NET ZERO 2050

NET ZERO BY 2050: FROM WHETHER TO HOW

ZERO EMISSIONS PATHWAYS TO THE EUROPE WE WANT

CLIMACT

SEPTEMBER 2018

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Model testers - the following organisations supported the analytical team in testing the model, which is itself derived from the ClimateWorks Foundation's Carbon Transparency Initiative (CTI):

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Members of these organisations tested the model during the summer of 2018 and explored a variety of decarbonisation pathways. These scenarios have informed our conclusions but were not used directly.

Other organisations were consulted on sector specific discussions:

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The views expressed in this paper are attributable only to the authors, and not the organisations that have supported or advised on its development.

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NET ZERO 2050

DISCLAIMER

This report has been commissioned by the European Climate Foundation (ECF). It is part of the Net-Zero 2050 series, an initiative of the ECF with contributions from a consortium of experts and organisations.

The objective of Net-Zero 2050 is to start building a vision and evidence base for the transition to net-zero emission societies in Europe and beyond, by mid-century at the latest. The Paris Agreement commits us to making this transition, and long-term strategic planning shows that many of the decisions and actions needed to get us on track must be taken imminently.

Reports in the series seek to enhance understanding of the implications and opportunities of moving to climate neutrality across the power, industry, buildings, transport, agriculture, Land Use, Land-Use Change and Forestry (LULUCF) sectors; to shed light on some of the near-term choices and actions needed to reach this goal, and to provide a basis for discussion and engagement with stakeholders and policy-makers.

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FOREWORD

Laurence Tubiana
CEO, European Climate Foundation

The 2015 Paris Agreement marked the moment when the global community committed to decisive climate action to keep warming well below 2°Celsius (°C). This will require transformational change – all countries, rich and poor, must reach carbon neutrality. Net-zero needs to be our goal, our direction of travel, and our rallying cry.

This is a challenge, but also an opportunity – for the EU and its Member States, it is an opportunity to demonstrate global leadership by charting a path to reach carbon neutrality by 2050. But in order to reach our goal, we need a plan – we need to know the pathways to net-zero, including the growth and innovation opportunities it presents, the trade-offs that may need to be made, and the policy designs we will need to get there.

The European Climate Foundation's collaboration on the CTI 2050 Roadmap Tool shows that while it is not easy, Europe can design these pathways – and the advantages far outweigh the difficulties. The project seeks to answer the question of 'how' we achieve the required transition.

The research makes it clear that the move forward must be holistic – all sectors must play their part in reducing emissions. The good news is that there are interdependencies that can and must be used to deliver maximum speed and efficiency of mitigation. There are major opportunities and need for technological innovation and investment, and enabling policies – this will be fundamental to achieving the required reductions quickly.

Net-zero is technically and economically possible. But the key driver of success will be political will, creative policy implementation, and societal understanding and ambition. This project shows that there are many compelling reasons to expect that a net-zero world will be cleaner, healthier, more prosperous, more equitable, and happier – not least because it will avoid the massive costs of large-scale climate impacts on food, infrastructure, health, and migration. The costs of transition are dwarfed by the costs of dealing with climate impacts in a scenario where we fail to reach net-zero by 2050. Setting net-zero as a clear direction of travel will help to achieve many of the societal goals we have set ourselves.

The "Europe we want" is one that protects its citizens from global threats such as climate change, which no one country can tackle on its own; and creates a safer, cleaner world. Net-zero is a path to a sustainable Europe in which prosperity and well-being are delivered alongside a clean and healthy environment.

METHODOLOGY & SCENARIOS OVERVIEW

This project has developed and used a simulation model of European emissions and the mitigation options available now and in the future, analysing possible pathways to reach net-zero greenhouse gas (GHG) emissions. The emissions scope of the model encompasses all sectors of the economy and all GHG emissions sources covered by national inventories, including international aviation, shipping, and Land Use, Land-Use Change and Forestry LULUCF.

It is a techno-economic simulation model; pathways illustrated in this report are designed as a combination of ambition levels across all GHG emitting sectors and mitigation options. The model was extensively discussed and tested with the wide range of stakeholders listed above. It relies on an extensive literature review and stakeholder consultation.

For each sector of the EU economy that emits GHGs (Power production, industry, buildings, transportation, and Agriculture, Forestry and Land-Use (AFOLU)), the GHG emissions drivers and means of reducing them – referred to as 'levers' – were modelled. Examples of levers include shifting from cars to softer modes of transport, deep retrofits of buildings to reduce their energy consumption, enhancing the circular economy with longer-lived assets, shifting to renewable forms of electricity production, and shifting to healthier diets to free up land for increasing forest covers.

Rather than calculating optimal pathways, the model allows the user to choose the ambition level of each individual lever (from a reference level up to maximum technical ambition) and thereby explore different scenarios or pathways to 2050. The costs of each pathway are estimated by adding the annual capital expenditures (e.g., new infrastructures or assets), operational costs (e.g., maintenance) and fuel costs. Other externalities (such as improved air quality, reduced noise, climate change damages, or biodiversity conservation) are not accounted in the cost estimates but discussed based on a literature research (see Section 3, p.14).

More details on the modelling and its scope can be found in the Appendix.

THREE MAIN NET-ZERO GHG EMISSIONS SCENARIOS ARE USED IN THE REPORT AND AVAILABLE ONLINE

More than 10 scenarios were modelled by the organisations who supported the model testing, while other scenarios were elaborated by the project team to explore the net-zero opportunities and trade-offs. Out of these scenarios, three typical pathways were selected to illustrate the conclusions of this report. All three reach net-zero emissions by 2050.

1. *The "Shared efforts" scenario: A comparable level of effort is maintained across sectors and levers, i.e., there is no emphasis on any specific mitigation option. Where conclusions are illustrated in the text with only one scenario, it is the Shared efforts scenario unless otherwise indicated.*
2. *The "Technology" scenario: Emphasises efficiency and innovative technological options by raising their ambition to the highest levels (e.g., energy efficiency, electrification, hydrogen, carbon capture, and storage (CCS)). It leads to -41% energy demand in 2050.*
3. *The "Demand-focus" scenario: Demand-side levers are used here to reduce the overall demand further, e.g., for energy (-64% by 2050), products, or meat, which implies that technological levers can be reduced compared to the Shared efforts scenario.*

These scenarios are used in the graphics of the report, but they can also be explored in more detail online. Additional scenarios are also available on the website.

One of the objectives of this work is to increase the analytical basis available to define the adequate political framework for the low-carbon transition, increasing model transparency, ease of use, the comparability of existing scenarios, and ultimately the access of policy makers to the most useful information for decision making. In this logic, a version of the model directly based on the full simulation model is accessible online. This allows for the pathways used in the analysis to be explored in much greater details, as well as to test additional pathways.

The webtool can be found at: *https://stakeholder.netzero2050.eu*

Hyperlinks are included as just above in the report text where relevant, so that readers can easily navigate between the report and the three main scenarios online.

EXECUTIVE SUMMARY

Impacts of climate change are already being felt today around the globe, including in Europe, and urgent action is now required by all countries. The Paris Agreement[1] states an objective of limiting global warming to "well below 2°C" above pre-industrial levels, but also of making all possible efforts to achieve the goal of 1.5°C climate stabilisation.

On the basis of the scientific underpinning of these goals provided by the Intergovernmental Panel on Climate Change (IPCC), signatories to the Paris Agreement also committed to ensure that global GHG emissions fall to net-zero as early as possible in the second half of this century, before going negative. ***This means developed economies such as the European Union's (EU), will need to achieve net-zero emissions by 2050, or even earlier. Numerous countries have already set goals consistent with this.[2]***

This is the starting point taken by the CTI 2050 Roadmap Tool project, which seeks to explore the feasibility and implications for the EU of reaching net-zero GHG emissions by 2050 at the latest. It finds that not only is it technically possible, but that the net-zero future is likely to be both economically beneficial, and desirable on many other grounds. However, it requires a collective commitment to transformational action and without delay.

REACHING NET-ZERO GHG EMISSIONS BY 2050 IS FEASIBLE

BUT REQUIRES ROBUST ACTION ACROSS ALL SECTORS, AND WIDENING THE RANGE OF LOW-CARBON OPTIONS USED FOR THE TRANSITION

Planning for net-zero GHG emissions requires a new way of thinking – more innovative, cross-sectoral, and beyond business-as-usual. It means ensuring that GHG emissions are reduced close to zero in all sectors, and that these remaining emissions are compensated by carbon sinks like forest growth or sustainable biomass coupled with carbon capture and storage (CCS).

Social patterns, societal organisation and energy efficiency are key to make it easier to reach net-zero (the contributions of each lever group relate to how ambitious the reference is (EU-REF16)).

(GHG emissions, [MtCO$_2$e])

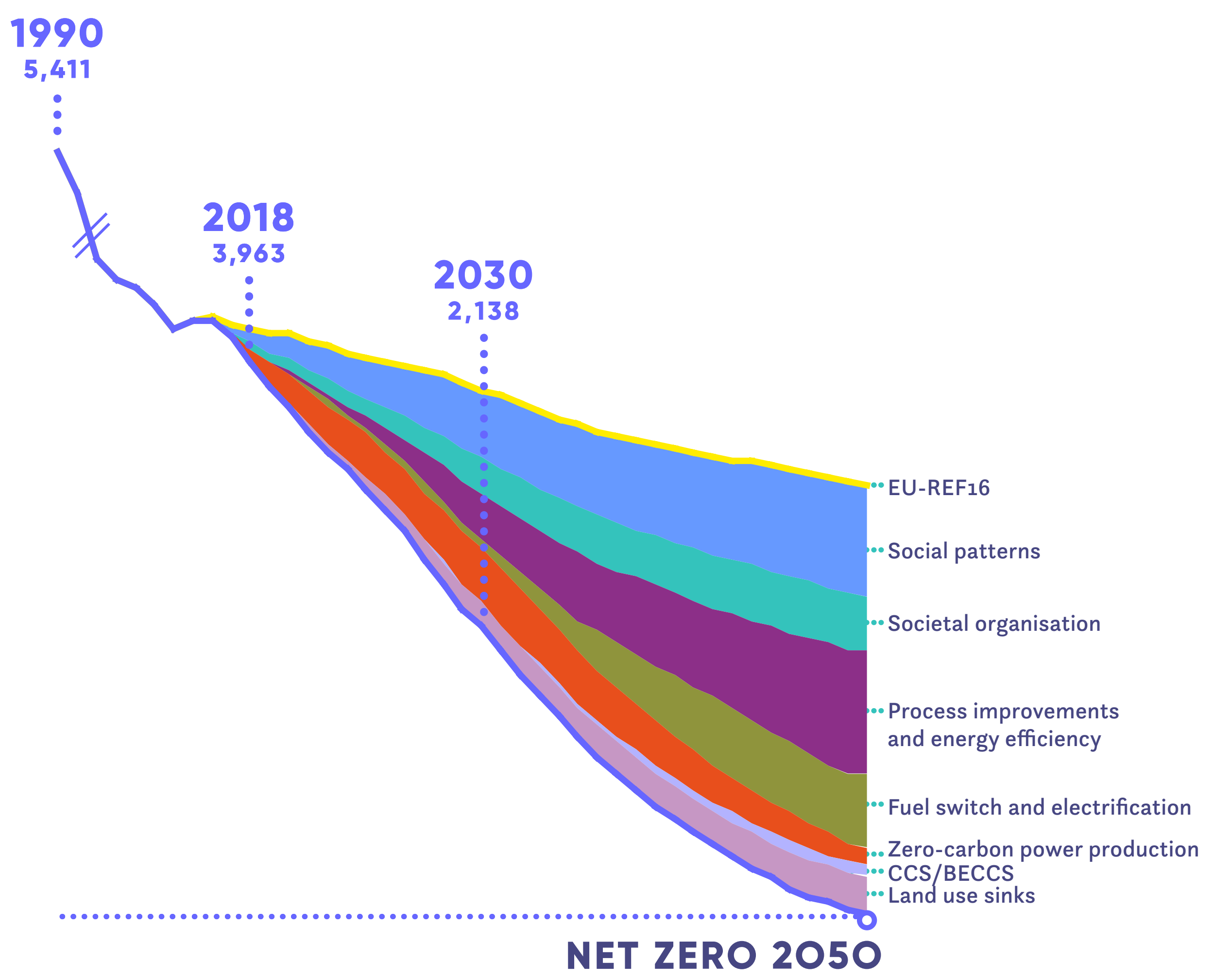


FIGURE 1. *GHG emission reductions by lever types in a Shared efforts (See the section on the "Analytical basis" p.7 to read on the various scenarios used in this report.) net-zero scenario [MtCO$_2$e]*

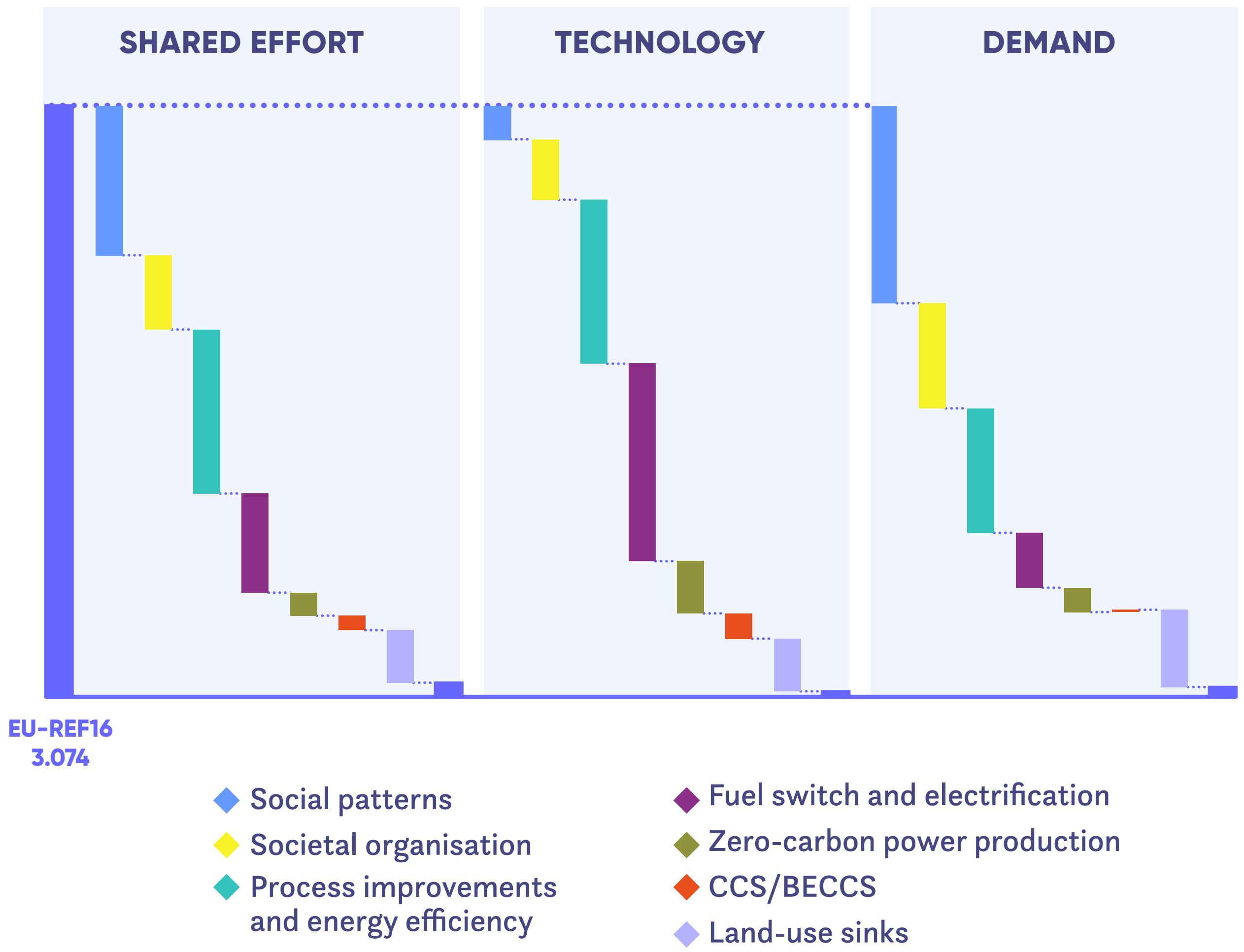
Planning to reach net-zero by 2050 at the latest means no sector can be left aside. We need to widen the range of options being used, including by putting more focus on how we operate as a society. Innovation in our consumption patterns and increasing potential natural carbon sinks need to be combined with the more typical technical options such as energy efficiency, fuel shift, zero-carbon power production and electrification.

Figure 1 illustrates the contribution of the various lever groups to reducing emissions over time and shows that actions of many types are involved in delivering the required emission reductions. This includes actions related to technology choices, but also about how society is organised, consumption patterns, and the impact of the circular economy principles, with better and more innovative product design leading to longer lifetimes and greater recycling and reuse of raw and processed materials. **All these demand-side choices have a major trickle-down effect on the entire value chain.**

While Figure 1 illustrates the "Shared efforts" scenario, which leverages all levers to a similar ambition, other pathways with different focuses can also lead to net-zero. Figure 2 shows how the key lever groupings differ across the three studied scenarios. This also connects to large differences across European countries in their approaches to the low-carbon transition. **Our research shows that there is not one way to decarbonise: each country, region, city or local authority has to define its own transition with the global objective in mind.**

The impact of key lever groups differs significantly across the three scenarios

(GHG emissions, [MtCO$_2$e])



(See the detailed grouping of all levers in the Appendix: Brief methodology description)

FIGURE 2. *Impact of each lever group on GHG emissions reductions for each scenario in 2050 [MtCO$_2$e]*

This transition means using all the best practices that are already being applied across Europe, and applying them at a much greater scale, as well as increasing investment and putting policies in place to ensure widespread uptake of more transformational solutions – in technical, business model, societal, and governance arenas. **A review of the scenarios points to the fact that commercially available solutions can already take us about 75% of the way to net-zero if deployed at scale. The remaining 25% can be achieved based on known approaches and technologies for which further scaling up and commercialisation is needed. This includes the wider implementation of innovative business models that frontrunners are already starting to use.**[3]

Net-zero requires increased deployment of efforts and solutions as well as upscaling the commercialisation and deployment of new technologies, and innovation in business models

(GHG emissions, [$MtCO_2e$])

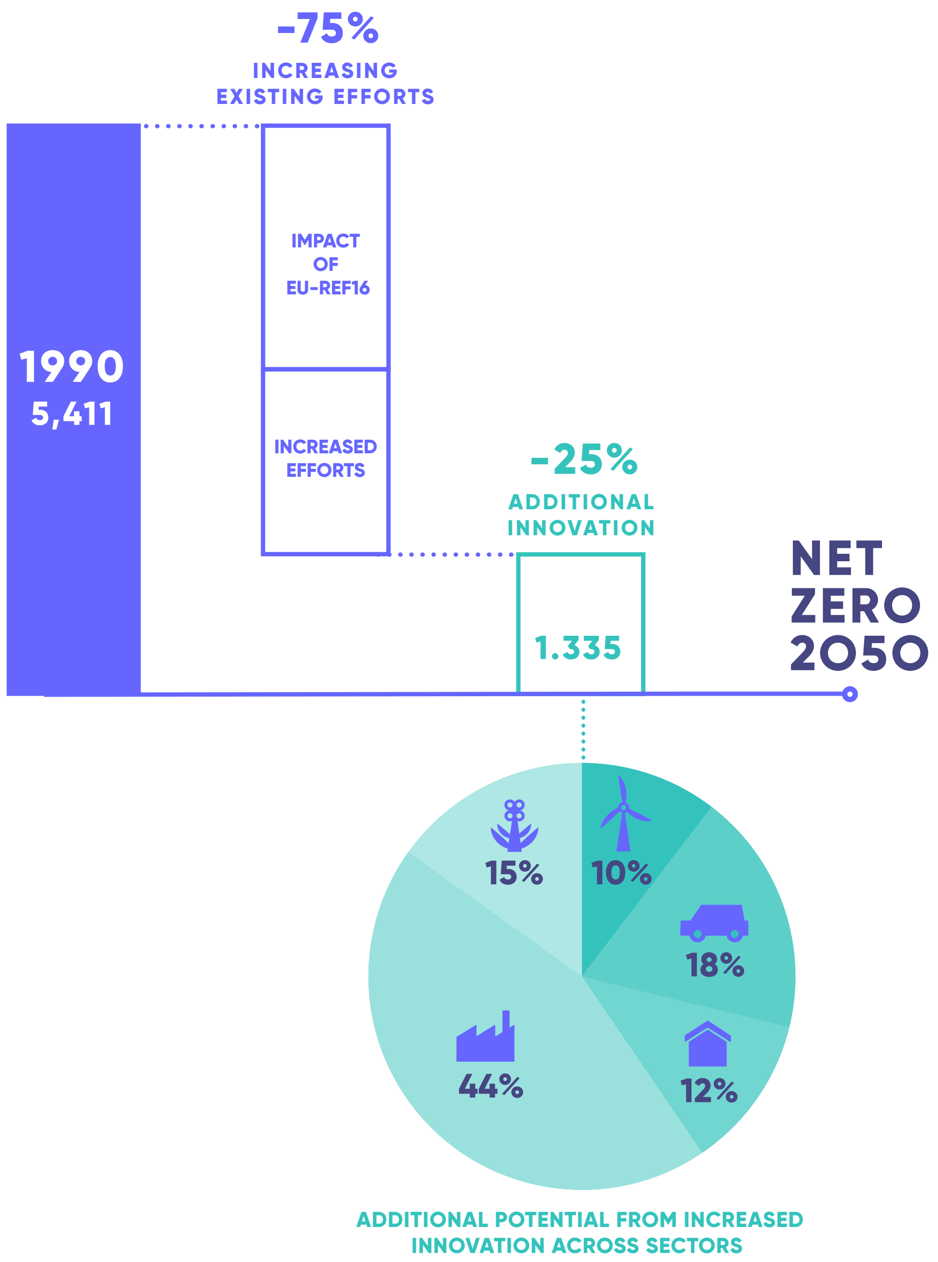


FIGURE 3. *GHG emission reductions split between increased efforts and additional innovation (see end note[3])*

Setting a firm and clear direction of travel, which is required to ensure that near-term choices are aligned with long-term goals, will help to ensure the required investment in scaling up these solutions. It is likely to also unleash further creativity regarding technologies and social developments, which can widen the range of options available for reaching net-zero.

