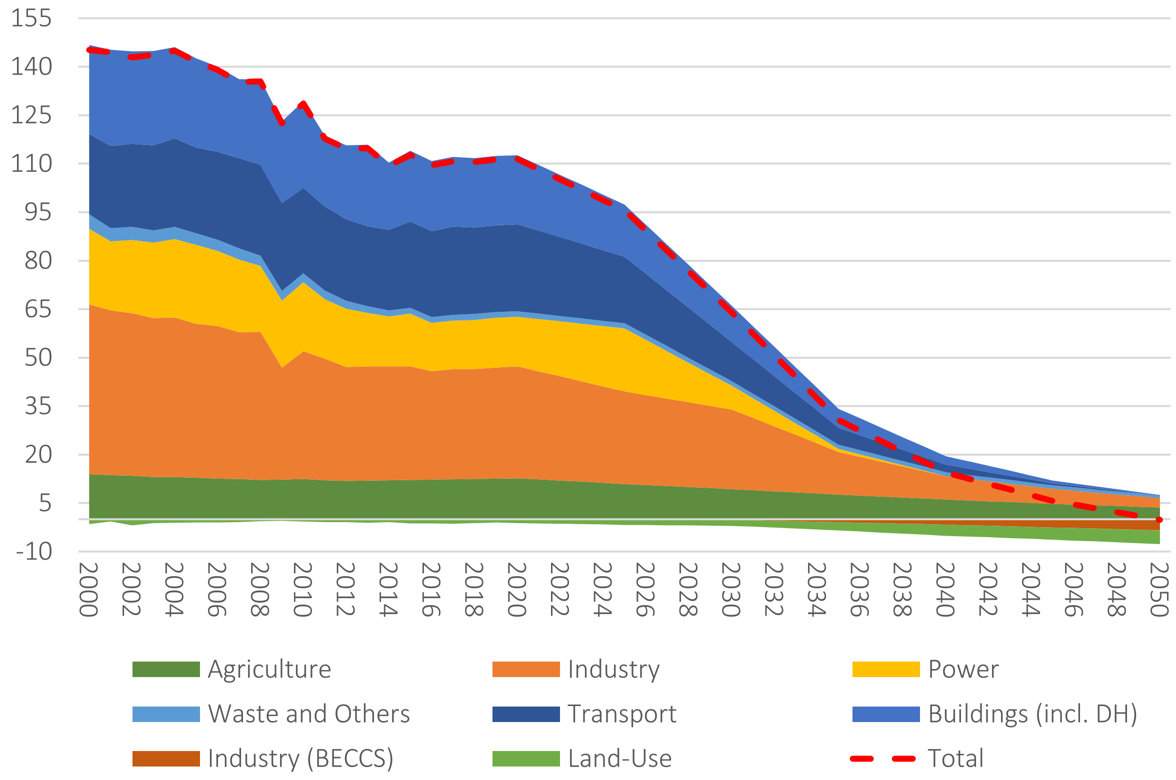
3.1. Greenhouse gas emissions

1

It is technically feasible to reach climate neutrality by 2050 in Belgium and several trajectories can be pursued. The hardest to abate sectors are the industry and agriculture. The buildings, transport and power sectors need to be completely decarbonised by 2050.

In 2013, the "Scenarios for a low-carbon Belgium by 2050" study showed that it was technically possible, although already very ambitious, to achieve emission reductions in the order of 80% or even 95% in 2050 compared to 1990. This study also showed that several trajectories could be followed in order to achieve such objectives.

Figure 2. GHG emissions – historical and CORE-95 scenario (2000-2050, $MtCO_2e$)



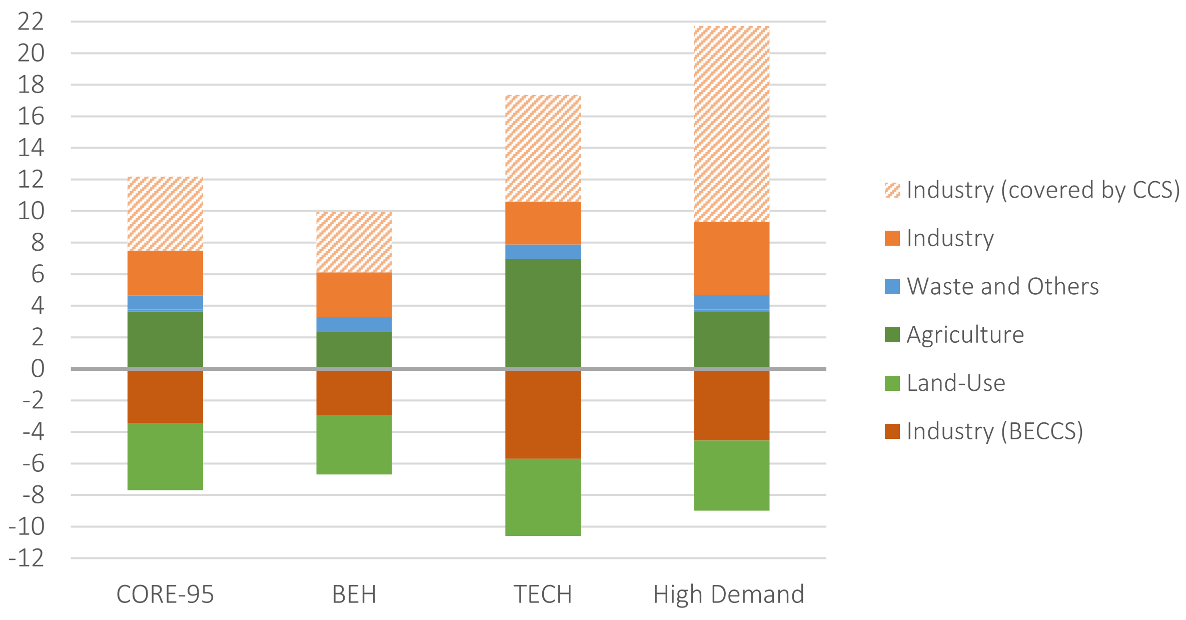
It is clear from the current study that aiming for climate neutrality by 2050 requires all available levers to be operated at very ambitious levels, as well as the implementation of new levers that had not been explored in 2013, such as those relating to the circular economy and the economy of functionality, land-use management and new technological solutions such as synthetic fuels, "direct air capture (DAC)" and "bioenergy with carbon capture and storage (BECCS)". In other words, systemic changes are needed across all sectors to reach climate neutrality, which will only be attained through the deployment of ambitious policies and measures that target both behavioural, societal and technological breakthroughs.

Industry and agriculture are the source of many GHG emissions that, unlike other sectors, do not originate or do not originate directly from energy use. In these cases, decarbonation of the emission source is not always feasible, as is the case with the replacement of fossil fuels by renewable energy sources in buildings or transport, for example.

Therefore, regardless of the climate-neutral scenario chosen, emissions must be reduced to zero or near-zero in the buildings, transport and power generation sectors. Emission reductions in the industry and agriculture sectors need to be extremely large, with residual emissions having to be offset by some form of sequestration. Figure 2 illustrates the evolution of GHG emissions in the different sectors and in total between 2000 and 2050 in the CORE-95 scenario, including the levels of sequestration needed to offset emissions from industry and agriculture and as such reach climate neutrality in 2050. In the main illustrative scenarios, total levels of emission reductions achieved by 2050 range between 93% and 96% compared to 1990. A more detailed discussion is provided in the sections relating to the different sectors concerned.

While the buildings, transport and power production sectors will have to be (almost) fully decarbonised in order to be able to reach climate neutrality by 2050, some emissions in the industry and agriculture sector will be hard to abate.

Figure 3. Emissions and removals in 2050 (in $MtCO_2e$)



The emissions in agriculture and industry combined amount to 11.2 Mt in the CORE95 scenario in 2050 and 9.0 and 16.4 Mt in the Behaviour ("BEH") and Technology ("TECH") scenarios, respectively (see Figure 3). In order to achieve climate neutrality, these will therefore have to be offset by natural carbon absorption, CCS, BECCS and/or DAC.

Regarding natural carbon uptake, its capacity will, to a large extent, depend on land use (management). The evolution of the agriculture sector (see message #17 below) will not only be a key variable for the reduction of non-CO_2 emissions from livestock and land use, but also in this context, because agricultural land could be freed up and transformed into forest or grasslands, thereby sequestering CO_2. This carbon sequestration varies between 3.7 and 4.9 Mt in the three main climate neutral scenarios (i.e. at least three times more than in 2015). More details are provided in message #18 below.

The BECCS technique is likely to be applicable to power generation and industry. Since energy production can be envisaged with a very limited use of sustainable biomass, the use of BECCS is limited to the industry in the illustrated scenarios. The emissions stored through this technique amount to between 3 and 5.7 Mt in the three main scenarios. Industry emissions covered by CCS vary between 3.8 and 6.8 Mt in the three main scenarios (while over 12 Mt of industry emissions would need to be covered through CCS in the High demand scenario, where industrial production in 2050 is kept at comparable levels from 2015).

DAC is the direct capture of carbon from the air. Given the low concentration of carbon dioxide in the air, this is a particularly energy-intensive process, its use requiring a significant amount of electricity. In the modelling, it was assumed that DAC is only used to provide the carbon needed to produce e-fuels in order to make them carbon neutral. It would also have been possible to imagine the deployment of DAC to achieve carbon uptake by combining it with subsequent sequestration or permanent use of carbon.

However, although the latter two technologies have been deployed in the illustrative scenarios, these have yet to be demonstrated at a large scale. Nevertheless, a lot of research on the full and large scale deployment of these technologies is being performed[5].

Finally, it is important to note that decarbonisation of feedstocks in industry is considered in the model, whereby fossil fuels are partly replaced by decarbonised alternatives (mainly biomass, hydrogen and e-fuels). Therefore, carbon is captured in these materials (feedstocks), which allows to lock-in negative emissions related to these feedstocks for many years. In the CORE 95 scenario, these amount to 10 Mt in 2050[6].

3.2 Energy

2

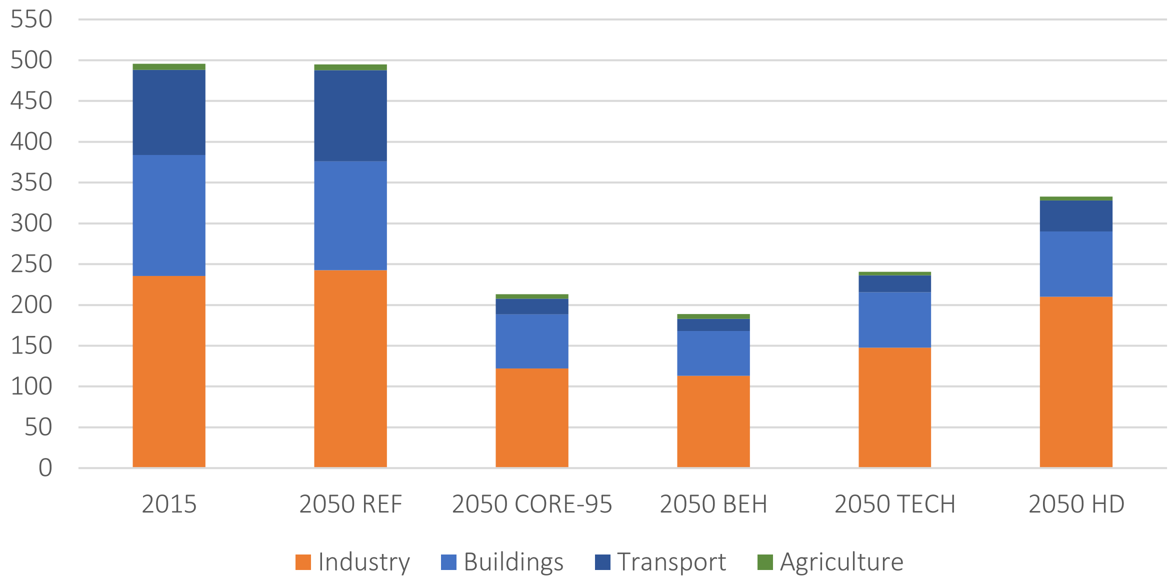
Energy demand decreases significantly in all sectors.

Total final energy demand (including feedstocks) reduces significantly in all decarbonisation scenarios and even drastically in some of them through both changes in activity levels resulting from strong behavioural changes and through technological switches and breakthroughs (see Figure 4).

[5] The European Commission also expects these technologies to be fully deployed over time and therefore has foreseen their use in the 2050 scenarios it presented in 2018.

[6] These data are shown in the "2050 Pathways Explorer", but are not accounted for in total GHG emission (reduction) levels. In this regard, total GHG emission (reduction) levels are considered to be conservative.

Figure 4. Final energy demand per sector and in total (in TWh, incl. industrial feedstocks)



Total reduction in final energy consumption with respect to the REF scenario amounts to 57%, 62% and 51% in the CORE-95, BEH and TECH scenarios respectively[7]. The reduction is drastic in several sectors, as can be seen in Figure 4. In industry, final energy consumption in 2050 is 50% lower in the CORE-95 scenario when compared to the REF scenario, while it is 53% lower in the BEH scenario and 39% lower in the TECH scenario. In the buildings sector, the final energy consumption reductions by 2050 amount to 50%, 59% and 49% respectively. Ambient energy, although not accounted for in final energy demand, amounts to around 17 TWh, 15 TWh and 28 TWh, respectively, representing between 26% and 41% of energy demand in the buildings sector in 2050 that would otherwise also have to be produced in a decarbonised way. In the transport sector, final energy consumption in 2050 is 83% lower in the CORE-95 scenario (compared to the REF scenario), 87% lower in the BEH scenario and 81% lower in the TECH scenario. In the agriculture sector, the respective final energy consumption reductions amount to 26%, 19% and 41%.

In the modelling approach, several levers related to behavioural and societal changes on the one hand, as well as levers related to important aspects of the circular economy and the "economy of functionality" on the other hand are well developed when compared to other modelling tools. As we shall see later on, the use of these levers contributes to a considerable energy demand decrease across all sectors. This is particularly noticeable in the BEH scenario and in the CORE-95 scenarios, while it is less pronounced in the TECH scenario. Alternative, higher demand scenarios are also explored in order to gain additional insights, as can be seen in Figure 4 and throughout this document. In the high demand scenario shown in Figure 4, total final energy demand in 2050 decreases by around 33% when compared to the REF scenario, while final energy consumption in 2050 decreases by around 13% in industry (feedstocks included), 40% in the buildings sector and 66% in transport.

Further insights on the levers potentially driving such drastic changes in energy demand are provided in the sectoral results section.

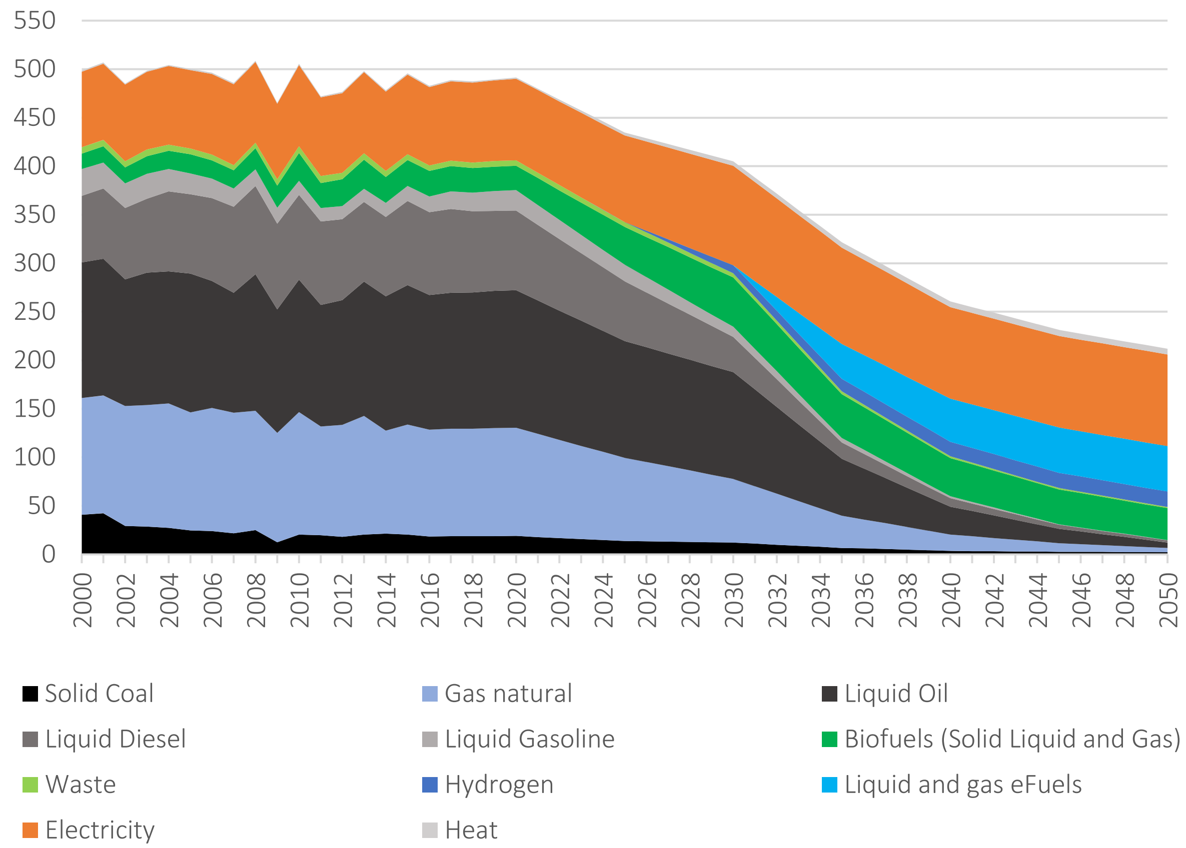
[7] Energy demand stemming from international transport (marine and aviation) is excluded from these figures, and energy use for energy production (e.g. electricity for the production of e-fuels/hydrogen) and ambient energy (energy --heat or cooling-- extracted from the environment (air or ground) - exclusively by heat pumps or district heating in the buildings sector) are not included in final energy demand.

3

Fossil fuels are gradually being phased out and replaced by carbon-free or carbon neutral energy sources. The limited remaining fossil fuels are used in industry and are combined with CCUS.

