EU 2050 long-term strategy

Appreciation document

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ABBREVIATIONS

BAU	Business As Usual
BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Usage
CH_4	Methane
CO_2	Carbon Dioxide
DACCS	Direct Air Capture and Carbon Sequestration
EC	European Commission
EPBD	Energy Performance of Buildings Directive
EU	European Union
F-gases	Fluorinated gases
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emissions
H_2	Hydrogen
IPCC	Intergovernmental Panel on Climate Change
ICT	Information and Communication Technology
LULUCF	Land Use, Land Use Change, and Forestry
Mt	Megatonne
N_2O	Nitrous Oxide
O&M	Operations & Maintenance
PV	Photovoltaics
SOC	Soil Organic Carbon
TRL	Technology Readiness Levels

EXECUTIVE SUMMARY

This report presents an appreciation of the EU 2050 long-term strategy for the Ministry of Economic Affairs and Climate Policy in The Netherlands.

Overall appreciation:
Navigant considers the EU 2050 long-term strategy a high-quality document on decarbonisation pathways. It is a comprehensive document and the overall approach is well chosen in presenting the results. It creates a narrative of options, including the rationale, with a focus on long-term objectives.

The EU 2050 long-term strategy uses best available models and includes the input from many recent studies. It provides a holistic view and helps to see cross-sectoral strategies. It also helps to prioritise action areas, advance understanding and create tangible action options for political debate. It is a good discussion starter for political decisions at an EU level.

Effectiveness of the EU 2050 long-term strategy
We see the strategy towards net-zero GHG emissions by 2050 as feasible. Below we describe the expected effects and uncertainties around the 7 key strategic actions from the EU 2050 long-term strategy:

1. **Maximise the benefits of energy efficiency, including zero emission buildings:** We see this action as achievable because it is techno-economically possible and can be done at limited costs to society. However, deep refurbishments of buildings at a moderate renovation rate are required.

2. **Maximise deployment of renewables and use of electricity to fully decarbonise the EU energy supply:** An increasing share of the EU's additional renewable energy shall come from offshore wind and we agree with this conclusion. There are uncertainties on how to best integrate the the last share (i.e. over 70%) of renewables into the grid, as no gas-powered power stations would be available to provide flexible back-up.

3. **Clean, safe and connected mobility:** The ambitions within this sector are achievable, but with some uncertainties. Clean mobility is at an early stage but seems to be fairing well and costs are declining. There are uncertainties, however, regarding the volume of e-fuels needed (which represent a significant share) and the related costs.

4. **A competitive EU industry and the circular economy:** The circular economy can have a huge potential, but there are large uncertainties on how to unlock it, such as how to induce significant behavioural changes and deep business model transformation while at the same time retaining value within the economic system.

5. **Develop an adequate smart network infrastructure and inter-connections:** The necessary infrastructure must be built up quickly as it can define the path of the transition. This network expansion may become one of the bottlenecks in the transition.

6. **Reap the full benefits of bio-economy and create essential carbon sinks:** The targeted share of biomass potential and natural carbon sinks in the EU both seem realisable.

7. **Tackle remaining CO_2 emissions with carbon capture and storage:** The CCS/CCU potential is realisable, but the technologies can be deployed earlier than 2040, as assumed in the scenarios. The role of CCS in net emission reduction is less prominent in the pathways considered than in previous scenario analyses.

Correctness of the EU 2050 long-term strategy

The main model underlying the EU long-term climate strategy is the PRIMES model which is a long-established model that has existed for 30 years. It is a modelling tool for EU analysis which was designed to stimulate behavioural modelling and detailed long-term projections of energy consumption, supply, prices, investments, emissions for each individual EU Member State as well as EU trade[1]. EU Member States have been given the opportunity to comment on it and the model has been continuously improved over the years.

By running the FORECAST model from Fraunhofer-ISI in parallel to the PRIMES model, a better representation of demand options has been achieved for the industry sectors and around circularity, but this could be further improved.

We believe that the latest insights on technology costs are incorporated. There are still technologies in an early stage with high cost uncertainties, such e-fuels and hydrogen. These areas require further study later to achieve more granularity and better cost estimates.

Finally, we believe that discount rates, the assumed interest rates on investments, applied in the model are especially high regarding end-use energy efficiency options. Given that energy efficiency should have a top priority according to the communication document, we think that the energy efficiency option could be further utilised.

Alignment of EU 2050 long-term strategy with Dutch climate policies

The proposed EU 2050 long-term strategy for 2050 is well in line with Dutch climate policy (Dutch Climate Law and Dutch Climate Agreement for 2030) although it is important to note that the EU 2050 long-term strategy is not prescriptive and general abatement potentials for the EU are not necessarily representative for the Netherlands. Solutions to enable the net-zero emissions scenario will differ per Member State, e.g. with regard to uptake of CCS versus circularity.

The EU 2050 long-term strategy offers multiple opportunities for the Netherlands. The Netherlands is well-positioned for growth areas such as, offshore wind, vehicle charging infrastructure, circular economy, sustainable procurement, reduction of natural gas, hydrogen and e-gas, CCS and smart building retrofitting.

Cost-effective interim goals for 2030 and 2040

A gap in the modelling and report is the lack of exploration of different scenarios prior to 2030. The starting point for 2030 is based on current policies, whereas early action could be a more cost-effective route to net-zero emissions in 2050. Early action could result in greater cumulative and annual emission reductions and prevent the lock-in of fossil intensive technologies. Investing in inefficient or high-carbon equipment can lead to higher emission reduction costs in the long term.

Effects of a less ambitious reduction path

If a less ambitious reduction path is taken, this could jeopardise reaching net carbon neutrality by 2050 and potentially increase overall costs. The scenarios assume that CCS/CCU only slowly develop before 2040 and if this is delayed these carbon removal technologies would not be mature enough to be implemented at scale by 2050. Delaying action also results in greater cumulative emissions which would need to be later removed with costly carbon removal technologies. Lastly, many sectors require the decarbonisation of the power sector so that they can decarbonise themselves. If the decarbonisation of power were delayed, this would have a chain effect on other sectors.

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[1] The EC: Modelling tools for EU analysis. https://ec.europa.eu/clima/policies/strategies/analysis/models_en#PRIMES

1. INTRODUCTION

On 28 November, 2018, the European Commission (EC) published a set of documents presenting its vision of long-term climate options in the European Union (EU). These provide the basis for discussion among the EU institutions to deliver Europe’s formal long-term climate strategy to the United Nations by 2020, as per the Paris Agreement. The 2050 vision is also intended to become a topic at the “Future of Europe” summit in May 2019. In the documents, the EC lays out a vision for a transition to a carbon neutral economy by 2050 - meaning Europe’s net greenhouse gas emissions (GHGs) will be zero in that year. The vision states that this is technologically possible, and that it can be done in a socially fair and cost-efficient manner.

This report presents a discussion and appreciation of the long-term climate policy for the Ministry of Economic Affairs and Climate Policy in The Netherlands. This appreciation document answers the following 4 questions:

1. To what extent is the EU 2050 long-term strategy correct, complete and effective in achieving the goal of net-zero emissions in 2050?

2. To what extent is the EU 2050 long-term strategy aligned with the Dutch climate policies?

3. What would be cost-effective interim goals for 2030 and 2040?

4. What would be the economic effects of a less ambitious reduction pathway?

Questions 1 and 2 are addressed in Section 2 of this interim report. Question 3 and 4 are addressed in section 3. Annex A provides a summary of the key elements of the EU 2050 long-term strategy per sector.

2. KEY ASSUMPTIONS AND EFFECTS OF THE EU 2050 LONG-TERM STRATEGY

In this section we address the following questions:

1. To which extent is the EU 2050 long-term strategy **correct**, **complete** and **effective** in reaching the goal (carbon neutral economy in 2050)?

   In answering this question, we address the following sub-questions:

   - To which extent are the **proposed methods** used for composing the EU 2050 long-term strategy correct and sufficient?
   - To which extent are the used **economic models, calculations and assumptions** correct and realistic?
   - Which **assumptions** have the **highest impact** and which impact would other (perhaps better defendable) assumptions have on the results?

2. To which extent are the **expected effects** of the EU 2050 long-term strategy (on among others climate, economy and energy market) correct and/or realistic?

   In answering this question, we address the following sub-questions:

   - To which extent is the EU 2050 long-term strategy **aligned with the Dutch climate policy**?
   - In which aspects is the EU 2050 long-term strategy **less aligned with the Dutch climate policies**?
   - What are the largest (economic and/or policy) **opportunities for the Netherlands** in the EU 2050 long-term strategy?
   - Does the EU 2050 long-term strategy contain **enough elements to underpin policy making** regarding such type of strategy?

Question 1 is answered in section 2.1. The answer on question 2 is provided in section 2.2.

2.1 To which extent is the EU 2050 long-term strategy correct, complete and effective in reaching the goal (carbon neutral economy in 2050)?

2.1.1 To which extent are the proposed methods used for composing the EU 2050 long-term strategy correct and sufficient?

Navigant considers the EU long-term climate strategy as one of the highest quality European Commission studies on decarbonisation pathways. The EU 2050 long-term strategy is a comprehensive document and the overall approach is well chosen in presenting the results. It creates a narrative of options, including the rationale, with a focus on long term objectives. The EU 2050 long-term strategy uses best available models and includes the input from many recent studies (see 500 footnotes). The EU 2050 long-term strategy provides a holistic view and helps to see cross-sectoral strategies. It helps to identify priority action areas, helps to advance understanding and makes action options tangible for political debate. It is a good discussion starter for political decisions at an EU level.

The European Commission has been in the driver's seat in developing the strategy and the headlines of the underlying scenarios, which were then further detailed by the modellers. The assumptions behind the strategy and the impact seem realistic and offer sufficient elements for policy making (e.g. by offering concrete supply and demand figures per sector).

At the core of the in-depth analysis, supporting the EU long-term climate strategy, there is the description of eight scenarios. Five of these scenarios stretch the application of specific technology options, i.e. energy efficiency, circular economy, electrification, hydrogen and power-to-X. The sixth scenario combines the five earlier scenarios to achieve 90% emission reduction. Two additional scenarios (LIFE and TECH) describe how net-zero emissions could be achieved by 2050. The scenarios are constructed with a number of assumptions and the model then decides on a deployment of investments, resulting in the model choosing the final power mix. In the various scenarios, conscious choices were made, e.g. different CO_2 emission standards for cars in different scenarios. The different scenarios were then run through the model based on potential and CO_2 prices, ultimately leading to different results and conclusions between scenarios. Given the chosen input constraints, one should be careful in stating that the scenarios are the most cost-effective way to achieve the target.

A complete analysis of the correctness, completeness and effectiveness of the EU 2050 long-term strategy would require more transparency. Many of the key results can now only be derived from the graphs. Ideally, the results would include complete energy balances. Next to primary energy demand and final energy consumption, it would be useful to have information on transformation processes, specifically the conversion efficiencies from primary to final energy assumed. Finally, because the 1990 emission levels are not clearly outlined in the report, there are some uncertainties regarding the accounting of 1990 numbers, for example regarding carbon sinks. This is important, as all targets are relative to 1990 levels.

With regard to completeness the EU 2050 long-term strategy could be improved on the following aspects: the European Commission decided to not consider additional action before 2030. The 2030 targets were kept the same as under the current policies. Also, the EU 2050 long-term strategy does not focus on the cumulative emissions towards net-zero emissions in 2050. Finally, the EU 2050 long-term strategy has few elements on postponing action.

In the following paragraphs we describe the correctness and the completeness further.

2.1.2 To which extent are the used economic models, calculations and assumptions correct and realistic?

The main model underlying the EU 2050 long-term strategy is the PRIMES model. The PRIMES model is a long-established model that has existed for 30 years. In the past, EU member states have been given the opportunity to comment on it and the model has been continuously improved over the years.

The following items have been considered as weaknesses of the PRIMES model:

1. Representation of end-use (demand) options
2. Sensitivity for technology costs assumptions
3. Non-uniform use of discount rates

In the following paragraphs we describe how these weaknesses are addressed in developing the EU long-trem strategy. In our opinion the weaknesses of the PRIMES model are reduced in the modelling for the EU 2050 long-term strategy. PRIMES is not a perfect model, but it has a long track record and is sufficient for the job at hand.

1. Representation of end-use (demand) options

For a stronger representation of the end-use options, the FORECAST model from Fraunhofer-ISI has been applied for the 2050 scenarios. Fraunhofer-ISI will publish its own report on FORECAST results soon. The FORECAST model is not an integral part of the PRIMES model. The FORECAST results are presented in parallel to the PRIMES results (as a second approach). The TECH and LIFE scenarios are only based on PRIMES.

The main uncertainties in the FORECAST modelling that remain are:

- **Introduction of new production processes.** How does it take place? Is a plant really replaced and being rebuilt? Or is it a major upgrade and renovation? This impacts the speed of transition significantly.
- **Regarding costs, the costs for materials efficiency and circular economy could not be included.** The data was not of good enough quality, so these materials are assumed at zero costs.
- **Where possible cost-benefit decisions were considered from a company perspective.** No future prices were considered for energy efficiency or fuel switching.
- **Future market share of radical new production process technologies is based on studies and not a result from running the model**. These include steel making based on hydrogen, electrolysis for new cement production types and processes and products regarding materials efficiency.

Overall, running the FORECAST model in parallel resulted in a better representation of demand options, e.g. in industry sectors and around circularity, but could be further improved.

2. Sensitivity for technology cost assumptions

The PRIMES model is sensitive to technology cost assumptions. The EC conducted a literature review and stakeholder consultation in 2018 to ensure robustness and representativeness of the technology assumptions in the PRIMES model as part of the ASSET[2] project. The updated technology assumptions are included in the PRIMES model.

The stakeholder consultation regarding costs of various technologies, focused on four areas:

- Households: heating and appliances
- Energy efficiency in the built environment (insulation)
- Industrial processes
- Power and heat

Attention has been paid to novel technologies. The consortium reached out to ca. 100 stakeholders and the EC reached out to additional ca. 100 stakeholders, receiving responses mainly in the novel technologies and new power and heat technologies.