Our work also highlights the importance of deploying all mitigation actions possible including land-use sinks and other options for removal of GHG from the atmosphere. In our three scenarios, improved land-use practices could support around 600 megatonnes of CO_2 equivalent ($MtCO_2e$) per year of GHG sinks, which amounts to about 10% of 1990 emissions and can help us reach net-zero by 2050. Other options to remove GHG from the atmosphere (e.g., biomass use combined with CCS) have significant limitations as well. However, the European carbon emissions budget is very tight and reaching net-zero by 2050 is unlikely to be sufficient. **Europe will need to compensate for some of its emissions by going net-negative after 2050. Therefore these limited natural sinks and other carbon dioxide removal (CDR) options will not be an alternative for the emitting sectors. Each sector needs to reach close to zero emissions around mid-century or shortly after.**

2 NET-ZERO GHG EMISSIONS IN 2050 REQUIRES RAISING THE 2030 AMBITION LEVEL

TO SET EUROPE ON THE RIGHT TRAJECTORY

2050 matters because of the guide it provides for near-term choices. It evidences the need to increase action now in order to leverage all the no-regrets options available and to avoid locking-in to the wrong technologies and processes. Not doing enough, or not anticipating correctly by 2030, will limit our options in the future and simply 'doing a bit more' after 2030 will not work since not all pathways will remain open. **This study finds that to be on a trajectory to net-zero by 2050, GHG emissions will need to be reduced from about 55–65% compared to 1990 levels (including LULUCF) by 2030.**

The 2030 ambition needs to be increased to be in line with net-zero scenarios

(GHG emissions, [$MtCO_2e$])

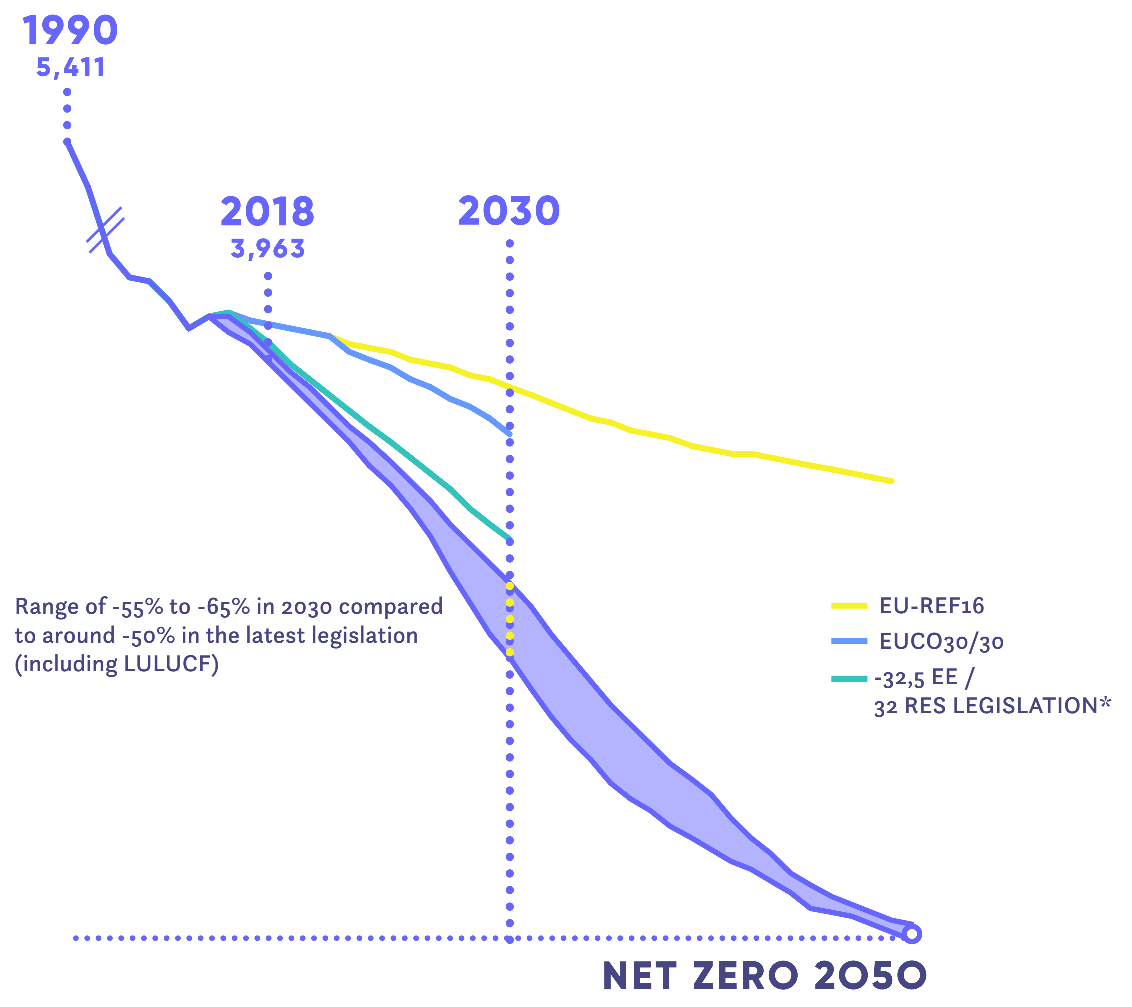


FIGURE 4. *GHG emission reduction range in net-zero scenarios compared to the EUCO scenario and the impact of the latest 32.5% energy efficiency and 32% renewables targets based on the non-paper by the EU Commission*

* This scenario is based on the latest « Non paper on complementary economic modelling undertaken by DG ENER regarding different energy policy scenarios » and is using the 33% RES / 33% EE figure for 2030, with a linear interpolation from 2016, so it slightly overestimates the latest legislation

This finding contradicts the current EU target[4] which leads to only 40% GHG reductions (including LULUCF, 35% excluding it) in 2030. It also contradicts the latest adopted EU legislation that gives targets of 32.5% on energy efficiency and 32% for renewables, which is estimated to lead to about 46% excluding LULUCF (or 50% reductions including them) in 2030. This would keep us still far from the range of reductions needed to set Europe on the required trajectory to net-zero just 20 years later.

Our findings, as well as the latest scientific evidence, tell us that the next 10 years are crucial if Europe and the world are to avoid the worst consequences of climate change. Our analysis identifies a set of "no-regrets" actions[5], which need to be taken in this time span. "No regrets" actions are those required in all zero emissions pathways, regardless of the emphasis they set on the various levers or sectors, and regardless of the 2030 ambition level:

TRANSPORT

By 2030, the focus must be to ensure transport demand is stabilised to today's levels, and that the modal shift away from cars has started in earnest. Car share should be down to 70% from around 80% today. After stabilisation of demand and modal shift, vehicle efficiency is the third key lever in the short term, with efficiency needing to improve by at least 15% for cars and even beyond 20% improvement for trucks. The support for Zero-Emission vehicles (ZEVs) must be reinforced so that Europe innovates in ZEV production and the actual penetration in the fleet starts to increase at a fast pace after 2030. Note that several countries, including those with relevant automotive sectors, have announced bans on sales of new conventional internal combustion cars, notably Ireland and Slovenia (2030), and France and the UK (2040). The Netherlands aims to have all new cars emission free by 2030. These can be effective policies to drive this shift. Charging infrastructure investment and deployment is also crucial to drive the shift toward ZEVs.

BUILDINGS

Significantly renovating 3% of the buildings each year with deep retrofits to improve energy efficiency to near-zero energy levels, and fully decarbonising heat by 2050 at the latest. Current annual renovation rates are below 1%. New constructions must be energy-positive "smart" buildings already in the decade to 2030 to avoid having to renovate those again until 2050.

INDUSTRY

By 2030, significantly reducing the demand for materials and products (5-10% by 2030, above 40% by 2050) by boosting the functional economy(Increase the products lifetime by 5%), the circular economy(Increase product utilisation by 5%, switch to more efficient material (e.g., 8% of steel switched to carbon fibres in automotive), reduced material intensity, increased share of recycled materials), and associated innovation. While deploying best practices in industrial processes (electrification, fuel switching) is expected to begin soon, the adoption of new innovative technologies is currently mostly expected in the 2030-2050 time horizon.

POWER

Close to complete phase-out of coal. Wind and solar should reach at least 50% of power production by 2030, around 60% by 2050, and 75% of the demand-side management (DSM) potential is being exploited by 2050. About half of the flexibility needed to compensate seasonal and daily intermittency is covered by a mix of zero-carbon flexibility options (storage, inter-connections, biomass-firing), which reduces the role of gas even as coal phases-out.

AGRICULTURE, FORESTRY AND LAND USE (AFOLU)

*Before 2030 land-use must fully integrate climate change considerations: policies and business models must be convincing to restore degraded forests and to reforest most surplus and abandoned land[6]. Incentives should effectively support a change of agriculture practices to boost land multi-use, stopping land degradation. On average, in 2030, meat consumption must be reduced by 25% (and at least halved by 2050) without increasing consumption of dairy products. Trends are already going in this direction.**

FINANCE

Sufficient investments in innovation is a fundamental requirement for this economy-wide decarbonisation, to accelerate lab-to-market for innovative net-zero technologies and the co-development of new products, businesses and services. These investments can be shaped by the public sector through flagship research and innovation programmes like Horizon Europe, but also require the strong engagement of European businesses.

*https://www.eea.europa.eu/data-and-maps/indicators/13.2-development-in-consumption-of-2/assessment-1

3 NET-ZERO PATHWAYS CAN COST LESS THAN BUSINESS-AS-USUAL

AND BUILD A MORE PROSPEROUS, RESILIENT SOCIETY

Reaching ambitious GHG emissions reductions is economically attractive. If all available levers are actioned, particularly on the demand side, the total energy system costs (Investment costs + operational expenditures + fuel costs) will be lower than in a business-as-usual scenario (here taken as the EU-REF16 scenario from the EU Commission). Essentially a net-zero society uses its resources much more efficiently across all sectors: products with longer lifetimes and increased asset utilisation (e.g., using fewer cars but using them more than the 5% of the time that is currently the case). Figure 5 illustrates these system costs in the Shared efforts scenario grouped by action type. **It shows how strong the impact of improving the way our society is organised can be.**

Net-zero pathways can cost less than business-as-usual, with a strong impact from the demand-side levers

Undiscounted cumulated total energy system costs by lever category [x10³ billion €]

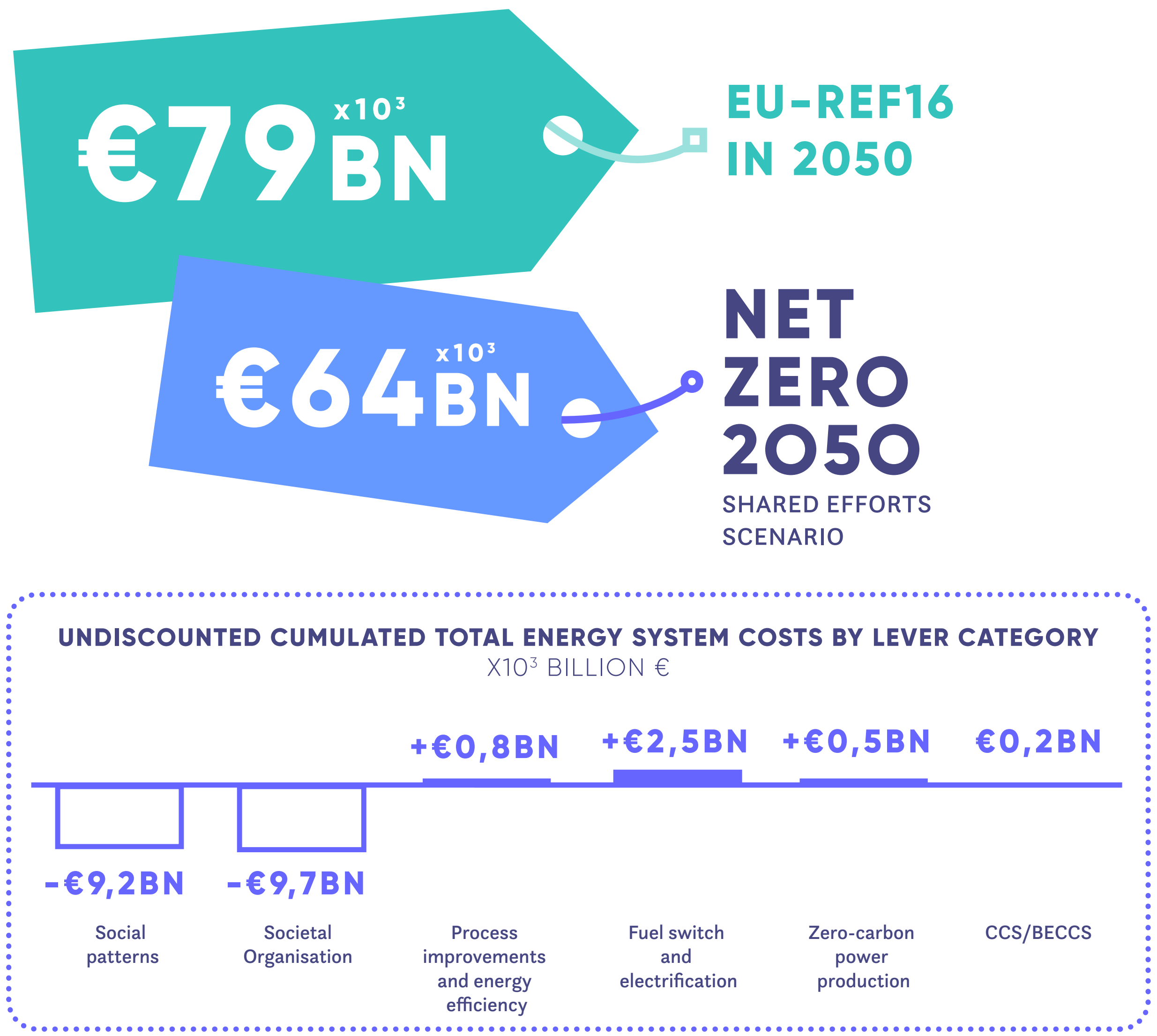


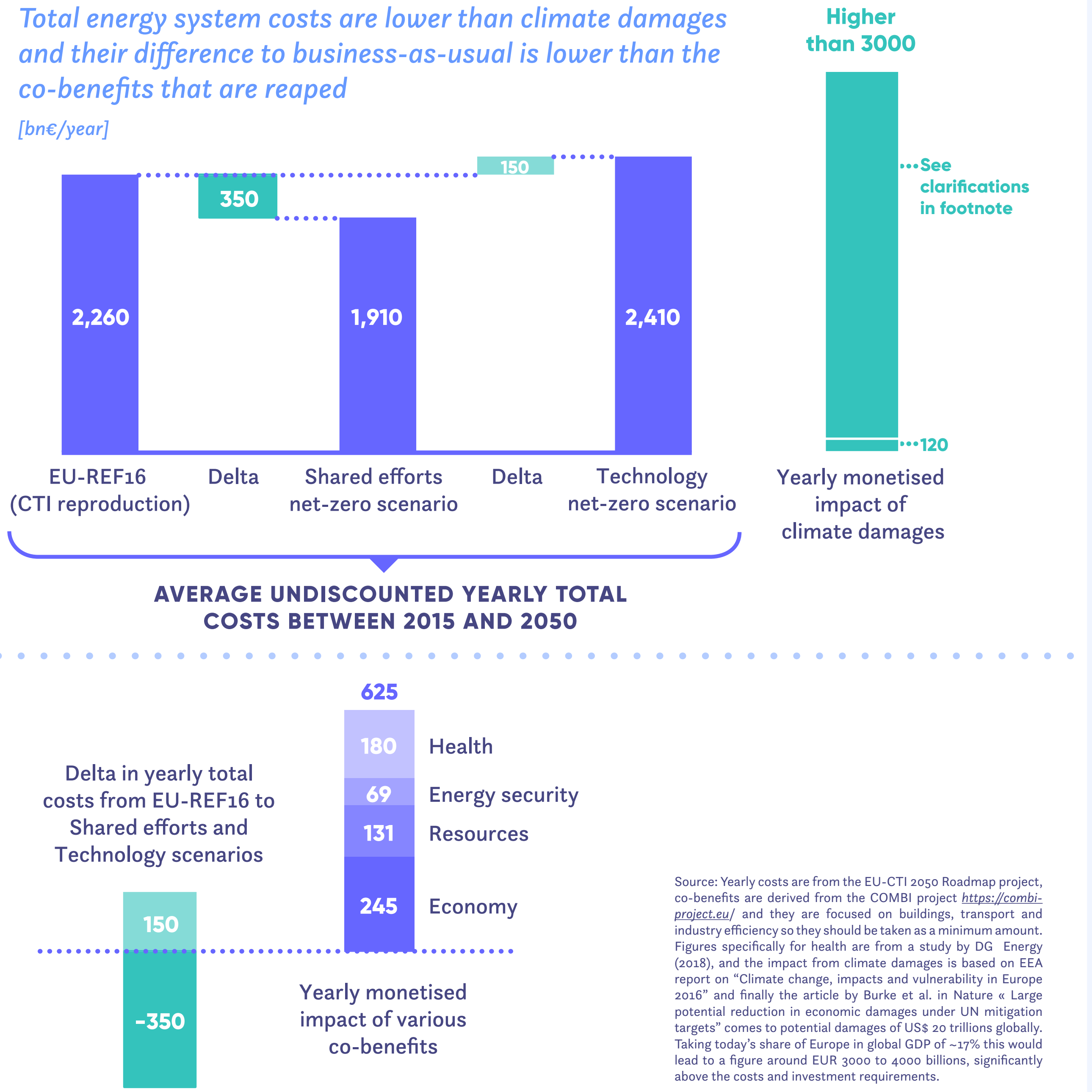
FIGURE 5. *Difference in total system costs by lever group between the EU-REF16 and the Shared efforts net-zero scenario*

Many of the 'net-zero' choices will also take us closer to other goals Europeans have set for themselves. A net-zero society can bring an attractive quality of life to its citizens, with a wide range of additional benefits and lower costs – e.g., cleaner air, less traffic and city congestion, better living environments, less money spent on fuels and more on infrastructure and innovation in Europe, leading to a more resilient economy with more and better jobs, more durable goods, higher biodiversity, and better forests.