In 2015, final energy demand (including feedstocks) was composed of about 77% fossil fuels, 17% of electricity and only 7% of biomass and waste. The electricity production still largely relied on fossil fuels with around 62% for the non-nuclear based production, the rest being based on renewable energy sources.

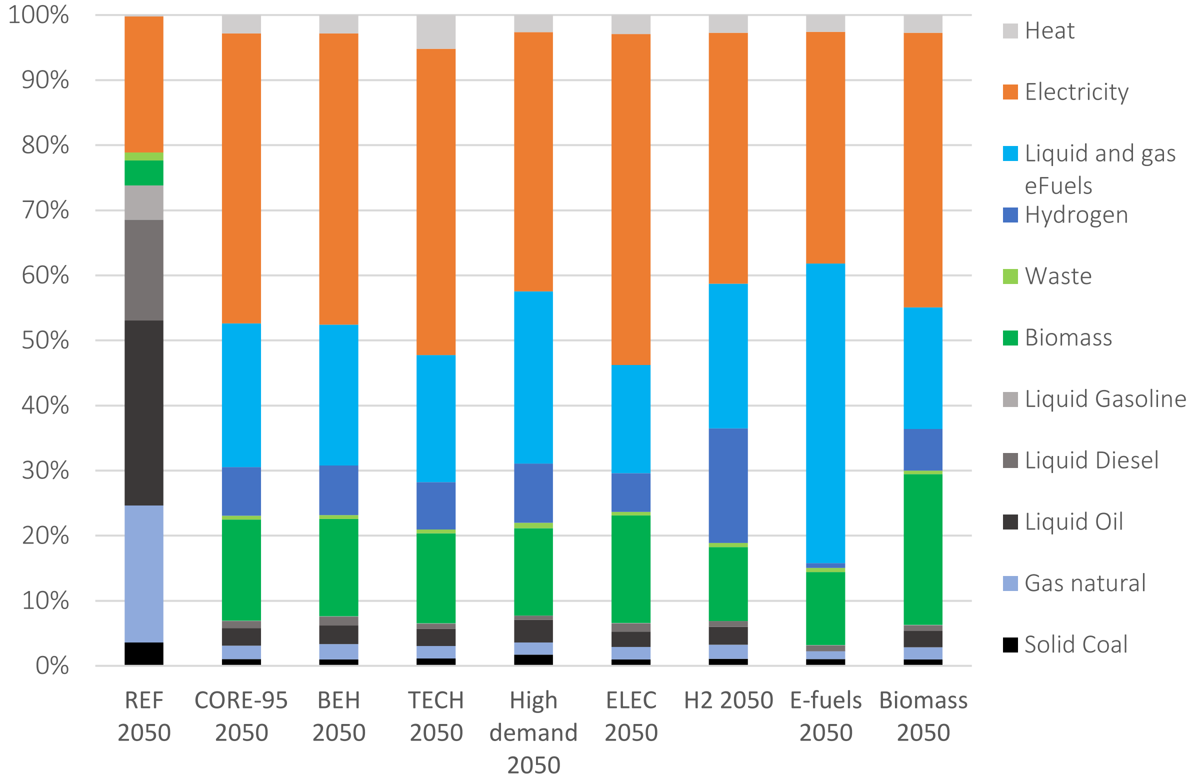
Figure 5. Evolution of final energy demand per vector (in TWh) - CORE-95 scenario



In 2050, fossil fuels are almost completely phased-out, as can be seen in Figure 5. Remaining fossil fuels in 2050 in the CORE-95 scenario (around 7% of total final energy demand) are used in industrial processes and as feedstocks, and are combined with Carbon Capture and Utilisation or Storage (CCUS).

The same is also true for the other two main scenarios (that have roughly the same energy mix as the CORE-95 scenario), as well as for the scenarios exploring alternative energy mixes (cf. Figure 6 below), where we observe that fossil fuels in 2050 never reach more than 8% of total final energy demand and are also mainly used in industrial processes and as feedstock. These alternative energy mix scenarios either increase the consumption of a specific (type of) energy vector (electricity, hydrogen, e-fuels or biomass) or of energy consumption in general (the high demand scenario). When pushing up electricity consumption in the ELEC scenario, we notice that electricity demand can reach around half the total final energy demand in 2050 (whereas it lies between 36% and 47% in the other scenarios, including the CORE-95 scenario). When pushing up hydrogen consumption in the H2 scenario, it can reach close to 20% of total final energy demand in 2050 (whereas it lies between 1% and 9% in the other scenarios). When pushing up e-fuels consumption in the respective scenario, they can reach over 45% of total final demand in 2050 (the share being between 17% and 26% in the other scenarios). In the scenario where biomass consumption is pushed up, it can almost reach 25%.

Figure 6. Final energy demand per vector (incl. industrial feedstocks, in % of total FED)



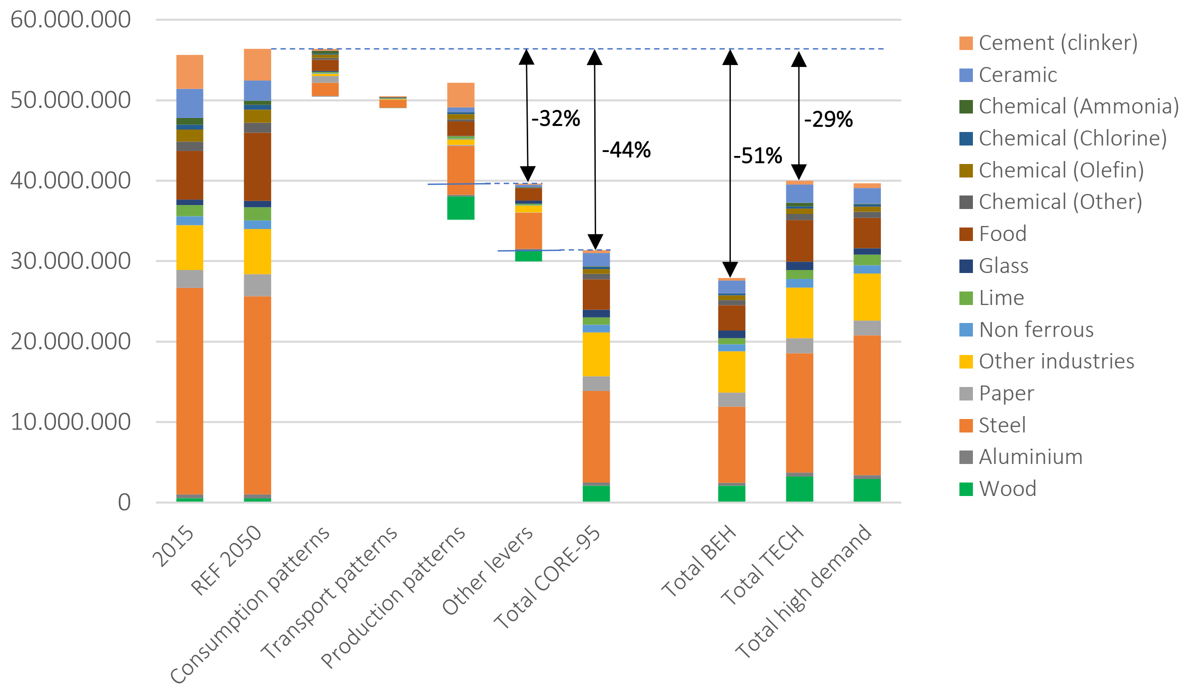
3.3 Materials and land

4 New production and consumption patterns have the potential to drastically reduce materials demand and thereby energy use and greenhouse gas emissions.

The different modelled levers that relate to behavioural and societal changes, as well as the circular economy, the sharing economy and the economy of functionality together have the potential to strongly impact the demand for materials, and thereby of energy consumption and GHG emissions.

When implemented at ambitious levels, the modeled levers related to the circular economy lead to a reduction of materials demand of around 32% in the CORE-95 scenario and around 34% in the BEH scenario with respect to the REF scenario (see Figure 7), while the reduction is of around 29% in the TECH scenario and 27% in the high demand scenario.

Figure 7. Impact of selected groups of circular economy-related levers on materials demand in 2050 (in t)



Indeed, changing *consumption patterns* have a considerable impact on material demand and thereby on GHG emissions. Reducing paper and plastic packaging, reducing food waste and adopting more sustainable consumption patterns leads to a reduction of the related production and distribution activities, including transport. In agriculture, more circular practices based on, amongst other, a reduction of fertilisers and pesticides, can also further reduce industrial GHG emissions.

New modes of transport also have a significant impact. Sharing cars and better organizing the travel demand in order to maximise the occupancy rate of vehicles reduces the number of vehicles on the road (see the section on transport) and the energy consumption in the transport sector. Improvements in logistics, such as a further increase of the load factor of trucks and relying more heavily on inland waterways, also has the potential to contribute to the reduction of material demand.

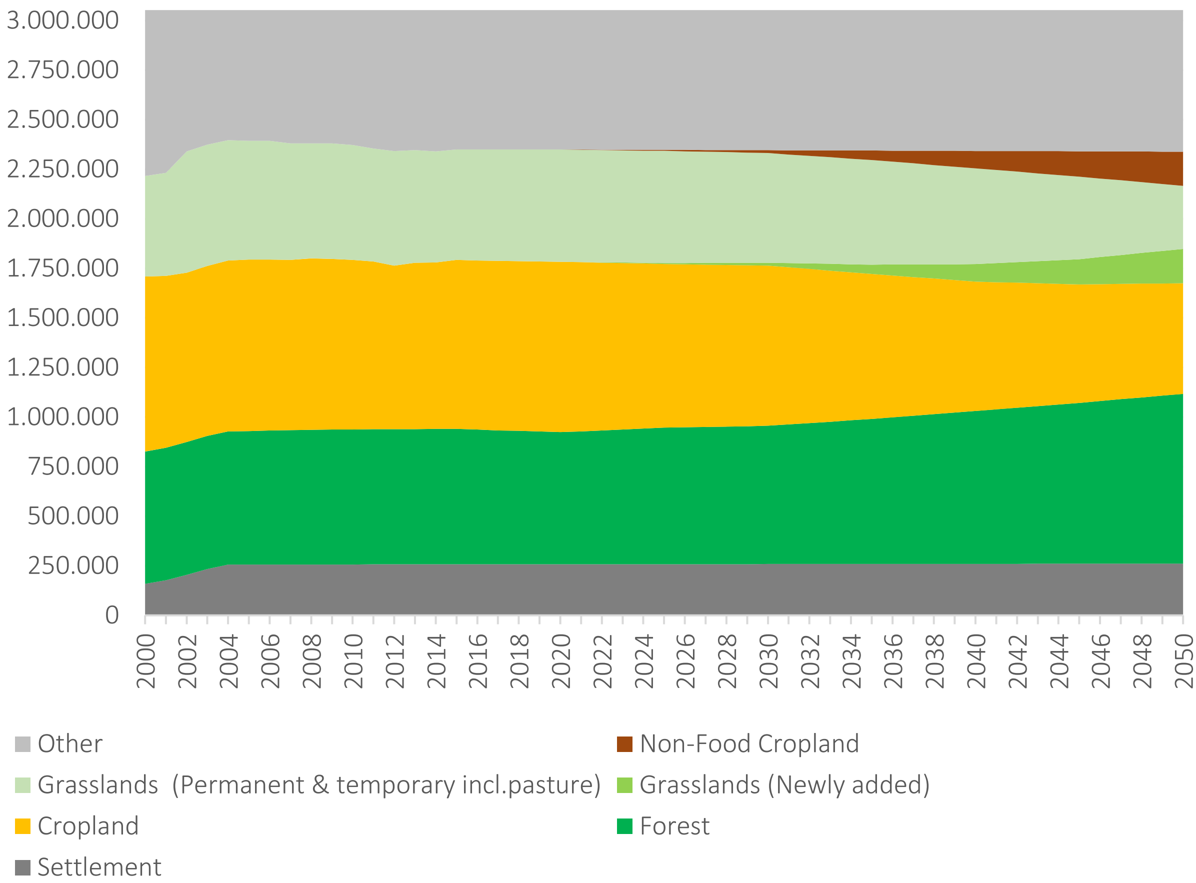
Finally, in industrial production, an increased *material efficiency* (lower amount of material per product) can be achieved by improving product design, using more efficient materials or reducing material losses. A change in the type of materials used in the production of cars, extending their lifetime or a change towards less GHG intensive materials in new or renovated buildings (e.g. the replacement of a proportion of steel by chemical products and/or aluminium in cars or the replacement of some steel or cement by wood or the replacement of chemical products by paper fibres or wood in buildings) leads to the reduction in GHG emissions. Finally, switching technologies in order to rely more heavily on secondary (recycled) materials (in steel and paper production for instance) or less emitting inputs (such as in cement) further reduces the demand for primary, GHG intensive resources. Besides this specific example of switching technologies that rely more heavily on secondary, recycled materials, the "2050

Pathways Explorer" does, however, currently not include specific recycling levers[8], which leads to an underestimation of the potential impact of recycling in the model.

5

Changes in the agricultural model can have a strong impact on land-use and thereby on carbon sequestration possibilities.

Figure 8. Land allocation (in ha) - CORE-95



Changes in agricultural practices can have a strong impact on land use, and thereby on carbon sequestration possibilities.

Indeed, as can be seen in Figure 3 regarding emissions and removals in 2050 in the three main climate neutral scenarios, different levels of sequestration through land use are achieved, resulting from different modelling assumptions and thus from different interactions between agriculture and bioenergy needs, and their impact on land. In the CORE-95 scenario, 4.27 Mt of CO_2 would be removed in 2050, while removals would reach 3.74 Mt in the BEH scenario and 4.89 Mt in the TECH scenario.

[8] Even though it implicitly takes some aspects of recycling into account through levers that result in extended lifetime of different products, for instance.

The results on land allocation of the different interactions of levers impacting the agriculture sector and bioenergy needs is illustrated in Figure 8 above[9].

On the one hand, if a transition towards a healthier diet (see message #18 below – reduced food consumption in general, and of meat in particular) is achieved by 2050 (which is the case in the CORE-95 scenario, the BEH scenario even going further than the recommendations of the Supreme Health Council), livestock can be reduced considerably, and thereby also the areas required to produce animal feed[10].

On the other hand, the transition towards agroecological practices (a full transition towards agroecological practices is achieved by 2050 in the BEH scenario, while the transition in the CORE-95 scenario is almost complete and the agricultural practices in the TECH scenario are similar to those practiced today) generates an additional demand for cropland and grassland in order to compensate for the reduced crop yield (less fertilisers used in agroecology) and due to the extensification of livestock management in agroecology (reduced number of animals per ha).

Still, whenever land is freed up, a choice must be made on how to use it[11]. Many considerations come into play in this respect, amongst which landscape considerations, bioenergy crop production considerations, etc., but in this context also the carbon sequestration capacity of the different types of land use is important. Both in the CORE-95 and in the TECH scenario, the choice was made to turn surplus land into forest land, natural prairies (i.e. the types of land use with the largest carbon soil absorption capacity) and non-food agriculture in an equal manner (i.e. of total surplus land, one third is allocated to each category by 2050). In the BEH scenario, given the full transition to agroecology practices, the stronger push in diet changes and the overall lower levels of removals required to reach climate neutrality, there is room for allocating a little less of the surplus land to afforestation and natural prairies.

3.4 Costs

6

Decarbonisation requires additional climate friendly investments in infrastructure in all sectors. Total capital expenditures can nevertheless be significantly reduced when the demand for the related energy services is reduced through behavioural changes and circular economy developments.

Fuel cost reductions tend to offset capital expenditure increases. Although electricity expenditures increase in all sectors, fossil fuel expenditures reach almost zero in the long run. The price and consumption levels of hydrogen and e-fuels, including as feedstock use, then become an important determinant of the total fuel expenditures.

Capital expenditures, operating expenditures and fuel expenditures are computed ex-post in the

[9] Wetlands are not modelled, but are an additional carbon sequestration option that could be considered.

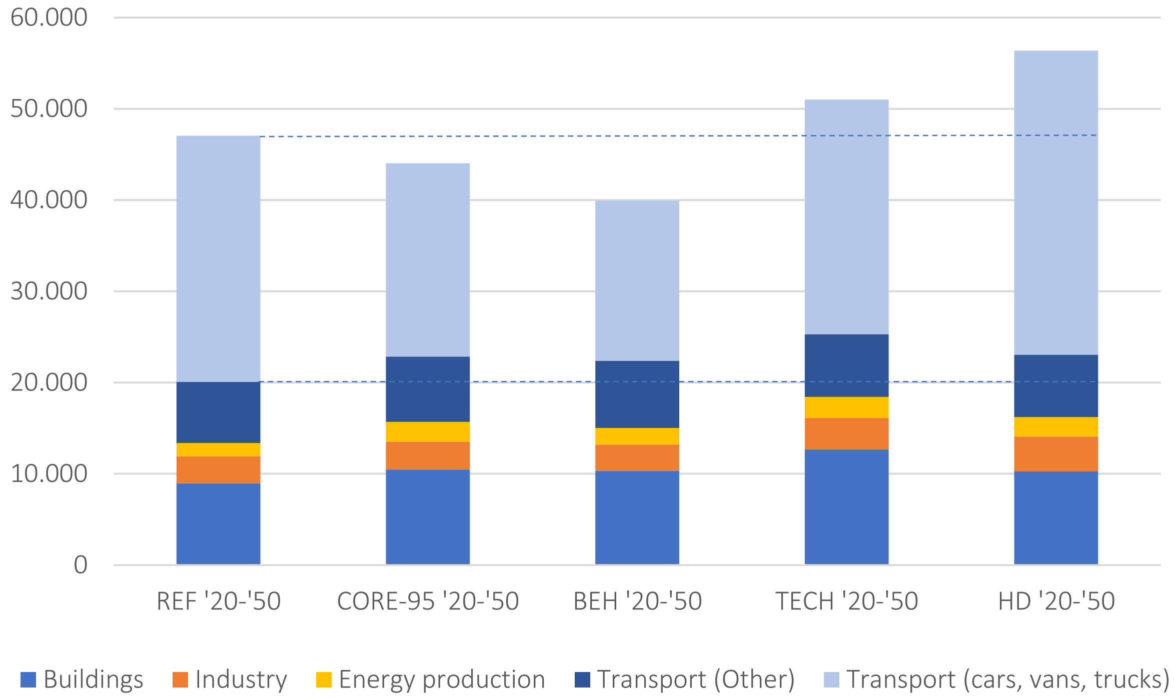
[10] Around 75% of the utilised agricultural area in Belgium is currently either directly or indirectly used for livestock management.