The stakeholder consultation regarding the actual costs of technologies were undertaken for the first time in history and raise a lot of attention in the respective industries. The EC has also promised to turn this initiative into a regular process.

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[2] https://ec.europa.eu/energy/en/studies/review-technology-assumptions-decarbonisation-scenarios

Main changes and new insights are that assumed costs for solar and wind energy have declined substantially. Also, several technologies - especially in the industry sector, and of that in the steel sector – have been added. Another factor is the cost connected to the use of variable renewable energy sources integration of very high shares of renewables (e.g. grid expansion, curtailment, storage losses, and hydrogen back-up capacity). The stakeholder consultation also provided insights into costs of new technologies, such as, for example various storage options, fuel cells, hydrogen, power-to-X, as well as CO_2- and hydrogen transmission networks.

The PRIMES team included data, for which there was literature proof and stakeholder confirmation. Sometimes (the case of solar PV), however, the stakeholders considered the cost of technology data as conservative and complained about the approach. These views were not always taken on board in case there was no literature proof.

Overall, we believe the latest insights on technology costs are incorporated. There are still technology areas in an early stage with high cost uncertainties, such as e-fuels and hydrogen. These areas require further studies to achieve more granularity. But according to industry stakeholders, e-fuel and hydrogen options are promising for upscaling even though the costs are still high and uncertain.

3. Non-uniform use of discount rates[3]

Discount rates being used as inputs for the PRIMES energy system scenarios. Discount rates are used to attribute a value to future cash flows. The higher the discount rate, the lower the value we assign to future savings in today's decisions. The choice of discount rates has a critical effect on the subsequent technology options chosen within the scenarios. Due to the nature of most energy efficiency measures, energy efficiency is less attractive with higher discount rates.

As an illustration: the total system energy cost for a 27% energy efficiency reduction target in 2030 with a 10% discount rate leads to the same system energy costs as with a 40% energy efficiency reduction target in 2030 with a lower (5.7%) discount rate. For more information about these issues we refer to the Ecofys report from 2015 and to Appendix B.

Within PRIMES a partly ***subjective discount rate*** is applied, which is intended to reflect not only the actual cost of capital, but also the perceived non-economic barriers and influences of policy. Applying high discount rates disguises feasible policy options for high energy efficiency. However, the EC has been open to modify discount rates considering influences of policies (see table below).

Assumptions for EU Reference Scenario 2016		
	Standard discount rate	**Modified discount rate due to Energy Efficiency policies**
Private cars and powered two wheelers	11%	
Households for renovation of houses and for heating equipment	14.75%	12%
Households for choice of appliances	13.5%	9.5%

Table 1. Discount rates of individuals in energy demand sectors.

Overall, we conclude that the applied discount rates are especially high regarding end-use energy efficiency options. Given that energy efficiency should be a top priority, according to the communication document,

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[3] Evaluating our future - The crucial role of discount rates in European Commission energy system modelling, De Jager and Hermelink, Ecofys, 2015

we think that the energy efficiency option potentially could be stretched further. It is true that it is important to consider non-economic barriers, but it is also true that non-economic policies, such as appliance of efficiency standards, can overcome these barriers without significant costs to society. We recommend to critically review the perceived barriers for applying measures in energy demand sectors and assess the options for introducing new policies and adjusting the discount rates. This is further elaborated in Appendix B.

2.1.3 Which assumptions have the highest impact and which impact would other (perhaps better defendable) assumptions have on the results?

From the electricity supply side, the scenarios are dominated by solar, wind and nuclear (see Figure 1). Hence, the cost assumptions behind these technologies become critical.

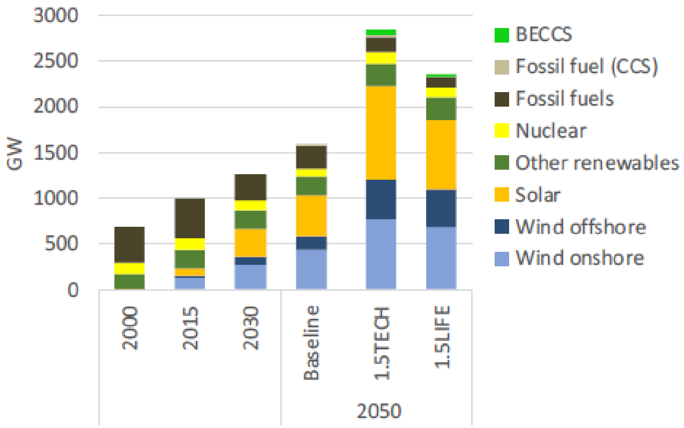

Figure 1. Power production net installed capacity

For wind, solar and nuclear the latest cost assumptions from the earlier mentioned ASSET project have been incorporated. For example, compared to the REF2016 scenario[4] the Levelised Costs of Electricity declined by a factor 3 to 4. The REF2016 scenario was a trend projection for GHG emissions in 2050 developed in 2016. Also reduced cost assumptions on wind have been incorporated. The assumptions applied, resulted in more renewables than in the REF2016 scenario.

Another large impact has the proposed role of e-fuels and hydrogen in the EU 2050 long-term strategy. There are not many sources with good data available. For e-fuels it is not even clear what technologies will be applied, and, for example, what the source of the carbon will be; several alternatives are mentioned, but not made explicit (see discussion on page 23). Currently, the costs of producing hydrogen and e-fuels are higher than many of their alternatives. It is likely that costs will come down, but still unclear to what extent. These areas require further studies to achieve more granularity. Industry stakeholders have indicated to the EC that the costs are still high but offer interesting opportunities for upscaling. Especially, we would recommend to further validate the conversion efficiencies and costs of synthetic fuels (e-liquids, e-gas).

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[4] EU Reference Scenario 2016, Energy, transport and GHG emissions, Trends to 2050

2.2 To which extent are the expected effects of the EU 2050 long-term strategy (on among others climate, economy and energy market) correct/realistic?

We think that that the expected effects of the EU 2050 long-term strategy are described correctly and are realistic.

- Regarding the **climate-related emissions,** the effect it is realistic. All the elements of the strategy seem to be feasible, although there are uncertainties, e.g. with respect to options like circularity and e-fuels. However, there is sufficient room to scale up one or more of the other options in case one of them does not deliver. Whether the strategy will be sufficient to limit GHG concentrations and global temperature increase is another point. This depends on the activities of other countries and regions. Several options for the so-called effort sharing are available[5], but there is no clarity which of them are acceptable in the international negotiation area.

- Regarding the expected effect on the **economy**, the outcomes (1% to 2% increase in GDP) are modest and in line with other studies and scenarios, so are probably correct. Also, we expect that over time cheaper solutions will appear.

- The in-depth analysis does not say much on the expected effect on the **energy market**. This is important, as it is still open how, for example, the energy market will react on a high (80%) share of renewables. The strategy doesn't give much guidance on how the energy market should develop (e.g. by introducing more advanced 'time-of-use' pricing) to support further roll out of smart infrastructure. The future organisation of the energy market will be instrumental for the proper electricity sector coupling with other energy sectors, such as transport and heating. A recent study from Brown et al.[6] shows that energy system costs are relatively small compared to (avoided) energy supply costs, but it is recommended to be further validated.

Overall, we see the strategy towards net-zero emissions as feasible. Below we describe the expected effects and uncertainties around the 7 key strategic actions from the communications document in more detail.

1. **Maximise the benefits of energy efficiency, including zero emission buildings**: The EU should aim to reach the full potential of energy efficiency - especially in the buildings sector, which currently accounts for 40% of energy demand. We see this action as doable. It is techno-economically possible and can be done at limited costs to society. Deep refurbishments of buildings at a moderate renovation rate are required. Building renovations are capital intensive, but have a good net present value due to the energy savings over the lifetime. Building renovations last long and energy prices for households are relatively high (compared to for example industry), which results in relatively high savings.

2. **Maximise deployment of renewables and use of electricity to fully decarbonise Europe's energy supply:** approximately 80% of an electricity supply that is fully decarbonised by 2050 must come from renewable generation (as per the EC's calculations). An increasing share of the EU's additional renewable energy should come from offshore wind and we see this being very possible. There is experience with effective policies and these will probably work well until we reach a share of 70% renewables. Afterwards there might be issues with grid expansion, interconnectivity, storage, demand

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[5] Van den Berg et al. (2019) Implications of various effort-sharing approaches for national carbon budgets and emission pathways, Climatic Change.

[6] Brown et al. (2018) Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system.

response and interplay with electric cars. Hydrogen as a fuel in power plants to balance the system may be expensive per unit of electricity, but probably only needed to a small extent. [6]

3. **Clean, safe and connected mobility**. The EU's transport sector must transition to cleaner, safer and more connected technologies and systems. Clean mobility is at an early stage but seems to be fairing well and costs are going down. However, we do not yet have the right solutions for shipping and heavy-duty vehicles. Also, there are some uncertainties regarding the volume of e-fuels needed (which represent a significant share) and the related costs.

4. **A competitive EU industry and the circular economy**: The EU's industries should increase their resource efficiency and recycling, becoming part of a circular economy. The circular economy can have a huge potential, however, there are large uncertainties on how to unlock it. Circularity is not so well represented in industry models yet. So, volumes as well as costs can be under or overestimated. Also, both the 1.5 ^{o}C scenarios include a continuation of the trend by EU consumers towards less carbon intensive diets, the sharing economy in transport, limiting growth in air transport demand and more rational use of energy demand for heating and cooling.

5. **Develop an adequate smart network infrastructure and inter-connections**: Smart solutions for the use of energy and electricity as well as for transportation and industrial operations are necessary to achieve efficiency and connectivity in the system. The necessary infrastructure must be built up quickly, as it can define the path of the transition. Especially the electricity infrastructure must be expanded very substantially, to prevent social costs becoming too high. This network expansion may become one of the bottlenecks in the transition. There are different paths to integrate high renewable energy shares in the system. E.g. to integrate large scale off-shore wind you need cross-border transmission. Integration of district heating needs a good regulatory framework. It is important to chose the right paths.

6. **Reap the full benefits of bio-economy and create essential carbon sinks**: Agriculture and forests play important roles in a net-zero transition. Information on biomass is a bit scattered in the in-depth report. The share of biomass (see Figure 83) is modest and seems to be realisable. The potential of natural carbon sinks in the EU is also realisable.

7. **Tackle remaining CO_2 emissions with carbon capture and storage**: CCS/CCU potential is realisable, however the technologies can be deployed earlier, especially considering that at the moment there are already many pilot projects and a few large scale projects running[7].

To summarise, we think that there are uncertainties around some of the effects, e.g. from circularity and lifestyle changes, from the actions as modelled in the LIFE scenario towards net-zero emissions. The LIFE and TECH scenarios are illustrative scenarios and are not prescriptive. The TECH scenario that has less uncertainties but is more costly could act as a fall-back scenario to achieve net-zero emissions in case the effects from circularity and behavioural changes do not deliver what is expected. Appendix C provides a more detailed overview of the expected results from the LIFE and TECH scenario.

2.2.1 To which extent is the EU 2050 long-term strategy aligned with the Dutch climate policy?

The proposed EU 2050 long-term strategy for 2050 is well in line with the Dutch climate policy (Dutch Climate Law and Dutch Climate Agreement for 2030) and vice versa.

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[7] IEA Energy Technologies Perspective 2017

As a general comment, it is important to note that the EU strategy is not prescriptive. General abatement potentials for the EU are not necessarily representative for the Netherlands. Solutions to enable the 2050 TECH or LIFE scenario will differ per member state.

Summarising:

- **2050 target.** The EC study aims for net-zero GHG emissions in 2050 compared to 1990 and the Dutch Climate law aims for 95% reduction. These targets are roughly comparable, also given the fact that land-use related negative emissions will primarily occur in countries with high land areas.

- **2030 target.** The current EU policy target for 2030 is at least 40% GHG reduction by 2030, and the in-depth analysis assumes the actual reductions to be 46% GHG emission reduction in 2030 compared to 1990 (based on current policies). The Dutch Climate Law and Climate Agreement include a 49% GHG emission reduction target for 2030 compared to 1990. The 49% target will be reviewed in function of the EU 2030 target, but will not necessarily be exactly the same as the EU target. The Netherlands is willing, if the EU collectively agrees, to increase the EU target to 55% emission reduction in 2030 compared to 1990. The Netherlands seems more ambitious on the short term (2030) than the EU; but, as said before, the 2030 target is not put to discussion in the document. The methodological choice to focus on the 2050 strategy on the 2030-2050 period is different from the Dutch approach.

- **Power sector scenario.** The EC power sector scenario for net-zero emission in 2050 is 80% renewables, 15% nuclear, the rest e-liquids/e-gas and some natural gas boilers with CCS. The power sector target for the Netherlands is 100% CO_2-neutral electricity production: electricity production for which no greenhouse gases are released into the atmosphere or for which biomass is used as a fuel. The EU scenarios and Dutch targets are thus both aiming at carbon neutral power production in 2050. Both EU scenario and Dutch target stress the need for energy efficiency, significantly ramping up renewable energy capacity, development of renewable energy carriers and significant investments in the electricity grid to cope with all changes in demand and supply and needed flexibility.

- **Buildings sector:** both the EC strategy and the Dutch Climate Agreement focus on significantly ramping up renovation of existing building stock and building zero energy buildings from 2030. The Dutch Climate Agreement, however, assumes a renovation rate that is double the rate assumed by the EC. In both approaches natural gas is mostly phased out.

- **Industry sector:** there are some differences in some areas and similarities in others:

    - Differences are observed in CCS and material efficiency and circularity. The Dutch draft Climate Agreement has a strong focus on CCS: 7 Mt CO_2 emission reduction of the total 20 Mt CO_2eq emission reduction planned in 2030 should be delivered by CCS. The Netherlands also plans to deliver CO_2 emission reductions through CCS relatively early (2030). In the EC strategy the focus seems more on material efficiency and circularity, whereas the contribution of these options is modest in the Netherlands, at least for 2030 (1 Mt CO_2eq emission reduction, out of 20 Mt CO_2eq for all options together). The differences may partly explained by the large share of energy-intensive companies in Dutch manufacturing industry.