Figure 6 shows how the latest estimates in the literature indicate that the difference in potential climate damages in a 2°C scenario compared to a 1.5°C scenario are foreseen to be much higher than the total costs of any scenario, low-carbon or not, and whether more technology-focused or not. The many co-benefits identified are also higher than the cost delta of the Technology scenario compared to the EU-REF16. **Clearly the low-carbon transition is attractive "on average", which does not take away the complexity of the substantial investments required, nor the strong variations in cost impacts across sectors. This can be addressed by having a vision and planning for a climate-proof, resilient and future-oriented society.**

Total energy system costs are lower than climate damages and their difference to business-as-usual is lower than the co-benefits that are reaped

[bn€/year]



Source: Yearly costs are from the EU-CTI 2050 Roadmap project, co-benefits are derived from the COMBI project *https://combi-project.eu/* and they are focused on buildings, transport and industry efficiency so they should be taken as a minimum amount. Figures specifically for health are from a study by DG Energy (2018), and the impact from climate damages is based on EEA report on "Climate change, impacts and vulnerability in Europe 2016" and finally the article by Burke et al. in Nature « Large potential reduction in economic damages under UN mitigation targets" comes to potential damages of US$ 20 trillions globally. Taking today's share of Europe in global GDP of ~17% this would lead to a figure around EUR 3000 to 4000 billions, significantly above the costs and investment requirements.

FIGURE 6. *Costs and investments compared to the potential impact of co-benefits and climate damages*

INTRODUCTION

The European project is about promoting peace and European values, and supporting the wellbeing of its citizens. It also seeks to contribute to global security, sustainable development, solidarity and mutual respect among peoples[7].

Climate change is a major threat to these aspirations. Rising sea levels, melting ice, heavier precipitation and increased coastal flooding, more frequent and intense heatwaves, longer and more damaging wildfire seasons, droughts, destruction of coral reefs and an increase in extreme weather events are all already happening. The higher the global temperature increase, the stronger will be these effects, and the greater the consequences in terms of damage to homes and infrastructure, disruptions to food supply, new threats to health, destruction of biodiversity, geopolitical instability, migration, to name just some. Scientists also warn of dangerous tipping points.

Fortunately, it is still within reach to avoid the worst impacts of dangerous climate change. The 2015 Paris Agreement[8] set a collective goal of holding the increase in global average temperature to 'well below 2°C' above pre-industrial levels, but also making all possible efforts to achieve the goal of 1.5°C climate stabilisation.

Science increasingly confirms that achieving climate stabilisation and avoiding catastrophic impacts of climate change requires a peak in global greenhouse gas emissions in the very near term, accelerated reductions to reach net-zero by mid-century, and then to go negative, removing more greenhouse gases (GHG) than we emit.

Pathways to net-zero emissions by mid-century (or even earlier) in industrialised countries are a therefore pre-requisite for meeting the Paris goals. Numerous countries have already set goals consistent with this[9], recognising that the low carbon transition offers exciting possibilities for positive economic and societal transformation.

The Carbon Transparency Initiative (CTI) 2050 Roadmap Tool project takes the need to reach net-zero emissions by 2050 at the latest as its starting point, and explores the feasibility and implications for the EU of reaching this objective. Please see the preceding pages and Annex for details of the methodology taken. The key conclusions are elaborated below.

1

REACHING NET-ZERO GHG EMISSIONS IN 2050 IS FEASIBLE

BUT REQUIRES ROBUST ACTION ACROSS ALL SECTORS, AND WIDENING THE RANGE OF LOW-CARBON OPTIONS USED FOR THE TRANSITION

Several contrasted pathways lead to net-zero GHG emissions by 2050.

The various scenarios developed with the model – both by the authors and by the various organisations who tested and used the model – highlight that a variety of routes exist to reach net-zero:

- Some scenarios rely on innovative technological or business model shifts, while others emphasise changes to living and working patterns, enabled by political incentives and societal innovation, including improving the way we use our land and consume food and products.
- Some low-carbon pathways show a higher reliance on electrification, while others rely more on biomass.
- Some are more focused on leveraging the sinks available in the soil and forests, while others rely more on sustainable bio-energy with carbon capture and storage (BECCS), assuming large amounts of CCS can and must be deployed by mid-century.

THREE MAIN NET-ZERO GHG EMISSIONS SCENARIOS ARE USED IN THE REPORT AND AVAILABLE ONLINE

More than 10 scenarios were modelled by the organisations who supported model testing, while other scenarios were elaborated by the project team to explore the net-zero opportunities and trade-offs. Out of these scenarios, three typical pathways were selected to illustrate the conclusions of this report. All three reach net-zero emissions by 2050.

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Hyperlinks are included as just above in the report text where relevant, so that readers can easily navigate between the report and the three main scenarios online.

Even across these differences in focus, all pathways show many elements in common with clear no-regret actions across all sectors. Reaching net-zero GHG emissions logically means that no sector can be left aside: **all sectors will need to reach (close to) net-zero at some point before or shortly after 2050 to be in line with the ambition stemming from the Paris Agreement.** The reductions per sector in the analysed scenarios (based on the potential for all the abatement options identified) range from a minimum of about 65% reduction for the Agriculture and Waste sector to 100% for Buildings, Power, and Transport (see Figure 7).

Figure 7 also shows that if the natural sinks in the land-use sectors are properly managed, they can remove some remaining emissions in 2050. With significant efforts, the Land Use, Land-Use Change and Forestry (LULUCF) total carbon sink could double by 2050 compared to 1990. An average net natural sink of around 584 megatonnes of CO_2 equivalent ($MtCO_2e$) is reached in the scenarios modelled by combining changes of agriculture practices, restoration of degraded forests, and massive biodiverse afforestation of land spared by reduced livestock and conservation policies. In our scenarios, this more than counterbalances the remaining 138 and 235 $MtCO_2e$ respectively from the industry and agriculture sectors. While this allows the industry and agriculture sectors to reach zero emissions a little later than the others, negative emissions will be required after 2050, which means the ultimate objective must be to reduce emissions to near zero for these two sectors as well.

High ambition is required in all sectors, whatever the chosen pathway

(GHG emissions, [$MtCO_2e$])

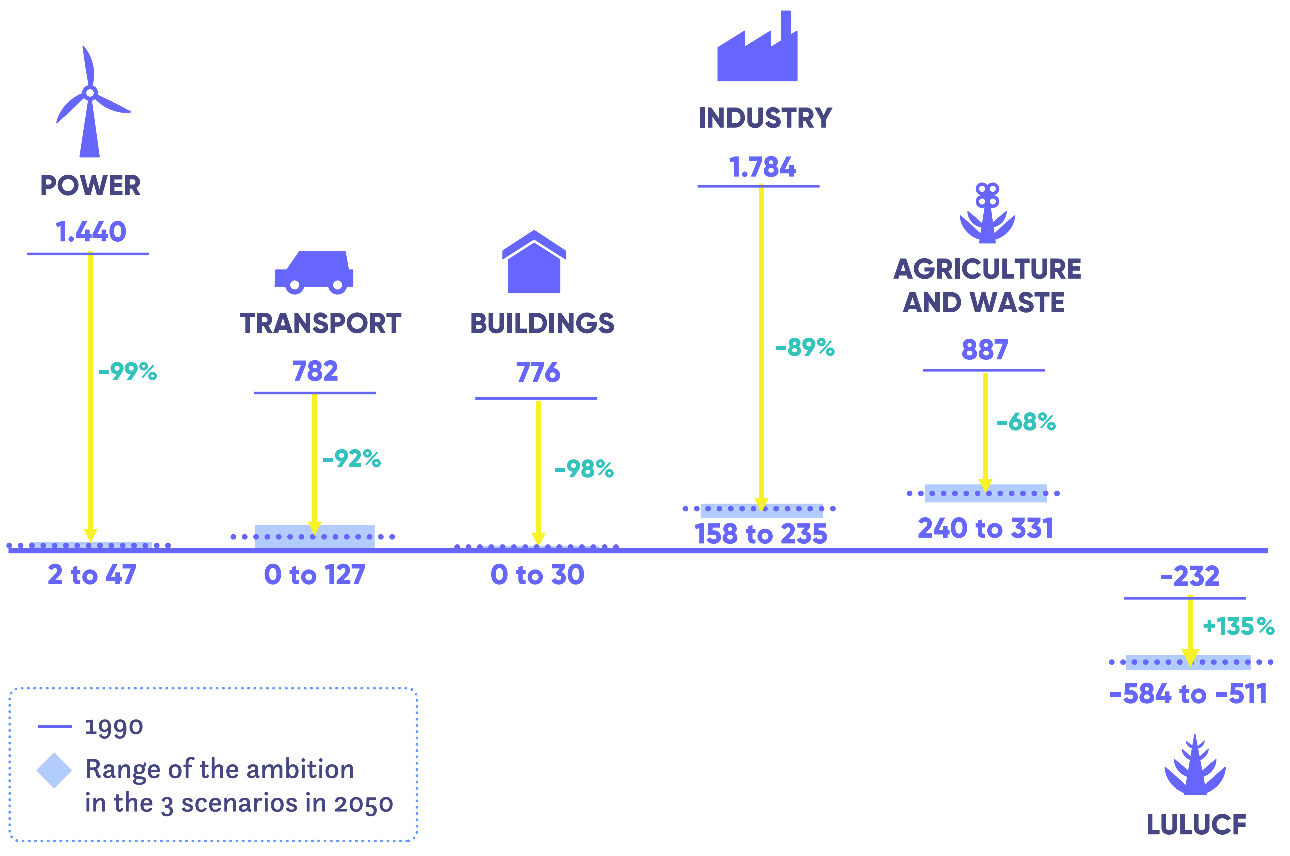


FIGURE 7. *GHG emission reductions (1990 to 2050) in the three scenarios (Shared efforts, Technology, Demand-focus)*

Figure 8 complements the GHG emissions view with the impact on energy consumption of the net-zero scenarios for the various sectors, showing that the industrial sector is the one with the largest variety of pathways to decarbonisation in terms of energy demand reductions versus supply-side solutions. However, all scenarios rely on a significant reduction of energy consumption in all sectors. Figure 9 shows how these reductions are split across lever groups in the Shared Efforts scenario, highlighting strong differences between sectors with societal organisation levers being especially relevant in industry (circular economy) and transport (modal shift).

All scenarios highlight large energy demand reductions

[TWh/year]

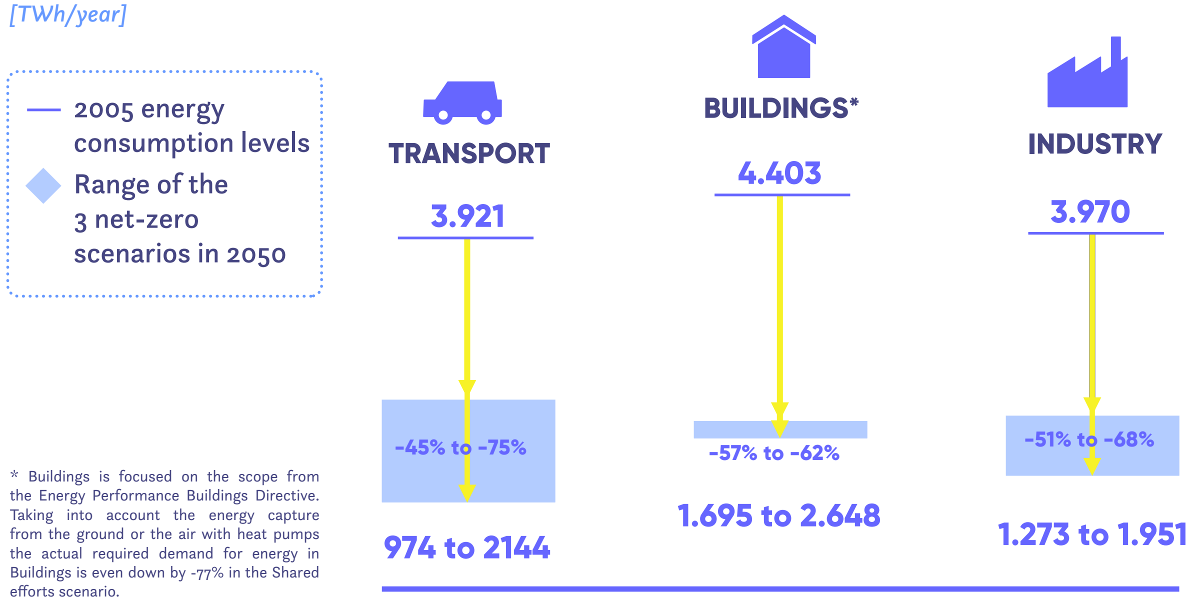
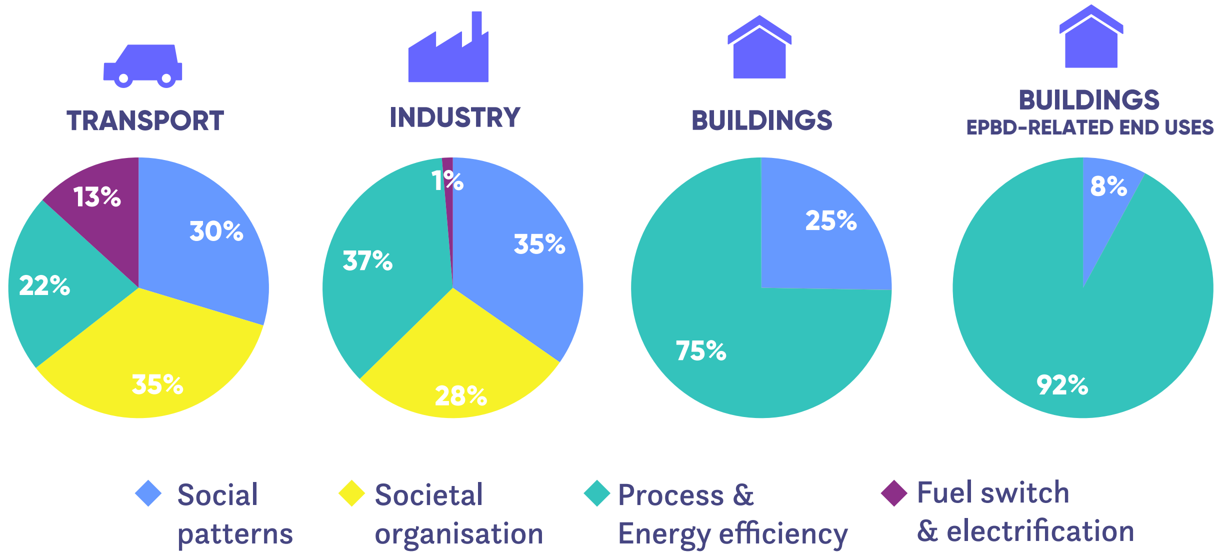


FIGURE 8. *Final energy consumption reductions by sector between 2005 and 2050 in the 3 net-zero scenarios (Shared efforts, Technology, Societal organisation)*

Key drivers of energy consumption reductions show significant differences across sectors



See the detailed grouping of all levers in the Appendix: Brief methodology description

FIGURE 9. *Share of the energy reduction in the Shared efforts scenario w.r.t. EU-REF16 in 2050*

The two figures below depict the GHG emissions reduction contributions in the Shared efforts scenario. It shows GHG emission reduction contributions starting from the 2016-EU REF scenario, with the impact by sector in Figure 10, and by type of lever in Figure 11.

All sectors need to contribute to the objective, but their contributions vary over time and depend on how ambitious the business-as-usual is in these sectors

(GHG emissions, [$MtCO_2e$])

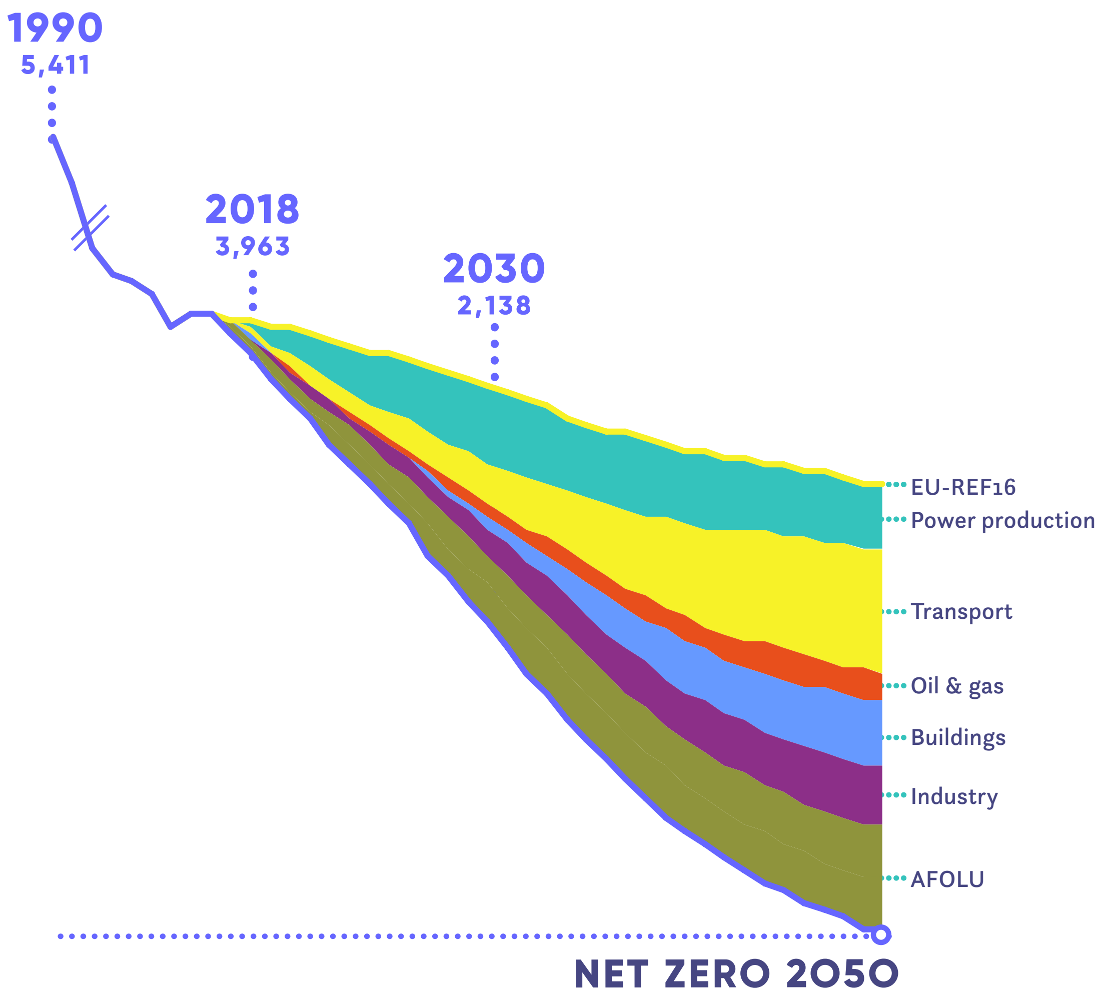


FIGURE 10. *GHG emission reductions by sector in a Shared efforts net-zero scenario*

Figure 11 complements the sector view by showing the contribution to net-zero of different lever groups. It highlights that widening the range of options being used is key, putting more focus on changing the way we function as a society on top of the more typical technical levers of efficiency, fuel shift and electrification, as well as shifting to low-carbon energy supply and increasing potential sinks. While more innovative technology-focussed pathways are shown to be feasible (not illustrated here), this work brings forward the significant impact of citizens' and political choices in terms of consumption patterns and the way society is organised. It also shows clearly the large impact of circular economy principles, with better product design leading to longer lifetimes, and the major trickle-down effects these innovations have on the entire value chain. This makes reaching net-zero in 2050 easier and more attractive as the energy system costs are lower, and the co-benefits increase, as will be highlighted in Section 3.