[11] As can be seen in message #8 below regarding the buildings sector, the choice was made in this tool that land allocated to settlements has reached a maximum level in 2020. Surplus land can therefore not be allocated to this type of land use in the tool.

model. Their interpretation requires a particularly cautious approach as their modelling is high-level and since their scope and the underlying assumptions influence the resulting figures and thereby the comparison across sectors and across scenarios.

Capital expenditures are computed in each sector[12]. Figure 9 illustrates the average annual capital expenditures over the period 2020-2050 in various scenarios. It suggests that capital expenditures in the different sectors are almost always higher in all climate neutral scenarios than in the reference scenario[13].

Figure 9: Average annual capital expenditures 2020-2050 in various scenarios (undiscounted, in M euros)



In the buildings sector, capital expenditures increase by 15 to 40% with respect to the REF scenario (+17% in the CORE-95 scenario), reflecting mostly the increase in the cost of renovating a large share of the buildings. In industry, capital expenditures are strongly related to production volumes. In the BEH scenario, they are at a similar level as the REF scenario level and they increase by more than 30% in the High Demand scenario. As for the energy production sector, capital expenditures increase by 24 to 57%

[12] In the buildings sector, they encompass renovation and construction expenditures both in the residential and non-residential sectors, expenditures for appliances, and expenditures for residential and non-residential heating systems (individual and shared). In the industry, capital expenditures in each subsector are based on production levels and production technology(e.g. hydrogen DRI or Hisarna or BF-BOF for steel production, wet or dry kiln or geopolymer cement production, expenditures related to the production of chemical products, etc.). In the transport sector, capital expenditures include rail and road infrastructure, trolley cables, vehicles for rail, waterway and for road transport (cars, vans and trucks). Finally, in the energy production sector, capital expenditures include those related to the production of electricity, heat, e-fuels and hydrogen, to refineries, to electricity international transmission integration and to electricity intermittency.

[13] Except potentially in the transport sector depending on the scope of the costs in this sector.

above their REF levels. In the transport sector, the absolute value of capital expenditures is particularly large due the perimeter choice, which includes the total cost of all vehicles. When the costs of road vehicles (cars, vans, trucks) are not accounted for, capital expenditures increase by 2 to 7% in the transport sector, reflecting the need to further invest in infrastructures. As regards road vehicles, their total capex is lower in several climate neutral scenarios than in the REF scenario. Although the price of climate-neutral vehicles is significantly higher than the price of conventional ones, the total number of road vehicles is drastically lower in all these scenarios due to the implementation of a whole series of levers (see below). As a result, the capital expenditures for these vehicles are lower in all climate neutral scenarios except the High Demand scenario, thus ranging from -35% in the BEH scenario to +24% in the High Demand scenario.

In total, CAPEX increase by 12 to 26% when the costs of vehicles are not accounted for. When these are included, total CAPEX are lower in some climate neutral scenarios, with changes from -15% in the BEH scenario to an increase by 20% in the High Demand scenario.

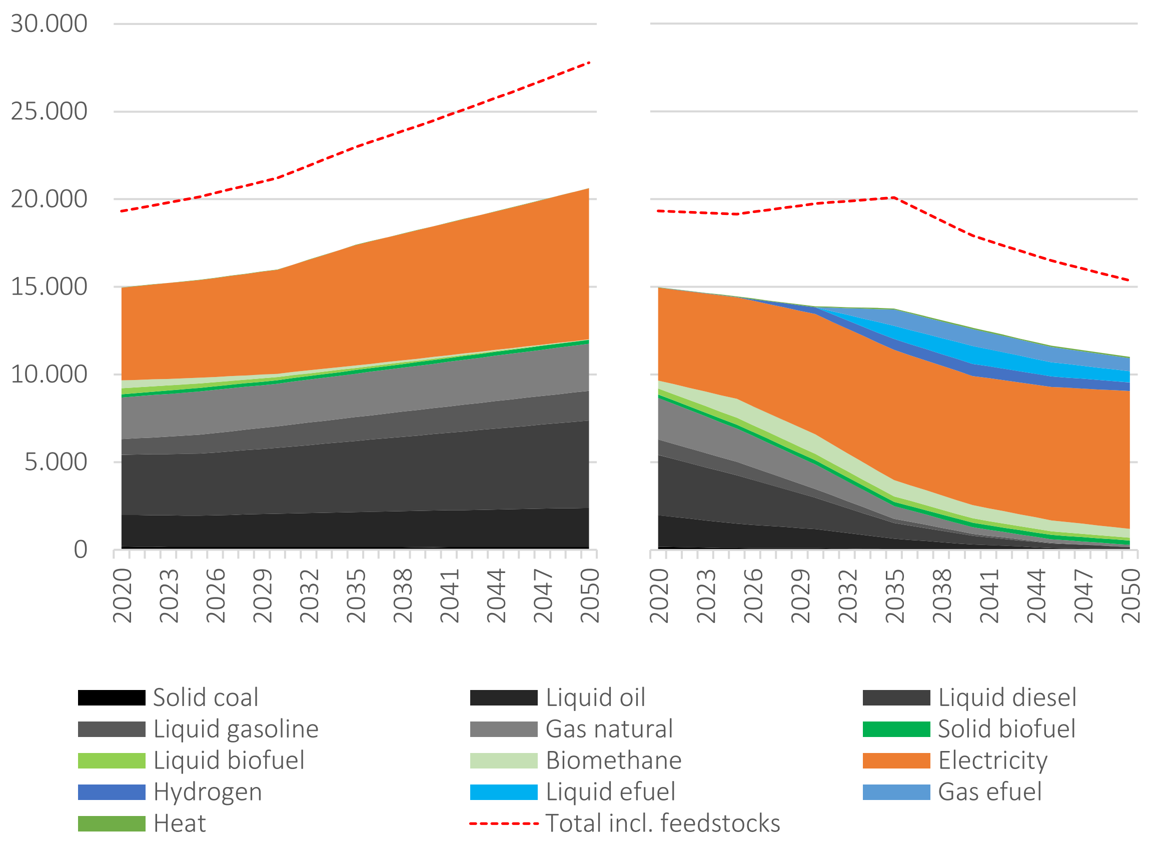
Operating costs generally follow the capex evolutions in each sector. Still, the higher electrification level in climate-neutral scenarios allows saving on operating expenditures vis-à-vis conventional technologies. In total, OPEX are reduced by 23% (BEH scenario) to 6% (HD scenario) when road vehicles are not accounted for, and by 40 to 11% when they are included.

The evolution of fuel costs deserves particular attention given the very large uncertainties as regards future energy prices in the different scenarios. Depending on the assumptions, in particular for hydrogen and e-fuel prices when industrial feedstocks are accounted for, total fuel costs can be either lower or higher in the climate neutral scenarios than in the REF scenario.

As illustrated in Figure 5 above, total fuel costs are driven by three main evolutions that lead to a fundamental change in the energy mix in the climate neutral scenarios. First, fossil fuels are progressively reduced to almost 0 by 2050, which tends to lower fuel costs although fossil fuel prices are relatively low when compared to prices of alternative energy vectors. Second, electrification takes place in all demand sectors. This tends to increase the share of electricity, although the absolute levels in the demand sectors are significantly reduced. Assuming a slightly increasing electricity price would thus only have a limited impact on the total fuels costs. Third, climate-neutral fuels are deployed for the uses that cannot be electrified. Biofuels (and biomethane in particular) slightly increase in the energy demand mix by 2050. However, the bulk of the fuel costs increase is likely to come from the increased use of H_2 and e-fuels in the different sectors, in particular in industry. As Figure 10 below shows, total fuel costs (excluding, but also including feedstocks) are lower in the CORE-95 scenario throughout the 2020-2050 period when compared to the Reference scenario. Underlying energy price assumptions are provided in Appendix 2[14].

[14] These are based on the VLAIO (2020) study (cf. footnote 4).

Figure 10: Evolution of fuel costs in the REF (left) and CORE-95 (right) scenarios (2020-2050, M€ - excl. feedstocks)



Overall, total energy system costs tend to be lower in the climate neutral scenarios even though the transition requires additional investments in infrastructure. In fact, under the energy price assumptions as presented above, total costs in 2050 are lower in all illustrative scenarios when compared with the reference scenario, both including and excluding CAPEX and OPEX related to road vehicles, except for the high demand scenario when road vehicles' CAPEX and OPEX are included. Sensitivity analyses suggest that these results do not significantly depend on the discount rate[15].

Two elements are indeed likely to play a key role in the evolution of the energy costs. First, scenarios that rely more heavily on behavioural, cultural changes and on the sharing economy, the circular economy and the economy of functionality (such as the BEH scenario typically) tend to require lower investments and use fewer materials and energy, thereby reducing the three components of the energy costs.

Second, hydrogen and e-fuels consumption levels and prices are likely to be an important determinant of energy costs in the future. Although they represent between 23 and 35% of the energy mix in the climate neutral scenarios when feedstocks are included (see above) and only 11% and 18% when these are not included, they can represent a larger share of fuel costs since they are particularly costly. A close monitoring of the evolution of the production costs and import prices of H_2 and e-fuels is therefore critical in controlling energy system costs. Again, trajectories that will rationalise the use of materials and other resources will also benefit from a lower use of industrial feedstocks, a large part of which is based on H_2 and e-fuels. This tends to further reduce the costs of these trajectories.

[15] Since investments gradually take place over the period.

4 Sectoral results

4.1 Buildings

The buildings sector will have to reach zero GHG emissions in order to attain climate neutrality in Belgium in 2050. For this sector, four key messages can be derived from the analysis of the scenarios described above.

> **7** Behavioural levers related to the use of space, heating and cooling behaviour and appliance use behaviour, play a key role in reducing energy demand in buildings.

Next to the importance of renovating our building stock (cf. message #8 below), the impact of behavioural changes is not to be underestimated. In what follows, the main behavioural levers available in the tool for the buildings sector have been grouped in three sets.

Figure 11. Energy demand per end-use in the buildings sector (in TWh) - Impact of behavioural and other levers

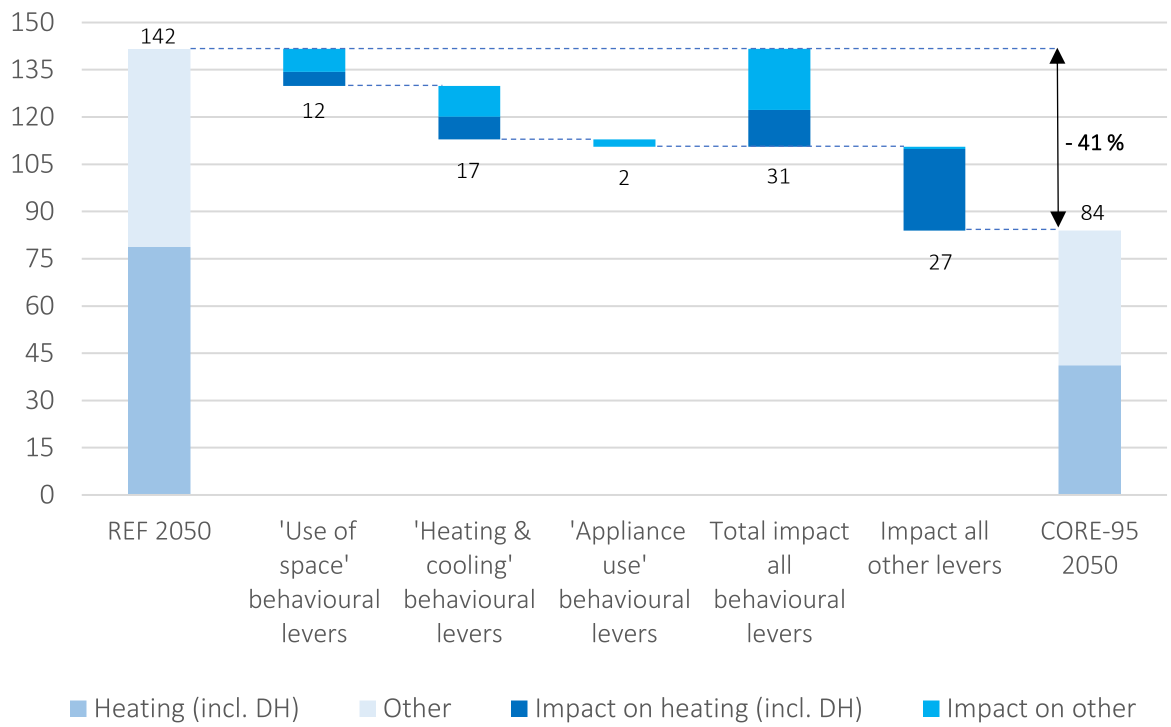


Figure 11 above shows the contribution of these three sets of levers in reaching the considerably lower level of energy demand in the CORE-95 scenario in 2050, when compared to the Reference scenario. We observe that, while total energy demand decreases by 41% to reach around 84 TWh, a little over half of this decrease is the result of behavioural levers when these are calculated first. These have an impact on both heating and other energy demand (mainly demand for hot water, cooling, lighting and cooking).

The first set of behavioural levers is related to the use of space, that is, to the living space per person and the percentage of this area that is heated, or the rational use of non-residential area (i.e. surfaces used for education, health, offices, trade and other purposes).

Second, a set of levers relates to temperature regulation inside dwellings where a given comfort temperature is reached among others through heating or cooling the dwelling, the amount of hot water used and the level of deployment of cooling systems. In this context, controlling the cooling demand, including through adequate renovations, is critical for the reduction of energy demand.

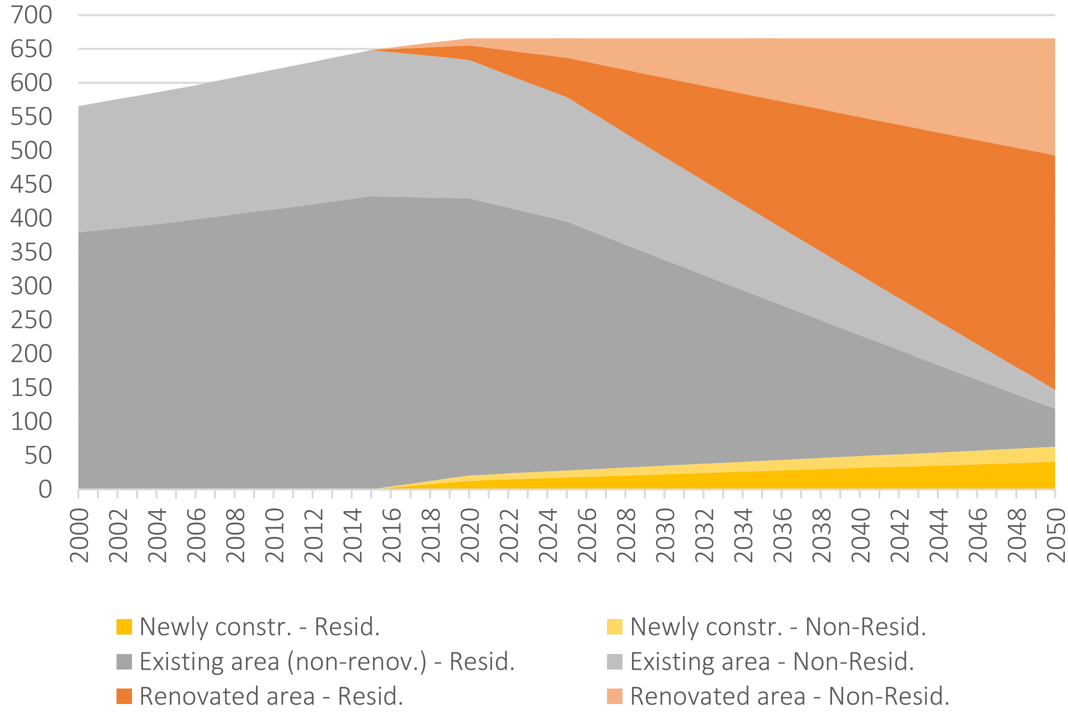
Third, a set related to the way household appliances are used (grouped under the term 'appliance use' behavioural levers) was identified. Energy demand from computers, dryers, TVs, washing machines, etc. can be significantly reduced although these do not represent the bulk of energy consumption in buildings.

If these behavioural levers would not be pushed up at the levels depicted, and in order to still reach the needed emission reductions in the buildings sector, other levers (e.g. renovation rate and depth, additional use of e-fuels in the energy mix, etc.) would then need to be deployed much further.

8 The renovation rate and depth need to drastically and quickly increase.

In order to reach zero GHG emissions in the buildings sector by 2050, the renovation rate of our building stock will need to increase drastically and quickly, from the current average of around 1% per year to between 2.5 to 3%. The renovation depth, i.e. the energy performance reached after the renovation, will need to increase as well, in order to no longer have shallow but mainly deep renovations.

Figure 12. Total floor area (in million m^2) - CORE-95 scenario



In our CORE-95 scenario, levers related to space use are set to stabilise total residential and non-residential floor area with respect to current levels (i.e. from 2020 onwards and up to 2050, total floor area remains constant at around 665 million m², as can be seen in Figure 10) and to decrease newly constructed area (compared to REF) even though some major renovations entail demolition and reconstruction of the buildings. By 2050, the remaining existing, non-renovated area would only represent a little over 10% of total floor area. Such an insulation effort leads to a drastic decrease of energy demand in the buildings sector of almost 40% when compared with the REF scenario, with remaining demand being met by carbon neutral supply in 2050.