    - Similarities are in energy efficiency, electrification and hydrogen. Both the EC strategy and the Dutch Climate Agreement consider these levers important for reaching the targets. For example, EU Energy efficiency improvement (up to 25%) for industry seems quite ambitious. Also the Dutch Climate Agreement is ambitious and states that Dutch companies should be among the 10% most energy efficient in Europe in 2030 in their sector.

- **Transport sector:** The approaches from the EU and The Netherlands are very similar. Both approaches place high importance on electrification and the development of renewable energy carriers like green hydrogen, sustainable biomass and e-fuels. Both approaches highlight the importance of behavioural change and modal shift.

- **Agriculture and land use (Dutch Climate Agreement) versus non-CO_2 emissions, land resources and negative emissions (EC 2050 study):** The proposed solutions are very similar: precision farming, CH_4 and N_2O reduction from dairy and cattle farming, improved soil management, avoided deforestation and afforestation, negative emissions, etc. Differences between the EU and the Netherlands are regarding the scale at which solutions will be possible. For example:

    - In the Netherlands, greenhouses form a large part of its agricultural business and therefore greenhouse related solutions form an important part of solutions to the Dutch agricultural sector.

    - The Netherlands is densely populated and has relatively little amounts of forested land. Therefore, increasing forests in the Netherlands to create natural sinks has smaller potential than the EU average.

2.2.2 In which aspects is the EU 2050 long-term strategy less aligned with the Dutch climate policies?

We do not see specific parts of the EC 2050 study as “problematic” for the Netherlands. In particular, because the EC strategy is not prescriptive in detail, as previously mentioned. The EC strategy contains an overall goal and ambition and it is up to individual member states to implement this. There will likely be differences between the optimal cost and most feasible pathway for the Netherlands and the pathway for the EC as a whole:

- **Nuclear:** The Netherlands does have limited nuclear capacity at the moment as a carbon-free power source, nor are there plans to add such capacity before 2030. So, it has identified alternative carbon-free energy generation sources.

- **Natural carbon sinks:** Specifically for Netherlands, a key challenge associated with this is the lack of forests and carbon release from dying peatlands (around 4 $MtCO_2$ per year). Climate change increases the peat oxidation and increases the GHG emission release. Several ways have been identified to mitigate these emissions.

- **E-fuels and green hydrogen.** Like in the EC strategy, the Dutch Climate Agreement relies in part on carbon free energy carriers such as green hydrogen and e-fuels. These fuels can provide a significant contribution to future carbon neutral targets. However, there is still much unclarity about how and where to produce these fuels and the costs implications of producing, transporting and consuming them.

- **Natural gas consumption.** The Netherlands still has a lot of gas boilers, which are relatively cheap in investments, and have relatively low emissions. Therefore for the Netherlands the switch to high investment cost and low operational cost will be even more prominent than in other EU member states.

2.2.3 Where are the largest (economic and/or policy) opportunities for the Netherlands in the EU 2050 long-term strategy?

There are multiple opportunities for the Netherlands:

- **Offshore wind:** The Netherlands is planning and building significant off-shore wind capacity in the coming years. Knowledge and experience can be exported.
- **Vehicle charging infrastructure:** The Netherlands is worldwide a leading nation regarding relative sales of electric vehicles and number of charging points per km^2. Also, in technology, standards, Netherlands has a lead. For example, fast charging production in Delft.This offers again good export possibilities.
- **Circular economy:** the Dutch chemical industry is very active on this topic, including depolymerisation and recycling of plastics. Such knowledge and experience will be much needed in other member states as well.
- **Sustainable procurement**: the Dutch CO_2 Performance Ladder as a green procurement tool for construction processes and the Dutch ambition to make infrastructural construction processes fully carbon neutral can be an inspiring example for any other nation looking to green these processes.
- **Reduction of natural gas:** The Netherlands can strive to achieve a high reduction of natural gas as early as in the next decade. The gas market in the Netherlands is currently dominated by gas coming from the Groningen gas field. Due to reoccurring earthquakes the gas use from Groningen will decrease significantly and consequently impact the Dutch gas market. New policy developments can stimulate consumers to reducetheir demand and find alternatives in hydrogen-based or other green based sources (or imported gas).
- **Hydrogen and e-gas:** The Netherlands can stimulate the use of hydrogen and e-gas. Considering the current planned wind installations, the Netherlands can create a surplus of renewable electricity, which can be stored as e-gas or converted into hydrogen used as feedstock in industrial processes. Important to consider is that alternative energy carriers can only be considered as contributors to decarbonisation if they replace fossil fuels (and not just be used to produce new products).
- **CCS:** In the Netherlands, CCS installations can be implemented at an earlier stage and to a larger extent then predicted by EC. According to the Draft Dutch Climate Agreement, 7 $MtCO_2$ shall be delivered already prior 2030. The early start of CCS technology implementation can put the Netherlands at the forefront of the EU CCS market.
- **Smart building retrofitting:** The Netherlands might be well-positioned to develop smart building retrofitting solutions that are able to retrofit buildings faster with modern technologies (combining digitisation and robotisation). With such technology, buildings could potentially be retrofitted with insulation in a few days.

2.2.4 Does the EU 2050 long-term strategy contain sufficient elements to underpin policy making regarding such type of strategy?

We consider the EC strategy as ambitious, but at the same time feasible and sufficiently concrete, with clear levers to pull and policy options to select. The LIFE scenario is the scenario with lower investments, but if needed, the TECH scenario functions as a fall-back option. This increases the chances to achieve carbon neutrality (net zero GHG emissions) by 2050.

For every sector it is clearly described what the needs are and how different sectors are expected to contribute to the overall goals.

There is uncertainty regarding the realisation of the high production of e-fuels that is needed (capacity to produce the needed electricity and associated costs) and what the best ways are to unlock the multiple benefits from the circular economy approaches.

3. INTERIM GOALS AND ALTERNATIVES

In this section we address the following questions:

1. What would be suitable and cost-effective interim goals for 2030 and 2040 to achieve net-zero emissions in 2050?
2. What are the effects of early action before 2030?
3. What are the effects of a less ambitious emission reduction path?
    - Is net-zero emissions in 2050 feasible under a less ambitious reduction path?
    - What are the cost implications of a less ambitious reduction path?

Questions 1 and 2 are answered in section 3.1 and the answer for question 2 is provided in section 3.2.

3.1 Analysis of appropriate goals for 2030 and 2040 to achieve carbon neutrality in 2050

The same business as usual (BAU) emission levels for 2030 are assumed in all scenarios of the EU 2050 long-term strategy rather than exploring the possibilities of taking more ambitious action before 2030. The Dutch government, for example, has proposed to increase 2030 targets from the current 40% reduction minimum established by the EU to a 55% reduction. Although it cannot be modelled in detail for this report, Figure 2 demonstrates how early action before 2030 can lead to a smoother and less drastic transition between 2030 and 2050. The baseline assumes a 48% reduction in emissions by 2030 (including LULUCF emissions), however, if a 55% reduction target as proposed by the Dutch government is achieved through more ambitious decarbonisation measures than the baseline, the starting point for reductions in 2030 is only 2.5 Gt/yr compared to 2.9 Gt/yr in the baseline. In addition, the cumulative emissions saved between 2020 and 2030 is 1.92 Gt. This means that 1.92 Gt less of carbon removal would need take place before 2050.

It is important to put into perspective what a 55% reduction would entail. With the current 32/32.5% targets for renewable energy and energy efficiency, this results in 45-46% of GHG emissions in 2030 compared to 1990. If both targets for energy efficiency and renewable energy were increased to 35%, this translates to a 50% reduction in 2030, still 5% shy of the target proposed by the Dutch government.[8] This means that greater action would need to be concurrently taken in sectors other than renewable energy and energy efficiency. This could be through increasing circularity, mitigating non-CO_2 emissions (see 3.2A.1.5), having more ambitious vehicle standards, or adjustments of the European Emissions Trading Scheme (ETS) or Effort Sharing Regulation (ESR) for non-ETS sectors, for example.

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[8] Ecofys (2018) The 35% renewable energy and 35% energy efficiency targets voted for by the European Parliament enable greenhouse gas emission reductions of 50% in 2030.

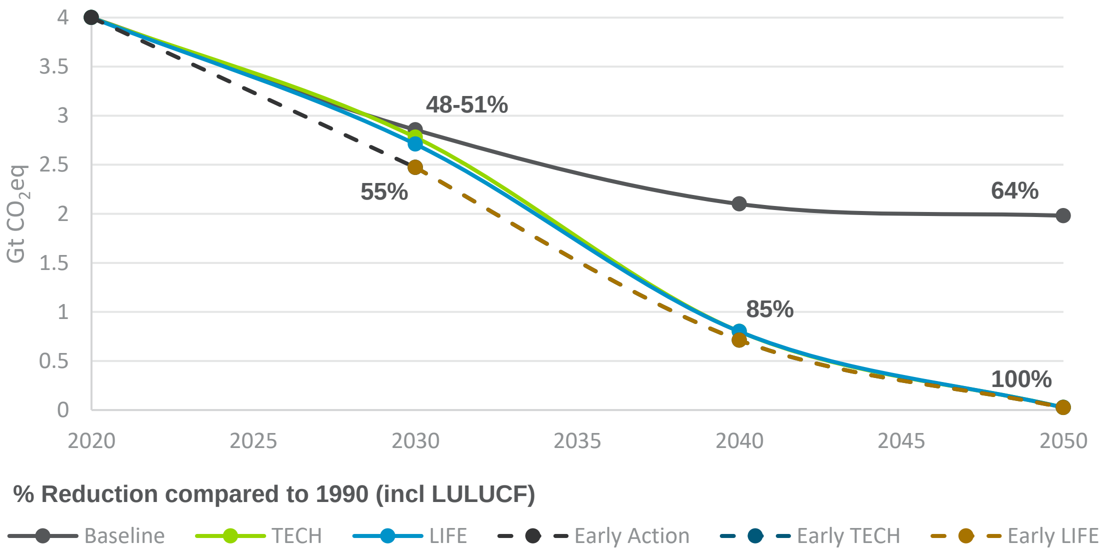

Figure 2. Net annual emissions of modeled scenarios (solid lines) and hypothetical early action scenarios (dashed lines) from 2020 to 2050 (note, curves are stylised).

Studies researching the potential benefits of global immediate action towards a low carbon economy by 2030 support taking early action before 2030. A study by The New Climate Economy estimated in a low carbon scenario a direct cumulative global economic gain of EUR 26 trillion through to 2030 compared to BAU and the creation of over 65 million new low-carbon jobs.[9] Although these results are not specific to the EU, they do demonstrate that there are **economic and employment gains to be had in early action in decarbonisation**.

Another advantage of early action is the **prevention of carbon lock-in**. Carbon lock-in refers to large investments being made in fossil fuel technologies and infrastructure that locks us into a carbon intensive pathway. In the long run, it thus becomes increasingly expensive to switch to a decarbonisation pathway once such large investments have been made. This is especially true for long-lived infrastructure such as buildings and industrial plants, but is even relevant for cars, other means of transport and electric appliances.

As for 2040, emission goals were not explicitly mentioned for this year. In the report, 2050 is discussed in great detail since carbon neutrality by 2050 was the starting point for modelling the scenarios. Emission goals for 2040 can still be extracted from the scenarios, and a reduction of 85% (compared to 1990 levels[10]) is modelled, as seen in Figure 2 (note, however, that the curves are stylized).

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[9] Unlocking The Inclusive Growth Story Of The 21st Century, The New Climate Economy (2018).

[10] 1990 levels are assumed to be 5.5 Gt CO_2eq (including LULUCF) using back calculations.

3.2 Analysis of the effects of following a less ambitious reduction path than the paths to carbon neutrality in 2050

Delaying actions until after 2030 is highly unadvisable. This would lead to greater costs in the long term, and jeopardise the 1.5 °C from still being reached by 2050.

Carbon removal is necessary for carbon neutrality and cannot be delayed
Carbon neutrality could be difficult to achieve if carbon removal is postponed because some emissions such as non-CO_2 emissions from agriculture cannot be fully eliminated with currently available and foreseen technology and management practices. Reaching the global objectives of the Paris Agreement without measures aiming at removing CO_2 from the atmosphere is extremely challenging and as stated in the EC report, “it could even become quickly impossible if no immediate and very ambitious global action is undertaken”.[11] Carbon removal measures are already implemented quite late in the 1.5 °C scenarios, and only pick up slowly after 2040. This is because these CCS and CCU technologies are deemed by the EC to have low technology readiness levels (TRL) and will require immediate investments in research to have them implementable by 2040 as modelled in the scenarios. If actions are postponed until after 2030, these technologies will not be implementable by 2050 to offset the emissions that are difficult to eliminate. Land use, land use change forestry (LULUCF) sinks are another option used in the 1.5 °C scenarios, and rely heavily on forest management and afforestation. Unlike CCU or CCS, natural carbon sinks cannot immediately capture CO_2 on demand, rather they are long processes with delayed sequestration results. In addition, they are limited in that forest management can only sequester so much CO_2 and afforestation is restricted by the amount of available land and sustainable land use change.

Cumulative emissions would increase and compensation is costly
One of the critiques of the EC report from several experts[12] is that cumulative emissions are not well addressed. Although most data is shown as annual emissions, the 1.5 °C target is actually derived from cumulative emissions, and this is the most critical figure for temperature rise. If actions are postponed, emissions will accumulate during the period of delay and these emissions would need to be compensated with carbon removal technologies to still achieve the 1.5 °C target by 2050. This would not only be difficult, for reasons stated above, but also potentially very costly. If action were delayed 5 years (from 2030 to 2035), the additional emissions accumulated compared to the 1.5 °C scenarios would be approximately 12 Gt at an EU level, and if action were delayed 10 years (2030 to 2040), approximately 23 Gt. Figure 3 shows the likely range of costs of carbon removal technologies considered within the report, bioenergy with carbon capture and sequestration (BECCS) and direct air capture and carbon sequestration (DACCS) (see 4.4.7). At an approximate cost of 200 USD/t (EUR 176/t), this would correspond to an additional cost of EUR 2.1 trillion for a 5 year delay and EUR 4.1 trillion for a 10 year delay.[13]

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[11] The EC - A Clean Planet for all (p. 187)

[12] Ecologic, summary of ‘A Clean Planet for all’ (January 2019)

[13] Assuming linear decarbonisation from year to year.