Social patterns, societal organisation and energy efficiency are key to make it easier to reach net-zero

(GHG emissions, [$MtCO_2e$])

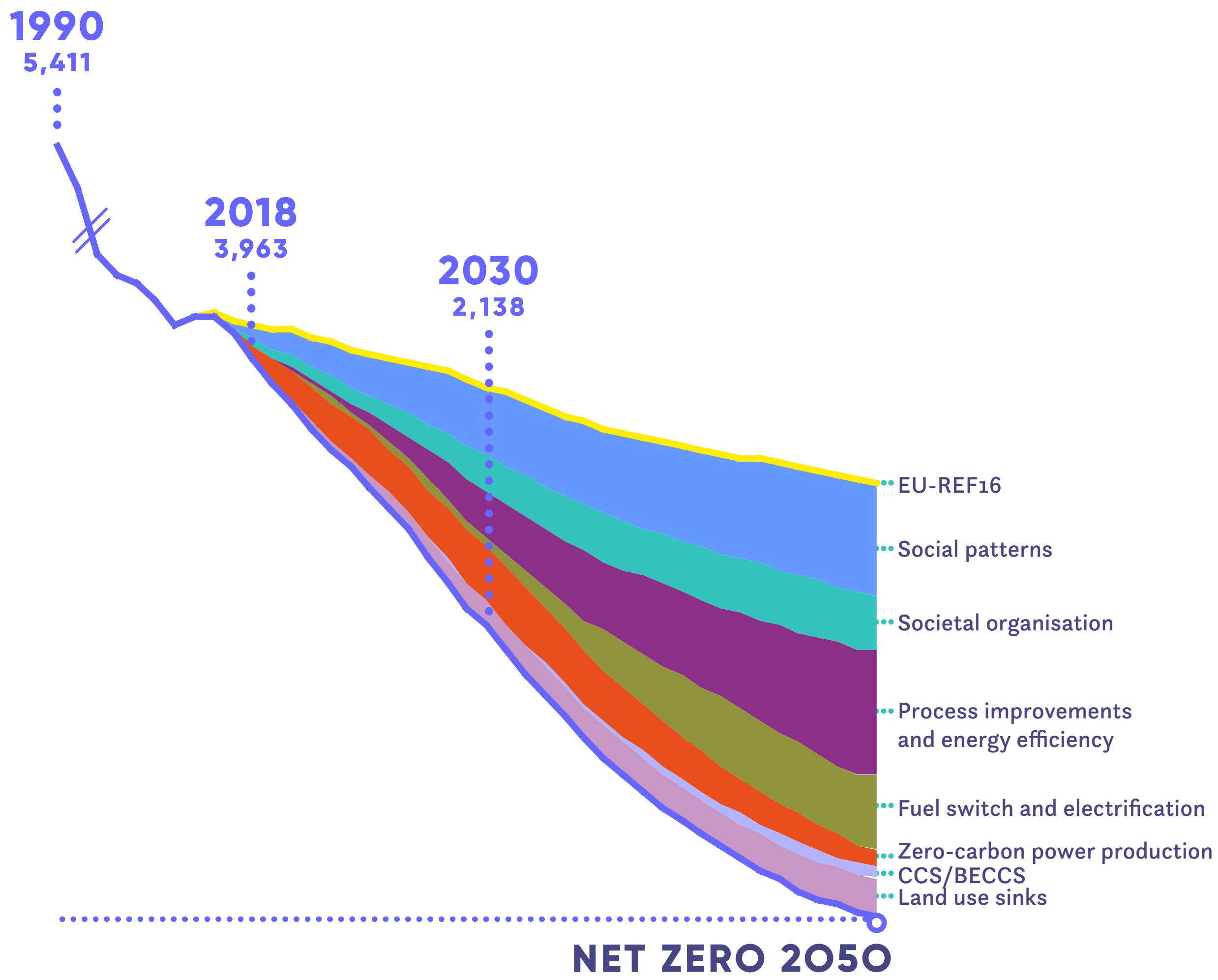


FIGURE 11. *GHG emission reductions by lever types in a Shared efforts net-zero scenario*

Figure 12 gives another view of the impact of lever groups by sector, and shows how the sectors differ in their focus. Transport and Industry leverage all types, while Buildings is more focused on efficiency improvements and electrification. The figure also highlights the important impact each of the lever groups has on the power sector.

All sectors rely on a variety of levers to reach net-zero, but the focus shifts

(GHG emissions, [$MtCO_2e$])

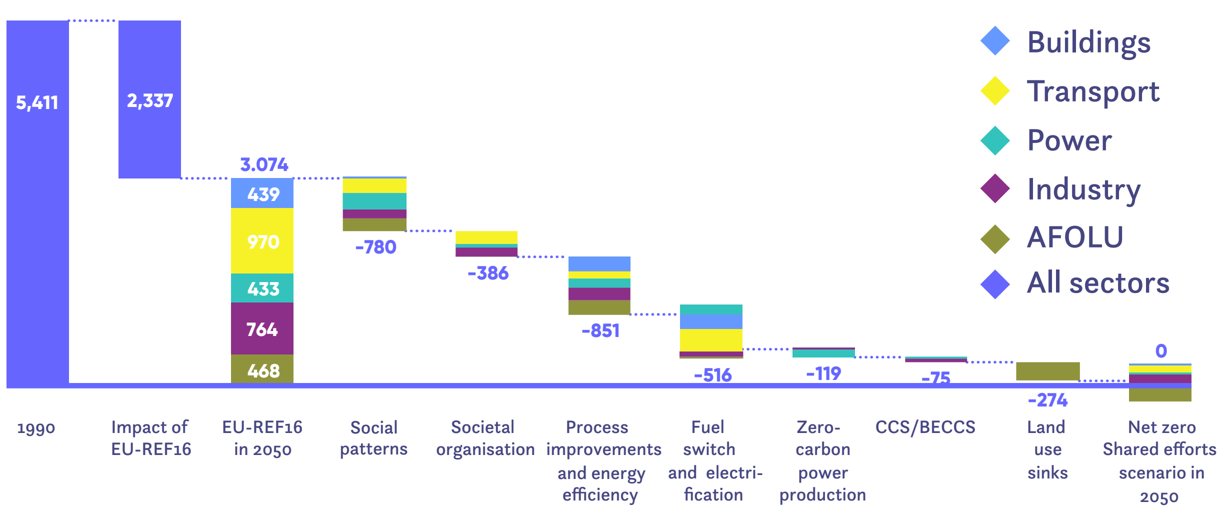


FIGURE 12. *GHG emissions reductions in the Shared efforts scenario split by lever group and by sectors.*

The transition is ambitious but technically feasible: many initiatives are already taking place across Europe but need to be stepped up significantly.

Many initiatives are already taking place across Europe in line with a very low-carbon society. Our model runs show that about 75% of necessary emissions reductions can be achieved by scaling up existing initiatives and best practices. Strong and coherent political support to those initiatives, efficient experience-sharing, and increased European cooperation can clearly speed up the process and help to reach the goals that have been set. The scenarios put forward are based on expanding best practices that are already underway with incremental improvement to make them more effective and cheaper.

Key initiatives across Europe are highlighted for each sector in the section: "A short overview of the key assumptions and implications by Sector" (Appendix)

Increased innovation investments are essential to bring key technologies and practices to readiness and scale. (See below for a definition of 'innovation'.)

Beyond existing practices and solutions, a certain share of GHG emissions reductions requires additional innovation. When we look at the abatement options in each of the sectors one by one and assess how advanced each technology is and the readiness of society to implement them, our study finds that some options still require further technical and societal innovation to bridge the gap from about 75% reductions (versus 1990) to net-zero. There are grounds to believe that it will be entirely possible to close this gap with the right commitment as all solutions used in the scenarios are already beyond the labs and tested at pilot scale, typically with Technology Readiness Levels (TRLs) halfway to large scale commercialisation. Some examples include: reaching a factor 10 in energy efficiency in buildings is technically feasible but requires further innovation to reach the massive scale required; e-fuels in transport are also technically feasible today but it will only be scaled when their wider application in the relevant transport areas is clarified; and CCS-leveraging solutions exist today but need to be scaled to reach commercialisation stages. Given the long lead times of innovation cycles, it is vital to set the right conditions to push these solutions from research and development through innovative product design and business model innovation, and then to be deployed at scale in EU economies.

DEFINING INNOVATION AND CONCRETE EXAMPLES OF THE TECHNOLOGIES USED IN THE MODEL

- Innovation is understood as the concrete application of ideas that are novel and useful for the low-carbon transition. Research and creativity can generate novel and useful ideas, processes, technologies, services, or techniques, but unless they are applied and scaled they remain at the idea level.
- This work does not address the research element, but focuses more on the scaling of solutions that currently exist, either at niche or pilot level, or that require further scaling to reduce costs.
- Examples of the increased innovation required include: autonomous vehicles, electric catenary systems for truck-based highway transport, large-scale deep retrofits (renovation reducing energy demand by a factor of 10), extended functional economy, wide application of CCS across industrial sites, the management of variable renewable energy sources, and the extension of vegetable alternatives to meat.
- Table 1 details further some of the key areas where increased investments are required to unlock the GHG reduction potential in all sectors all the way to net-zero.

Net-zero requires increased deployment of existing efforts and solutions, as well as upscaling the commercialisation and deployment of new technologies and innovation in business models

(GHG emissions, [$MtCO_2e$])

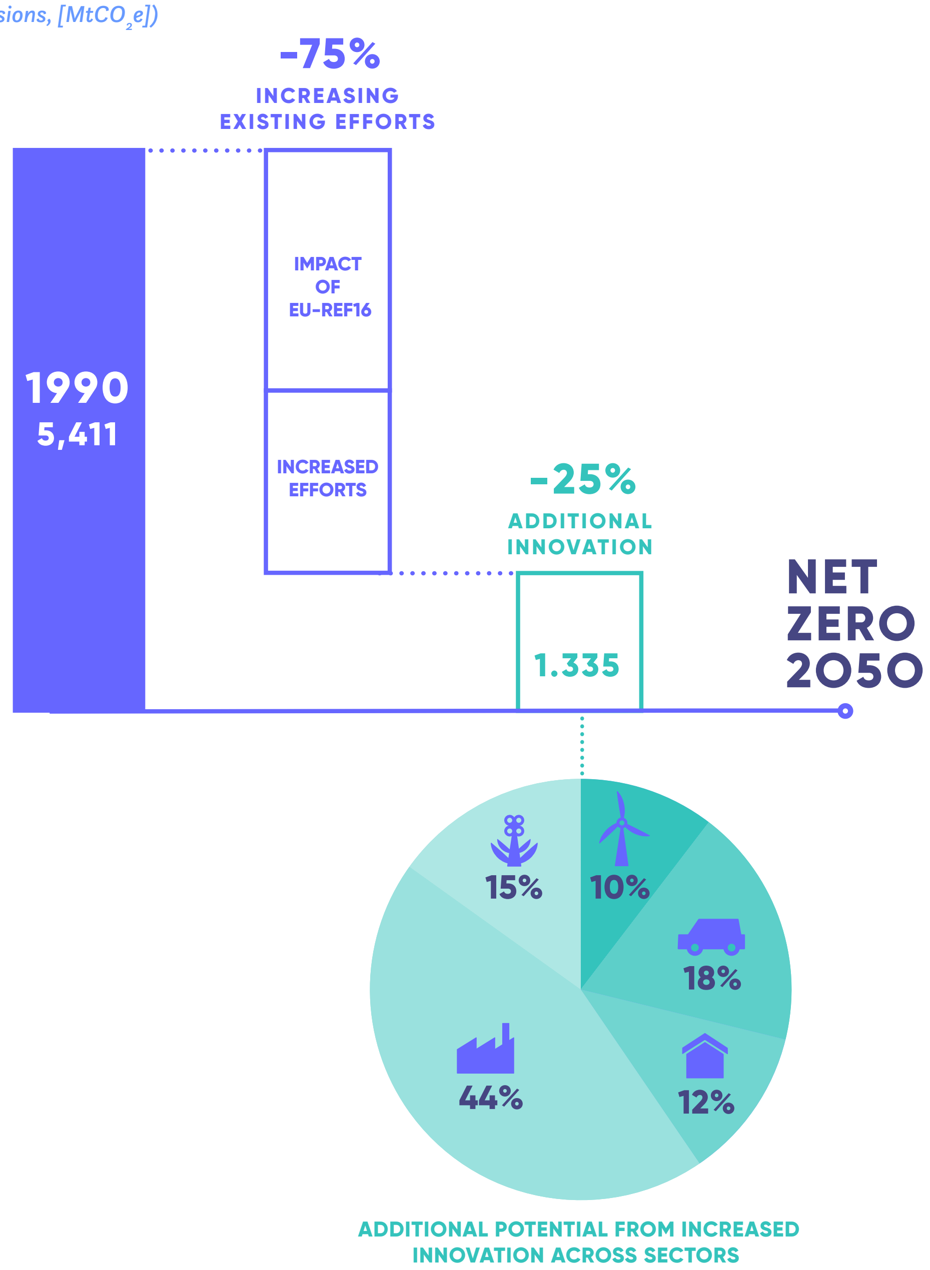


FIGURE 13. *GHG emission reductions split between increased efforts, and additional innovation (see Table below)*

Some net-zero innovation will be technological and product-related, but much of it will need to be focused on innovative business models, and some will be of a more societal nature. Governments will need provide investment support for this, as well as put in place policies to ensure the legal framework and social fabric is there to support and receive these innovations. Societal innovation to be encouraged includes ensuring that the potential of the shared economy is fully exploited; reducing the demand for transport through improvements in shared transport systems, and improving office infrastructure (distributed work places). Other examples include supporting changing diet patterns and reducing meat and dairy consumption, requiring innovation in protein alternatives; or deeply coupling land-use and carbon capture (massive afforestation + preservation of grasslands).

Initiatives such as "Mission innovation", which seeks to significantly increase clean energy research and development (R&D) in transformative clean energy technologies, plus net-zero mission-orientation from both governments and the private sector, are a step in the right direction but require a solid legal and policy framework and joint follow-through from public and private entities together. In a context where the EU should strive for 3% GDP dedicated to R&D, strengthening EU leadership on climate innovation appears essential.

Recent work by the Stockholm Resilience Center supports the idea that the digital revolution can support the transformation at hand. "Technology can directly influence 30% of the emissions cuts needed by about 2030, and indirectly affect the rest through influencing consumer habits, scaling up a sharing economy and supporting business transformation to a circular economy."[10]

Table 1. Examples of the increased innovation that is required to reach net-zero in each sector

TRANSPORT

Some transport modes do not have good solutions that emit little or no carbon yet, such as air and sea transport. Levers like biokerosene and e-fuels are still in development phases and it will be extremely difficult to decarbonise transport fully without them. Electrification of shipping and aviation is assumed to be at a very early stage, and will only take off after 2040. Hydrogen alternatives for all vehicles also require further up-scaling and commercialisation.

Societal innovation needs to be encouraged to reduce the demand for transport, which requires changes in the way our societies are organised, improvements in shared transport systems and office infrastructure (distributed work places), as well as strong political signals to reduce passenger aviation demand and favour local consumption.

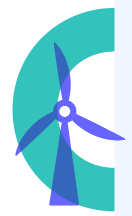
Autonomous and shared vehicles are partly technological and partly societal in nature, with citizens needing to embrace these new alternatives without massively increasing travel demand.

BUILDINGS

The key in this sector is to continue to bring down the cost of deep-retrofits – with innovative and "people-centric" business models (i.e., based on individual needs for a building as a starting point rather than carbon reduction as a starting point) and industrialisation – and to improve its productivity by incorporating digital platforms and finding other ways to improve coordination in a fragmented sector. Innovation is also required for mass heat sector decarbonisation.

INDUSTRY

The industry sector must reinvent itself, and the concepts of the circular economy must be converted to tangible innovation, facilitating a functional economy and the reuse of material components and raw materials. In addition, innovation is required in production processes. Biomass and hydrogen are good example of technologies that require additional research and support to become a reliable and competitive energy vector. CCS can also have a huge impact, and net-zero pathways not using CCS could go negative later on with support of technology.



ENERGY SUPPLY

While renewables are on the rise in power, it is clear that managing increasing levels of variable sources will require further innovation, as well as a much stronger energy systems perspective, linking the electrification of demand to its supply. System integration of demand and supply variability needs to be researched further as the penetration of electric vehicles, heat pumps, and variable renewable energy sources will increase.

AFOLU

Meat consumption, particularly from ruminants, is leading to significant emissions. New dietary options must be made available to increase the switch to lower ruminant meat diets, with alternative sources of protein. Land multiuse must be further developed to improve soil quality and spare land. This will leave room for afforestation, which will again require a significant shift from agricultural to forestry practices. Large-scale afforestation will require societal changes.

2

NET-ZERO GHG EMISSIONS IN 2050 REQUIRES RAISING THE 2030 AMBITION LEVEL

TO LEVERAGE THE NO REGRETS OPTIONS AND SET EUROPE ON THE RIGHT TRAJECTORY

This study finds that reaching net-zero by 2050 requires reducing GHG emissions in Europe by -55% to -65% from 1990 levels (including LULUCF) (Compared to 1990 level) by 2030. This means a significant increase in ambition from the current 2030 target.

The 2030 emissions milestone of each pathway depends on its activated abatement levers in terms of their nature (technological, societal, commercial) and implementation timing. This leads to a range of 55–65% reduction versus 1990.

This compares to the current EU trajectory which leads to only 40% emissions reductions (including LULUCF, 35% excluding it) in 2030. This means over 1 gigatonne of CO_2 equivalent ($GtCO_2e$) in excessive emissions that year relative to the EU Reference scenario. It also implies an upgrade on the latest political ambition, with targets of 32,5% on energy efficiency and 32% for renewables, which is estimated to lead to about 50% emissions (including LULUCF, 46% excluding it) in 2030. That is 40 years after 1990, and still very far from what is required to set Europe on the required trajectory to net-zero just 20 years later, and after the low-hanging fruits will have been reaped.