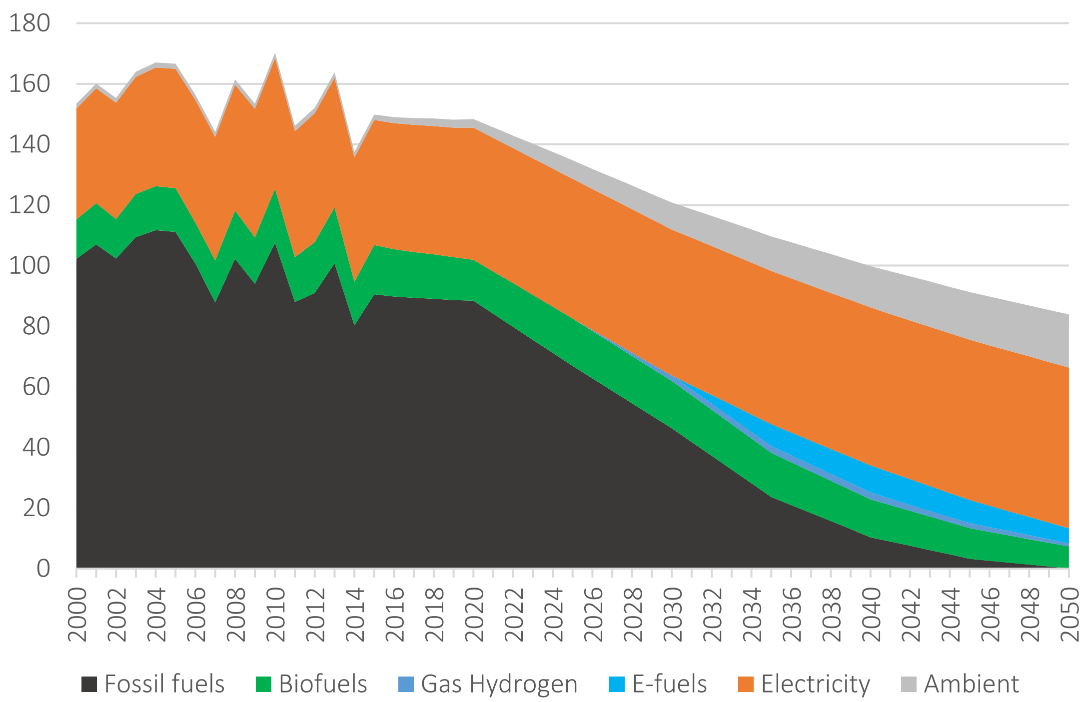
If one would choose to only do half the renovation effort (rate and depth) of the CORE-95 scenario, energy consumption for heating in the buildings sector in 2050 would be around 35% higher. In order to still be able to reach the required decrease in GHG emissions in the buildings sector, the share of district heating, biofuels and e-fuels would then need to increase significantly to meet the increased energy demand.

9

In buildings, electricity becomes the main energy vector complemented by biomass and synthetic fuels where electrification proves not to be feasible or particularly costly.

In the buildings sector, total final energy demand decreases by between 54 and 63% by 2050 in the climate neutral scenarios when compared to current levels (see Figure 4 – it amounts to -46% in the High demand scenario).

Figure 13. Energy demand per vector in the buildings sector (in TWh) - CORE-95 scenario



In this context, fossil fuels are completely or almost completely phased out by 2050, while electricity becomes the most important energy vector, representing more than 80% of final energy demand, as can be observed in Figure 13 above. Indeed, most fossil fuel-based technologies will be replaced by heat pumps (driven by electricity and ambient energy), either directly in the buildings or through district heating.

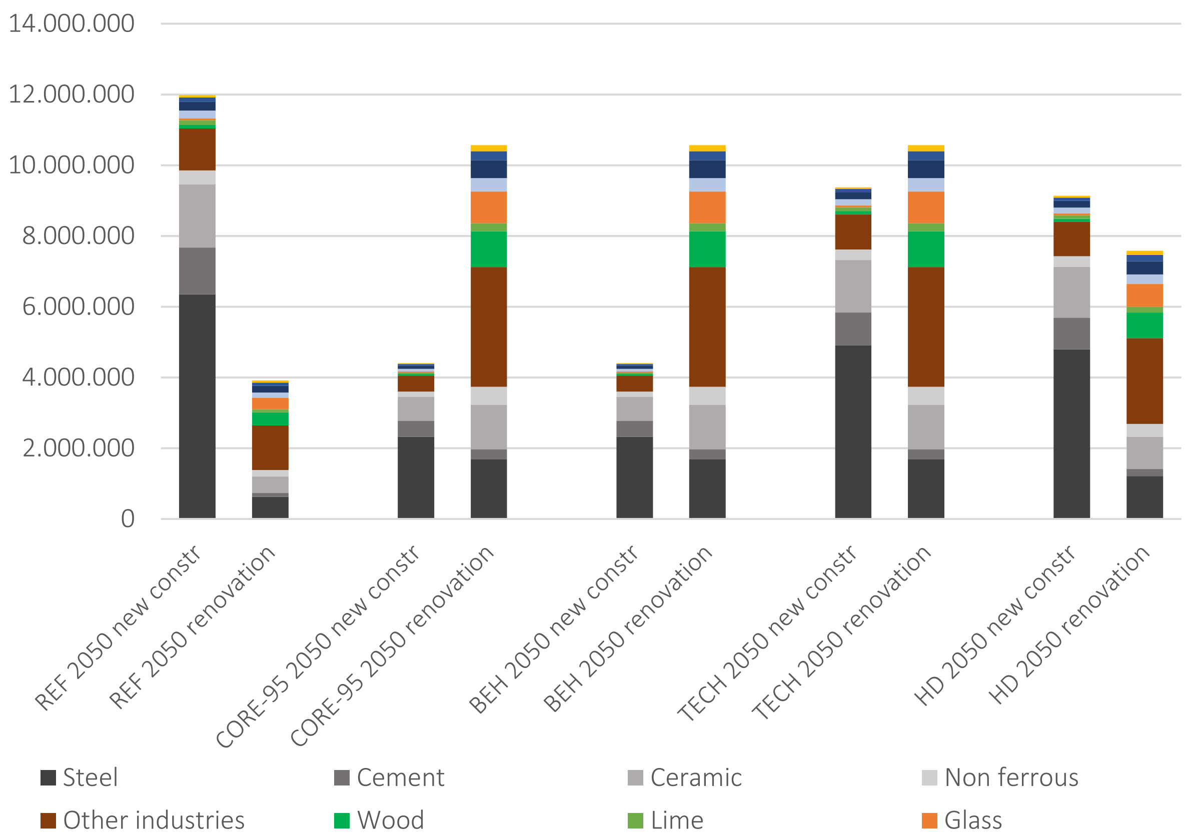
Still, other energy vectors are likely to complement the energy mix. First, biomass (9% of buildings final energy demand in the CORE-95 scenario) can be used, depending on the availability of sustainable biomethane and of solid biomass. As for solid biomass, the technology needs to be almost emissions free in terms of air pollutants, with conventional boilers and fireplaces replaced by e.g. high standards pellets heating stoves.

Synthetic fuels (9% in the CORE-95 scenario), namely hydrogen, e-gases and e-liquids, can also complement the mix, in particular when high degree renovations prove not to be feasible or extremely costly and when biomethane potential has been reached.

10 Circularity of materials in renovations becomes a key issue.

The construction of new buildings and the renovation of existing buildings require a massive use of materials of different types.

Figure 14. Material demand in the buildings sector (in tons)



New buildings rely heavily on steel (over half of the required material/m², both for residential and non-residential buildings) and to a lesser degree on ceramic and cement. As for renovations, that require only around one fifth (for residential buildings, even less for non-residential buildings) of material/m² than new constructions, while steel (around 9% to 20% for non-residential and residential buildings, respectively) and ceramic (around 14% to 11%, respectively) remain significant materials, other materials are more important when renovating, compared to constructing new buildings, such as glass (14% to 5%, respectively) and wood (9% to 10%, respectively).

In the climate neutral scenarios, far fewer buildings are constructed than currently or than in the REF scenario, as can be seen from Figure 14. The total demand for materials is therefore divided by a factor of about 3 in the CORE-95 scenario when compared to its current level. Although the development of circularity in the construction of new buildings is essential, the focus must be on resource efficiency and circular business models in the renovation of existing buildings. In the CORE-95 scenario, total material demand for renovations is about 3 times higher than current levels.

Furthermore, the evolution of material demand in the climate neutral scenarios is also the result of material efficiency and material switches in both the new and the renovated built environment. In terms of efficiency, smart design, light weighting, and reduction of over-specifications, together with the use of high strength steel and thinner walls can significantly reduce material demand. As for material switches, the CORE-95 scenario assumes for instance that 16% of steel and 30% of cement is replaced by wood in new buildings while 25% of chemical products are replaced by paper fibres and wood in renovations.

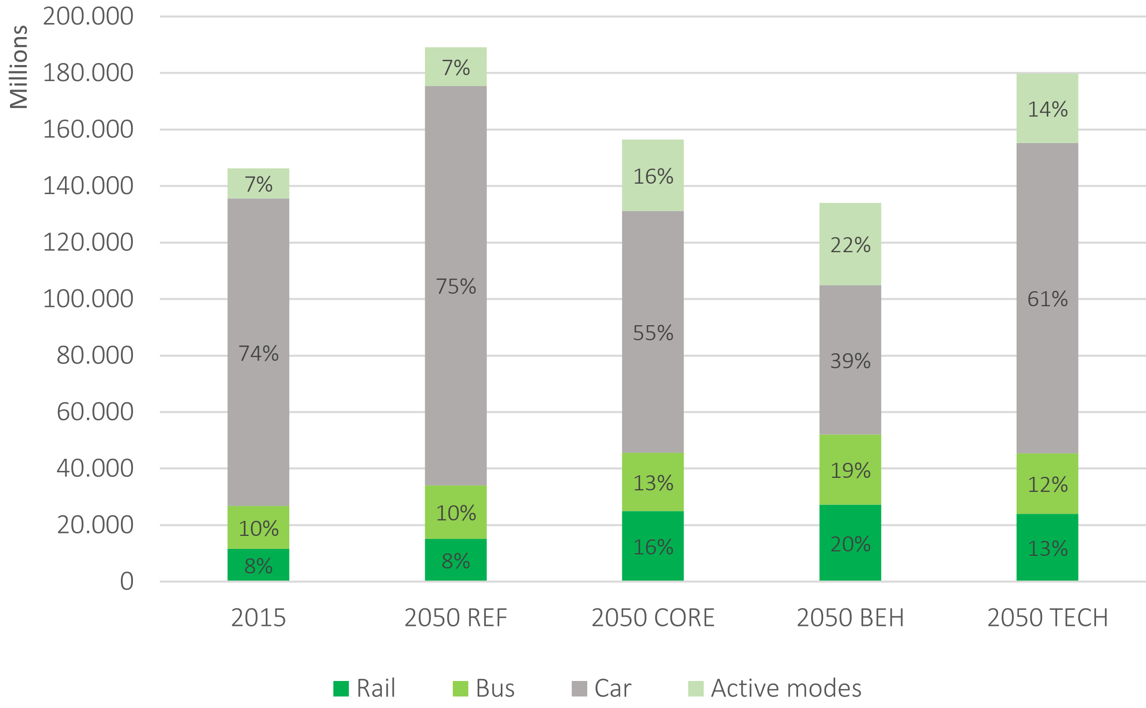
4.2 Transport

As already mentioned, the transport sector will have to reach (almost) 100% GHG emission reductions in order to ensure climate neutrality in Belgium in 2050.

11

The total number of cars shrinks by 2050 due to modal shift, higher occupancy and increased usage per vehicle.

Figure 15. Total passenger transport demand (pkm) - modal share



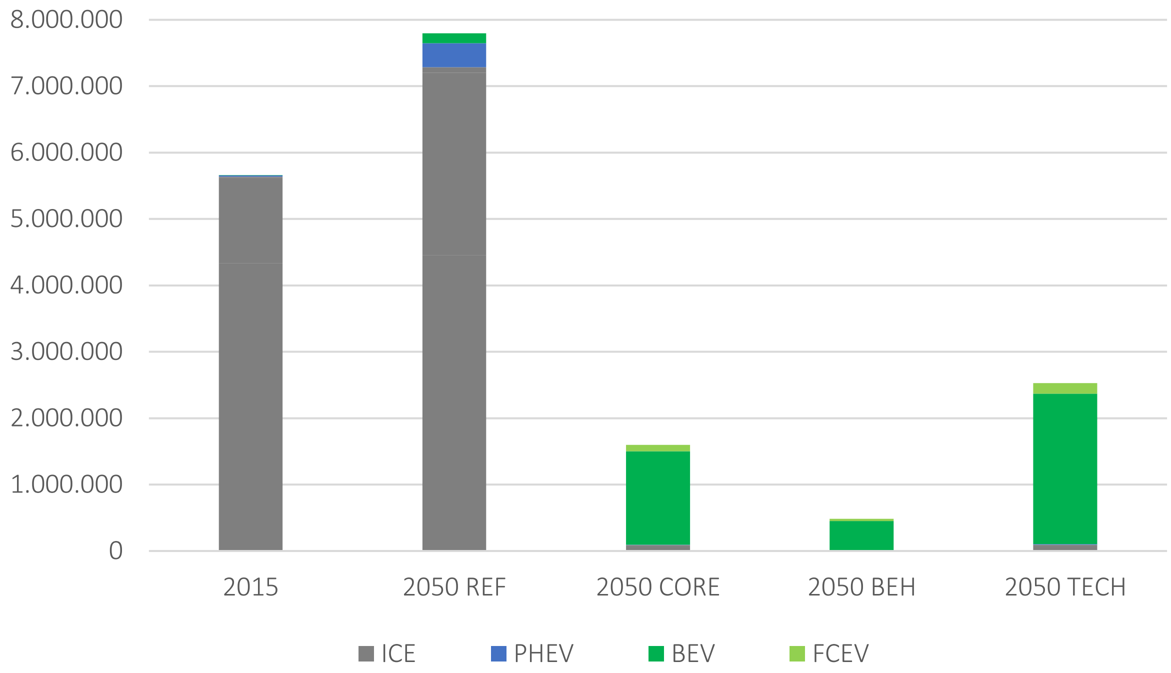
By 2050, despite a growing population, behavioural and societal changes[16] will have led to a reduced need to travel, this being reflected through a decrease of total passenger transport demand when compared to the Reference scenario in the three main scenarios illustrated in Figure 15 (i.e. a decrease of more than 17% in the CORE-95 scenario, of over 29% in the BEH scenario and of around 5% in the TECH scenario).

Moreover, when compared to the Reference scenario, we observe a modal shift away from the use of cars in the three main scenarios (with around 55%, 39% and 61% of passenger transport demand being met by cars in the CORE-95, BEH and TECH scenarios, respectively - down from 75%) towards an increased use of rail (16% in the CORE-95 scenario, up from 8%), bus (13% in the CORE-95 scenario, up from 10%) and soft modes (bicycle, walking, etc. - 16% in the CORE-95 scenario, up from 7%).

[16] In the transport sector, a significant part of these changes is related to how society is organized, for example whether working from home is encouraged, and how much urban sprawling is limited to encourage urban density instead.

This modal shift therefore allows to further reduce the number of car-kilometres. On top of that, a higher occupancy rate of cars (where the average number of people in a car would increase from 1.5 in 2015 to 2.25 in 2050 in the CORE-95 scenario) drives down the number of cars needed to fulfil this demand. Moreover, a higher utilisation rate of vehicles due to a further development of the sharing economy (where the distance travelled by each car per year would double by 2050 when compared to 2015), leads to a drastic decrease of the number of (registered) cars in 2050 in the CORE-95 scenario of around 80% when compared with the reference scenario (see Figure 16).

Figure 16. Number of cars by type

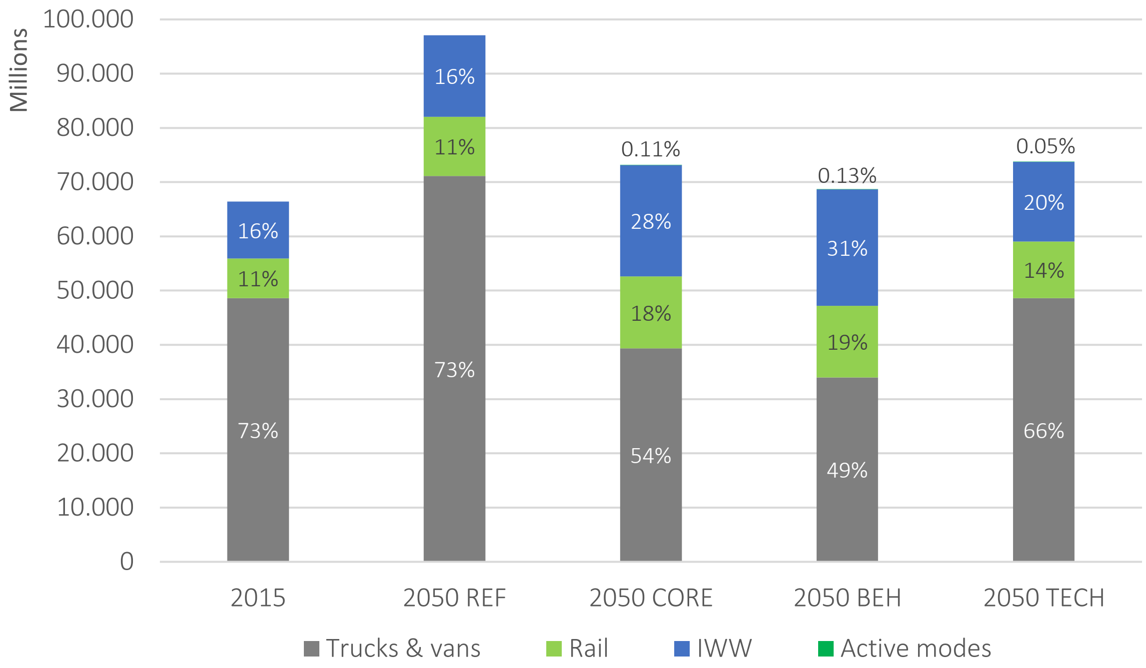


12

The total number of trucks and vans decreases significantly by 2050 due to modal shift, a higher load factor and increased utilisation rate.

By 2050, total freight transport demand decreases when compared to the Reference scenario in the three main scenarios illustrated in Figure 17 (i.e. a decrease of around 25% in the CORE-95 scenario, of 29% in the BEH scenario and of around 24% in the TECH scenario). In each of these scenarios, however, demand rises slightly from its level in 2015.