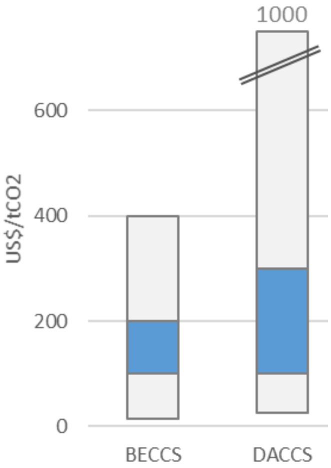

Figure 3. Cost of carbon removal technologies (*blue reflects the part of the ranges the authors of the study consider as the most likely*).

The assumed total energy system costs in the EC report (see Figure 4) in 2050 is nearly EUR 2.4 trillion in the LIFE scenario and nearly EUR 2.8 trillion in the TECH scenario. If the additional costs for carbon removal are EUR 2.1 trillion for a **5 year delay, this could nearly double the total energy system costs.** If the additional costs for carbon removal are EUR 4.1 trillion for a **10 year delay, this could more than double these costs** according to the scenario models**.**

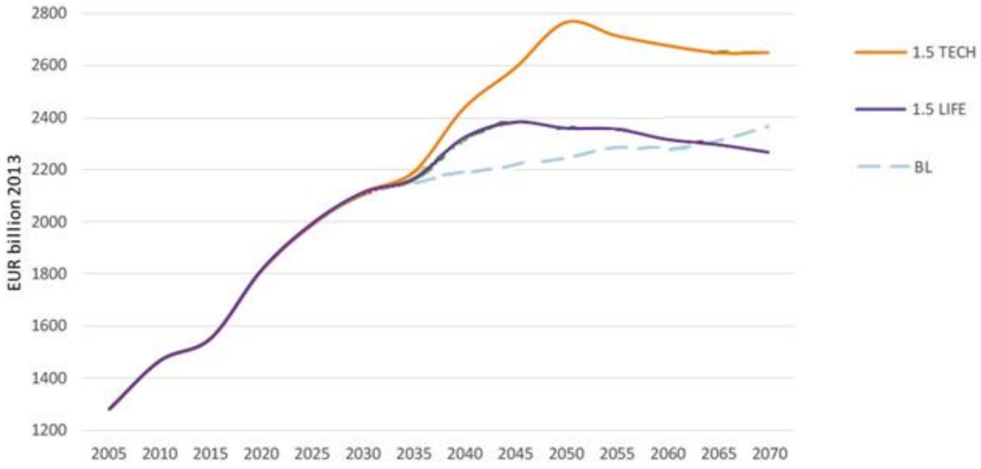

Figure 4. Total energy system costs in the baseline and 1.5 °C scenarios.

The IPCC has found similar results on a global scale and have shown that delaying action to 2030 would “require substantially higher rates of emissions reductions from 2030 to 2050, a much more rapid scale-up of low-carbon energy over this period, a larger reliance on CDR (carbon dioxide removal) in the long term and higher transitional and long-term economic impacts”. Their modelling showed that delayed mitigation costs could be 15-44% greater compared to immediate mitigation depending on the level of ambition in each scenario.[14]

Delaying power sector decarbonisation delays other sectors from decarbonising
In the 1.5 °C scenarios, the power sector is the first to fully decarbonise, taking approximately 20 years from 2020 to 2040 (see Figure 5). If this were to be postponed 10 years, the power sector could still be decarbonised by 2050, but this would also influence other sectors such as transport and industry. These sectors are heavily reliant on clean electricity for decarbonisation and postponing renewable energy installations and infrastructure in the power sector could jeapordise these sectors from decarbonising by 2050.

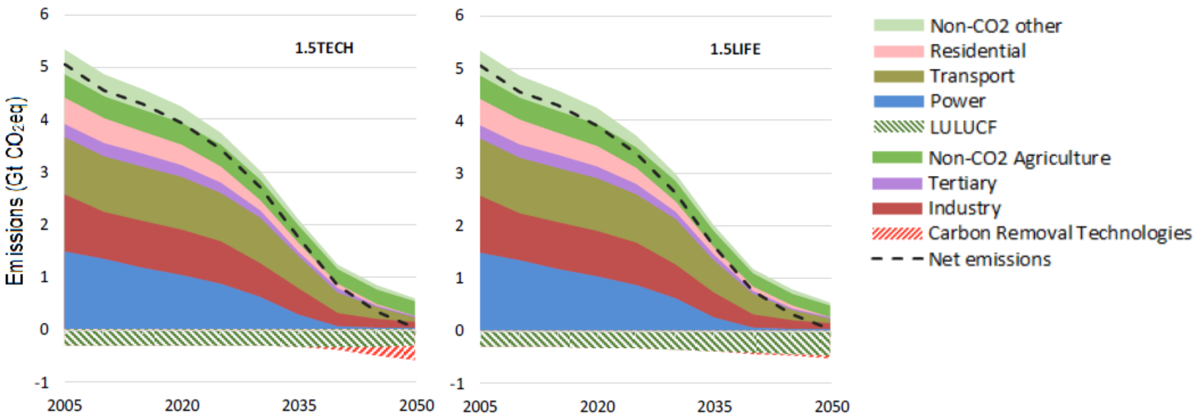

Figure 5. Emission pathways for the TECH and LIFE 1.5 °C scenarios.

In summary, the EU should not postpone action until after 2030 as this could jeopardise reaching carbon neutrality in 2050, and even if still achievable, carbon neutrality could come at a greater cost. In fact, taking action even earlier than 2030 would be even more beneficial as this has been linked to economic and employment gains. If the EU were to achieve a more ambitious 55% reduction in GHGs in 2030 compared to 1990 levels, this would also generate smaller cumulative emissions from now to 2030, meaning less emissions that would need to be mitigated in the future through carbon sinks or carbon removal technologies. Lastly, early action could prevent investments being made in carbon intensive actions which could be more costly in the long term.

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[14] IPCC (2014) Fifth Assessment Report: Summary for Policymakers.

APPENDIX A. SUMMARY OF THE KEY ELEMENTS OF THE EU 2050 LONG-TERM STRATEGY PER SECTOR

The EU 2050 long-term strategy “A Clean Planet for All” aims at achieving net-zero greenhouse gas emissions by 2050 across the EU. It includes nearly all EU policies and is in line with the Paris Agreement temperature goals. The strategy consists of the Commission communication document and the in-depth analysis. The Communication document summarises following seven main strategic building blocks that the EU must focus on in order to reach carbon neutrality by 2050:

1. Maximise energy efficiency
2. Large-scale deployment of renewables and use of electricity
3. Clean, safe and connected mobility
4. Competitive EU industry and circular economy
5. Adequate and smart network infrastructure including sectoral cross-border integration
6. Bioeconomy and natural carbon sinks
7. Carbon capture and storage

The in-depth analysis describes eight scenarios that are built on different degrees of technological, economic, environmental and social solutions. Scenarios 1-5 achieve a 80% cut in emissions and are modelled based on different intensity of applied technologies and actions based on electrification, hydrogen and e-fuels (i.e. power-to-X), energy efficiency and circular economy. The sixth scenario is a combination of all options considered in scenarios 1-5 with but at lower levels. It leads to a reduction in GHG emissions of 90% (including the LULUCF sink). Scenario 7 (1.5TECH) maximises the use of technological solutions and energy efficiency and relies on carbon removal technologies. Scenario 8 (1.5LIFE) builds upon the 1.5TECH with emphasising the beneficial role of a highly circular economy and a change in consumer choices. Since 1.5TECH and 1.5LIFE are the only net-zero options, we looked at them closely when summarising the key elements per sector.

A.1 Overview per sector

A.1.1 Energy Supply

A.1.1.1. Energy Supply Options

Today’s energy supply greatly relies on fossil fuels. Of the total GHG emissions in the EU, 80% are emitted by the energy sector, mainly from fossil fuel combustion. The EC foresees the following mitigation options as the main enablers of decarbonisation of the energy supply:

- **Reduction of the energy demand** and an overall **increase in energy efficiency**
- Large-scale **deployment of zero-carbon energy sources** from renewables[15] (mainly wind) and nuclear used for power generation (electricity and fuel) or heating
- **Carbon capture and sequestration/utilisation** technology application to capture remaining GHGs
- **Maximising the use of electricity and thermal storage solutions**

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[15] The EC includes in the renewable sources wind, solar (solar thermal and solar photovoltaic), geothermal energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases.

- Integration of **new carbon-free energy carriers**, such as hydrogen (H_2), e-gas (e-CH_4) and e-liquids
- **Sector coupling** of the energy, transport and industrial network infrastructure

A.1.1.2. Energy supply results

Primary energy consumption is expected to already rapidly decrease by 2030 because of energy efficiency measures (26% reduction compared to 2005). By 2050, 37% – 43% reductions are achieved in the 1.5 ºC scenarios, with most reduction in the industry sector and least in the service sector. This is the effect of combining deep savings in final energy consumption with increased electricity needs for production of e-fuels and hydrogen.

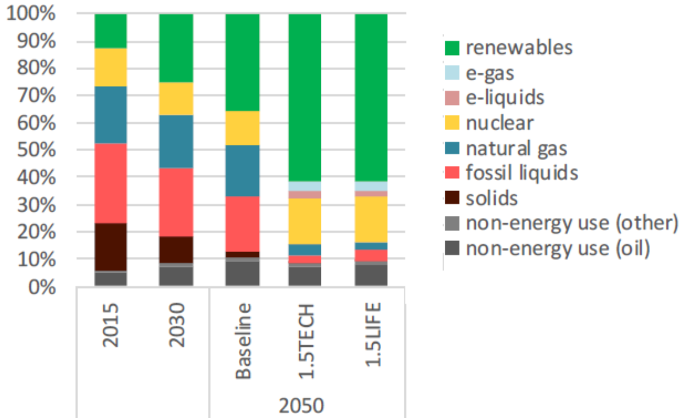

Figure 6. Projected energy mix by fuel type.[16]

Large-scale electrification and penetration of renewable energy sources coupled with new energy carriers will be the main drivers of the decarbonisation of the energy supply.[17] Figure 6 shows the projected energy mix in 2050, and in both 1.5 ºC scenarios the use of fossil liquids and natural gas is largely replaced by renewables and nuclear. The relative share of nuclear power increases although the absolute values remain the same as it allows the EU to decrease fossil fuel imports. The sharp decrease in fossil fuels in the 1.5 ºC scenarios occurs most notably in transport, as these scenarios have the most ambitious CO_2 efficiency for light duty vehicles, and in the case of 1.5LIFE, there is the additional effect of lifestyle changes shifting mobility to low energy options. The drastic decline in natural gas is driven by the substitution with renewables, and to a smaller extent with e-gas (4-6% of gross inland consumption).

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[16] The EC - A Clean Planet for all (Fig. 18)

[17] Compared to 2005 the most significant energy reduction is achieved by the residential sector, followed by transport (due to the penetration of electric vehicles and energy efficiency gains). Industry and services (including agriculture) expect lower energy reductions due to assumptions on macroeconomic growth.

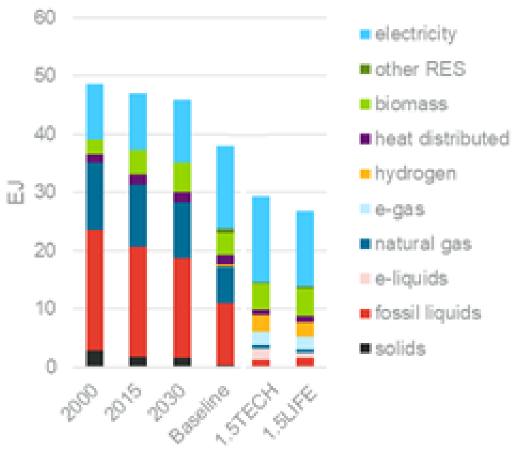

Figure 7. Energy carriers in final energy consumption.[18]

As seen in Figure 7, electricity will serve as the primary energy carrier (50% of final energy consumption), due to increased electrification in sectors such as transport. Biomass and waste will also increase its share as an energy carrier due to increased use of advanced biofuels and biogas.

A.1.1.3. Transition enablers, opportunities and challenges

Transition…	Summary
Enablers	Technology development, right policy incentives, infrastructure
Opportunities	Positioning EU on global markets as a leader in low carbon technologies and services, decreasing dependency on fossil fuel imports, development of heat and electricity storage and other flexibility options, sector coupling.
Challenges	Sufficient investments and financial support schemes, regulatory barriers (especially for nuclear) and framework (to support the change of the energy market), adaptation of infrastructure, creating conditions that enable the development of new energy carriers, improved energy system with high balancing capacities, development of efficient markets for electricity and new fuels

Table 2. Transition enablers, opportunities and challenges of the energy supply system.

A.1.1.4. Expert appreciation

Energy experts appreciate the assumptions concerning energy in the scenarios as follows:

- **Energy efficiency targets assumed in the scenarios are reasonable and achievable.**
- **The role of electricity is high in all scenarios which is to be expected and in line with other scenarios.**[19]

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[18] Remade after Fig. 20 of "A Clean Planet for all"

[19] Eurelectric (2018). Decarbonisation Pathways: Full study results.
Key World Energy Statistics (IEA) 2018
World Energy Outlook 2018, International Energy Agency, 2018.