The 2030 ambition needs to be increased to be in line with net-zero scenarios

(GHG emissions, [$MtCO_2e$])

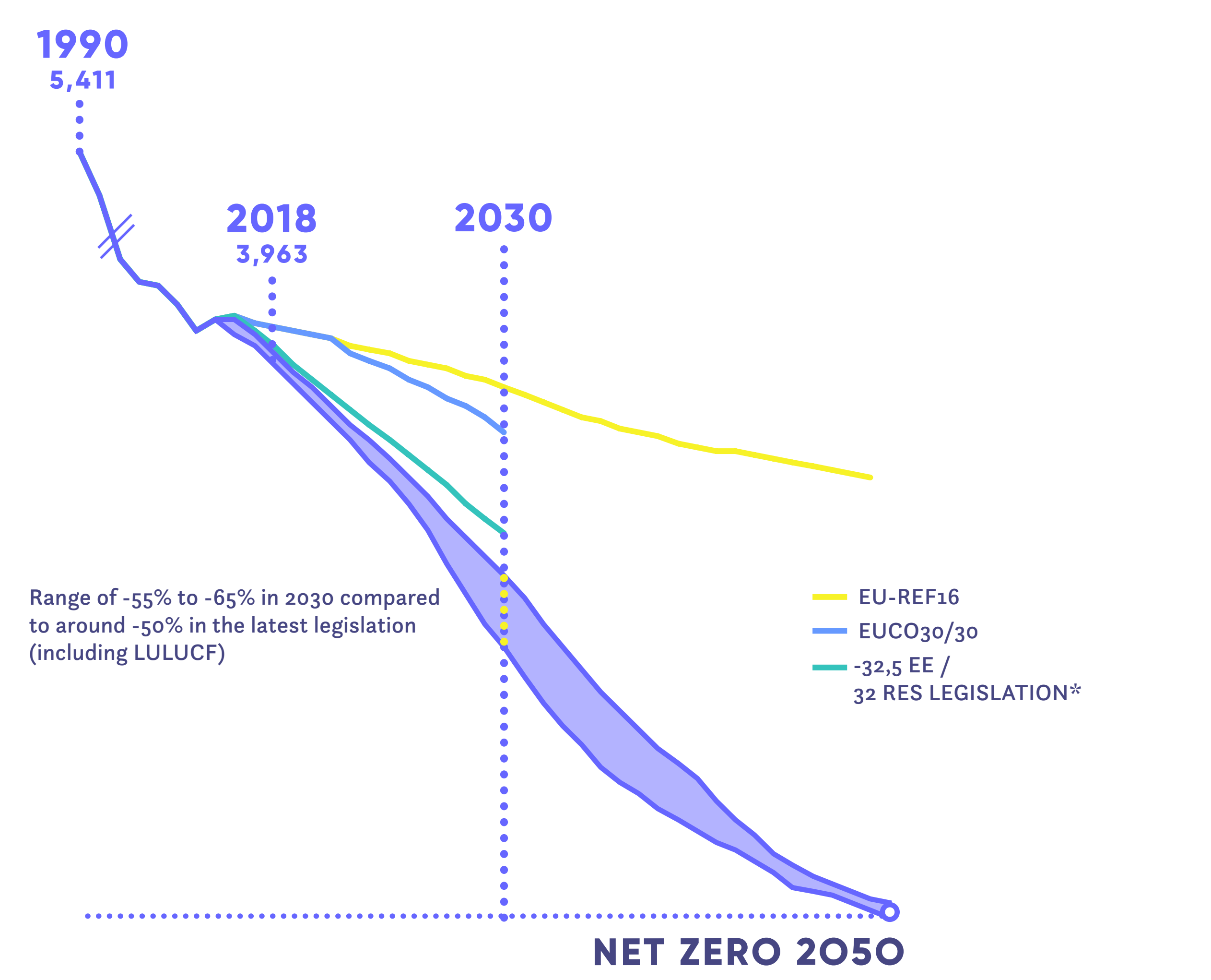


FIGURE 14. *GHG emission reduction range in net-zero scenarios compared to the EUCO scenario and the impact of the latest 32.5% energy efficiency and 32% renewables targets based on the non-paper by the EU Commission*

* This scenario is based on the latest « Non paper on complementary economic modelling undertaken by DG ENER regarding different energy policy scenarios » and is using the 33% RES / 33% EE figure for 2030, with a linear interpolation from 2016, so it slightly overestimating the latest legislation

The scenarios under consideration point to a set of common short-term choices that need to be prioritised without delay to keep the net-zero ambition within reach.

Examples of "no-regrets" options to prioritise between now and 2030 include:

TRANSPORT

By 2030, the focus must be to ensure transport demand is stabilised to today's levels, and that the modal shift away from cars has started in earnest. Car share should be down to 70% from around 80% today. After stabilisation of demand and modal shift, vehicle efficiency is the third key lever in the short term, with efficiency needing to improve by at least 15% for cars and even beyond 20% improvement for trucks. The support for Zero-Emission vehicles (ZEVs) must be reinforced so that Europe innovates in ZEV production and the actual penetration in the fleet starts to increase at a fast pace after 2030. Note that several countries, including those with relevant automotive sectors, have announced bans on sales of new conventional internal combustion cars, notably Ireland and Slovenia (2030), and France and the UK (2040). The Netherlands aims to have all new cars emission free by 2030. These can be effective policies to drive this shift. Charging infrastructure investment and deployment is also crucial to drive the shift toward ZEVs.

BUILDINGS

Significantly renovating 3% of the buildings each year with deep retrofits to improve energy efficiency to near-zero energy levels, and fully decarbonising heat by 2050 at the latest. Current annual renovation rates are below 1%. New constructions must be energy-positive "smart" buildings already in the decade to 2030 to avoid having to renovate those again until 2050.

INDUSTRY

By 2030, significantly reducing the demand for materials and products (5-10% by 2030, above 40% by 2050) by boosting the functional economy(Increase the products lifetime by 5%), the circular economy(Increase product utilisation by 5%, switch to more efficient material (e.g., 8% of steel switched to carbon fibres in automotive), reduced material intensity, increased share of recycled materials), and associated innovation. While deploying best practices in industrial processes (electrification, fuel switching) is expected to begin soon, the adoption of new innovative technologies is currently mostly expected in the 2030-2050 time horizon.

POWER

Close to complete phase-out of coal. Wind and solar should reach at least 50% of power production by 2030, around 60% by 2050, and 75% of the demand-side management (DSM) potential is being exploited by 2050. About half of the flexibility needed to compensate seasonal and daily intermittency is covered by a mix of zero-carbon flexibility options (storage, inter-connections, biomass-firing), which reduces the role of gas even as coal phases-out.

AGRICULTURE, FORESTRY AND LAND USE (AFOLU)

*Before 2030 land-use must fully integrate climate change considerations: policies and business models must be convincing to restore degraded forests and to reforest most surplus and abandoned land[11]. Incentives should effectively support a change of agriculture practices to boost land multi-use, stopping land degradation. On average, in 2030, meat consumption must be reduced by 25% (and at least halved by 2050) without increasing consumption of dairy products. Trends are already going in this direction.**

FINANCE

Sufficient investments in innovation is a fundamental requirement for this economy-wide decarbonisation, to accelerate lab-to-market for innovative net-zero technologies and the co-development of new products, businesses and services. These investments can be shaped by the public sector through flagship research and innovation programmes like Horizon Europe, but also require the strong engagement of European businesses.

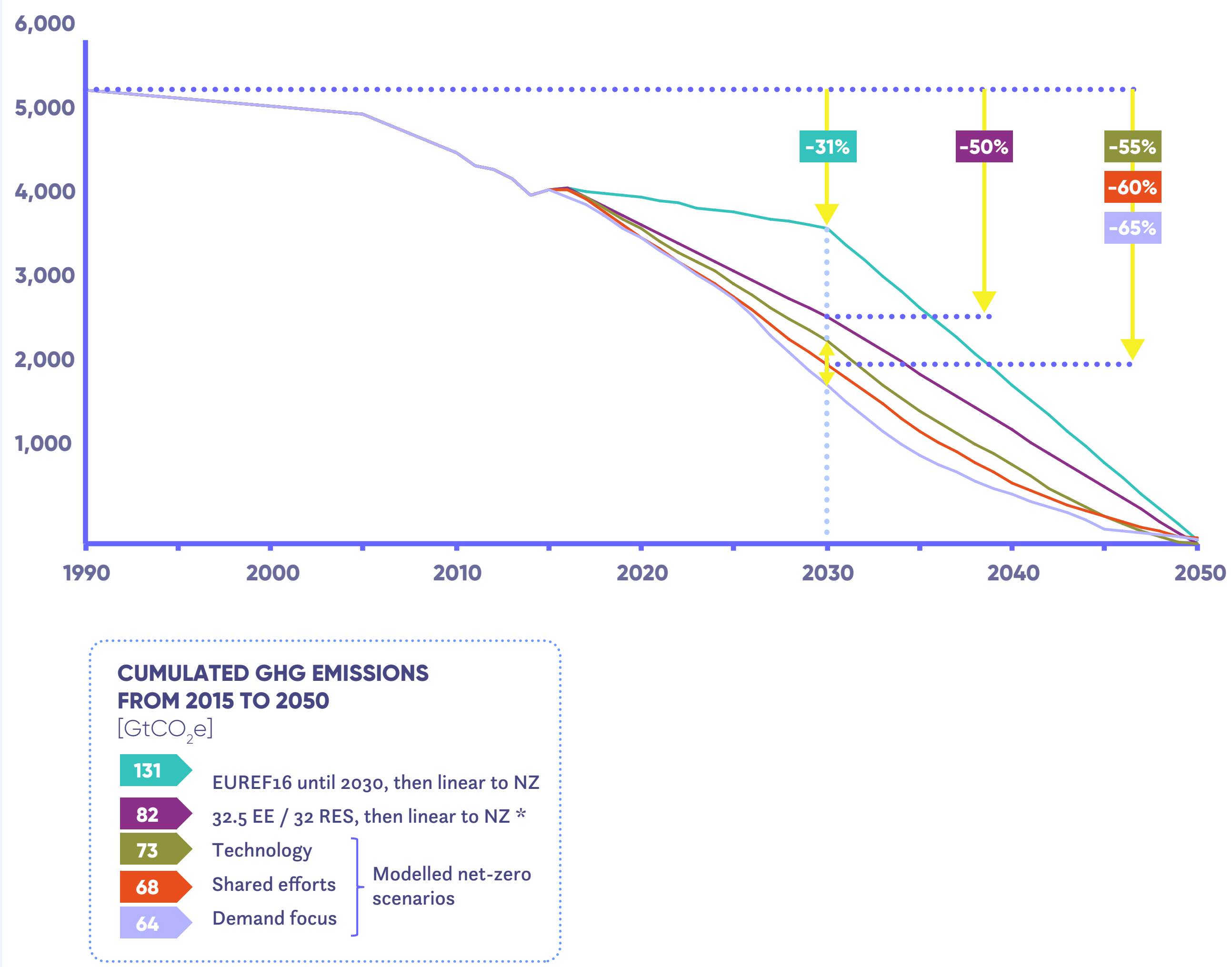
*https://www.eea.europa.eu/data-and-maps/indicators/13.2-development-in-consumption-of-2/assessment-1

Delaying these "no regret" actions will increase the pace of emissions reduction required after 2030 in order to reach net-zero by 2050, and result in higher total emissions over the period.

Figure 15 shows the trajectories required to reach net-zero based on various ambition levels in 2030, which also has implications for the total emissions emitted over the period, i.e., the carbon budget. Sticking to the EU-REF16 trajectory would emit about 131 $GtCO_2e$ between 2015 and 2050, while the Shared efforts scenario would only emit 64 $GtCO_2e$ for the same period.

The latest legislation reaches ~-50% below 1990 GHG emissions in 2030 (incl. LULUCF) but falls short of the range of the 3 net-zero scenarios, and emits more cumulatively*

(GHG emissions, [$MtCO_2e$])



* And -46% excl. LULUCF. This scenario is based on the latest « Non paper on complementary economic modelling undertaken by DG ENER regarding different energy policy scenarios » and is using the 33% RES / 33% EE figure for 2030, with a linear interpolation from 2016, so it slightly overestimating the latest legislation

FIGURE 15. *Required emissions reduction effort between 2030 and 2050 under various net-zero scenarios*

Delaying these "no regret" actions also risks creating lock-ins, stranded assets, and reducing the set of emissions reduction options available.

Besides the climate science aspects, we also need to move fast practically speaking. Some of the required investments have intrinsically long lead times, so delaying them will mean some reduction options are lost in the required time frame – risking that reaching net-zero by 2050 will not be possible. As much of the relevant infrastructure has only one or two investment cycles still to come before 2050, not taking firm action now in some sectors can reduce the impact of certain options in the future, and risks locking in high-carbon options. Examples include:

- Major investments are required in electricity infrastructures to produce, transport and distribute renewable (and variable) energy sources. They also need to facilitate further demand-side management. Major investments are also required in hydrogen and biofuel distribution networks.
- Renovation of existing buildings should aim at making individual buildings or clusters of buildings positive energy to avoid lock-in of the savings potential and to reduce the overall cost of energy renovation programmes. Renovation strategies should be sequenced appropriately such that energy efficiency measures are targeted first, allowing appropriate sizing of the energy system, for example, to reduce the scale of the challenge of decarbonising heat supply.
- Similarly, GHG removal technologies need to be researched and scaled further, otherwise the scope for negative emissions will be much reduced.
- Forests need to be restored and made more biodiverse/resilient before temperatures rise further and fire risks threaten the carbon sinks.

The need for immediate action is true for levers requiring significant innovation like CCS, but it also true for the societal organisation – or what are also called "energy sufficiency" levers – that constitute a large part of the abatement potential (as illustrated in Figure 11). For example, developing a large-scale functional economy based on services instead of products, and designing innovative forestry business models, will require significant policy intervention and investment. So too will organising our mobility with the required infrastructure for reducing the need for transport: enhancing the use of bikes and shared transportation will certainly take more than 20 years to reach the scale required all over Europe, unless energy sufficiency policies are put in place starting from now.

Clearly, the earlier and faster we move, the broader the options will be. The more we wait, the higher the risks of locking in infrastructure and societal organisation incompatible with reaching net-zero, except at the cost of large write-offs of stranded assets. This highlights again how EU ambition is disconnected with a net-zero trajectory: reaching net-zero in 2050 requires much more ambition in 2030.

Moving faster is also a way to reap faster a large range of multiple benefits, and open new opportunities. The next section will look at these co-benefits in more detail, but many of these co-benefits are urgently needed.

Other reports commissioned by the ECF are producing higher levels of granularity on certain sectoral issues and will complement the messages in this report, particularly on some sectoral choices that were not explored in detail. For example, the choice between a hydrogen or an electric infrastructure in transport, heat pumps compared to district heating in buildings, pushing for a higher solar- or wind-based electricity production mix, increasing demand-side management at the expense of other flexibility solutions, etc. Forthcoming work commissioned by the ECF includes the Energy 2050 project, the Agriculture Vision, and the Industrial Transformation 2050 project.

3

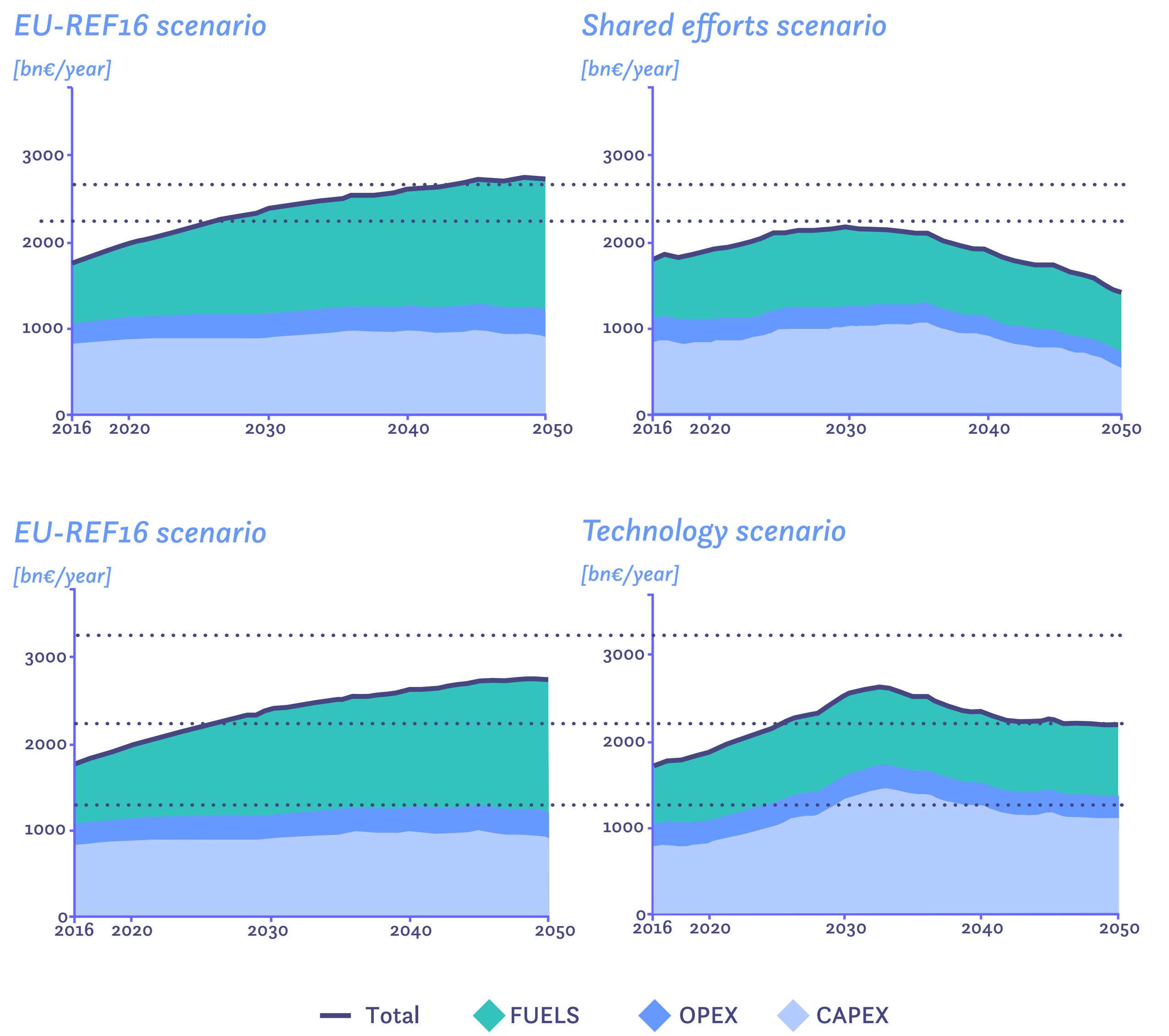
NET-ZERO PATHWAYS CAN COST LESS THAN BUSINESS-AS-USUAL

AND BUILD A MORE PROSPEROUS, RESILIENT SOCIETY

For the energy system, net-zero GHG emissions pathways can be cost-negative in the medium to long term, particularly if social and business model innovation can be channelled to increase asset utilisation.

In a “Shared efforts” net-zero scenario, investments increase by 20% up to 2030, compared to an 8% increase in the EU-REF16. However much of that increase is compensated by lower spending on fuel. Later, investment requirements decrease below those in the EU-REF16 as the significant technical and societal innovation that the low-carbon transition requires leads to lower requirements. An overall net reduction in total system costs of around 20% is reached by 2050 (versus 2016).

The Technology-driven scenario, which has lower ambition on the more demand-focused levers such as reducing transport demand, increasing vehicle utilisation, and increasing the lifetime of products is shown below, and leads to a much starker increase in investments of 68% in 2030 compared to 2016 (+55% versus the EU-REF16), which is only partly compensated by fuel-cost reductions.



For a clearer comparison of the impact of the levers, the same fossil fuel prices are assumed in the three scenarios shown in Figure 16, while it is usually assumed that low-carbon scenarios should lead to lower fossil fuel prices.