Figure 17. Freight transport demand – modal share (tkm)



Moreover, when compared to the Reference scenario, we observe a modal shift away from the use of trucks in the three main scenarios (with around 54%, 49% and 66% of freight transport demand being met by trucks in the CORE-95, BEH and TECH scenarios, respectively - down from 73%) towards an increased use of inland waterways that are currently underdeveloped and offer the big advantage of avoiding congested roads and delivering the freight in the city centre (IWW - 28% in the CORE-95 scenario, up from 16%) and rail (18% in the CORE-95 scenario, up from 11%), while short distance deliveries via soft modes (bicycle, walking, etc.) further develop for bridging the last mile.

This modal shift, together with a higher load factor of trucks and vans (where the average load in the CORE-95 scenario would increase by 12.5% when compared to 2015 levels) and a higher utilisation rate (where the distance travelled by each truck per year would increase with 75% by 2050 when compared to 2015), leads to approximately halving the number of trucks in 2050 in the CORE-95 scenario compared to the Reference scenario.

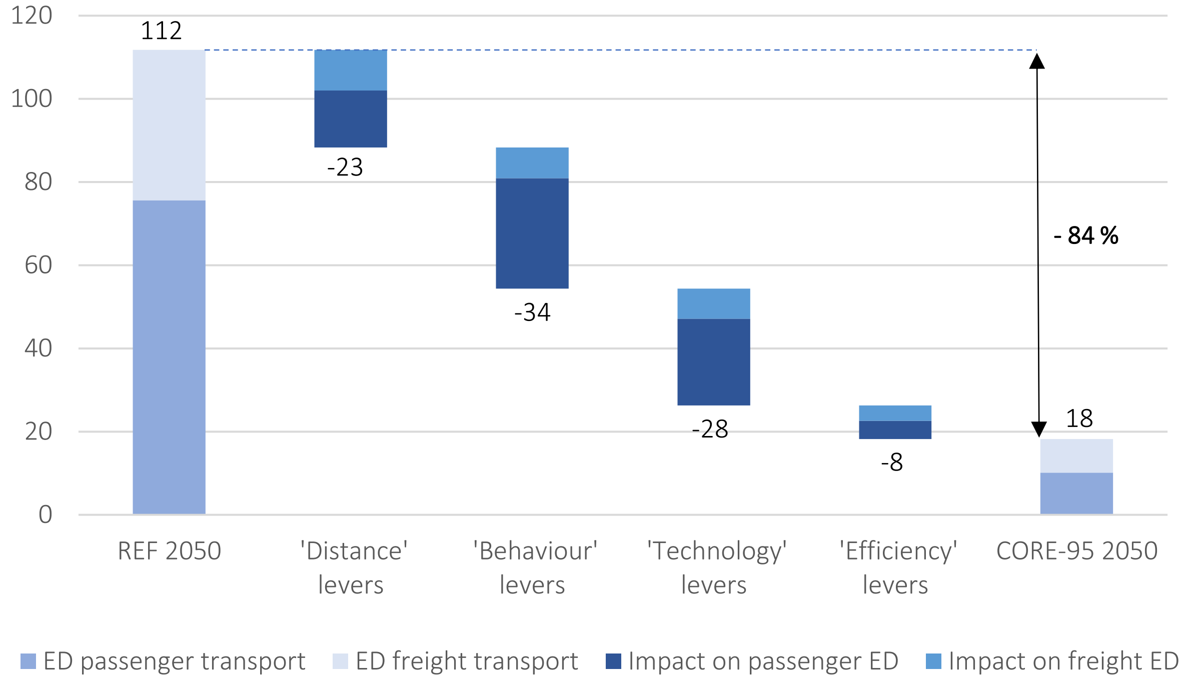
13

Besides behavioural changes, technological evolutions contribute to the drastic reduction of energy demand. Most new cars are powered by electricity while freight relies significantly on hydrogen, e-fuels and potentially biomass.

The role of distance and (other) behavioural levers in changing transport patterns and, thereby, total energy demand has been emphasized just above. Figure 18 illustrates the drastic impact of these levers on both passenger and freight transport energy demand (see the first two groups of levers). They lead to a reduction of the energy demand between 1% in the High Demand scenario and 64% in the BEHAVIOUR scenario with respect to the REFERENCE scenario, with about 50% in the CORE-95 scenario.

Still, technological switches, in particular electrification, also have a major impact on total energy consumption given the huge energy losses associated with internal combustion engines. Obviously, such a sharp reduction in final energy demand in the transport sector is partially offset by the primary energy required to supply the new energy vectors such as electricity, hydrogen and e-fuels. These are accounted for in the energy supply sector.

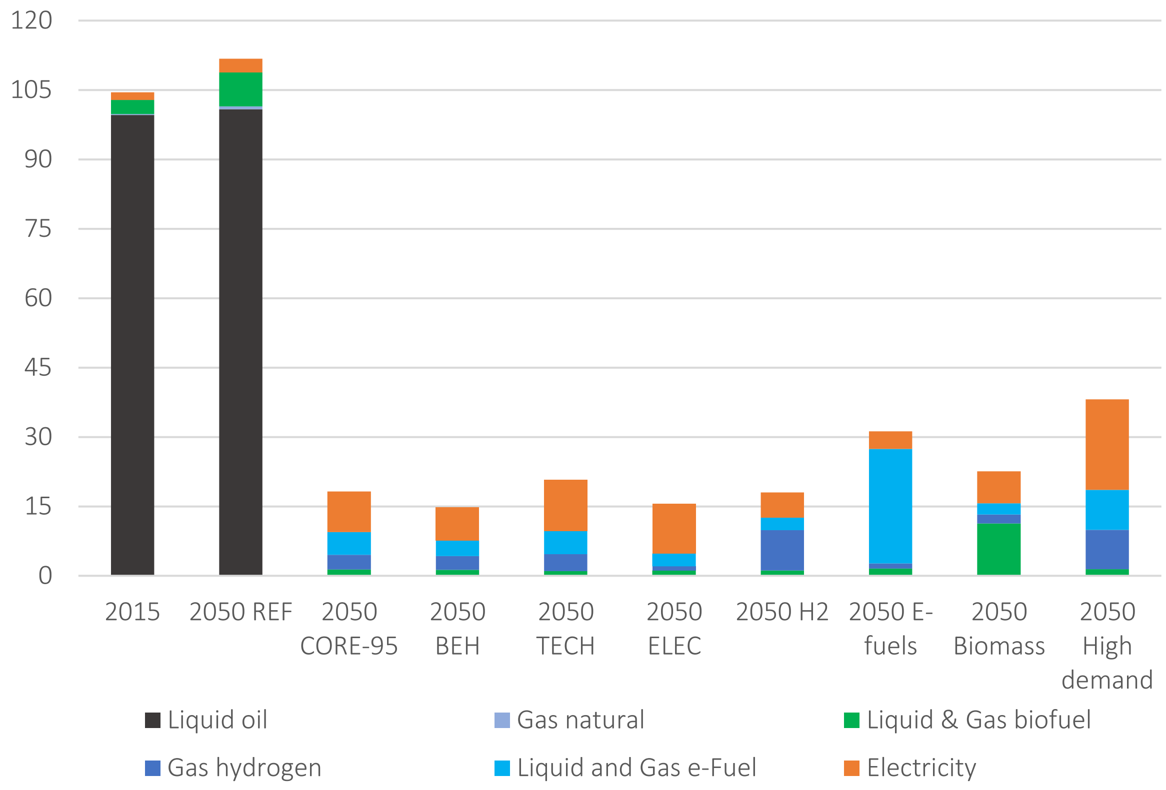
Figure 18: Contribution of different groups of levers to the reduction of energy demand in transport (in TWh) - CORE-95 scenario



Given the decreased total transport demand in the three main scenarios as well as the considerable electrification of vehicles, final energy demand in the transport sector decreases drastically by 2050 when compared to the Reference scenario with a decrease of around 84% in the CORE-95 scenario, 87% in the BEH scenario and 81% in the TECH scenario (see Figure 19). In a scenario of higher energy demand, this reduction still reaches 66%.

Figure 19 also shows different scenarios (all based on the CORE-95 scenario) with varying energy mixes, where the demand of either electricity (through further electrification), gas hydrogen, e-fuels or biomass is pushed to considerably higher levels, and a scenario where energy demand is higher in general when compared to the CORE-95 scenario. We observe that only the ELEC scenario has a lower level of final energy demand in 2050 than the CORE-95 scenario, while the other scenarios have higher levels, although still considerably lower than the Reference scenario. In the CORE-95 scenario, given the technological developments and the high penetration rate of LEV and ZEV into the car market over the period 2015-2050, almost 90% of the car fleet in 2050 would be battery electric vehicles (BEV), around 6% would be fuel-cell electric vehicles (FCEV), and 6% would be remaining internal combustion vehicles (ICE) fuelled by synthetic fuels (hydrogen or e-fuels) or biofuels.

Figure 19. Total transport energy demand per vector (in TWh)



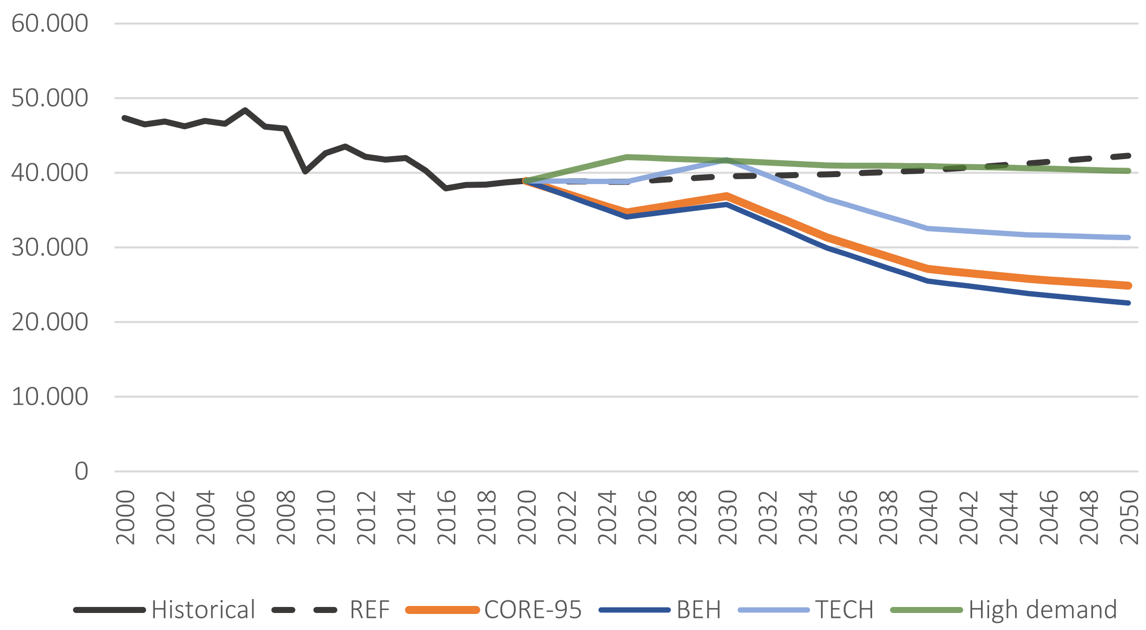
Regarding the truck fleet over the period 2015-2050, around 25% of the fleet in 2050 would be battery electric vehicles (BEV) and around 51% would be fuel-cell electric vehicles (FCEV), while the remaining vehicles would still have an ICE fuelled by synthetic fuels or biofuels.

4.3 Industry

While in the scenarios modelled the buildings and transport sectors are fully decarbonised, and while industry decarbonises to a large extent, this sector is still a net emitter in 2050, thus requiring an offset by some form of absorption in order to reach climate neutrality.

In section 3.3, we have seen that different levers can have a strong impact on material demand in Belgium. How does material production relate to material demand? The answer to that question involves at least two aspects. First, our industries operate at EU and even at international level. Therefore, any change in the demand for products and materials at national level need not necessarily impact significantly the demand at company level. The question becomes: to what extent are the other countries likely to go through similar change towards a circular economy and other related systemic changes. It is considered to be the case for our climate neutral scenarios, that is that they necessarily take place in a context of decarbonisation at EU (cf. Green Deal) and international (cf. Paris Agreement) level. Second, competitiveness aspects also come into play. Any reduction in total demand does not necessarily, at least in the short to medium terms, lead to a reduction of the demand addressed to companies located in Belgium.

Figure 20. Material production volumes trajectories (in kt)



Therefore, in order to illustrate those challenges, two different assumptions are being tested.

First, in the three main scenarios leading to climate neutrality (i.e. the CORE-95, BEH and TECH scenarios), material production levels are linked to the materials demand stemming from the different sectors in order to highlight the potential contribution of the circular economy in reducing GHG emissions. Given the lower levels of materials demand in these climate-neutral transition scenarios in a period up to 2050 (see above), material production levels consequently follow a decreasing path in the respective scenarios, as is observed in Figure 20. The decreasing trend is less pronounced in the

TECH scenario where products manufacturing is kept relatively high due to less behavioural changes than the CORE-95 and especially the BEH scenarios.

Such trajectories need to be interpreted cautiously considering what has been mentioned just above and taking into account that a reduction in materials production volumes does not necessarily imply as a reduction in added value. The new production patterns involve innovative processes whereby the value of products can increase[17], while the value of the material is also likely to increase.

Second, in the “High demand” scenario, industrial production levels are defined exogenously. We assume here that production is kept constant over the whole period at its 2015 level. Given the higher level of production volumes, energy requirements will be higher in such a scenario. This in turn impacts the energy supply side, as we shall see.

Again, this assumption is made for illustrative purposes and it is possible for anyone to analyse other, sector specific trajectories and the implications of these on the system level.

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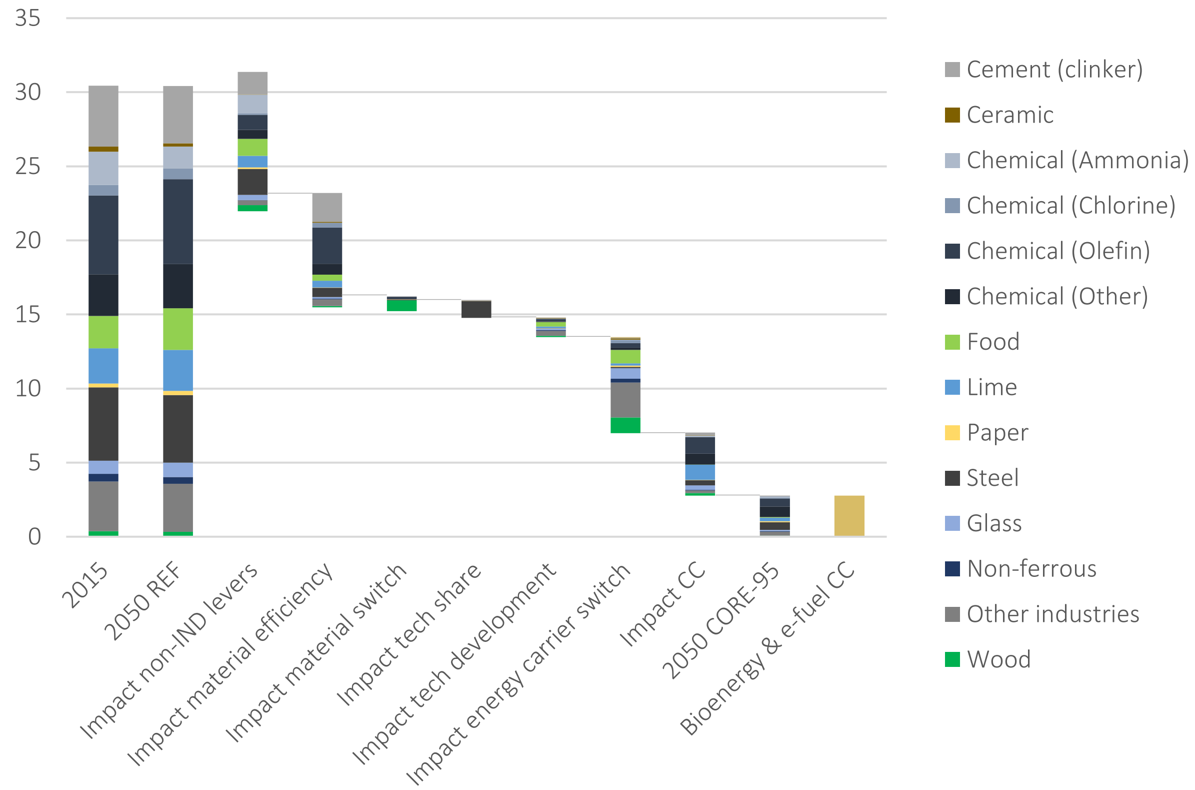
Besides circular economy, technological developments and energy and feedstock switches are essential levers to reduce GHG emissions in industry. Still, a significant level of CCUS will be required for the sources that cannot be decarbonised.

Figure 21. GHG emissions in industry – Impact of groups of levers ($MtCO_2e$) – CORE-95 scenario



[17]European Climate Foundation (2018), *Net zero by 2050: From whether to how*, September.

As highlighted previously, behavioural and circular economy levers are potentially very powerful, which can also clearly be seen at the level of related GHG emission reductions. Figure 21 illustrates such an impact when these levers are calculated first, in the CORE-95 scenario (see the first three groups of impacts).

In order to further reduce industrial GHG emissions, the more traditionally studied emission reduction levers then have to be applied: change of type of technology, technological development, energy carrier switch and CCS/U.

In terms of technology share, a switch to the best available technologies contributes to reducing GHG emissions, especially for the manufacturing of steel and cement.

Technological developments allow for further improvements in terms of energy demand per ton of manufactured material, leading to an efficiency increase of around 7.5% for manufacturing steel to a little over 30% for manufacturing lime. In terms of GHG emissions, the largest reductions through technological developments are achieved in the other industries category and in the food sector.

The most important remaining lever is the energy carrier switch, even when calculated after the other lever groups. This lever results in very large emission reductions, whereby in the CORE-95 scenario, almost the full potential of electrification in industrial processes is achieved and near full potential switches to gaseous fuels, synthetic fuels and biomass are reached by 2050, including for feedstocks.

At this stage, carbon capture and storage is applied to the maximum share of remaining emissions from combustion and industrial processes. In the CORE-95 scenario, this results in about 3 $MtCO_2e$ still emitted by 2050 that need to be compensated through additional carbon capture on emissions from biomass, or potentially e-fuels.