- **Electricity derived fuels (hydrogen, e-gas) are higher than what most experts consider so far**, although this is the envisioned direction.
- **For primary energy consumption, the role of nuclear is possibly overestimated.** The share of renewables and nuclear energy in the energy mix depends on the accounting method used to convert renewables sources into primary energy equivalents. Renewable energy sources are converted by using a 100% efficiency while nuclear electricity shall be counted by using only its average process efficiencies (33%). As some methods (e.g. IPCC method) tend to use 100% efficiency for nuclear conversion, this causes an overestimation of nuclear's share.[20] From the report it is unclear which accounting method was used.
- **Self-consumption and distributed generation are growing.** There will be more flexibility needed through storage, hydrogen and batteries as well as interconnections.

A.1.2 Buildings

A.1.2.1. Buildings options

In 2005, residential and service buildings accounted for 40% of total energy consumption. Most energy in the sector is used for space heating and cooling and hot water production. It is estimated that nearly 75% of existing EU buildings were built before energy performance standards existed and that approximately 97% of buildings built before 2010 need to be renovated to comply with long-term strategy goals. There are several policies already in place promoting decarbonisation of the building sector, including the EU EPBD Directive requiring all new buildings build from 2021 onwards to be nearly zero-energy buildings in terms of energy consumption.[21] This regulation is expected to affect approximately 23% of the stock of residential houses in 2050 and 28% of floor area in service buildings. Emissions from the building sector are moderately declining over the past years.

Key options include:

- **Reducing cooling and heating demand,** especially by improving thermal insulation.
- **Using efficient equipment** (for water heating, cooking, space heating and cooling, other appliances) and **setting standards** via eco-regulations and labelling.
- Switching to **zero-carbon energy carriers** (renewable electricity, solar thermal, hydrogen, e-gas and or/biogas mixture, geothermal, district heating).
- **Digitalisation** of the sector including deployment of smart buildings (e.g. ICT), appliances and management services.
- **Behavioural, societal and consumer change** (e.g. rational use of energy, reducing number of appliances, customer engagement).
- Integrating principles of **circular economy** (e.g. reducing material used for buildings, producing and using them more efficiently).

A.1.2.2. Buildings results

An unprecedented energy efficiency improvement is needed for the 1.5 °C scenarios. In the 1.5LIFE scenario, the uptake of energy efficiency measures in combination with smart equipment and increased insulation will reduce the overall energy consumption by 57% in the residential sector and by 38% in the services sector (from 2005 to 2050). Maximisation of energy efficiency and ambitious eco-design will nearly

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[20] IRENA REMAP 2030: Doubling the Global Share of Renewable Energy: A Roadmap to 2030, 2013.

[21] Nearly zero-energy buildings use sustainable renewable heating and are characterized by a high energy performance.

halve the demand of appliances for both scenarios compared to the baseline. In heating and cooling, energy savings up to 66% of 2005 energy consumption can be reached.

The share of electricity used in buildings will increase significantly, growing from 50% currently to around 80% in 2050 for services and from 25% to over 60% for residential. Natural gas is nearly fully phased out by 2050 in the scnearios (i.e. 3%). Next to other sources low-carbon fuels (mostly e-gas) are deployed with a significant share in the 1.5 °C scenarios.

Figure 8. Average yearly renovation rate from 2016-2030 and 2031-2050.[22]

Considering that most of the housing stock existing today will still stand in 2050, most buildings will require deep renovations. In the 1.5 °C scenarios, buildings are renovated at a rate of 1.7-1.8% per year in the residential sector and 1.5-1.6% in the services sector from 2031 to 2050 to comply with the long-term strategy ambition (as shown in Figure 8). To enable homeowners to make the required investments in a short time span, financing instruments need to be provided at scale.

A.1.2.3. Transition enablers, opportunities and challenges

Transition…	Summary
Enablers	Energy efficiency improvements and digitalisation, home automation, EU energy labelling, eco-design rules and regulatory requirements on buildings
Opportunities	Energy savings, technology development (automation, digitalisation, smart buildings), developing a deep renovation market
Challenges	Technological challenges (e.g. production of energy and cost-efficient materials, keeping the large-scale production of materials in the construction sector with the pace of renovations), shift from exploitation costs to investments, increase of renovation rates, local infrastructure supporting electrification rates, maturity of local markets, consumer engagement, public acceptance due to long pay-back times and high O&M costs

Table 3. Transition enablers, opportunities and challenges of the building system.

A.1.2.4. Expert appreciation

- **The profile of the building sector differs across different EU member states** (mainly due to different building stock, macroeconomic and demographic drivers). The results from the study can

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[22] The EC - A Clean Planet for all (Fig. 41)

differ significantly by country and should thus be specified on a per-country basis (e.g. yearly renovation rates, heat demand reduction, electrification rates)

- **The mentioned energy demand reductions of well over 50% of final energy demand will be difficult to achieve and would require significant renovation of most of the buildings**. For example, the real-world reduction in final energy demand between a Dutch G label terraced house and a Dutch A label terraced house is only about 45%.[23]
- **The renovation rates seem too low.** To achieve zero-emission buildings EU with the specified 97% of buildings needing renovation, a step up of the current renovation rates will be required (min 2%)[24]. Renovation processes will require industrialisation (e.g. pre-fabrication).
- **Modelled energy efficiency share for buildings is low**, most likely due to the applied discount rates.[25]
- **Electricity shares in scenarios are high and require deep refurbishment of buildings to achieve the foreseen electrification. It** will also require an extensive improvement of electricity infrastructure. High electrification rates, especially without deep renovation, can increase the societal costs substantially[26].
- **Total impact of individual appliances use will reduce over time** because of the growth of energy efficiency. Efficiency of appliances will reduce autonomously due to existing eco-standards.
- **Smart material use for new buildings was only partly elaborated in the 2050 strategy.** Steel and concrete are still core materials used as building materials. Advanced building materials such as new forms of concrete (e.g. with fibres that increase its durability and resistance), glass (e.g. PV integrated glass), innovative wood materials, cork, bamboo and woven flooring will be an important driver of future design and architecture.[27] It furthermore needs to be considered that better materials can reduce the energy consumption but do not necessarily increase the environmental performance of the building (e.g. using in-built PV can be more beneficial from the environmental context but might not provide the best insulation).

A.1.3 Transport

A.1.3.1. Transport options

The transport sector emits around a quarter of all GHG emissions and consumes one third of the final energy in the EU, most of which is fossil origin. To decarbonise the sector, it requires heavy investments in following emission reduction options:

- Emergence of **low- and zero emission vehicle technology** with **carbon neutral fuels** (hydrogen, advanced biofuels and biomethane, as well as e-fuels).
- **Improved infrastructure** and **better organised mobility** digitalisation).

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[23] Majcen D. et al.: Energy labels in Dutch dwellings – their actual energy consumption and implications for reduction targets (2013) https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2013/7-monitoring-and-evaluation/energy-labels-in-dutch-dwellings-their-actual-energy-consumption-and-implications-for-reduction-targets/2013/7-043-13_Majcen.pdf

[24] Appreciation by Navigant's in-house experts

[25] Evaluating our future - The crucial role of discount rates in European Commission energy system modelling, De Jager and Hermelink, Ecofys, 2015

[26] ECN Beleidsstudies: De systeemkosten van warmte voor woningen (2015) https://www.ecn.nl/publicaties/PdfFetch.aspx?nr=ECN-O--15-050

[27] European Commission: Smart Leaving – Advanced building materials (2014)

- **Increased vehicle efficiency** (e.g. more efficient powertrains) and **efficiency** of the transport system (e.g. increasing connectivity or autonomous driving solutions).
- **Changing societal and consumer behaviour** (e.g. reducing the number of business trips by using video conferences).
- **Modal shift** from road transport to rail and waterborne as well as to public transport and active modes (walking, cycling).

A.1.3.2. Transport results

In all scenarios, a strong energy consumption change is expected in all sectors, ranging from 25% to 50%. The most significant change will be induced in road transport where the energy consumption is expected to drop by approximately half. An increase of air transport is expected by 2050, however relative to the baseline the aviation in most scenarios decreases by up to 5% (as shown in Figure 9). The most extreme change will be induced in the 1.5LIFE scenario, where aviation activity is expected to drop almost to 20%, driven societal and consumer changes (e.g. using video/tele conferencing facilities instead of business travel) and by efficiency improvements. A modal shift from road to mainly rail and inland navigation is characterised in the LIFE scenario.

Figure 9. Change in energy consumption per mode in 2050 compared to 2005.[28]

By 2050 oil products and natural gas will almost entirely be substituted by electricity and alternative fuels. All transport modes will be ready to use electricity as an energy source, especially in road and rail transport. As evident in 10 below, liquid biofuels consumption will increase, mainly due to increased used in road, air and inland navigation. The uptake of liquid biofuels, e-fuels as well as hydrogen will be an important enabler of decarbonisation, also for the maritime and inland waterways transport modes. The aviation sector has limited options for decarbonisation, however advanced biofuels and e-fuels will to a limited extent substitute remaining jet fuels. For heavy duty road transport, decarbonisation can be achieved mainly by electricity and hydrogen. However, a mix of liquid biofuels, biomethane and e-fuels will also be necessary to enable the transition.

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[28] Source: The EC - A Clean Planet for all (Fig. 56)

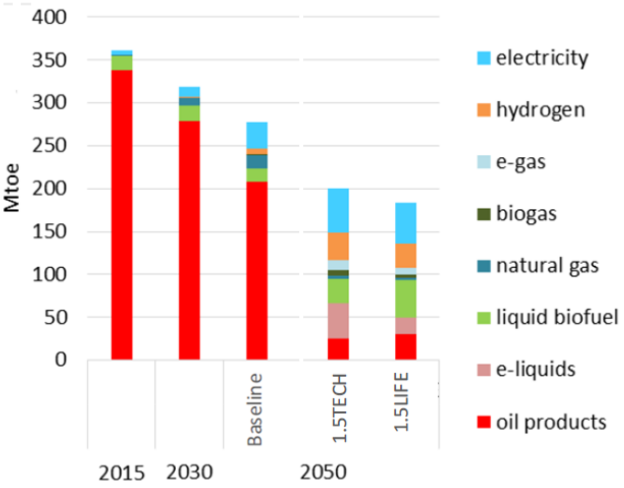

Figure 10. Fuels consumed in the transport sector in 2015, 2030, and 2050.[29]

A.1.3.3. Transition enablers, opportunities and challenges

Transition…	Summary
Enablers	Technology development (e.g. energy storage, smart charging stations, digitalisation, automatization), low costs for alternative fuel vehicles, research and innovation financing programmes, new policies (new rules on road pricing, phase-out of fossil fuel subsidies)
Opportunities	Increasing EU competitiveness and market
Challenges	Technological readiness, competitiveness of inland navigation and railway compared to road freight, operational and technical barriers between national networks, too little regulatory action, market barriers (market design, split incentives, lack of internalisation of externalities), governance issues (e.g. consumer rights, transparency of information, sectoral integration), societal challenges (decrease of employment in some professions

Table 4. Transition enablers, opportunities and challenges of the transport system.

A.1.3.4. Expert appreciation

- **Decarbonising road transport as proposed by the EC is feasible**, however aviation and shipping will need strong incentives and policy regulations decrease their emissions as modelled in the LIFE and TECH scenarios. The Commission has acknowledged the high risks related to regulatory action being delayed but explicit policy requirements for EU member states that will enable a real uptake of advanced fuels in aviation and shipping are unclear.
- **There are conflicts between studies on the decarbonisation of international shipping.** By 2050, the European Commission foresees some electrification (up to 3%) for domestic and intra-EU and none for international shipping. Dominant energy carriers for international shipping are oil, followed by liquid biofuels (32%) and hydrogen (23%). Alternatively, a Transport and Environment study[30] recommends that battery-electric and hydrogen technologies from sustainable renewable sources will decarbonise shipping. The study foresees a large-scale electrification of domestic

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[29] Source: The EC - A Clean Planet for all (Fig. 57)
[30] Transport & Environment, Roadmap to decarbonising European shipping (2018)

shipping, especially that passenger ferries[31] and smaller cargo ships will prefer battery electric propulsion. It assumes that the intra-EU shipping on short shipping routes will be either electrified or fuelled by ammonia or hydrogen fuel-cells.

- **The replacement rate of aircrafts is in general relatively low.** Commercially available long-haul all-electric aircraft at scale are not likely to occur before 2040[32]. Short-range (<200 km) all-electric aircraft may arrive sooner.[33]
- **Development of four different fuel types in parallel is not cost effective** as separate charging and refuelling structure needs to be put in place. Ideally two fuels should be dominant and fully deployed.
- **Large-scale, EU-wide charging infrastructure is required for electrification of road transport.** Heavy duty vehicles for example that travel long distances in a short amount of time need to make sure that the fuel they use is available in other countries they are traveling to.
- **The increase of electricity and reduction of demand of other fuels can be further achieved by development of catenary lines**. The overhead electricity lines that charge vehicles while driving along the major transportation routes in Europe has the potential to increase the adoption of heavy-duty vehicles (hybrid electric trucks, long-distance hybrid electric coaches).
- **To fully decarbonise the transport sector is challenging as it depends on carbon offsetting by biological systems or carbon removal from the atmosphere**. This can thus only be achieved by strong and adequate cross-sectoral collaboration.

A.1.4 Industry

A.1.4.1. Industry options

EU industries are already reducing emissions with a multitude of solutions. A high share of emissions remain hard to eliminate due to complexity and high energy needs of many industrial processes, especially in the chemical, steel and cement industries. More than 60% of the industrial emissions are generated through high-temperature process heat or from direct firing of furnaces, and 21% of the emissions consist of process related emissions (e.g. chemical reactions other than combustion), while the rest is emitted by space heating.

Circular economy measures are key components of decarbonisation of the industry sector, especially recycling and reducing material losses in energy-intensive sectors (plastic, aluminium, steel, aluminium and cement industries). Options to further reduce emissions in the industry sector include:

- **Reducing the demand side** by increasing resource and energy efficiency (lower energy use per produced volume).
- **Material substitution** (e.g. new binders replacing limestone in the cement industry).
- **Electrification** (mainly of low temperature industrial heat) and **fuel switching** (integrating alternative low carbon processes by using e.g. biomass in chemical production or hydrogen in ammonia production).