FIGURE 16. *Evolution of annual total system costs in the EU-REF16 (left) and in Shared efforts and Technology net-zero scenarios (right)*

Figure 17 illustrates the energy system costs in the “Shared efforts” scenario grouped by lever type. **It shows how strong the impact from the demand-side levers can be on the costs,** particularly the impact of improving the way our society is organised, on the transport sector, and on the important investments required in buildings energy efficiency. It also clarifies **the impact of fuel switching** (i.e., ZEVs, heat pumps, and some industrial processes)

Net-zero pathways can cost less than business-as-usual, with a strong impact from the demand-side levers

Undiscounted cumulated total energy system costs by sector and lever category [x10³ billion €]

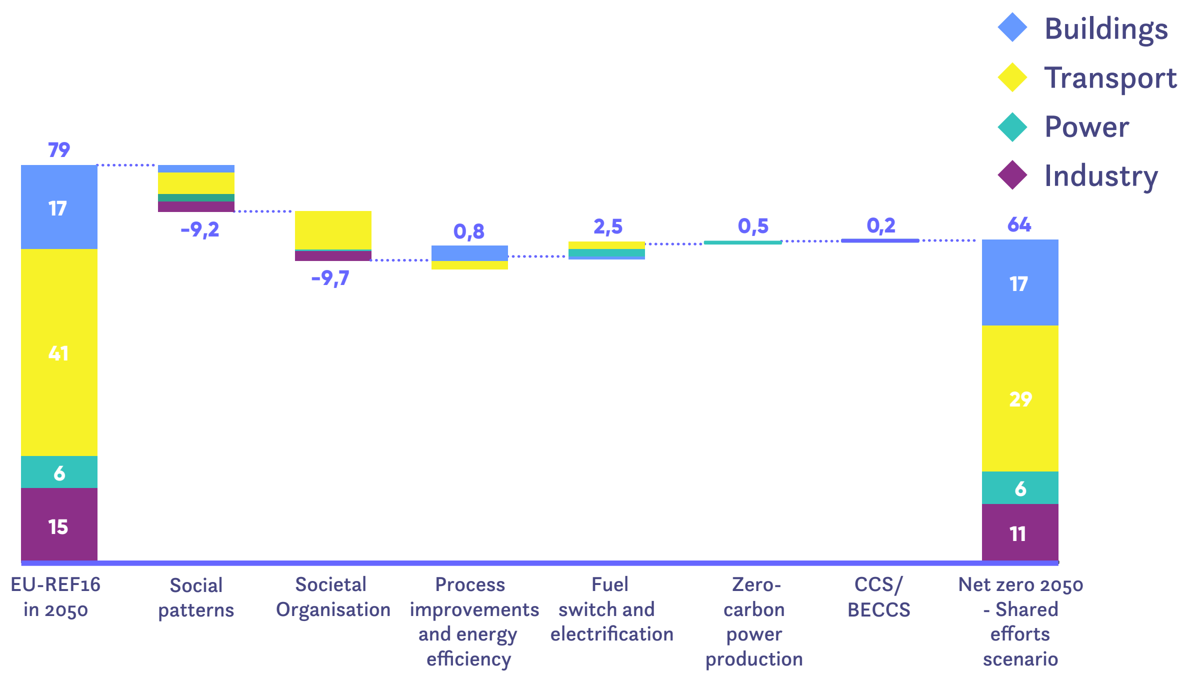


FIGURE 17. *Total system costs evolution by lever group in the Shared efforts net-zero scenario*

Discounting these figures does not lead to a change in the message, even if it does reduce the cost difference as discounting has a stronger impact on future cash flows like later fuel expenditures in the reference scenario.

Discounting shows a reduced delta as future fuel expenditures are discounted more strongly than early investments, but the message on lower costs remains the same

[Cumulated total energy system costs, x10³ billion €]

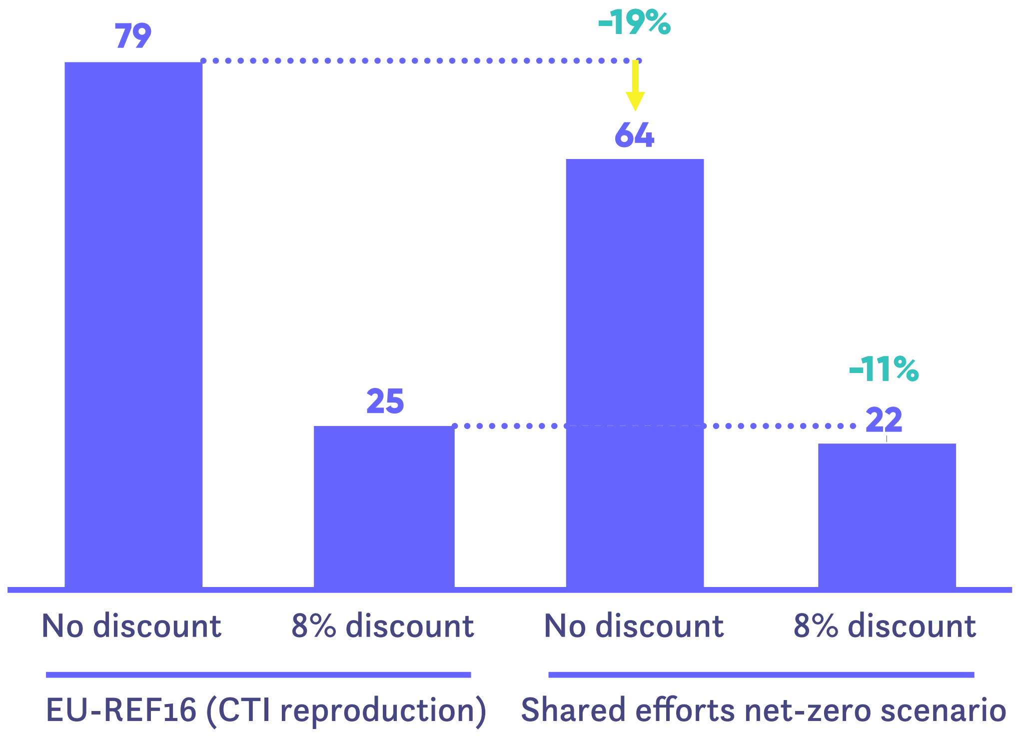


FIGURE 18. *Impact of discounting on total system costs in the Shared efforts and EU-REF16 scenarios*

Beyond the lower overall energy system costs, the energy transition supports the achievement of many of the United Nations (UN) Sustainable Development Goals (SDGs), to which the EU has signed up. These have significant positive economic impacts and all cost calculations must also be compared to those of avoided climate damages.

First, there is a major shift from spending outside of the EU to domestic spending. This is one of the key drivers of the positive impact the net-zero transition will have on Europe in the medium and long term. This is naturally related to an increase in energy sovereignty, with important implications for the EU's strategic position in the world.

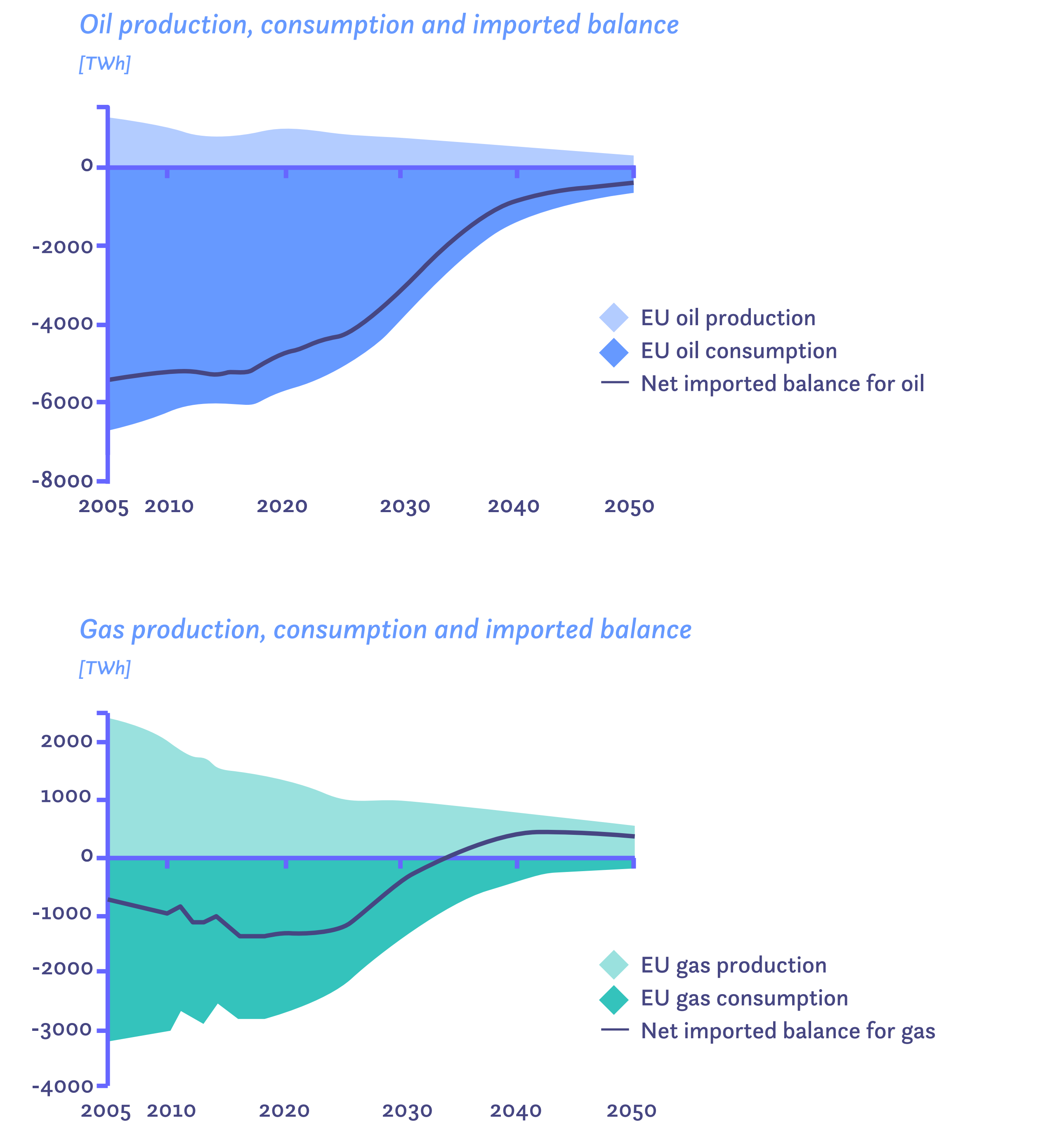


FIGURE 19. *Evolution of oil and gas imports in the Shared efforts net-zero scenario*

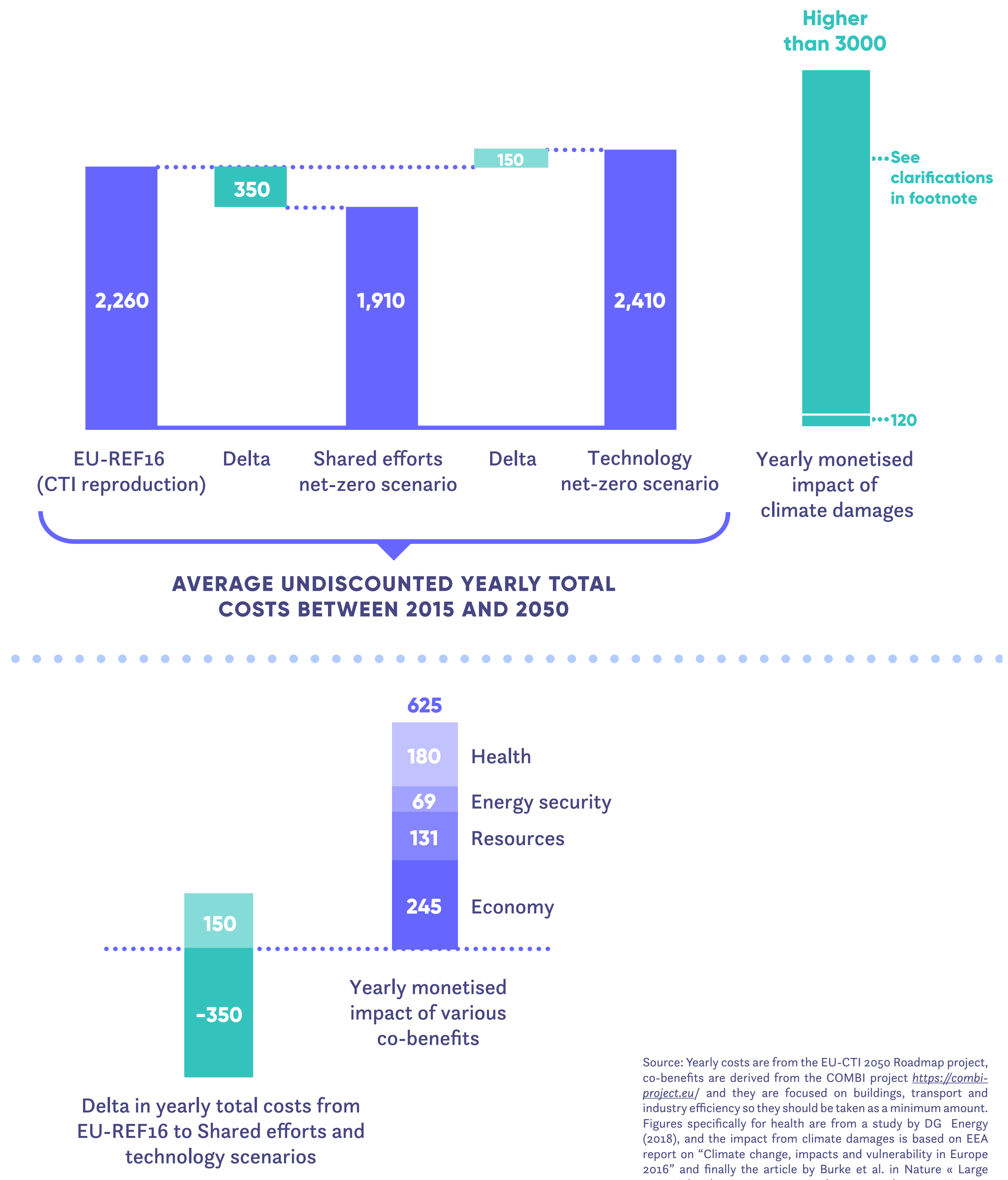
Many of the 'net-zero' choices will also take us closer to other goals Europeans have set for themselves, and which are encapsulated in the SDGs (see box). A net-zero society is a positive and innovative society that can bring an attractive quality of life to its citizens, with cleaner air, less traffic and city congestion, better living environments, less money spent on fuels and more on infrastructure and innovation in Europe. In turn this can lead to a more resilient economy with more and better jobs, more durable goods, higher biodiversity, and larger and healthier forests and forest ecosystems.

On 25 September 2015, the UN General Assembly formally adopted the 2030 Agenda for Sustainable Development, along with a set of *17 Sustainable Development Goals* (SDGs). Climate action features in it as a stand-alone goal, *Goal 13*, but most of the others are also intrinsically related with the actions proposed for moving towards a net-zero emissions society – for example affordable and clean energy, health and wellbeing, decent work, industrial innovation and infrastructure, sustainable cities and communities, natural resource management and democracy.

The EU has *committed* to implement the SDGs both in its internal and external policies.

Total energy system costs are lower than climate damages and their difference to business-as-usual is lower than the co-benefits that are reaped

[bn€/year]



Source: Yearly costs are from the EU-CTI 2050 Roadmap project, co-benefits are derived from the COMBI project *https://combi-project.eu/* and they are focused on buildings, transport and industry efficiency so they should be taken as a minimum amount. Figures specifically for health are from a study by DG Energy (2018), and the impact from climate damages is based on EEA report on "Climate change, impacts and vulnerability in Europe 2016" and finally the article by Burke et al. in Nature « Large potential reduction in economic damages under UN mitigation targets" comes to potential damages of US$ 20 trillions globally. Taking today's share of Europe in global GDP of ~17% this would lead to a figure around EUR 3000 to 4000 billions, significantly above the costs and investment requirements.

FIGURE 20. *Investments in the Shared efforts scenario compared to the impact of co-benefits*

The required costs also always need to be compared to the cost of damages caused by increased temperatures. The pathways highlighted would strengthen European leadership and bring us closer to avoiding some of these damages. Figure 6 shows how the latest estimates in the literature indicate that the difference in potential climate damages in a 2°C scenario compared to a 1.5°C scenario will be much higher than the total system costs of any scenario, net-zero or not, and whether more technology focused or not. In summary, the costs of climate impacts resulting from not taking action are far greater than the costs of taking action.

In addition to these potentially avoided climate damages, the many co-benefits identified are also higher than the cost delta of the Technology scenario compared to the EU-REF16. In other words, investments in the energy system are not only compensated by reduced fuel costs, they also bring a whole series of co-benefits, which can arguably be said to be coming "for free".[12]

Clearly the low-carbon transition **is attractive "on average",** which does not take away the complexity of the substantial investments required, nor the strong variations in cost impacts across sectors.

Implementing circular economy principles implies significant changes in industry, but ultimately brings added-value and resilience to the economy.

The choices in how we decarbonise the transport, buildings, and industry sectors will define whether the total energy system bill increases or decreases, in both the short and long term. **Indeed, changes in the way society is organised and functions (together called "societal innovation") will support a cheaper technical transition:**

- In transport, lower transport demand, autonomous vehicles, car sharing, higher modal share, and occupancy rates in public transport all significantly reduce the number of cars and road infrastructure required (See Figure 21), which in turn leads to significant reductions in the investments required in transport. It is worth noting that much of this reduced fleet is based on autonomous vehicles, a trend that will increase with or without the low-carbon transition. Co-benefits are also expected on well-being, traffic congestion, and air pollution as described above.
- The circular economy and the functional economy bring costs down for consumers while offering large innovation potential for EU industry. When assets are provided "as-a-service", their costs for the user are limited to when they are actually being used. For example, consumers will pay for their car when they use it and avoid paying for it when it sits idle in a parking space (as well as avoiding paying for the parking). The circular economy typically increases the lifetime of goods, thereby reducing the asset cost per year even if maintenance costs can increase. For the producers, it will decrease the production capacity requirements, while keeping similar revenues with higher valued-added assets.
- Innovative business models need to emerge to ensure the focus is on the increased added value of products through services, lowering the volumes of goods sold while still supporting the European economy. There is tremendous room for an economy to develop in the design of products, in their maintenance and in the facilitation of a functional use of products.
- Coherent policies can shift capital from unnecessary to other longer-term infrastructure investments like in buildings energy efficiency or renewable energy electricity production.

Impact of societal changes on the transport sector

Assumptions in the balanced scenario

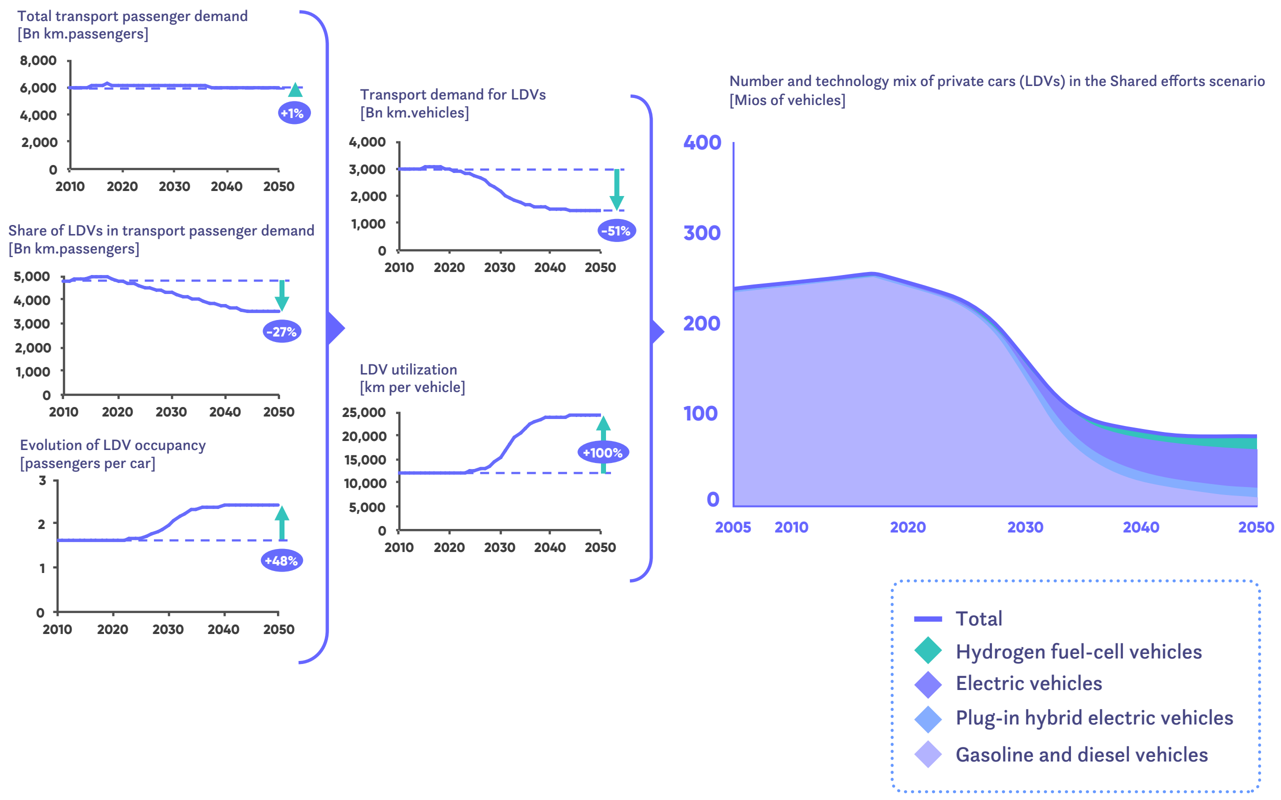


FIGURE 21. *Number of private cars and their mix in the Shared efforts scenario, with the detailed model drivers*

Ambitious decarbonisation options have a large impact on the whole value chain. They enable major benefits through better welfare, GDP, and employment outcomes. Net benefits are estimated at €1.8 trillion by 2030[13]. Circular economy companies are already estimated to have a higher economic performance on average[14] than their less efficient competitors. The major implications for manufacturers are summarised below.