It must also be noted that fossil fuel-based industrial feedstocks, which account for about 45% of industrial energy demand in 2015, are progressively replaced by carbon-neutral alternatives (hydrogen, e-fuels and biomass) (see below). In accordance with the official GHG accounting rules, the fossil fuel emissions embedded in these feedstocks are not accounted for at the industrial stage, as these emissions take place at the end of life of the products when these are incinerated or disposed. Also, the replacement of these fossil fuel feedstocks by carbon neutral feedstocks leads to –all other things being equal—a significant additional reduction in the order of 10 $MtCO_2e$ in 2050 in the CORE-95 scenario with respect to the REF scenario. Given that the waste sector is not explicitly modelled, we adopt the conservative approach not to account for this important additional reduction when assessing the balance between emissions and removals, although these feedstocks require significant efforts in terms of e-fuels and hydrogen production as well as biomass availability. Further analyses and modelling work integrating the bioeconomy and a detailed representation of materials recycling would shed more light on this important element.

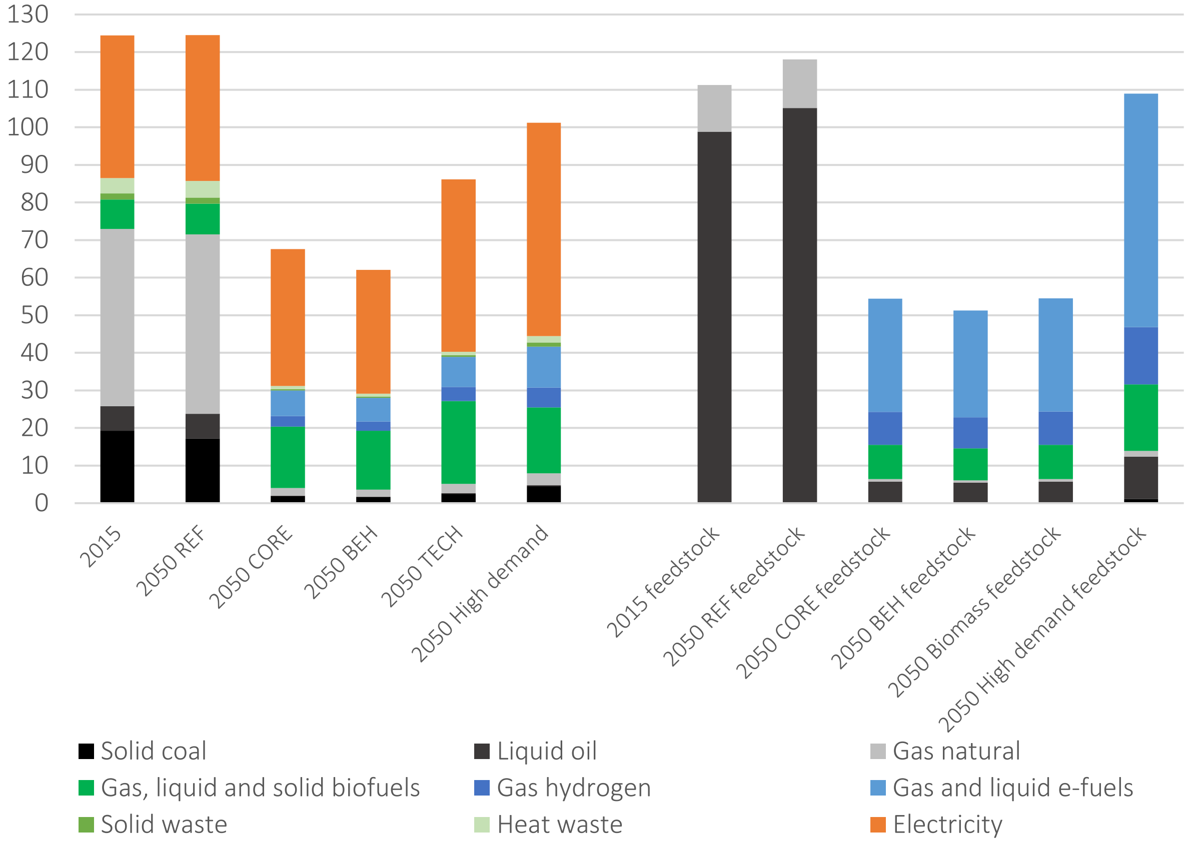
15

Electrification is important in industry but plays a smaller role than in other sectors, while synthetic fuels and biomass are required to decarbonise a large part of the energy supplied.

While the electrification potential in industry is not as large as in other sectors, it still plays an important role. In the CORE-95 scenario, near-full potential of electrification of heat is deployed by 2050, through a switch to electrification of about 10% in glass, 50% in chemicals, and 60% in aluminium, food, nonferrous and other industries. This leads to a share of electricity in the energy mix (excluding feedstocks) of just over 50% in 2050 in the CORE-95 scenario (but also in the BEH, TECH and high demand scenarios, cf. Figure 22 below).

Figure 22 also shows that biomass (biomethane, solid and liquid biofuels) and synthetic fuels (liquid and gas e-fuels) are needed in industry in order to be able to decarbonize a large share of the required energy vectors for energy use and for use as feedstocks. Indeed, in the CORE-95 scenario, while biomass represents a little less than 25% of the energy mix excluding feedstocks in industry in 2050, synthetic fuels (gas and liquid e-fuels in this case) and hydrogen represent almost 15% of the energy mix. More importantly, most of the fossil fuels used as feedstock in 2050 in the Reference scenario are replaced by synthetic fuels (around 55% of the energy vector mix used as feedstocks), hydrogen (around 15%) and biomass (almost 20%) in the CORE-95 scenario. The same is observed in the BEH, TECH and high demand scenarios.

Figure 22. Final energy demand per vector without feedstocks (left) and feedstocks only (right) (in TWh)



Consequently, in the industry, regarding energy vectors for energy use on the one hand, a big push in electrification of heat processes will be required together with a switch from fossil fuels to synthetic fuels, hydrogen and biomass. On the other hand, regarding the use of energy vectors as feedstock, most fossil fuels (around 90% in all transition scenarios depicted in Figure 22, when compared to the REF scenario) will have to be replaced by synthetic fuels, hydrogen and biomass.

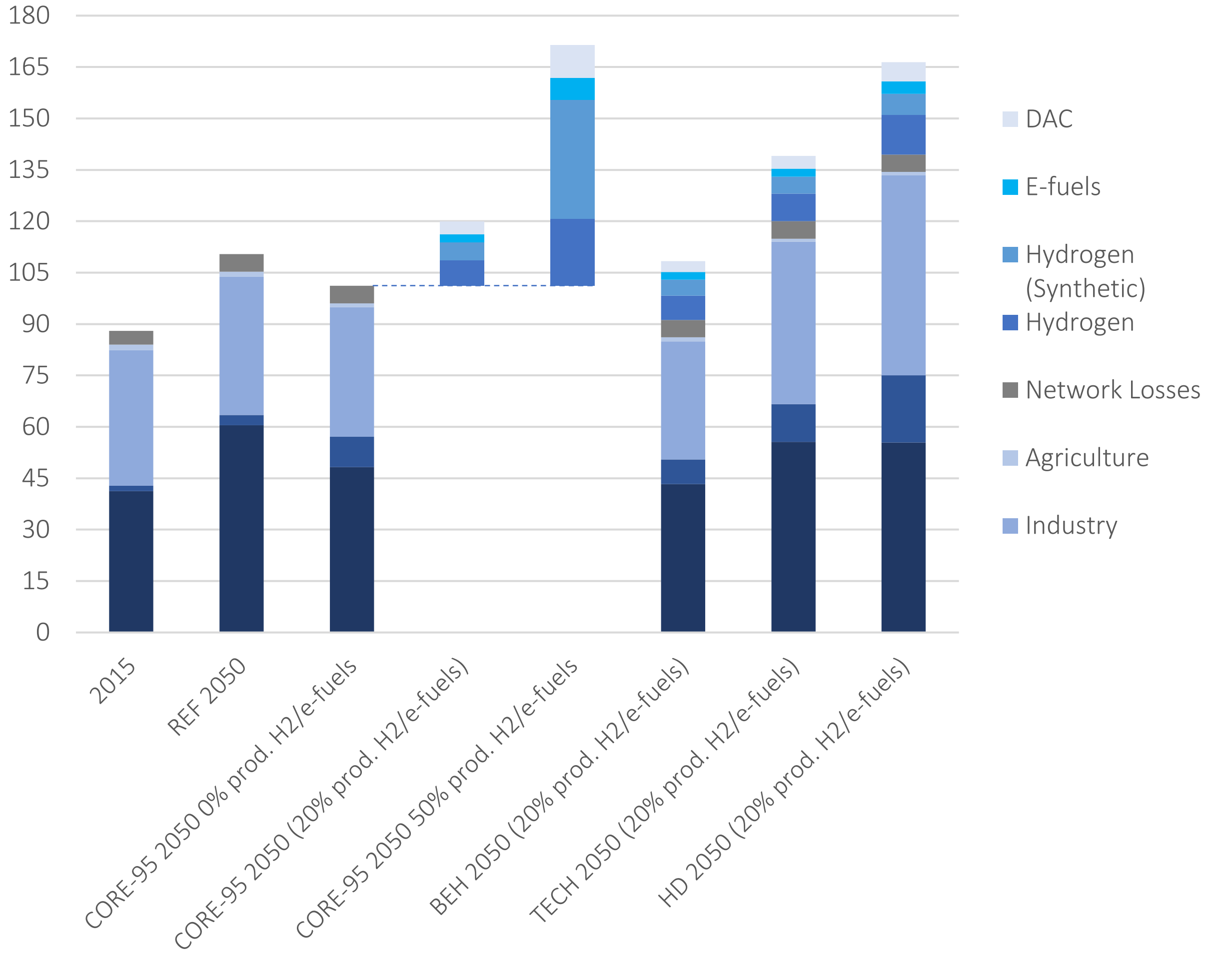
4.4 Power

16

Reaching climate neutrality by 2050 requires a higher electricity production level than at present. The share of carbon neutral hydrogen and synthetic fuels produced domestically has a key impact on total electricity demand.

Total electricity demand depends not only on the direct electricity demand of the buildings, transport and industrial sectors - which are electrified at a significant level - but also on the electricity required in order to produce hydrogen (via electrolysers) and e-fuels (including the direct capture of carbon from the air). Given the large demand for hydrogen and e-fuels in all climate neutral scenarios, assumptions made on the level of domestic production (vs import) of these energy vectors play a key role in determining total electricity demand.

Figure 23. Total electricity demand per sector (in TWh)



The CORE-95 scenario is characterised by an import level of hydrogen and e-fuels of 80% of its total demand by 2050 (and thus of 20% domestic production). As can be seen in Figure 23, total electricity demand increases by around 10% by 2050 in this scenario, when compared to the reference scenario.

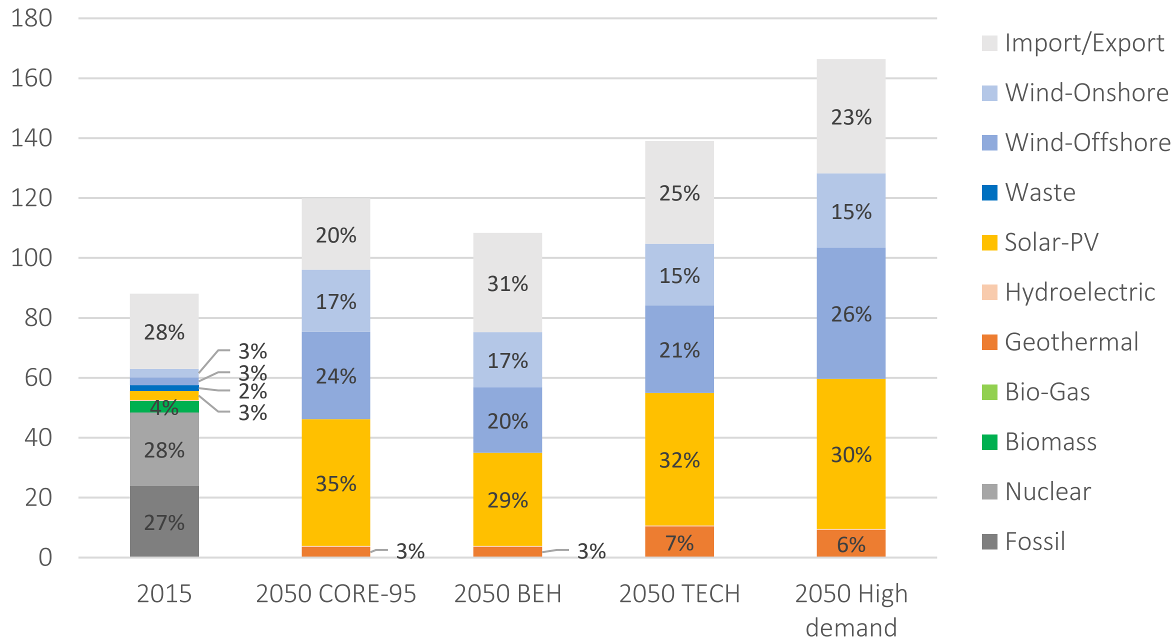
An increased electricity demand in absolute terms is noticeable in the transport sector, but most of the increase is related to the production of hydrogen and e-fuels (and related technologies used to produce these fuels). The electricity demand increase is even larger in the TECH (around 30%) and in the high demand (a little over 50%) scenarios, where larger amounts of synthetic fuels and hydrogen are required, which increases the need for domestic production (even if the level of domestic production remains at 20% of total demand).

The share of hydrogen/e-fuels supply that is produced in Belgium (via the technologies to produce them in a climate neutral manner), rather than imported from abroad, therefore plays a crucial role on the electricity demand (and therefore also on electricity production) in Belgium. Indeed, if all required hydrogen and e-fuels under the CORE-95 scenario would be imported from abroad (instead of producing 20% thereof locally), electricity demand in 2050 would decrease by 7% when compared with the Reference scenario. If hydrogen/e-fuels imports would be limited to 50%, electricity demand in 2050 would increase by over 40% when compared to the CORE-95 scenario (where 80% of required hydrogen/e-fuels is imported). It would, nevertheless, likely be challenging to meet this level of electricity demand with the available renewable potential in Belgium or with acceptable levels of electricity imports.

17

Even in high electricity demand scenarios, producing 100% renewable electricity is achievable provided that intermittency is adequately managed.

Figure 24. Electricity production (in TWh)



In this context, as can be seen in Figure 23 above, electricity demand under the CORE-95 scenario is significantly higher (around 10%) in 2050 when compared to the reference scenario. While lower than in the CORE-95 scenario, the behaviour scenario also shows a higher electricity demand in 2050 when compared to current levels, at a comparable level to the reference scenario. The technology scenario on the other hand shows a significantly higher electricity demand (around 30%) than the Reference scenario. Nevertheless, the analysis shows that the available renewable energy potential in Belgium is large enough to reach a 100% renewables-based electricity production by 2050 in each of the illustrative scenarios with levels of electricity imports comparable to current levels (see Figure 24).

In order for this to happen, solar PV installed capacity reaches between 28.8GW in the behaviour scenario and 46.4GW in the high demand scenario (with 39.2GW needed in the CORE-95 scenario) by 2050. Onshore wind installed capacity reaches 9GW by 2050 in both the CORE-95 and TECH scenarios (8GW in the BEH scenario and 10.8GW in the high demand scenario), while offshore wind installed capacity amount to between 6GW in the behaviour scenario and 12GW in the high demand scenario (8GW in the CORE-95 and technology scenarios). Offshore wind capacity above 6GW would have to be installed in other parts of the North Sea than the Belgian waters, through agreements with other countries. Geothermal installed capacity needs to reach between 0.5GW by 2050 in the CORE-95 and behaviour scenarios and 1.4GW in the technology scenario. Limited evolutions are expected as regards hydroelectric or tidal energy. Gas-fired power plants are likely to be required as back-up capacity, but are not accounted for in total electricity production as their actual level of production is expected to be marginal (see below)[18].

In this context, the management of intermittent renewable energy sources will be key[19]. Indeed, the reliability of the energy system will need to be ensured through efficient grid management, improved storage capacities and other flexibilities. The integration of renewable energy will be facilitated through decentralized and large-scale storage, different types of demand response and also partly through gas-fired power plants fuelled by synthetic gas or biogas. When economically viable and in order to ensure better storage, periodic surpluses of produced renewable electricity are transformed into heat, hydrogen or other energy carriers.

As mentioned earlier, the assumption made in the main illustrative scenarios is that 20 to 30% of electricity demand is imported. The model allows making different assumptions, which will of course impact the levels of required production in Belgium.

[18] Modelled costs for the electricity sector include costs related to back-up capacities.
[19] This issue is not explicitly modelled in the "2050 Pathways Explorer" and would benefit from complementary analyses based on complementary modelling tools (see references given above).

4.5 Agriculture, forestry and other

18

Changes towards healthier diets together with gradual but transformative changes in our agricultural model are required in order to reach significant emission reductions by 2050.

Behavioural changes and transforming agricultural practices are essential to deliver climate neutrality by 2050. Yet, these changes impact different dimensions and trade-offs need to be carefully analysed.