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[31] Lambert F.: A new fleet of all-electric ferries with massive battery packs is going into production (2018) https://electrek.co/2018/03/05/all-electric-ferries-battery-packs/

[32] Transport & Environment, Roadmap to decarbonising European aviation (2018)

[33] Roland Berger, Aircraft electrical propulsion, September 2017 provides a good sense of what these developments might ultimately deliver – and where we are today.

- **Carbon capture and sequestration and or use** (CCS and CCU) technology implementation (e.g. for lime and cement processes that cannot be reduced otherwise).
- **Innovative processes** (e.g. alternative electrochemical production processes).
- **Industrial symbiosis** (e.g. sharing infrastructure or reuse waste from industries heat across sectors).

A.1.4.2. Industry results

Between 2020 and 2030 the sector largely improves energy efficiency through measures such as waste heat recovery and implementation of circular measures such as re-using, recycling, and recovery of materials and heat. The 1.5 TECH and LIFE scenarios reduce final energy consumption 22 and 31% respectively from 2015 to 2050.

There are also significant changes in the fuel mix. The 1.5 °C scenarios predict a strong decrease of natural gas (>60Mtoe) and a significant increase of hydrogen (>30Mtoe) compared to the baseline, as seen in Figure 11.

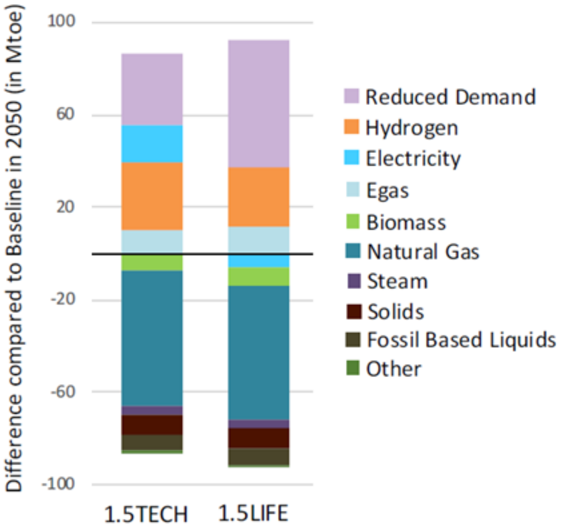

Figure 11. Differences in final energy consumption by carrier in industry compared to baseline in 2050.[34]

Emissions from industry cannot decline to zero without CCS/CCU measures, therefore, emissions must either be captured and stored or reused in materials and fuels. Because of high carbon prices in the 1.5 °C scenarios, 54/58 $MtCO_2$ are captured for the LIFE/TECH respectively already in 2040. By 2050 the amount increases to 71/80 $MtCO_2$ and continues growing post 2050 (112/128 $MtCO_2$). Additionally, CCU technology emerges in 2050 with 47/80 $MtCO_2$ stored in plastics by 2050 for LIFE/TECH respectively.

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[34] Source: The EC - A Clean Planet for all (Fig. 69)

A.1.4.3. Transition enablers, opportunities and challenges

Transition…	Summary
Enablers	Research and innovation, extensive network of sufficient infrastructure, market design that increases the demand for industrial decarbonisation technologies
Opportunities	EU as a global leader in the transition towards low-carbon industry
Challenges	Early stage of low carbon technologies development, speed of technology and infrastructure development, reliability and availability of alternative fuels and feedstocks, high investment needs, existing infrastructure to become a stranded asset (such as gas infrastructure)

Table 5. Transition enablers, opportunities and challenges of the industry system.

A.1.4.4. Expert appreciation

Industry experts appreciate the assumptions in the scenarios as follows:

- **Energy efficiency improvement (up to 25%) for industry seem quite ambitious** as most energy intensive industries, such as is cement and steel, most likely cannot save more than 20%.[35]
- **Industry decarbonisation heavily depends on the circular economy materialising.** Industries will have to change their product design by offering the same functionality for end users while minimising emissions. This significantly influences business models of all involved industries. Despite circular measures being extensively discussed, the circularity in scenarios lack quantitative explanations.[36]
- **Circular economies are heavily impacted by industrial symbiosis** and this requires systems thinking at both country and EU levels. Multi-stakeholder cooperation across industries and over value chains is of key importance, however slow and complicated processes can hamper the speed of uptake.
- **Societal resistance presents a substantial challenge in storing CO_2 underground.**
- **Risk of CO_2 leakage can occur due to an uncoordinated CCU approach** (e.g. if plastics with stored CO_2 are not kept in a controlled system and are exported outside Europe). The report does not further elaborate whether such products end up in waste incinerators and/or if CCS is applied to waste incinerators. Only if we take care of the end-of-life of products we really go to a net-zero economy.

A.1.5 Non-CO_2 Emissions

A.1.5.1. Non-CO_2 emissions options

In 2015, approximately 18% of the GHGs emitted in the EU were non-CO_2 gases, mainly methane (CH_4) and nitrous oxide (N_2O), and the remainder various fluorinated gases. The agricultural sector is responsible

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[35] Expert opinion by Fraunhofer.

[36] Material efficiency and recycling of products like steel, aluminium and paper is based on production in tonnes and an increased share of recycling, however it was not possible to include full costs of recycling.[36] Volumes, costs and potentials can therefore be either under- or overestimated. As statements about how circular concepts are modelled are not substantiated, it is difficult to judge how ambitious Netherlands can be and what the economic impact on the Dutch market will be.

for more than half of the non-CO_2 emissions, of which 22.3% emissions are N_2O that result from agricultural soils and 21.7% is CH_4 from livestock (enteric fermentation). The waste sector is also a large source of pollutant (14% of CH_4 and N_2O emissions from solid waste) and F-gases from air conditioning, refrigeration and industry (11.3%). These emissions can be reduced by following options:

- **Reduction in agriculture** by increasing productivity, adopting innovative technologies[37] and shifting of EU diet demands to reduce animal product consumption.
- **Reduction in the energy sector** by reducing emissions from fuel combustion, fossil fuel extraction, and fugitive emissions from transmissions and distribution with technological mitigation and decreased fuel consumption.
- **Reduction in the waste sector** by mainly mitigating methane emissions with policy or existing technologies.
- **Reduction in refrigerant and air conditioning sectors** by technological mitigation.

A.1.5.2. Non-CO_2 emissions results

Agricultural Sector

Reducing emissions in the agricultural sector can be achieved by a combination of changing food consumption patterns and applying technical mitigation measures. Applying the latter to the baseline would reduce emissions by nearly one third (<300 $MtCO_2eq$) with 60% less N_2O and 40% less CH_4 emissions. In combination with dietary change[38] non-CO_2 GHG emissions could be nearly halved (from 430 $MtCO_2eq$ in 2015 to 230 $MtCO_2eq$ in 2050). This is the equivalent of just below 5% of 1990 EU GHG emissions, which would reduce pressure for negative emissions to reach the full decarbonisation potential.

Non-agricultural Sectors

Non-CO_2 emissions from non-agricultural sectors[39] are projected to reduce by almost 85% compared to the baseline for both 1.5°C scenarios (see Figure). The projected scenarios foresee a four-fold reduction mainly in F-gases (>90%), followed by methane (~70%) and nitrous oxide (~40%), as shown in Figure. The reduction in F-gases is mainly due to improvement in refrigeration and air conditioning technologies. For methane, the reduction is largely driven by legislative and technical implementations in the waste sector and the energy sector transitioning away from fossil fuels. For nitrous oxide, the reductions stem mainly from reduced fossil fuel consumption in the energy sector and improved nitric acid production (for fertilisers) in industry.

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[37] Anaerobic digestion, minimising enteric fermentation, management of agricultural soil, optimised breeding, better fertilizer usage (such as precision farming) feed and manure management.

[38] Proposed diets 1-5 differ in the animal based calorific consumption (meat, milk and egg products) with diet 1 having the highest animal based calorific consumption and diet 5 the lowest. 34 $MtCO_2eq$ can be reduced with Diet 1 and up to 110 $MtCO_2eq$ with Diet 5, which represents approximately 8% to 25% of 2015 emissions from agriculture.

[39] Sources are fugitive emissions from the energy sector (e.g. coal mining, oil and gas production, gas distribution, fossil fuel power plants), emissions related to waste (solid waste, wastewaters) and F-gases (from air conditioning, refrigeration and industry).

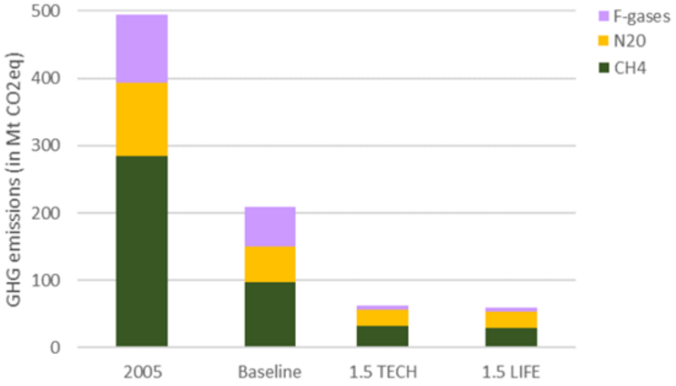

Figure 12. Reduction in non-CO_2 emission in non-agricultural sectors.[40]

A.1.5.3. Transition enablers, opportunities and challenges

Transition…	Summary
Enablers	Reduction in fossil fuels, effective policy, diet changes, investments in technology development
Opportunities	Simultaneous reduction of CH_4 and N_2O, waste improvements also create more circular economy, increased renewable energy, increased agricultural productivity
Challenges	Diverse sources, technology investment for F-gases, effective policy implementation for waste, policy for methane reduction across different sectors

Table 6. Transition enablers, opportunities and challenges of non-CO2 emissions.

A.1.5.4. Expert appreciation

Emission reduction in the agricultural sector is challenging. Despite the detailed (technical) mitigation options proposed in the scenarios, some of key observations that need to be further addressed are:

- The agricultural sector is responsible for more than half of the non-CO_2 emissions. Therefore, the scenarios depend a lot on how **food consumption patterns** will change and what **technical mitigation measures** will be applied in this sector.
- **Tendency of farmers to choose short-term economic benefits from increased productivity over sustainable agricultural practices.** Long payback time of investments and lack of strong EU economic framework hinders farmers (especially small farmers) to adopt management practices. Nitrous oxide and methane emissions are hard to abate and can only be tackled with strong policies focusing on advanced technical measures and diet change[41].
- **The diet change scenarions used in the modelling seems on the conservative side**, with the current changes in consumption patterns already going on.

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[40] The EC - A Clean Planet for all (Fig. 79).

[41] Existing Common Agricultural Policy (CAP) generally lacks a strong focus on specifying requirements for climate adaptation and mitigation. There is a common concern that it entails too little requirements and too much flexibility for member states. A robust and reliable regulatory framework is needed that can catalyse this change, such as the inclusions of agriculture in EU ETS. [41]

A.1.6 Land resources

A.1.6.1. Land resource options

Land is a finite resource that has many competing uses including food and feed production, forestry, bioenergy, and the increasing demand for housing and infrastructures. In 2016, 38% of the EU land was covered by forest and 22% by cropland, 21% by grassland and 7% shrubland. From a CO_2 perspective, the land use, land use change and forestry (LULUCF) sector in the EU today is a net carbon sink, with a net balance of 314 $MtCO_2$ sequestered. There are several options for decarbonising land use including:

- **Preserving carbon from agricultural soils,** especially by limiting the use of organic soil and peatlands for agriculture production and using sustainable agricultural practices with mineral soil to maintain the soil organic carbon (SOC).
- **Maintaining forests as a carbon sink,** by afforestation (planting additional forests), reforestation (replanting previous forests), as well as reducing the amount of wood harvested and having cascading uses of this wood.
- **Using land to cultivate biomass to substitute fossil-based equivalents** for materials like timber, bio-based plastics, bio-based chemicals or for bioenergy uses such as biogas or biofuels.

A.1.6.2. Land resource results

Bioenergy

The 1.5 °C scenarios rely significantly on bioenergy as an energy source. In the 1.5TECH scenario, 320 Mtoe of biomass is consumed in 2050 compared to 140 Mtoe in 2016. Biomass consumption peaks in 2045 and decreases thereafter due to the deployment of other energy carriers (e.g. e-fuels). In 2050, the share of bioenergy will not change dramatically in comparison to baseline, however its total use will increase up to 44% in the 1.5TECH scenario. It is assumed that biomass is mostly produced within the EU to avoid issues of certified sustainable biomass (only 4 to 6% of the solid biomass imported by 2050). An additional LIFE-LB variant scenario is created to model a scenario in which considerably less biomass is used by alternatively using more available technology options from the TECH scenario, primarily in the industry, residential, and transport sectors.

Power generation and residential heating are consuming today most of the biomass demand. In the 2050 scenarios, there is a sharp decline of its use in the residential sector, and the main use is in the power sector followed by industry. The decarbonisation of road and air transport also requires advanced biofuels that could be produced at scale after 2030, nevertheless it does not represent more than 20% of the total use of biomass.

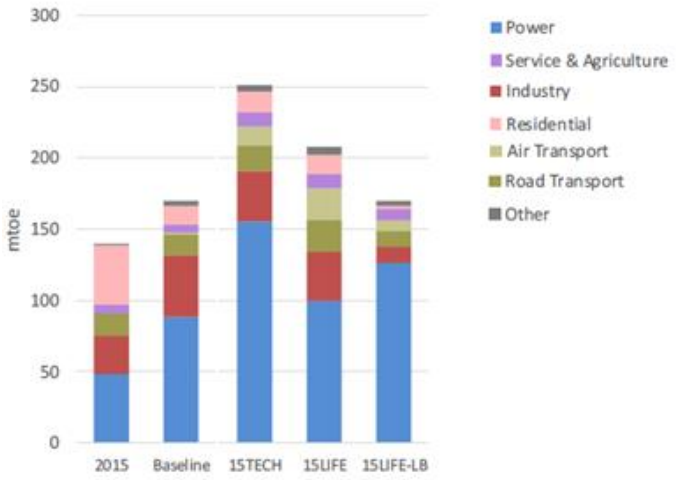

Figure 13. Use of bioenergy by sector and by scenario in 2050.[42]

A significant share of feedstock comes from waste in the 1.5 °C scenarios due to an improvement in the industrial and municipal waste collection that could supply about 100 Mtoe of feedstock to the energy sector (as seen in Figure). Biogas or biofuels produced from food crops are marginal by 2050 and this is countered by an increase in forestry residues and energy crops such as lignocellulosic grasses and short rotation coppice.