The lower materials requirements will require a transformation of industries but does not have to translate into a loss of economic activity. Rather, economic flows will reallocate to improve asset utilisation, reduce resource depletion, and finance waste collection. It also enables industrial actors to shift to models that are more resilient to fundamental trends: the need for cleaner industrial production with less impact on the planet and human health, and the clear need to price externalities like carbon emissions and other pollution. The front-runners who manage that transformation properly will increase their market share and reduce the burden of environmental taxes.

Table 2. Circular economy impacts on the industry

	NUMBER OF PRODUCTS	MATERIAL USE AND COSTS	EMISSIONS AND ENVIRONMENTAL COSTS & RISKS	VALUE PER PRODUCT	MAINTENANCE & SERVICES
TREND	↘ Fewer new products	↘ Less material per product	↘ Lower emissions and waste costs per product	↗ More value per product (last longer, better utilisation)	↗ More revenues
RATIONALE	Changes in social patterns and the impact of the functional economy	Better product design, less waste Less factory capacity required	Less materials, less emitting materials, less emitting manufacturing technologies	More R&D investments per product Higher added value materials	More maintenance revenues More services to increase asset utilisation

The industry's low-carbon transition will reorganise the competitive landscape, by creating some markets and reducing other ones. Here are three examples, with the first one illustrated in Table 3 below:

1) Interface is today the world leader of carpet tiles. It was originally a manufacturer of fossil-based carpets, but set its "mission zero" strategy to include the switch towards selling a 'carpet service' providing carpet repair services, but also manufacturing new carpets from more sustainable materials and less impacting processes.

2) Umicore made a complete turn around and developed markets by recovering and recycling several metals.

3) Several European car manufacturers currently have a higher margin on maintenance than on selling cars. In addition, European cars are repaired and maintained in Europe, while their components are not always manufactured in Europe. Negative trends are also expected in the automotive sector, especially for the equipment suppliers of the car manufacturers. This is because a better design means not all the car needs to be replaced when one component has defects.

Table 3. Detailing how the levers in the CTI Industry sector are linked to circular economy principles, and illustrating them with the Interface company example.

CTI INDUSTRY LEVER	LINK WITH THE CIRCULAR ECONOMY PRINCIPLES[15]	INTERFACE COMPANY EXAMPLE[15]
FUNCTIONAL ECONOMY	Through the functional economy, the exchanges between consumers are facilitated, increasing asset utilisation. This covers the following dimensions: Share, Re-use, Redistribute, Refurbish, and Remanufacture. Digitalisation trends supports theses exchanges.	Interface switched from product to service by renting its carpets, with operations to share, re-use, and redistribute
LIFETIME	The product lifetime can be increased through a better design as well as through maintenance and prolonging services.	As part of its renting services, Interface repairs its carpets to prolong their lives
MATERIAL INTENSITY	Less finite resources are used through a better design.	
MATERIAL SWITCH	Use of materials which are less finite or which minimise the systematic leakage and negative externalities.	Interface made carpets from biomaterials.
RECYCLED	Increased recycling, in case it is associated with a higher value for raw materials, to lead to extracting waste materials from the environment to create new products (e.g. plastic carpets from ocean fishnets).	Interface recycles ocean waste to make carpets.
PROCESS	These are the levers which are furthest away from a pure circular economy principle but are still essential to reduce energy consumption and emissions further.	Use of efficient technologies.
ENERGY EFFICIENCY		High energy efficiency in processes.
FUEL SWITCHES		Use of renewable energy and biofuels.
CCS		Currently not applied.

The EU CTI 2050 model used in the context of this study focuses on the first two columns of this table. It shows we can significantly reduce the amount of materials that need to be manufactured. Figure 22 shows the cumulative impact the demand side levers have across the whole value chain leading to significant reductions on production volumes.

The European industrial production is expected to decrease by 2050 as a result from new consumption patterns, business models and production technologies

Production volumes per sector [Mtonnes of production]

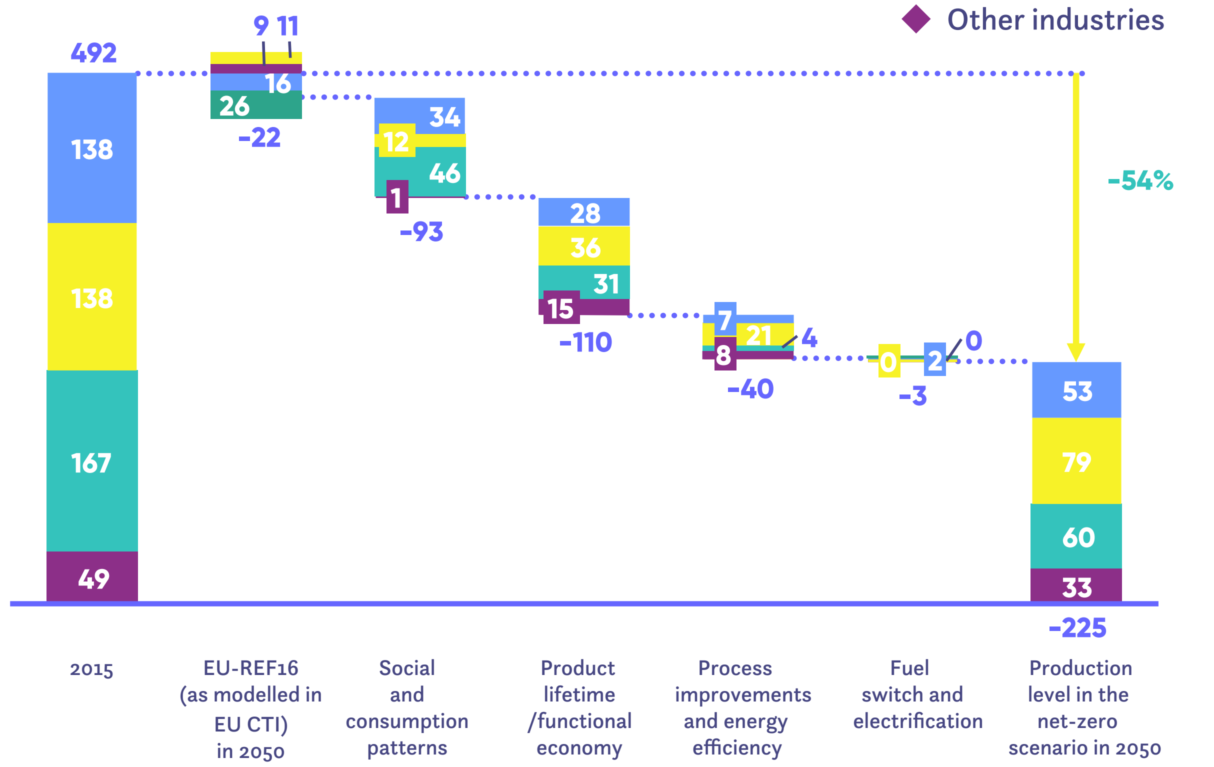


FIGURE 22. *Production volumes per sector, in megatonnes*

SOURCE: (1) EURef, CTI2050, Climact analysis

Concretely, categories of levers 1b and 2 above correspond to a change of business model, not a loss of added value.

- Products with a longer lifetime have more added value and can be sold at a higher price. To facilitate the longer lifetime, more operations and maintenance activities are foreseen. They also cause lower societal costs to handle end of life waste and recycling.
- A functional economy delivers products with a higher utilisation rate. While this reduces the number of products manufactured, it can also translate into a higher price per product. In addition, the functional economy will create service activity to handle the utilisation of the products.
- A lower material intensity is a process improvement that requires less materials per product, both through a better design and through a manufacturing process generating less material waste.
- Material switch is a process improvement which covers the switching from a more carbon intensive material to a less intensive one (over the product lifecycle). Less carbon intensive materials typically have more added value per tonne (e.g., carbon fibres).

The share of recycled materials increases by 70% to 36% of total material production. This enables allocation of financial flows towards waste management, instead of depleting further natural resources which are often imported from outside of the EU. This in turn brings back the added value to Europe.

CONCLUSION

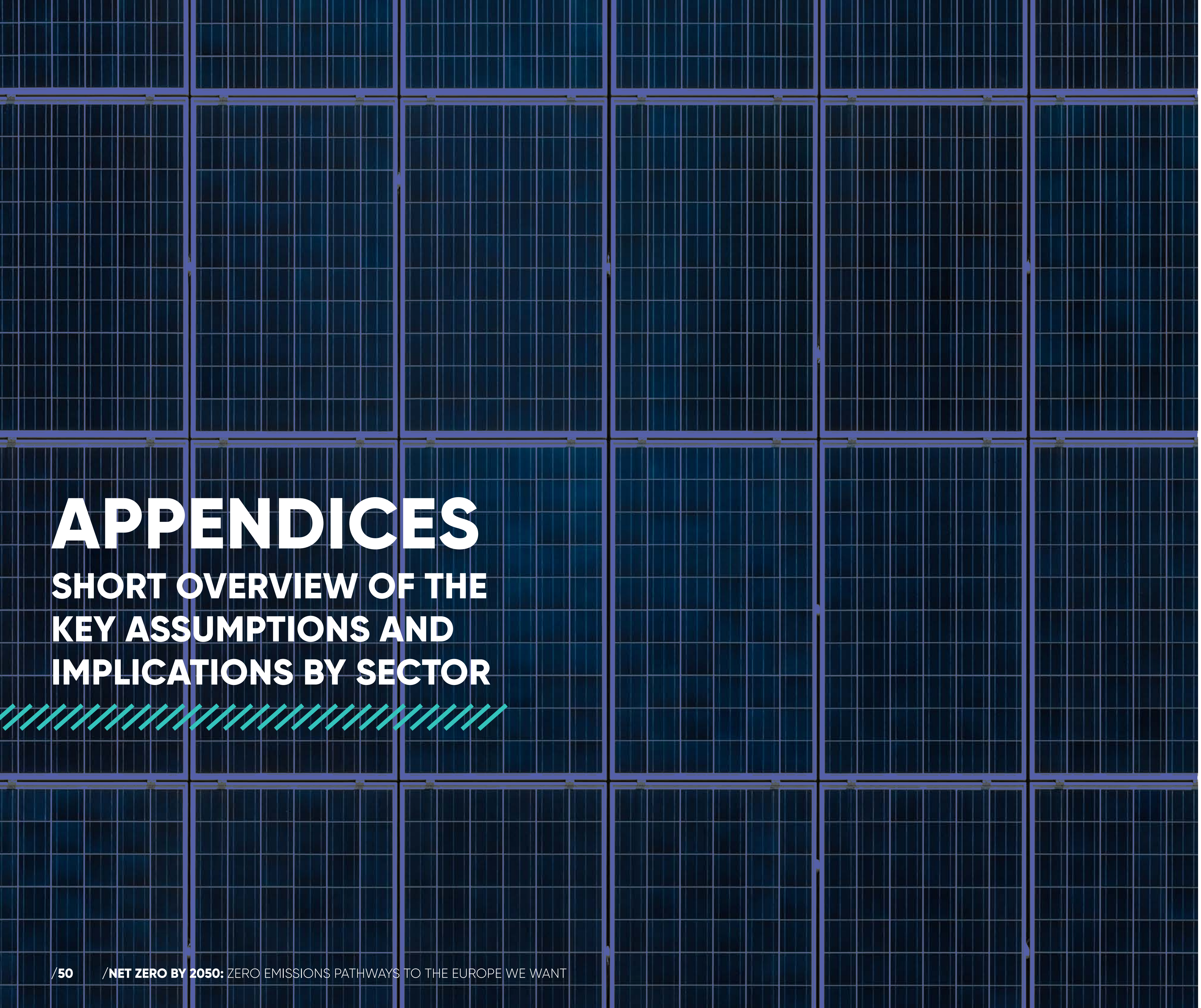
WHAT DOES THIS MEAN FOR THE EU ?

This project has explored different pathways to reach net-zero GHG emissions by 2050 at the latest and finds that, not only is it possible, but the future thus created may be very desirable. The options put forward in this report have the capacity to strengthen Europe's economy, enhance wellbeing, and give EU citizens the opportunity to move towards a more resilient society.

A goal as clear as net-zero can helpfully galvanise the minds of policy-makers, businesses and citizens to unleash creativity in terms of business models, working patterns, lifestyle choices and urban design, as well as scaling up the deployment of low-carbon technologies. Many of these shifts may offer exciting possibilities for competitive edge, cleaner, healthier cities and lifestyles, and enhanced quality of life. Such a goal also reinforces the idea that this is a collective challenge, to which all sectors and citizens must contribute.

With its Roadmap to a Low Carbon Economy from 2011, the EU has already demonstrated the power of setting a long-term, economy-wide vision to guide near-term policy choices, and to help identify milestones for infrastructure investment and other key decisions. Its existing 2030 targets are, however, derived from an 80% reduction in GHG emissions by 2050. This will not be sufficient to achieve the Paris Agreement's goals.

The EU is currently preparing a revised long-term vision, which it will need to submit to the United Nations Framework Convention on Climate Change (UNFCCC) by 2020. This is therefore the right time to review this ambition, for which we hope this project can offer a guide and inspiration.



APPENDICES

SHORT OVERVIEW OF THE KEY ASSUMPTIONS AND IMPLICATIONS BY SECTOR

APPENDIX:
SHORT OVERVIEW OF THE KEY ASSUMPTIONS AND IMPLICATIONS BY SECTOR

The diversity of the scenarios tested by the authors and by the model testers shows that different emphasis and trade-offs are possible, be it across sectors or across change drivers within sectors.

The table below summarises the efforts required by the "Shared-effort" net-zero scenario. The characterisation and definition of the drivers was itself the result of extensive consultation with experts. 2015 is the baseline year to compare with ambition levels.

More information on this scenario can be explored online: *The "Shared efforts" scenario.*

Table 4. Key actions in sectors to reach net-zero in the Shared efforts scenario

TRANSPORT	*Passenger*	The car share decreases from 80% of passenger kilometres (km) to 56%. The passenger distance per vehicle doubles to 24,000 km/year, while the occupancy rate increases by 20%. 82% of new cars are ZEV by 2050. Around three quarters of cars are fuel cell vehicles.
	Freight	The truck share decreases from 50% to 36% in 2050. 85% of new trucks are ZEV by 2050.
BUILDINGS	*Envelope and heating efficiency*	By 2025, people renovate their buildings at a rate of 3%/year compared to 1% today. The average renovation depth (energy efficiency) reaches 75% on average by 2030. Heat is fully decarbonised by 2050 at latest.
	Appliances & consumer goods	Demand for electricity-dependant services is 13% lower in 2050 than in 2015 and energy efficiency is improved by 46%. The use of appliances increases by 70%.
INDUSTRY	*Product design*	For a same European activity, 26% fewer products need to be manufactured each year. The products are of higher added value with a better design lasting on average 13% longer. In addition, the use of functional economy enables to manufacture 13% fewer products. A major material switch is undertaken: in land vehicles, 10% of steel is replaced by carbon fibres, and 25% in airplanes; in buildings 10% of cement is replaced by plastics; in appliances 5% of steel is replaced by plastics. The improved design and the use of more efficient materials enables reducing the material use per product by 14% in steel, 26% in high value chemicals (HVC), 12% in cement, and 6% in other industries. The share of recycled materials in new products increases to 60% for steel, 16% for HVC, 45% for cement, and 44% for the other industries (These shares exclude the manufacturing waste recycling flows).
	Processes	New technologies are deployed: 25% of primary steel is manufactured through HIsarna, 18% of primary cement is manufactured through polymers. Within existing technologies, energy efficiency is improved by 5-45%. Processes are further electrified, assuming a major use of resistive heating. 56-66% of fossil fuels processes are substituted by electrification in steel, chemicals and other (smaller industries). Fuel switches are major. First 28% of the remaining coal and oil are replaced by gas in HVC. Second, of the remaining fossil fuels, 22-48% are substituted by hydrogen (in oxygen steel, ammonia nitrogen and other chemicals, and other industries). Third, fossil fuels processes are substituted at 15-62% by biomass (in in oxygen steel, chemicals (HVA, ammonia, nitrogen), cement, and other materials). Emissions captured on manufacturing sites reach 53% for oxygen steel, 55% for HVC, 60% for ammonia and nitrogen, 60% for clinker cement, and 34% for other industries (assuming a capture rate of 85% on sites equipped with CCS).
ENERGY SUPPLY	*Electricity production*	Coal is phased out by 2035. RES production reaches 75% of the power production by 2030 and 94% by 2050. 70% of the remaining gas (66% lower than 2015 level) is substituted by hydrogen. From 2030 onward, 70% of new biomass plants and the remaining natural gas plants are equipped with CCS.
	Intermittency and DSM	Variable renewable energy source production reaches 57% of the total by 2030 and 79% by 2050. This is capped by the available network flexibility. 75% of the demand-side management potential is captured from 2025 onward. Several zero-carbon flexibility options cover the daily and weekly flexibility needs (storage, inter-connections, biomass-firing). Seasonal flexibility is answered by zero-carbon dispatchable generation.
AFOLU	*Diets*	Diet must be improved and become healthier: calories consumption in 2050 should be 8% lower than 2015 level, with the meat consumption per person halved without increasing dairy products consumption. The share of ruminant meat decreases to around 10% of the consumed meat (versus 20% in 2015)
	Agriculture practices	Maximum potential of waste collection is achieved: 50% on-farm food crops waste and 80% of post-farm food waste are collected. Yields increase by 28% in the same time period while minimising the use of nitrous fertilisers.
	Land use	Maximum effort is done to stop land degradation. 24% less land is required to produce food thanks to multi-cropping and other changes in agriculture practices (2050 versus 2015). 76% of all surplus land is afforested and 20% is dedicated to grasslands. The forest harvesting intensity is lowered by 25% (2050 versus 2015) corresponding either to an average intensity reduction or the set-aside preservation of 25% of EU forests. The 2050 demand for sustainable bioenergy is met. No additional dedicated biofuel/energy crops are necessary

Net-zero is possible - highlighting the feasibility by sector.

Our report highlights the feasibility of reaching net-zero but it does not dispute the challenges that are inherent to all sectors if they are to fully decarbonise. We cover these two dimensions in the two tables below, the first highlighting the elements encouraging the feasibility of the required changes, and the second detailing the additional elements of innovation required to reach all the way.

The transition is ambitious but feasible: reaching net-zero does not mean we have to reinvent the wheel or fully disrupt all sectors

There are many challenges to reach net-zero, but a large number of initiatives are already taking place across Europe in line with a very low-carbon society. These lessons and practices must be transferred to other areas and scaled up to reach European scale. Sharing these and increasing European cooperation can help achieving 75% of the needed GHG emissions reduction without any breakthrough innovation. Most of the scenarios therefore require leveraging all these best practices. The table below provides a short selection of them.