Figure 25. Impact of behavioural and agricultural practice levers on total emissions (in $MtCO_2e$) as compared to REF in 2050

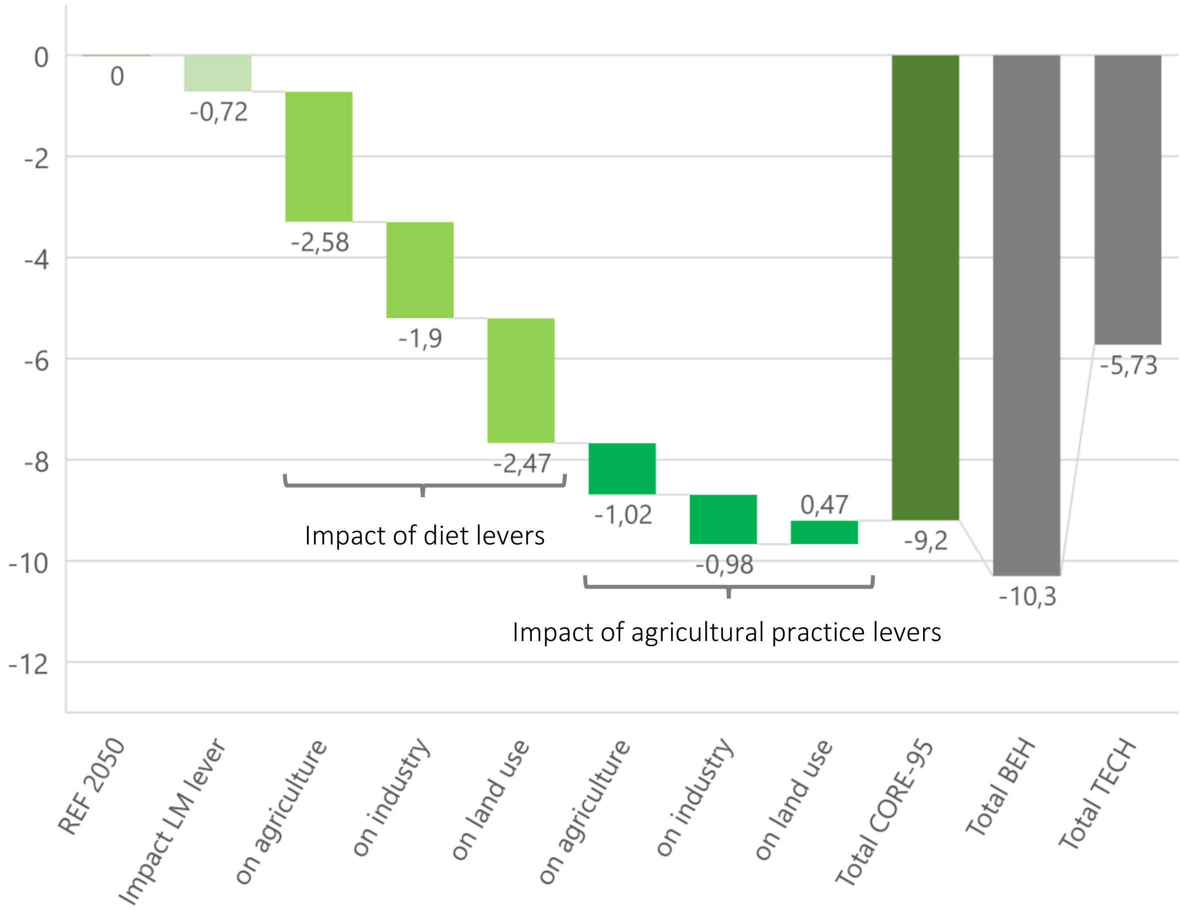


Figure 25 shows the decrease in GHG emissions related to the agriculture, forestry and land use sector when moving from the REF scenario to the CORE-95 scenario.

First, before analysing in more detail the behavioural and agricultural practice levers that can be deployed and their impact on GHG emissions, it should be noted that land management is a powerful lever that relates to the way that surplus land, freed-up by the impact of other levers, is allocated by 2050. Under 'Impact LM lever' in the lightest green, Figure 25 shows that by modifying land management practices from using surplus land either for non-food agriculture (e.g. textile) or just leaving it as unmanaged land (as is the case under the Reference scenario) to using this surplus land equally for afforestation (1/3), natural prairies (1/3) and non-food agriculture (1/3) by 2050 (as is the case under the CORE-95 scenario), total emissions in 2050 are reduced by almost 1 $MtCO_2e$. The impact of changing this land management lever is moreover further reflected in Figure 25 in the illustrated impact of diet and agricultural practice levers on land use.

Second, of the behavioural levers considered here (illustrated in light green in Figure 25 above), two key levers related to a change in diet are distinguished in the model. The first lever concerns food consumption (expressed in expressed in $kcal.cap^{-1}.day^{-1}$), whereby we consider that by 2050, calories consumption will have decreased by 29% in the CORE-95 scenario, which is in line with the recommendations of the Supreme Health Council[20]. The second lever controls the type of diet, specifically the quantity of meat consumed (expressed in $kcal.cap^{-1}.day^{-1}$) and the share of ruminant meat in total meat consumption. In the CORE-95 scenario, meat consumption decreases by 56% in 2050 as compared to 2015 (which is also in line with the recommendations of the Supreme Health Council), with the share of ruminant meat decreasing from 21% to 13%.

The contribution of these levers is significant and leads to a decrease of about 7 $MtCO_2e$ when switching from the configuration of levers of the REF scenario to the one of the CORE-95 scenario (see Figure 25, sum of the three light green bars related to diet levers). Diet levers have three distinct impacts. Emissions in the agriculture sector itself are reduced through lower N_2O emissions from fertilizer application on cropland soils and lower CH_4 emissions from manure. Less food and animal proteins' consumption impacts the manufacturing sector: directly via a lower level of food processing and indirectly via less production of fertilisers[21]. Finally, these behavioural changes also have an impact on land use through a potential reallocation of freed-up surfaces. Diet changes indeed lead to a reduction of the required feed crops and thus of related surfaces. They also reduce the area needed for livestock pasture. In other words, diet changes result in an important amount of land being freed-up, which is why it is important to ensure an appropriate land-use management is put in place (also to ensure coherence when converting one type of land into another). The specific impact of diet changes on land use between the Reference and the CORE-95 scenario) is illustrated in Figure 25. As forests' soil and biomass contain more carbon than the ones of cropland and grassland, a conversion into forest will always lead to carbon storage. As grasslands' soils contain more carbon than the one of croplands, a conversion of cropland into grassland will also lead to carbon storage.

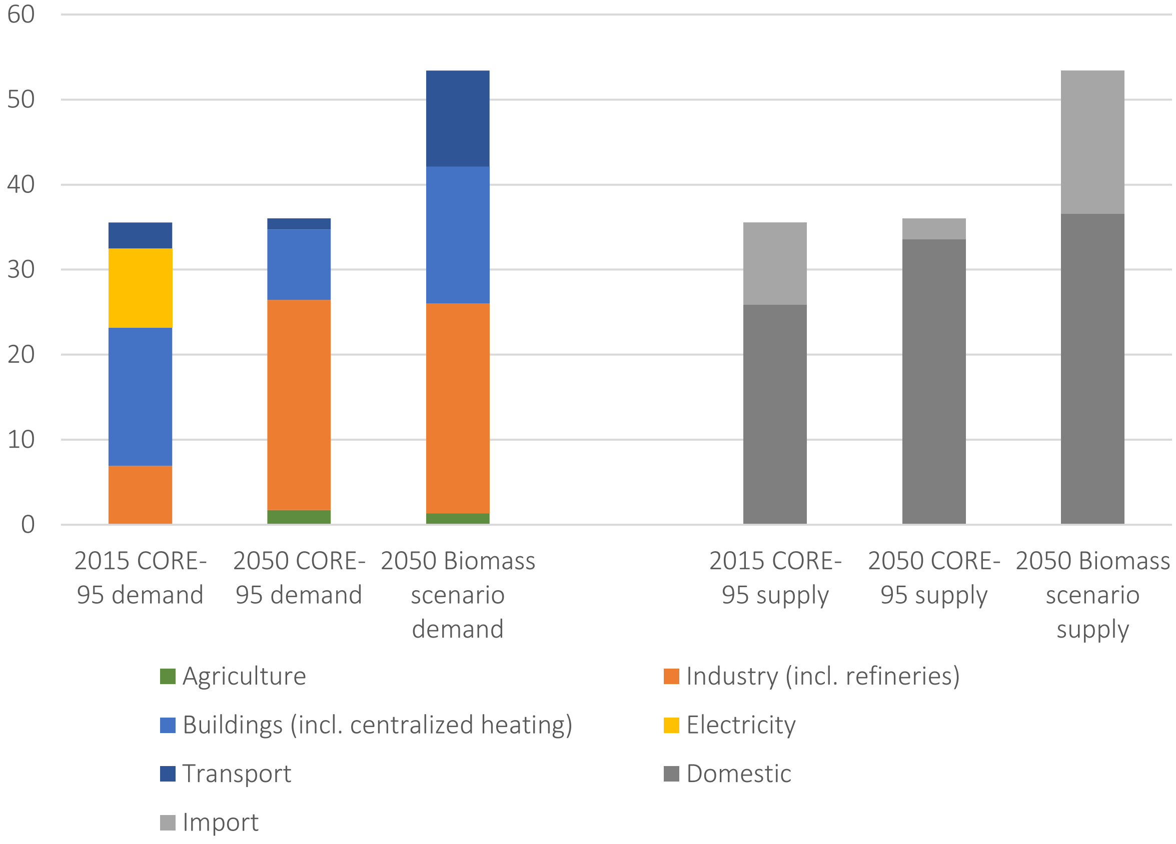
Third, agricultural practices (the impact of their related levers are illustrated in dark green in Figure 25) need to evolve towards agroecology practices for all crops where, by 2050 in the CORE-95 scenario, chemical pesticides are no longer used and the use of synthetic fertilisers decreases by 80% when compared to 2015. This, in turn, results in a reduction of crop yields by around 19% when compared to 2015. It is also important to replace a fraction of animal feed with alternative protein sources that do not require crops (e.g. insects, algae). In the CORE-95 scenario, on average 7% of animals feed is replaced by such alternative protein sources. Finally, livestock management follows agroecology type of standards in the CORE-95 scenario by 2050, which results in an extensification of livestock on pasture (i.e. 50% of livestock units/ha), a lower increase of animal yields (i.e. only an 11% increase of dairy milk production when compared to 2015), an increase of the grass share in animal feed (+30% compared to 2015) and different manure management where 5% is treated, 50% is left on the pasture and 45% is applied on fields. The emission reductions achieved through these agricultural practice levers, amounting to around 1.5Mt in 2050 when compared to the Reference scenario, are also the result of

[20] Hoge Gezondheidsraad (2016), *Voedingsaanbevelingen voor België*, September 2016.
[21] Assuming endogenous production.

interactions in the agriculture and industry sectors as well as due to changes in land use: e.g. almost no remaining emissions from the use of fertilisers and pesticides in the agriculture sector, as an almost complete switch is made to agro-ecology practices for all crops; emission reductions in industry due to reduced production of fertilisers in the chemical sector; and various interactions in the use of land with either a positive or negative impact on its absorption capacities.

19 The domestic bioenergy potential represents a large part of the total sustainable biomass demand by 2050 so that biomass imports are limited.

Figure 26. Bioenergy demand and supply in the CORE-95 and biomass scenarios (in TWh)



In the CORE-95 scenario, the choice was made to use the available biomass as a priority in the sectors that are harder to decarbonize (i.e. mainly the industry, but also international aviation and maritime transport – this last transport category not being considered here). Since sufficient alternatives are available for biomass in the power production sector, biomass is hardly used in this sector, except for the temporary, relatively important use of biogas in the period 2025-2035, where it is used to partly replace the natural gas electricity production that covered the phased-out nuclear-based electricity production (and this for the period needed to deploy RES technologies up to the levels required to phase out the use of biogas).

Several observations can be made when looking at Figure 26. Firstly, we observe that total sustainable biomass demand in 2050 in the CORE-95 scenario (that includes feedstocks) is largely met by domestic biomass supply (over 90%), thus limiting the need for biomass imports. Moreover, total levels of sustainable biomass demand in this scenario remain well below the maximum estimated share of sustainable biomass available worldwide that could be attributed to Belgium according to our former 2013 study (i.e. a maximum of 80-100 TWh[22]). Even when pushing the use of sustainable biomass to considerably higher levels (cf. the Biomass scenario illustrated in Figure 26 – where the share of biomass in the energy mix increases from 16% in the CORE-95 scenario to 23%), we observe that, although demand increases to reach levels within the 80-100 TWh range of the maximum estimated share of sustainable biomass for Belgium between 2030 and 2035, it never exceeds it throughout the period up to 2050 (and it remains well below it in 2050, as can be observed in Figure 26). The import share increases in the Biomass scenario, but is limited to around 30% of total demand in 2050.

Secondly, we observe that total biomass demand in 2050 in the CORE-95 scenario reaches similar levels as in 2015. This is the result of an overall decreasing demand for biomass for energy purposes between 2015 and 2050 on the one hand, and an increasing demand for biomass for use as feedstock in industry on the other hand.

Finally, we observe there is still a relatively important bioenergy demand stemming from agriculture in 2050 in the CORE-95 scenario, where a switch from natural gas to biogas takes place to cover energy demand from greenhouses.

20

Reducing greenhouse gas emissions will substantially reduce emissions of air pollutants.

Environmental pollution is linked to a range of diseases, including cancer, stroke, heart diseases, respiratory diseases and neurological disorders. According to the EEA[23], 13% of all deaths in Europe in 2012 were attributable to the environment (estimated at around 630,000 deaths), air pollution being the principal environmental factor driving diseases and as such being responsible for over 60% of these premature deaths.

In the context of the transition to a decarbonised and climate-neutral society by 2050, the phasing out of fossil fuels across all sectors will go hand in hand with a phasing out of emissions of air pollutants, bringing about substantial benefits in terms of health, well-being, etc. Still, the use of biomass for heating in the buildings sector will also require a particular attention in the context of the transition.

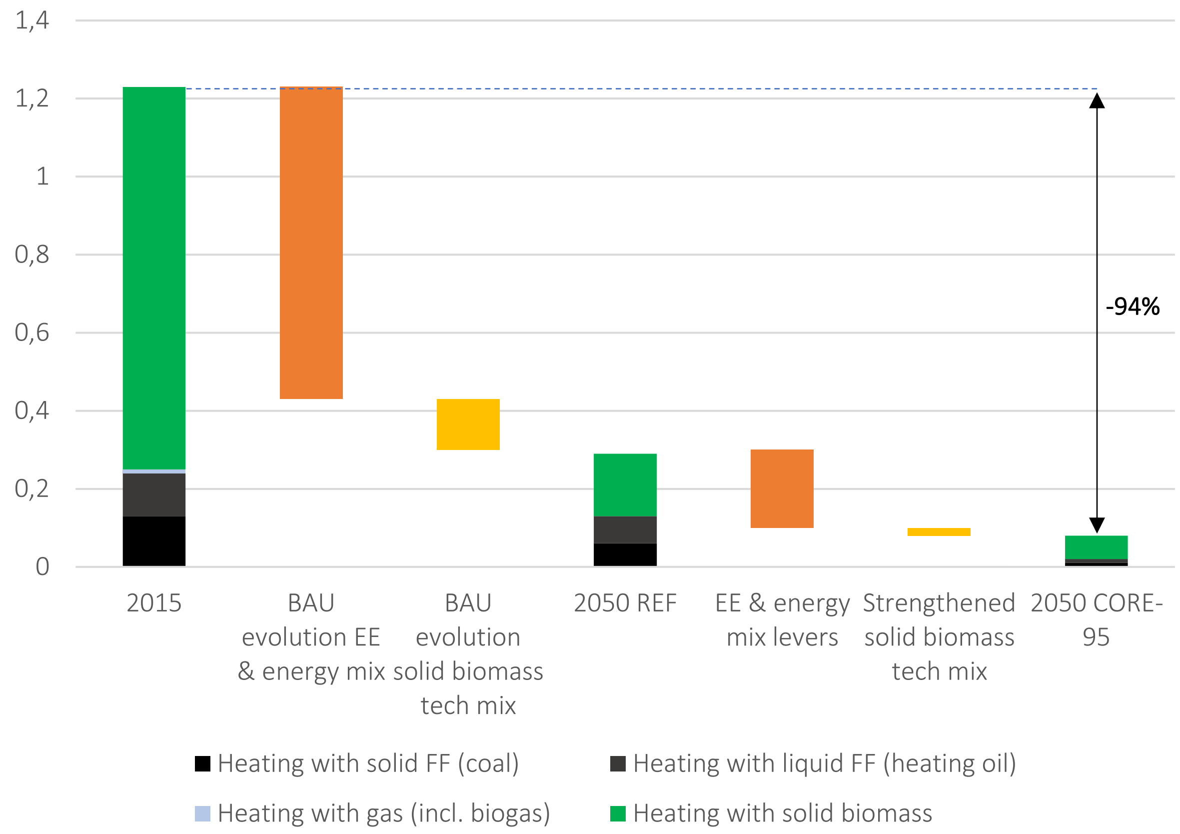
PM2.5 and VOC emissions have been modelled for the buildings sector. As we observe in Figure 27, the emissions of air pollutants for heating buildings (expressed in µg PM2.5eq/m³) are already expected to decrease considerably by 2050 in the Reference scenario when compared to 2015, through the already expected evolution of the energy mix and of expected energy efficiency measures, as well as of the expected evolution of the solid biomass technology mix. Together with the extra push of energy efficiency, energy mix and solid biomass technology mix levers in the context of the CORE-95 scenario,

[22] See https://klimaat.be/doc/Low_Carbon_Scenarios_for_BE_2050_-_Final_Report.pdf, p. 40.
[23] European Environment Agency (2019), *Healthy environment, healthy lives: how the environment influences health and well-being in Europe*, (the report stating that data on (premature) deaths are the most recently available WHO data published in 2016 for the year 2012)

total emissions of air pollutants in 2050 are expected to decrease by about 95% when compared to current levels.

When comparing the technology mix of biomass-fuelled heating systems in 2050 in the CORE-95 scenario with the current situation, fireplaces would no longer be used and the share of heating stoves (pellets/wood) in heating systems would decrease drastically, while automatic boilers would become largely predominant.

Figure 27. Emissions of air pollutants (in µg PM2.5eq/m³) for heating buildings



5 Conclusions and way forward

Climate neutrality is the new policy context in which any societal prospective analysis needs to be framed. This work provides new insights on pathways and on actions to be deployed for reaching climate neutrality by 2050 in Belgium. As such, the analysis contributes to underpin the development of a broad, quantitative vision on the transition in Belgium while identifying the necessary transformations. Therefore, it allows us to take more informed strategic decisions in this regard.

Firstly, we show that reaching climate neutrality in Belgium by 2050 is technically feasible, even though it is particularly challenging and requires systemic changes. When compared with the previous work that targeted lower emission reduction levels by 2050, new levers and options are needed to reach climate neutrality, in particular new technologies such as hydrogen, e-fuels, direct air capture or BECCS, as well as new consumption and production patterns. Furthermore, while GHG emissions can be reduced to zero in the buildings, transport and energy production sectors, some hard to abate emissions in the industry and agriculture sectors will remain and will need to be compensated with negative emissions through land use, direct air capture or bioenergy with carbon capture.