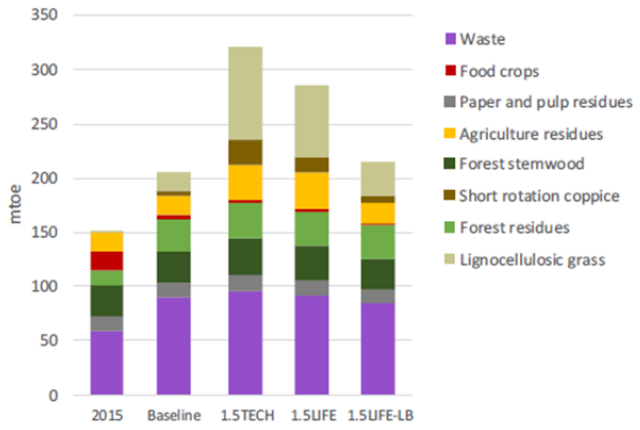

Figure 14. Bioenergy by feedstock type in 2050.[43]

LULUCF emissions

All scenarios could maintain a net LULUCF sink above 350 $MtCO_2$ by 2050, as seen in Figure 5, with the largest potentials for forest management and afforestation. The LULUCF sink could be further enhanced through economic incentives targeting various mitigation options. For example, a carbon price of EUR 150 in 2050 could increase the total LULUCF sink by more than 160 $MtCO_2$.

Strong penetration of energy crops and improving soil carbon sequestration in the 1.5TECH scenario can turn EU cropland from a net carbon source to net carbon sink by 2050, with a LULUCF sink in EU increasing close to 400 $MtCO_2$. This scenario even assumes limited incentive to enhance the LULUCF sink (30€/tCO_2).

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[42] *The EC - A Clean Planet for all (Fig. 83).*

[43] *The EC - A Clean Planet for all (Fig. 84)*

The 1.5LIFE scenario assumes land becomes available for afforestation, and combined with stronger incentives (80€/tCO_2) to enhance the LULUC sink, this allows a further increase up to 500 MtCO_2. With stronger incentives the carbon price reliance on BECCS and other carbon dioxide removal technologies can be reduced.

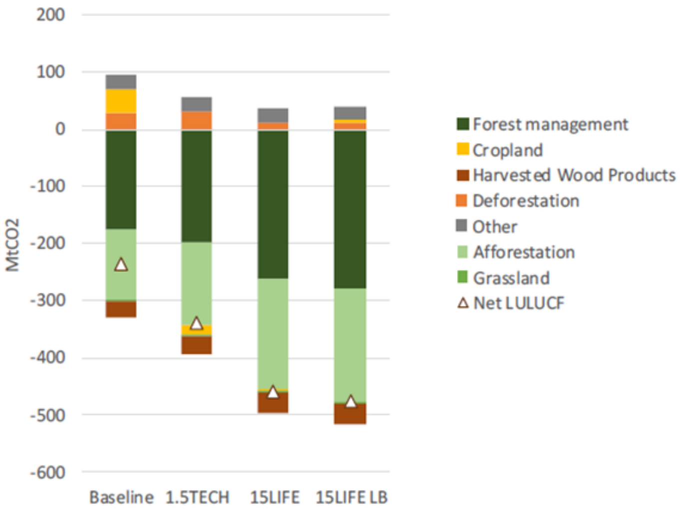

Figure 5. LULUCF emissions across the scenarios.[44]

A.1.6.3. Transition enablers, opportunities and challenges

Transition…	Summary
Enablers	Sustainable management of forests, energy crops, better monitoring of below-ground CO_2, and increased waste and residue usage.
Opportunities	Replacing fossil-based materials, chemicals, and energy with bio-based alternatives.
Challenges	Increasing biomass while not competing with agriculture or having negative environmental impacts caused by land use change.

Table 7. Transition enablers, opportunities and challenges of land resources.

A.1.6.4. Expert appreciation

- **The amounts of biomass projected to be used is within reason to produce domestically and sustainably within the EU**. Feasibility studies conclude that a range of 143-717 Mtoe can be collected within the EU in 2050, but this upper range is the technical potential rather than sustainable potential.[45] The LIFE and TECH scenarios require 287 and 320 Mtoe respectively which is feasible, but potential negative impacts on land such as biodiversity, soil quality, land use change and land use competition need to be considered as well.

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[44] *The EC - A Clean Planet for all (Fig. 87)*

[45] Faaij, A. (2018). Securing sustainable resource availability of biomass for energy applications in Europe; review of recent literature.

- **The use of biomass in the power sector is higher than expected** given that there are many other renewable alternatives in 2050 (such as solar or wind) and options to balance the grid with such as batteries or power-to-liquids. It would be expected that only biomass based on wastes or a relatively small amount of biomass would be used in the power to balance the volatility of renewables, and that more would be used in the transport sector such as advanced biofuels or aviation fuel.

- **Significant regional differences in the afforestation and reforestation potential need to be taken into account.** Targeted policies are more important for some countries than for others due to different LULUCF potential.

- **Afforestation should take place where competition with other uses is low to encourage permanent land use changes** (e.g not to compete with agriculture).

- **Afforestation, reforestation and build-up of soil organic matter is a slow process**. Farmers for example may be reluctant to invest if the effects are only visible in the far future. Furthermore, banks could find it difficult to provide financial products on such long-term projects and to quantify the benefits.[46] Adequate and transparent incentives are needed to speed up this transition.

- **Soil organic carbon stocks and sequestration on a farm level is difficult to monitor.** Under- or overestimations are likely to occur. Monitoring emissions needs to be supported by stringent, automated EU monitoring systems.

- **The role of lignocellulosic grasses is overestimated considering the uncertainty.** These crops account for nearly a quarter of biomass feedstock but it but it is highly uncertain whether they will be commercially viable by 2050 as there are little to none currently cultivated in the EU.

A.1.7 Carbon removal

A.1.7.1. Carbon removal options

A net zero emission economy will require carbon sinks to be created and CO_2 to be removed from the atmosphere. This can be done by:

- **Enhancing the natural carbon sink** by ecosystems restoration, afforestation, reforestation, improved forest management and enhancing soil carbon sequestration.
- **Using engineering technologies** such as biomass for energy coupled with carbon capture and storage technologies (BECCS)[47], direct air CO_2 capture and subsequent storage (DACCS), biochar, enhanced weathering, ocean alkalinisation, and ocean fertilisation.
- **Combination of both.**

The only ones assessed in the scenarios were BECCS and DACCS, as the other options still have uncertainties regarding the effectiveness and scalability. Most carbon removal technologies are immature thus it is difficult to estimate costs, although most have an estimated cost below 200 €/tCO_2.

A.1.7.2. Carbon removal results

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[46] Wironen, 2018. *Decision support for agricultural soil carbon sequestration: Multi-lateral development banks' needs and challenges.*

[47] BECCS is a hybrid of carbon sink and technology

In the 1.5LIFE scenario, the carbon captured is assumed to be directly stored underground or reused to produce synthetic fuels and synthetic material. It favours the reuse of the CO_2 rather than long-term geological storage, whereas the 1.5TECH favours the opposite. A significant amount of technological carbon removal is needed for the 1.5TECH scenario to generate negative emissions (BECCS) that can offset the residual emissions (especially non-CO_2 emissions from agriculture).

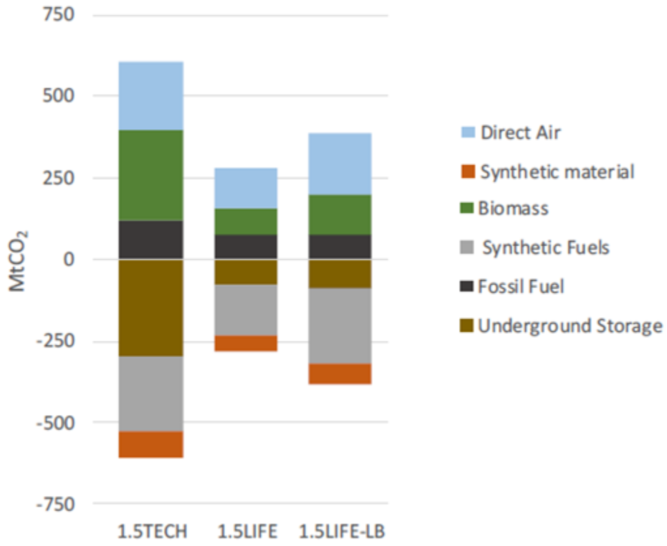

Figure 6. CO_2 capture and storage or reuse in 2050.[48]

The highest potential of CCS/CCU is realised in the 1.5TECH scenario with the highest ratios of CO_2 capture and reuse in biomass, underground storage, synthetic materials and fossil fuels (as shown in Figure 16). Nearly 75% of CO_2 captured is from the power sector and the remainder from industry. In the 1.5LIFE scenarios however, most of the CO_2 stored underground is of fossil fuel origin and mainly captured in the industry sector.

A.1.7.3. Transition enablers, opportunities and challenges

Transition…	Summary
Enablers	Technology development.
Opportunities	Achieving negative emissions to offset those that are most difficult or impossible to abate.
Challenges	Current cost of capture and storage, public acceptance, CO_2 transport infrastructure, unknown full environmental impacts of some negative emissions options (e.g. enhanced weathering/alkalinity).

Table 8. Transition enablers, opportunities and challenges of carbon removal technologies.

A.1.7.4. Expert appreciation

- **Negative emissions technologies will put a cap to the maximum cost of emission reduction.** For example, a tonne of negative emissions will be the maximum cost to abate a tonne of CO_2

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[48] The EC - A Clean Planet for all (Fig. 89)

elsewhere. This helps reducing emissions faster especially when combined with enhanced land sinks.

- **How the CO_2 is mitigated and how the storage in materials is defined can have a large influence on the final potential of negative emissions.** The key discussion point is permanence: when CO_2 is captured in plastics, the emissions are only stored for a short time (10-15 years), however when stored in synthetic materials, for example concrete, the storage duration is extended up to 100 years.

- **Underground storage is underestimated by approximately one third**. Furthermore, underground storage is more effective measure than capturing CO_2 in plastics.[49]

- **Negative emissions heavily rely on the direct air capture, but whether this will truly be a viable option in the future is an unknown.** Until now only limited small-scale pilots have been launched. The associated high costs (200-300/tonne CO_2) increases the unpredictability of this option in the future.

A.2 Analysis of impact on employment and finance

The decarbonisation of the EU economy is expected to generate significant transformations. The decoupling of economic growth and GHG emissions is possible and the EU economy is expected to more than double by 2050 compared to 1990, even as it fully decarbonises. This is achieved by increasing output (GDP) per energy consumed. Note that cost figures are to a large extent based on the discount rates used to annuitize investments. Discount rates are discussed in section 2.1.2 and in Appendix A.

Investment requirements

The investments needed in the 1.5 °C scenarios are higher than the baseline and less ambitious scenarios. Many of these investments are needed to replace assets at the end of their economic lifetime and additional investment requirements are not constant over time. The additional investment needed compared to the baseline is highest between 2040 and 2050. For the 1.5TECH scenario, this is largely due to greater investments in power plants, the power grid, transport and tertiary sector when compared to the baseline (seen in Figure 17). For the 1.5LIFE scenario the larger investments compared to the baseline are in power plants, transport and residential sector.

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[49] Appreciation by Navigant's in-house experts

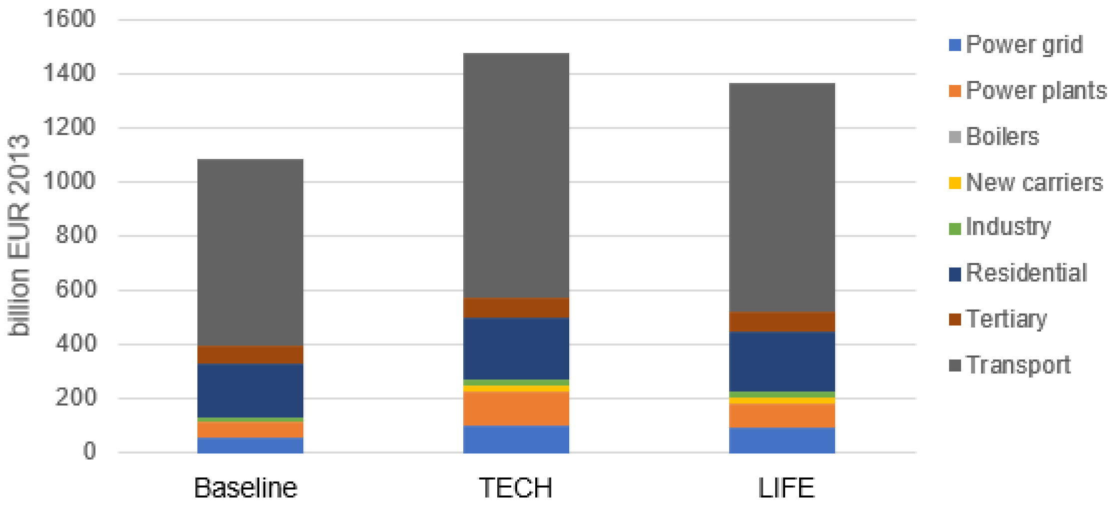

Figure 17. Average annual investments from 2031-2050 by sector.