Secondly, regarding the overall costs, we have shown that the transition requires additional capital expenditures in carbon neutral infrastructure in all sectors. Total capital expenditures can nevertheless be significantly reduced by decreasing the demand for energy-consuming activities, products or services through behavioural changes and a more circular economy. Fuel cost reductions tend to compensate capital expenditure increases. Although electricity expenditure increases in all sectors, fossil fuel expenditure reaches almost zero in the long run. The price of hydrogen and e-fuels, including for use as feedstock, then becomes a determinant element of the total energy bill.

Thirdly, the illustrated scenarios confirm that electrification of the demand sectors, associated with a power production system based entirely or almost entirely on renewable energy sources, is the main avenue to gradually phase out fossil fuels. Since electrification is not possible for all energy end uses, it needs to be complemented with climate neutral fuels. Biomass will be used to some extent but its potential, although significant, remains limited and is strongly linked to land use choices. Hydrogen and e-fuels will be required to close the gap, especially for use as industrial feedstocks. The share of the domestic production (vs import) of these fuels becomes essential for the dimensioning of the electricity system.

Fourthly, the scenarios have also highlighted the importance of looking beyond the energy system so as to encompass key aspects related to the use of other resources and land. For instance, the massive renovation of buildings will be material-intensive. The circularity of the resources becomes an important issue in this context, together with material switches. Replacing some energy-intensive materials by wood, for instance, will contribute to reducing the energy consumption and thereby the GHG emissions from industrial production. At the same time, this raises issues regarding the availability of biomass and the related impact on land use and agriculture and, thereby, on carbon sequestration possibilities. This example illustrates how the interlinkages between these different dimensions are strong and therefore important to take into account when designing policies.

Fifthly, in order to enable the transition, systemic changes are required not only in terms of technological developments but also at the societal and cultural levels: changes related to the way we move, eat, consume, think about spatial planning will be crucial. In the transport sector, new mobility patterns based on mobility-as-a-service, modal shift, car sharing and new freight transport models can considerably reduce energy consumption and material use. New diets based on a lower consumption of proteins from animals together with decreasing the level of food waste are required for the drastic reduction of GHG emissions in an agricultural sector relying on new, environmentally friendly practices. The development of the sharing economy and the economy of functionality allows to significantly reduce the need for materials and products and thereby contribute to the reduction of emissions in the production sectors. Housing behaviours, based among others on a rational use of space, also contribute to the decarbonisation through similar channels.

Finally, given its particularly broad scope, this analysis complements work that has already been undertaken (at least partly) or that still needs to be fully developed based on specific modelling tools or methodologies[24]. Such work includes a more targeted analysis of the energy production system and intermittency challenges, the specific implementation of decarbonisation policies in industrial sectors, the availability of biomass in the context of a bio-based economy, the profitability of low carbon investments at a micro level in all sectors and the social and distributive impacts of pursuing the different decarbonisation pathways/actions, just to name a few.

[24] See footnote 4 for instance.

Appendix 1 Main levers

The table below lists the main levers and illustrates their ambition levels in the main illustrative scenarios. As most levers encompass several indicators, only the most illustrative indicator(s) is (are) described. For some levers, the diversity (such as across industrial sectors for instance) is such that the ambition levels are described qualitatively. All details are available online in the “2050 Pathways Explorer”.

Table 1. Main levers and their levels in the main scenarios

	2015	REF	CORE 95	BEH	TECH	High Demand
KEY BEHAVIOURS						
Passenger distance (km/cap/y, excl. aviation)	13373	15414.2 (+15.3%)	12570.8 (-6%)	10699 (-20%)	14507 (+8.5%)	15414.2 (+15.3%)
Transport mode - Car modal share in urban / nonurban areas (%)	65% / 80%	65% / 80%	42.5% / 62%	33% / 44%	47% / 69%	65% / 80%
Occupancy rate - Number of pers/car	1.5	1.5	2.3	2.5	1.8	1.5
Car own/hire - Car util. rate (vkm/veh)	12829	12829	25658 (x2)	44901.5 (x3.5)	25658 (x2)	25658 (x2)
Living space per person (m^2/cap)	38.2	38.2 (+0%)	32 (-16%)	27 (-29%)	38.2 (+0%)	38.2 (+0%)
Non-residential floor area demand - Evolution vs 2015 (%)	227512	+22%	-7.5%	-15%	+7.5	+7.5
Food consumption (kcal/cap/day)		-1%	-29%	-34%	-15%	-29%
Evolution of meat consumption (in %)		-14%	-56%	-75%	-30%	-56%
Use of plastic packaging (kg/cap/year)	30	+14%	-33%	-59%	-22%	-33%
Appliances’ Lifetime (% of lifetime when replaced)	-	90%	123%	130%	120%	123%
Food waste at farm and post-farm (%)	13%	12.6% (-3%)	4.8% (-63%)	3.0% (-77%)	9.1% (-30%)	4.8% (-63%)
Freight distance (Gtkm/year)	109	145 (+33%)	106 (-3%)	98 (-10%)	109 (+0%)	145 (+33%)
TRANSPORT						
Transport - freight						
EE - Consumption of new diesel trucks (MJ/km)	22	20 (-10%)	12 (-43.5%)	14 (-37%)	11 (-50%)	17 (-24%)
Freight mode - Truck modal share for intra-BE long distance freight (%)	82%	82%	63%	60%	74%	82%
Share of Zero-Emission Vehicles (ZEV) in new truck sales (%)	0.01%	5%	76.9%	76.9%	76.9%	76.9%

Share of Low-emission vehicles (LEV) in remaining new truck sales (%)	0.01%	25%	100%	100%	100%	100%
Share of of BEV / FCEV in new ZEV truck sales (%)	100% / 0%	100% / 0%	33.33% / 66.67%	33.33% / 66.67%	33.33% / 66.67%	33.33% / 66.67%
Share of PHEV / PHEV-CE / ICE-gas vehicles in new LEV truck sales (%)	100% / 0% / 0%	50% / 50% / 0%	40% / 40% / 20%	40% / 40% / 20%	40% / 40% / 20%	40% / 40% / 20%
Load factor vans and trucks (tkm/vkm)	12.4	12.4 (+0%)	13.95 (+12.5%)	13.64 (+10%)	14.26 (+15%)	13.02 (+5%)
Utilisation rate - Distance travelled by vans and trucks vs 2015 (km/year)	20976	20976 (+0%)	36708 (+75%)	31464 (+50%)	41952 (+100%)	36708 (+75%)
Transport – passenger						
EE – Consumption of new diesel car (MJ/km)	2.68	2.14 (-20%)	1.47 (-45%)	1.61 (-40%)	1.34 (-50%)	1.88 (-30%)
Automation of LDVs - Share of empty km						
Share of ZEV in new car sales (%)	0.07%	2%	100%	100%	100%	100%
Share of LEV in remaining new car sales (%)	0.1%	6%	100%	100%	100%	100%
Share of BEV / FCEV in new ZEV car sales (%)	100% / 0%	100% / 0%	93.33% / 6.67%	93.33% / 6.67%	93.33% / 6.67%	93.33% / 6.67%
Share of PHEV / ICE-gas vehicles in new LEV car sales (%)	81% / 19%	81% / 19%	10% / 90%	10% / 90%	10% / 90%	10% / 90%
Transport - technology and fuels						
Share of new, electrified IWW ships (%)	0%	0%	20%	20%	30%	20%
Share of biofuels in fuels used for road transport (passenger and freight) (%)	3%	7%	7%	7%	7%	7%
Share of biofuels in fuels used for IWW transport (%)	0%	0%	66%	66%	66%	66%
Share of e-fuels in the residual fuel demand in road transport ((%)	0%	0%	100%	100%	100%	100%
Share of e-fuels in the residual fuel demand in IWW transport (%)	0%	0%	100%	100%	100%	100%
BUILDINGS						
Buildings - Residential						
Space heating and cooling behaviour – Average temperature (°C)	20°C	20°C	18°C	16°C	20°C	19°C
Hot water demand (kWh/HH/year)	2435	2435	1623.33 (-1/3)	1217.5 (-50%)	2069.75 (-15%)	1846.46 (-24.17%)
% of residential buildings with cooling systems	1.5%	40%	3%	1.5%	20%	11.5%
Renovation rate (%/year)	1%	1%	2.8% by 2025	2.8% by 2025	2.8% by 2025	2% by 2025
Renovation depth - Share of shallow (85 kWh/m²/year) / med (64 kWh/m²/year) / deep (25 kWh/m²/year) renovations (%)	80%/15%/5%	80%/15%/ 5%	40%/50%/10% by 2025	40%/50%/10% by 2025	40%/50%/10% by 2025	60%/32.5%/7.5% by 2025
Demolition rate (%/year)	0.1%	0.1%	0.225% by 2025	0.225% by 2025	0.225% by 2025	0.2% by 2025

New-build efficiency - Share of new-build with an energy efficiency level of 75 / 45 / 15 kWh/m²/year (%)	80%/15%/5%	40%/50%/10%	0%/40%/60%	0%/40%/60%	0%/40%/60%	0%/80%/20%
Overheating reductions - Evolution of cooling energy needs vs 2015 (%)		-0%	-10%	-10%	-15%	-10%
% of DH in the heating energy demand	2.5%	2.5%	30%	30%	55%	30%
Contribution of solid biomass - space heating	9%	10%	5%	0%	0%	5%
Electrification of space & water heating - % of heat pumps for space heating	3%	25%	63%	75%	85%	63%
% electricity in energy cons. for cooking	42%	51%	90%	80%	100%	90%
Appliance ownership - # computers / HH	2.3	2.5	1.7	1.3	2.1	1.7
Appliance use - Evolution of # of hours using given appliances vs 2015 (%)		+14%	+0%	-30%	+43%	+0%
Appliance efficiency - Evolution of energy cons. of appliances vs 2015 (%)			-40%	-35%	-45%	-40%
Buildings - Services						
Hot water demand - Evolution vs 2015		-0%	-33%	-50%	-15%	-24%
Share of non-residential buildings equipped with cooling systems (%)	24%	70%	50%	24%	60%	55%
Renovation rate (%/year)	1%	1%	2.8% by 2025	2.8% by 2025	2.8% by 2025	2% by 2025
Renovation depth - Share of shallow (85 kWh/m²/year) / med (64 kWh/m²/year) / deep (25 kWh/m²/year) renovations (%)	80%/15%/5%	60%/32.5%/7.5%	40%/50%/10% by 2025	40%/50%/10% by 2025	40%/50%/10% by 2025	60%/32.5%/7.5% by 2025
Demolition rate (%/year)	0.1%	0.1%	0.225% by 2025	0.225% by 2025	0.225% by 2025	0.225% by 2025
New-build efficiency - Share of new-build with an energy efficiency level of 75 / 45 / 15 kWh/m²/year (%)	80%/15%/5%	40%/50%/10%	0%/40%/60% by 2025	0%/40%/60% by 2025	0%/40%/60% by 2025	0%/40%/60% by 2025
Overheating reductions - Evolution of cooling energy needs vs 2015 (%)		-0%	-12.5%	-10%	-15%	-12.5%
Contribution of solid biomass - space heating	0.6%	10%	5%	0%	0%	5%
Electrification of space & water heating - % of heat pumps for space heating	12%	30%	71%	75%	85%	71%
% electricity in energy consumption for catering	57%	57%	92.8%	85.6%	100%	92.8%
Buildings - Residential and Services						
% of gas demand met by biomethane	10%	0%	50%	50%	50%	50%
% of gas demand met by hydrogen	0%	0%	34%	34%	34%	34%
% remaining gas demand met by syn gas	0%	0%	100%	100%	100%	100%
% of liquid fuels met by bioliquids	10%	0%	30%	100%	30%	30%
% remaining liquid fuels met by syn liquids	10%	0%	100%	100%	100%	100%

Efficiency improvements for all technologies (except appliances) - Efficiency of heat pumps (SCOP)	1.5	1.5	2.25	2	3	2.25
MANUFACTURING						
Material production (kt/sector)		Linked to demand	Linked to demand	Linked to demand	Linked to demand	Constant production
Material efficiency - # of materials required per product vs 2015 (%)		Between -0% & -10% across sectors	Between -8.5% & -85%	Between -8.5% & -85%	Between -8.5% & - 85%	Between -8.5% & -85%
Material switch (e.g.: in cars, replace steel by chemical and aluminium; in new buildings, cement and steel by wood)		No major switches	Important switches	Important switches	Important switches	Important switches
Technology share/recycling (in steel, cement and paper)		No major changes in tech %	Strong technology switch	Strong technology switch	Strong technology switch	Strong technology switch
Evolution of energy efficiency vs 2015 (%)		Between 0% and 9% across sectors	Between 7.5% and 30.5%	Between 7.5% and 30.5%	Between 7.5% and 30.5%	Between 7.5% and 30.5%
Shift towards less carbon intensive fuels (decarbonised electricity mix, switch to gaseous fuels, or to biomass)		Current energy mix; no major shifts towards less carbon int. fuels	Attain almost the full potential of electrification of heat, of the use of zero-carbon hydrogen and of the switch to sustainable biomass, leaving small shares of fossil-fuels in the energy mix			
Share of fossil fuels replaced by e-fuels	0%	0%	83%	83%	83%	83%
Share of fossil fuels replaced by H_2	0%	0%	Between 7.5% & 45% across sectors	Between 7.5% & 45%	Between 7.5% & 45%	Between 7.5% & 45%
Carbon capture	No comm. viable CC technology options	Do not capture GHG emissions (except for Steel HIsarna)	Significant share of the CCS potential applied (sector specific)	Significant share of the CCS potential applied (sector specific)	Significant share of the CCS potential applied (sector specific)	Significant share of the CCS potential applied (sector specific)
ENERGY PRODUCTION						
Energy Production - Electricity						
Biomass capacity (GW)	0.47	0	0.47	0.47	0.47	0.47
Hydro, geo & tidal – e.g. Geothermal capacity (GW)	Very limited capacity deployed	1 geothermal plant operational in 2019 in Mol	0.5	0.5	1.4	1.25
Solar PV capacity (GW)	3.77	10	39.2	28.8	41	46.4
Onshore wind power capacity (GW)	1.65	7	9	8	9	10.8
Offshore wind power capacity (GW)	0.71	4	8	6	8	12
Nuclear phase out - Nuclear capacity (GW)	6.18	Performed by 2025	Idem	Idem	Idem	Idem

Energy Production - Oil						
Activity level for refineries (if exogenous methodology is used) (TWh)	426	Linked to demand from sectors	Linked to demand from sectors	Linked to demand from sectors	Linked to demand from sectors	Linked to demand from sectors
Energy Production - Technology						
Technology mix for centralized heating production - Share of large-scale heat pumps (non CHP)	13%	40%	77%	77%	77%	77%
Use of CO_2 from CCS or Direct Air capture (DAC) in e-fuel production	No e-fuel production	CCS	DAC	DAC	DAC	DAC
Share of gas replaced by biogas in electricity production vs 2015 (%)		0%	100% by 2040	100% by 2040	100% by 2040	100% by 2040
Share of oil replaced by gas / gas by e-gas / remaining gas by biogas in refineries vs 2015 (%)		No energy carrier switch	75% / 75% / 75%	75% / 75% / 75%	75% / 75% / 75%	75% / 75% / 75%
Evolution of energy efficiency vs 2015 (%)		+2%	+7.5%	+5%	+10%	+7.5%
Share of emissions captured by CCS for electricity production (%)	0%	0%	0%	0%	0%	0%
AGRICULTURE, FORESTRY AND LAND USE (AFOLU)						
Climate Smart Crop Production Systems		- 30% entrants and pesticides; loss of 6.5% of crop yields (vs. 2015)	No chem. pesticides and - 60% of entrants; loss of 13% of crops yields (vs. 2015)	Agro-ecology practices: no fertilisers nor pesticides; loss of 25% of crops yields (vs. 2015)	Constant entrants use and yields (vs. 2015)	No chem. pesticides and - 60% of entrants; loss of 13% of crops yields (vs. 2015)
% animals feed replaced by alt. protein sources requiring no crops vs 2015		0%	7%	0%	10%	7%
Climate Smart Livestock - Evolution % of pasture in animals feed vs 2015	50%	+0%	+30%	+40%	+0%	+30%
Evolution emissions from the energy mix consumed in agriculture vs 2015 (%)		-12.5%	-100%	-100%	-100%	-100%
Bioenergy Priorities and Import Strategy - % liquid biofuels coming from Import		100%	0%	0%	0%	25%
% surplus land allocated to afforestation / natural prairies / non-food cropland		0% / 0% / 100%	33% / 33% / 33%	27% / 27% / 47%	33% / 33% / 33%	33% / 33% / 33%
Demographic and long term						
Evolution of the population vs 2015 (%)	11.24 million	+10%	+10%	+10%	+10%	+10%
Share of population living in urban areas	79%	75%	79%	79%	79%	79%
Average # of persons / HH (capita)	2.3	2.2 (-5%)	2.2 (-5%)	2.2 (-5%)	2.2 (-5%)	2.2 (-5%)
IMPORTS & EXPORTS						
Evolution of the % of the food demand produced locally vs 2015		+0%	+0%	+0%	+0%	+0%
Evolution of the % of products demand manufactured locally vs 2015		+0%	+0%	+0%	+0%	+0%

Evolution of the % of materials demand manufactured locally vs 2015		+0%	+0%	+0%	+0%	+0%
Imports & exports - Energy						
% of the electricity demand produced locally*	72%	78%	80%	69%	75%	77%
% of coal / oil / natural gas demand produced locally	0% / 16% / 0%	0% / 116% / 0%	0% / 116% / 0%	0% / 116% / 0%	0% / 116% / 0%	0% / 116% / 0%
% of heat demand produced locally	100%	100%	100%	100%	100%	100%
% of hydrogen demand produced locally	100%	20%	20%	20%	20%	16%
% of e-fuel demand (liquid and gas) produced locally	100%	20%	20%	20%	20%	16%

* Resulting values in 2050

Appendix 2 Energy price assumptions

Table 2. Energy price assumptions (in €/MWh)

Energy vector	2015	2050
Electricity	59.6	83.2
Hydrogen	160	70.4
E-fuels	203	85.3
Natural gas	20.4	25.7
Coal	10.2	8.8
Oil	38	65
Biogas	95	59.8
Liquid biofuel	103	85.5
Solid biofuel	14.4	20.6