Energy system costs and prices

The level of total system cost is strongly correlated with the level of ambition, with the baseline having the lowest and the 1.5TECH scenario the highest. Energy system costs are expected to increase from around EUR 1.8 trillion in 2020 to around EUR 2.1 trillion in 2030. Post-2030 the energy system costs differ per scenario (see Figure 18). With the Commission's GDP projections, the energy system costs as a percentage of GDP peaks in 2030 and then decreases towards 2070.

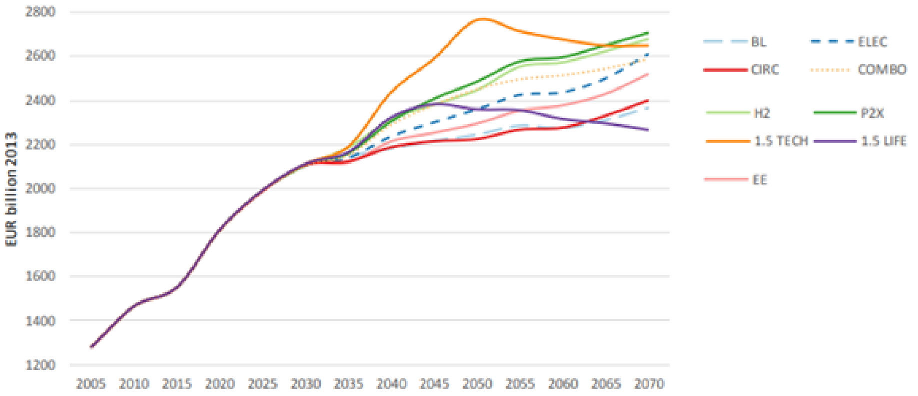

Figure 18. Total energy system costs as a percentage of GDP, 2005-2070.[50]

Electricity prices increase until 2030, reflecting the costs of power system decarbonisation. After 2030, the electricity price stabilises at a level similar to the baseline for the 1.5LIFE scenario but remains the highest in the 1.5TECH scenario.

Social aspects related to the fuel expenses

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[50] The EC - A Clean Planet for all (Figure 97).

Energy-related expenses (including fuel costs and energy equipment expenditure) per household are expected to increase significantly in absolute terms under the baseline and all scenarios up to 2030. After 2030, the results vary significantly across scenarios; the Energy Efficiency scenario yields a pay off because of lower fuel expenditure and the high-ambition 1.5 TECH scenario yields higher energy-related expenses for households, as seen in Figure .

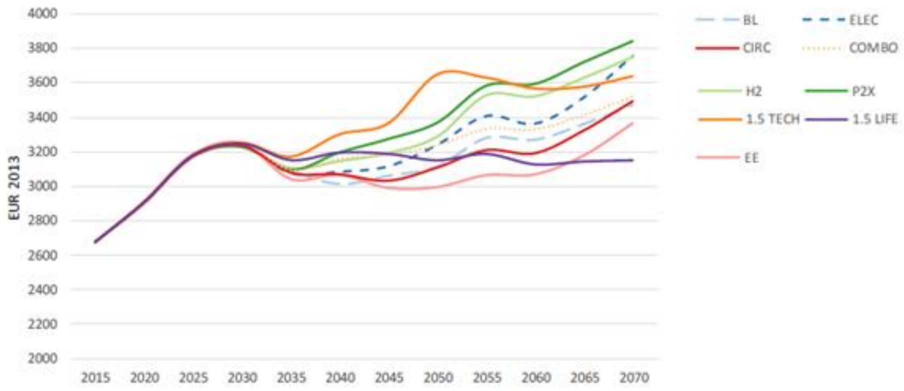

Figure 19. Energy related expenses per households in different scenarios. [51]

Increases in energy-related expenses in the recent past highlight the need for the EU to increase efforts to mitigate the social costs of the transition. Guaranteeing continued and inclusive economic growth and rising living standard are the most important measures to offset the sustained high-levels of energy-related expenses through the 2030 horizon.

Impact on energy import expenditure

As a net energy importer (55% imported, almost entirely as fossil fuels) the EU will benefit from increasing the amount of renewables and subsequently reducing dependence on imported fossil fuels. The value of net fossil fuel imports decreases in all decarbonisation scenarios, with an estimated cumulative savings of EUR 1.4-3 trillion from 2031-50. Although the energy transition will improve the energy trade balance of the EU, it is important to note that it might also increase import dependency on other raw materials used in low-carbon technologies such as lithium, cobalt, and graphite.

Macroeconomic impacts of the climate and energy transition

Despite variation across scenarios and different models, macro-economic modelling concluded that the impact of decarbonisation on GDP will be limited. At worst, real GDP would be 1.3% lower in 2050 than under the baseline, and 2.2% higher at best.

Employment impacts of the climate and energy transition

The low carbon transition will see significant increases in turnover for sectors involved in renewable energy and energy efficiency, and associated job increases. This is because renewable energy and energy efficiency have a higher labour intensity compared to power generation from fossil fuels, for instance, and because the EU is currently a net fossil fuel importer. The transition to renewables will affect different sectors quite differently. It will trigger more investments in construction, agriculture (bioenergy), and power generation, leading to higher employment, but the mining and extraction sector will contract as demand shifts away from fossil fuels (but only represents 0.5% of the labour market).

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[51] The EC - A Clean Planet for all (Figure 102).

Although the macroeconomic models demonstrate varying amounts, they agree that overall, additional jobs will be created by the decarbonisation transition. Compared to the Baseline scenario, the 1.5 °C scenarios model up to 2.1 million *additional* jobs being created.

Figure 20. Range of change in jobs by 2050 compared to baseline in different sectors in all scenarios. [52]

Expert appreciation

- Different models conclude different impacts on the GDP. **It can be expected that the 1.5 °C scenarios will result in a decrease in the GDP**[53]. Other benefits are expected to compensate for the decrease in GDP.
- The in-depth analysis suggests that investments ccosts are substantially lower in the 1.5LIFE secenario than in the 1.5TECH scenario. **However, the uncertainties in the 1.5LIFE scenario, may be underestimated**.
- **It seems realistic that the 1.5 °C scenarios model up to 2.1 million *additional* jobs being created**. One needs to realise that these jobs require different skills than in a fossil fuel economy. It is not certain that the shift can be made.
- **Many additional jobs will be local**, such as installation of small scale solar and insulation, but other jobs (e.g. in production of solar panel components) might be outside the EU. This modelling has high uncertainty.
- **The additional job predictions might be on the high end.** Installation jobs are not very sustainable – you basically do the job once -. In addition, with an increasing shift in foreign investments it is often the case that domestic jobs leak with it.

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[52] The EC - A Clean Planet for all (Table 17). Includes 80% GHG reduction scenarios in range.

[53] Interview Matthioas Duwe, Ecologic

APPENDIX B. DISCOUNT RATES

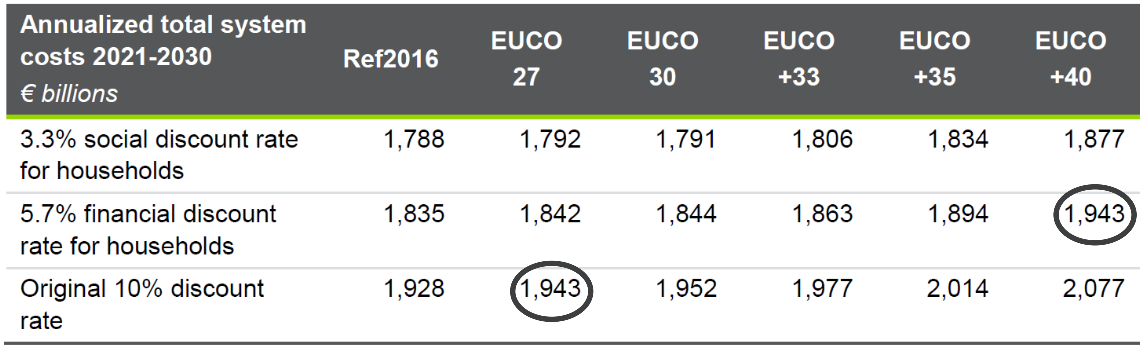
The choice of discount rate has a critical effect on the subsequent technology options chosen within the scenarios. Discount rates are important, as they attribute a weight to future cash flows, however the choice should be well understood as they can highly influence outcomes of a scenario.

There has been some critique in recent years over the use of discount rates in the Commission's impact assessments based on modelling in the PRIMES model[54]. A 2015 report by Ecofys investigated the limitations in discount rates[55].

Although the commission did review the use of discount rates in the PRIMES modelling after this critique, a few key issues remain related to the use of discount rates in the Commission's modelling:

1. The Commission is ***not clear and transparent*** about how discount rates are used in its modelling.
2. There is ***no or limited sensitivity assessment*** on key parameters, such as discount rates.
3. The same high discount rates that are used to represent ***decision-making by economic actors*** are also used to express total energy system capital costs in annuity payments, which is used to facilitate ***decision-making by policymakers***. Note that there is some ambiguity about this in the Commission's documentation and Q&A responses.
4. Discount rates are used to ***express a range of implementation barriers*** in monetary terms. This simplistic way to represent the barriers overlooks the possible ways to remove the barriers.

The table below shows the effect of reducing the discount rate for households from 10% to 5.7% (financial discount rate) and 3.3% (societal discount rate). With lower discount rates, the total system costs of more ambitious energy efficiency targets are significantly lower than they were in the Commission's impact assessment from 2016.



Annualized total system costs 2021-2030 *€ billions*	**Ref2016**	**EUCO 27**	**EUCO 30**	**EUCO +33**	**EUCO +35**	**EUCO +40**
3.3% social discount rate for households	1,788	1,792	1,791	1,806	1,834	1,877
5.7% financial discount rate for households	1,835	1,842	1,844	1,863	1,894	1,943
Original 10% discount rate	1,928	1,943	1,952	1,977	2,014	2,077

Table 9. Annualized total system costs 2021-2030 for different 2030 EE target scenarios

As an illustration: the total system cost for a 27% reduction target in 2030 with the applied 10% discount rate leads to the same system costs as with a 40% reduction target in 2030 with a lower (5.7%) financial discount rate. For more information about these issues we refer to the Ecofys report from 2015.

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[54] See for example: Navigant (2018) *Energy System Costs under EU Energy Efficiency Targets*, Ecofys (2015*) Costs and Benefits of Energy Efficiency Targets*, Ecofys & Coalition for Energy Savings (2017) *2030 energy efficiency target ambition*

[55] Ecofys (2015) *Evaluating our future: The crucial role of discount rates in European Commission energy system modelling*

APPENDIX C. OVERVIEW OF 1.5 °C SCENARIOS

Please find below a summary of main specificities of the 1.5 °C scenarios (TECH and LIFE) in all sectors. The summaries apply to both scenarios if not specificied otherwise.

SECTOR	1.5 SCENARIOS
Energy supply	Lowest energy import (>70% compared to 2015) with a 5-fold decrease of natural gas decrease especially for residential & services. Doubling of electricity share (in comparison to 2015) with a significant increase of hydrogen, biomass, e-gas (residential & services), e-liquids (transport sector). CCS plays a noticeable role only in 1.5TECH, where it reaches 5% of the total net electricity generation (mostly because of biomass power generation to generate negative emissions).
Buildings	Maximising energy efficiency, technological deployment, high renovation rates are main drivers for energy reduction in 1.5TECH scenario, coupled with consumer choice in 1.5LIFE scenario. Rapid penetration of electricity (60-80% of the final energy demand in buildings), especially used for space heating (30-50%). Phase-out of natural gas (3%), increased role of e-gas (approximately 40%).
Transport	Improved overall vehicle efficiency, promoting low- and zero emission vehicles and infrastructure, and the long-term switch to alternative and net-zero carbon fuels for transport, emphasis on electrifying most cars and light commercial vehicles. Cooperative and automated logistics coupled with sharing economy. Strong reduction in energy demand, characterised by much lower (3 fold) consumption of oil products and a higher share of hydrogen and e-liquids in comparison to other scenarios (driven by the lower growth in transport activity and energy efficiency improvements). LIFE has lowest growth of the aviation activity due to consumer choices changes and increased efficiency with a high share of energy coming from liquid biofuels in combination with e-fuels.

Industry	Circularity (re-using, recycling, and recovery of materials and heat) is the key enabler of industry decarbonisation. LIFE has the most significant decrease of the total final energy consumption (-31% compared to 2015). LIFE is only scenario expecting a decrease of electricity consumption compared to the baseline. In both scenarios the consumption of biomass decreases, and hydrogen increases. Higher carbon prices allow the appearance of CCS/CCU installations from 2040 onwards, with 54/58 MtCO_2 captured (for 1.5LIFE / 1.5TECH respectively), increasing to 71/80 MtCO_2 in 2050 and further to 112/128 MtCO_2 post-2050. In 2050 47/80 MtCO_2 are stored in materials for these two scenarios.
Non-CO_2 emissions	The agricultural sector is by far the biggest emitter of non-CO_2 greenhouse gases, especially nitrous oxides coming from agricultural soils due to use of fertilisers and methane emissions from livestock. Technical measures in combination with dietary change can reduce non-CO_2 GHG emissions by two thirds of 2005 levels.
Land resources	The demand for biomass after 2030 is higher for 1.5 °C scenarios than in others. After 2045 the biomass demand starts decreasing again in 1.5 °C scenarios due to the deployment of other energy carriers (e.g. e-fuels). TECH expects the highest use for bioenergy (44% increase in comparison to baseline), LIFE predicts the lowest (a similar total bioenergy use than baseline).
Negative emissions	1.5 °C scenarios require a substantial amount of CO_2 captured by 2050. TECH predicts the highest CO_2 capture and storage or reuse among all scenarios (most from power sector), with almost four times more CO_2 stored in underground and twice as much in synfuels in comparison to LIFE scenario. Biogenic carbon in TECH scenario is supplying the largest share of CO_2 stored in geological storage sites.

Table 10. Summary of main specificities of the 1.5 °C scenarios (TECH and LIFE) in all sectors