Table 5. Illustrating the feasibility across sectors based on existing initiatives

TRANSPORT	A wide variety of new mobility initiatives is on the rise across Europe, with new fleets of shared bike, electric scooters, and cars, with multi-modal apps supporting modal shift and autonomous electric vehicles putting a significant boost to this trend if the right conditions are met. Beyond specific mobility initiatives, there are also other trends supporting working from home and increasing the amount of smaller regional offices to avoid traffic jams. Therefore, the assumption is that stabilising transport demand to today's levels does not require massive social innovation. What will require further technological innovation is to reach large decarbonisation in freight and particularly in air transport as described in Table 1 (p. 29)
BUILDINGS	The net-zero scenarios show that the total – i.e., not limited to the end uses scoped by the Energy Performance of Buildings Directive (EPBD) – final energy consumption in buildings must to be lowered by 50–60% in 2050 with regards to. 2005, and emissions must be reduced by at least 90% or even 100% with regards to 1990. Energy efficiency ambition is fully aligned with some existing national renovation strategies, e.g., the French and Walloon renovation strategies target the renovation of all the buildings stock at low-consumption levels by 2050. Examples of factor-10 energy renovation are rising on all buildings typologies and in all countries. To help scale this up, many cities are experimenting with deep building retrofits initiatives, testing new business models and industrial practices to make this cheaper and less cumbersome for citizens. Besides energy efficiency, many cities have already pledge for zero-carbon heat. The region of Upper Austria has pledge for 100% reneable energy sourced heat by 2030, and Denmark targets it by 2050.
INDUSTRY	Industry has already evolved to improve its process efficiency. To reach net-zero it must take a product lifecycle perspective, continue improving its process efficiency, and deploy innovative technologies. Most of the lifecycle reduction potential is behavioural. It is a) dependent on the activities in the other sectors, leading a lower demand for products mainly in transport, buildings, and consumer goods; b) relative to how the functional economy is embedded in the norms, with a shared economy requiring less new products; and c) relative to a more sustainable product design and access to a better maintenance, leading to longer lasting, higher added value products, manufactured with less material and a higher share of recycled materials. A large potential also remains in the process efficiencies, mainly the technological changes, the energy efficiency, electrification, and fuel switches. As we will highlight in the innovation section, three innovative technologies require major breakthroughs prior being rolled out: the transition to hydrogen processes, the use of a major and reliable biomass supply, and the use of BECCS and CCS. We do not assume changes in the trade balance, because relocating the production outside Europe would reduce emissions in Europe, only to increase them in the other regions.
ENERGY SUPPLY	The net-zero scenarios show that power emissions must be reduced by between 90% and more than 100% with regards to 1990. Renewables are on the rise in many European states and building new wind and solar has become cheaper than new conventional sources in most of them. Big market players believe in and are re-structuring their business model around zero-carbon power production technologies. There are no investments planned in coal in the EU. Its phase-out is a matter of timing, dependent on political ambition to design and reinforce the appropriate policy instruments. Solutions to deal with the variable nature of wind and solar are scaling up, in particular demand-side management solutions. From market players, zero-carbon flexibility solutions to deal with variability are available. The challenge is on the appropriate market design to allow these technologies to scale up. Seasonal storage remains the area where technology innovation is required. There too, small-scale initiatives are demonstrating that hydrogen-electrolise can be combined with the deployment of wind, and the first hydrogen-ready gas plants have already be proposed. Achieving the massive deployment of renewable energy sources allows to limit betting on new technology disruption, e.g., massive deployment of CCS. However, as we will highlight in the innovation section, reaching negative emissions in the power sector would require BECCS, and therefore both biomass and CCS deployment.
AFOLU	There is a rising trend towards healthier diets, and the levels we use in our ambition scenarios match World Health Organisation (WHO) recommendations. Also, meat consumption is already decreasing in several EU Member States, and vegetarian alternatives to meat and dairy are appearing. Land multiuse is a key lever of land-use, but with the increasing pressure on polluting fertiliser alternatives, there are a lot of promising agro-ecology experiences taking place. As for the large afforestation and forest restoration required, no significant technical innovation is required, and, when based on biodiverse species, it brings several co-benefits (biodiversity, landscape, recreation, flood, fire, and erosion prevention, harvested wood products).

APPENDIX:
BRIEF METHODOLOGY DESCRIPTION

BACKGROUND OF THE CARBON TRANSPARENCY INITIATIVE (CTI) MODEL

The Carbon Transparency Initiative (CTI) helps decision makers within the climate community project and track progress toward a low-carbon economy by analysing the drivers of emissions trends. It has three components: a) models, b) tracker, and c) advisory services. We only describe the models in this appendix.

The CTI models determine GHG emission pathways up to 2050 across all sectors of the economy for select geographies. The analyses in this report are built on the European component of the CTI, which has been developed by the ECF with the support of Climact.

OVERVIEW OF THE CTI MODEL

Sectors and links between them

The European model covers the following sectors, as illustrated on Figure 23 : Lifestyles, Food production, Transport, Buildings, Manufacturing, Energy supply, Land-use, Fossil fuels-use, and Trade balance outside the EU. In addition to GHG emissions, it covers Energy, Resources & Costs pathways. The model is driven by 'lifestyle', 'technology', and 'physical' changes and allows a high flexibility in the simulation of pathways. The model can be classified as a directed graphs model (a simulation model without optimisation) calibrated with effort ambitions.

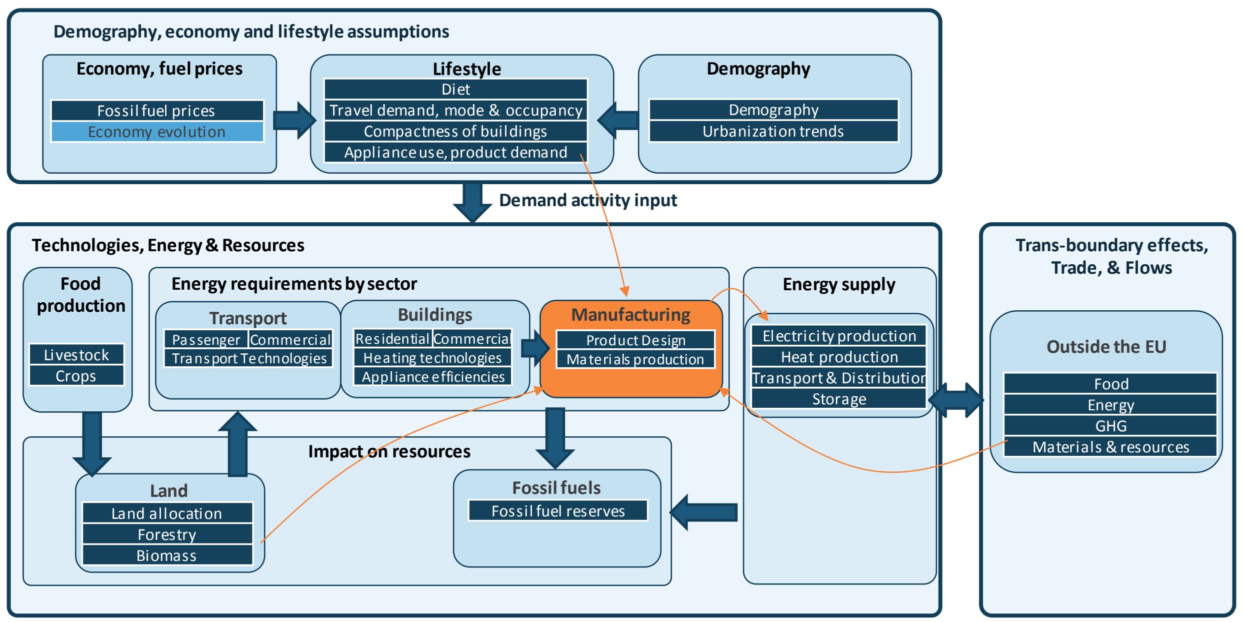


FIGURE 23. *Impact of the lever groups on the energy system costs*

Scenarios based on levers with ambition levels

To simulate a pathway, users change the inputs to the calculator by making choices using a number of "levers" (six macro levers that can be decomposed into more than 100 sub-levers). These levers typically make a change in either the supply or demand of energy in a particular sector, for example building nuclear power stations, or reducing the distance people travel by car. We can take as an example the table below for the proportion of people travelling by car. The levers are described transparently, are exclusive, and can be moved freely by the user within the defined range.

Table 6. Ambition definition – example for buildings renovation depth

AMBITION -2	*Minimal abatement* Current depth: application of low cost or easy to implement measures resulting in a 20% average energy savings versus consumption before renovation.
AMBITION -1	*Mildly ambitious* Factor 2 energy renovation observed in current initiatives is deployed. This results in a 50% average energy savings versus consumption before renovation.
AMBITION +1	*Ambitious* Factor 4 energy renovation corresponding to best-practice policies and initiatives is deployed. This results in a 75% average energy savings versus consumption before renovation.
AMBITION +2	*Very ambitious* Factor 10 energy renovation achieved in pilot projects is scaled up. This results in a 90% average energy savings versus consumption before renovation.

To determine the ambitions of each lever, the model provides two interfaces. In the simple interface, one single slider (lever) enables to choose one of the four ambitions, or an intermediary position. In the Expert mode, **we enable to specify independently 1) a target, 2) a start period, and 3) an implementation duration.**

A combination of all the lever choices creates a scenario. The model outputs for a given input scenario are named "pathways" because the focus is on the final impact and overall evolution trend (we would name the scenarios "trajectories" if the milestones were detailed and the trajectories were operationalised in more depth). For each pathway, the calculator displays the implications over time (for example, in terms of energy, emissions, resource use, job creation, and land-use).

PROJECT SCOPE

Coverage

The model assesses the following dimensions: Emissions, Energy, Resources such as land and materials, and Trade balances. It also provides a good view on the direct cost implications (capex/fuels/other opex).

The model supports the development of scenarios based on realistic and transparent assumptions. It is based on an open and dynamic model, with an online version to increase reach and use.

The assumptions and interpretations result from the engagement of a wide group of experts on sector findings. The sector findings include the identification of the key decision points, and of timing implications.

The emissions scope encompasses all sectors of the economy and all GHG emissions sources covered by national inventories (including international aviation, shipping, and LULUCF).

Exclusions

The model does not leverage an equilibrium models nor an optimisation engine. It does not cover macro-economic analysis or climate change co-benefits. Societal cost could not be covered, nor the allocation of taxes and subsidies to certain actors.

Scenarios are not projections, and the project does not include the choice of an ideal scenario.

Why it is helpful

It provides a recent and credible analysis of net-zero scenarios across multiple sectors.

There is currently only a limited amount of net-zero pathway analysis. The project is backed by numerous experts and recognised organisations. The model provides a common discussion framework and several of organisations even proposed their scenarios.

The model brings value to the current debate by linking all emitting sectors and clearly highlighting high level trade-offs between sectors.

It provides a complementary approach to PRIMES or TIMES

Compared to PRIMES or TIMES, the CTI model:

- Is more open and transparent, and simpler to use. The model is accessible either through an Excel file or through the web interface (see Figure 24). Both provide instant results. All key assumptions have been detailed.
- Can reproduce existing scenarios and compares the outputs and ambitions.
- Provides a harmonised logic across all sectors; starting from 1) behaviour activities, to 2) product demand, to 3) material & resources demand, to 4) energy, and to 5) emissions. This leads to novel links, like the impact of eating habits on land requirements, or buildings renovation on material demand. This also leads to novel action points, like the impact of a functional economy or material shifts.
- Addresses land-use and other sinks, clarifying their joint impact directly.

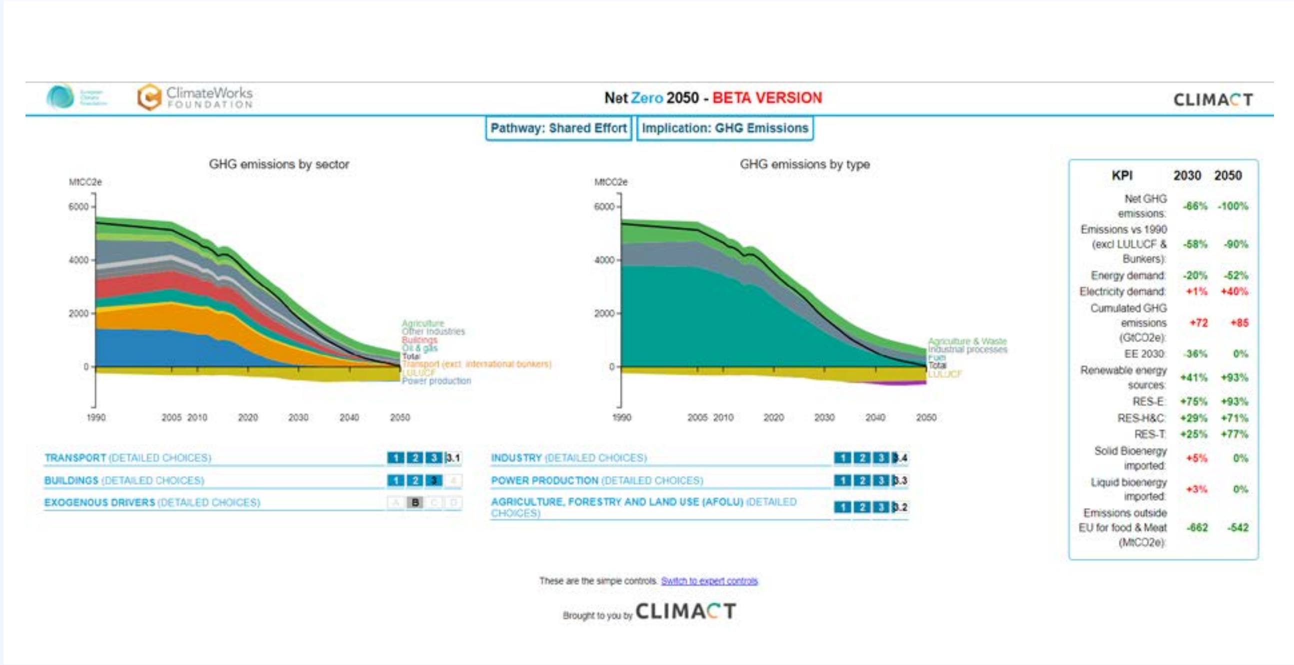


FIGURE 24. *CTI tool web interface (available on stakeholder.netzero2050.eu)*

Robustness and development process

The model results from a large co-construction process. Sectorial workshops have been conducted with experts. In addition, workshops have been performed on the scope validation, on the architecture and usability. Finally, workshops have been conducted to collect feedback from beta-testing organisation. To make this traceable, key assumptions have been transparently documented.

Links to other existing scenarios. The model's robustness is also ensured by providing the output of scenarios from other models such as the Regional Reference Frame Sub-Commission for Europe (EUREF).

LEVER GROUPINGS

Table 7. Full list of levers with the related group it belongs to

TRANSPORT GENERAL LEVERS	**Energy efficiency**	
	Cars	2. Process improvements and energy efficiency
	Trucks & Buses	2. Process improvements and energy efficiency
	Rail	2. Process improvements and energy efficiency
	Navigation	2. Process improvements and energy efficiency
	Aviation	2. Process improvements and energy efficiency
	Biofuels	
	Road transport	3. Fuel switch and electrification
	Aviation	3. Fuel switch and electrification
	Shipping	3. Fuel switch and electrification
	E-fuels (if not electrified or shifted to H2)	3. Fuel switch and electrification
	Shipping electrification	3. Fuel switch and electrification
	Short-haul flights electrification	3. Fuel switch and electrification
PASSENGER TRANSPORT LEVERS	Land transport demand	1.a Social patterns
	Aviation transport demand	1.a Social patterns
	Modal share	
	LDV	1.b Societal organisation
	2W	1.b Societal organisation
	Bus	1.b Societal organisation
	Passenger vehicles utilisation and occupancy	
	Utilisation rate	1.b Societal organisation
	Occupancy	1.b Societal organisation
	Technology evolution	
	Technology share LDV - ZEV	3. Fuel switch and electrification
	Share of FCEV in ZEV	3. Fuel switch and electrification
	Technology share LDV - LEV	3. Fuel switch and electrification
FREIGHT TRANSPORT LEVERS	Freight transport demand	1.b Societal organisation
	Modal share	
	Trucks	2. Process improvements and energy efficiency
	Rail	2. Process improvements and energy efficiency
	Aviation	2. Process improvements and energy efficiency
	Maritime and IWW	2. Process improvements and energy efficiency
	Freight vehicles utilisation and load factor	
	Utilisation rate	2. Process improvements and energy efficiency
	Load factor (ton.km/vkm)	2. Process improvements and energy efficiency
	Technology evolution	
	Technology share HDV - ZEV	3. Fuel switch and electrification
	Technology share HDV - LEV	3. Fuel switch and electrification
RESIDENTIAL	**Compactness**	
	Floor area requirements	1.a Social patterns
	Household size	1.a Social patterns
	Residential buildings efficiency	
	Renovation depth	2. Process improvements and energy efficiency
	Renovation rate	2. Process improvements and energy efficiency
	Demolition rate	2. Process improvements and energy efficiency
	Decarbonising heat	
	In new built	3. Fuel switch and electrification
	In renovated	3. Fuel switch and electrification
	In remaining buildings	3. Fuel switch and electrification
	Mix of low-carbon heating technologies	
	Heat district technologies	3. Fuel switch and electrification
	Individual RES-based technologies	3. Fuel switch and electrification
	... of which individual heat pumps	3. Fuel switch and electrification
	Appliances utilisation and efficiency	
	Appliance utilisation growth rate	1.b Societal organisation
	Appliance standards	2. Process improvements and energy efficiency
	Electrification of cooking	3. Fuel switch and electrification
SERVICES	Floor area requirements	1.a Social patterns
	Services buildings efficiency	
	Renovation depth	2. Process improvements and energy efficiency
	Renovation rate	2. Process improvements and energy efficiency
	Demolition rate	2. Process improvements and energy efficiency
	Decarbonised buildings	
	Decarbonising heat in new built	3. Fuel switch and electrification
	Decarbonising heat in renovated	3. Fuel switch and electrification
	Decarbonising heat in remaining buildings	3. Fuel switch and electrification
	Mix of low-carbon heating technologies	
	Heat district technologies	3. Fuel switch and electrification
	Individual RES-based technologies	3. Fuel switch and electrification
	... of which individual heat pumps	3. Fuel switch and electrification
	Appliances utilisation and efficiency	
	Appliance utilisation growth rate	1.b Societal organisation
	Appliance standards	2. Process improvements and energy efficiency
	Electrification of Other uses in services	3. Fuel switch and electrification

INDUSTRY	EU Activity (consumer goods)	1.a Social patterns
	Product lifetime/Functional economy	
	Transport	1.b Societal organisation
	Buildings	1.b Societal organisation
	Power	1.b Societal organisation
	Agriculture and Others	1.b Societal organisation
	Share of product manufactured in EU	
	Transport	1.b Societal organisation
	Buildings	1.b Societal organisation
	Power	1.b Societal organisation
	Agriculture and Others	1.b Societal organisation
	Product material switch	
	Transport	2. Process improvements and energy efficiency
	Buildings	2. Process improvements and energy efficiency
	Material intensity	
	Steel	2. Process improvements and energy efficiency
	Chemical	2. Process improvements and energy efficiency
	Cement	2. Process improvements and energy efficiency
	Other industries	2. Process improvements and energy efficiency
	Recycled materials ratio	
	Steel	2. Process improvements and energy efficiency
	Chemical	2. Process improvements and energy efficiency
	Cement	2. Process improvements and energy efficiency
	Other industries	2. Process improvements and energy efficiency
	Share of materials manufactured in EU	
	Steel	1.b Societal organisation
	Chemical	1.b Societal organisation
	Cement	1.b Societal organisation
	Other industries	1.b Societal organisation
	Processes (incl. EE, switch to gas & electric)	
	Steel	2. Process improvements and energy efficiency
	Chemical	2. Process improvements and energy efficiency
	Cement	2. Process improvements and energy efficiency
	Other industries	2. Process improvements and energy efficiency
	Switch to hydrogen	
	Steel	2. Process improvements and energy efficiency
	Chemical	2. Process improvements and energy efficiency
	Other industries	2. Process improvements and energy efficiency
	Switch to biomass (incl. CCU)	
	Steel	3. Fuel switch and electrification
	Chemical	3. Fuel switch and electrification
	Cement	3. Fuel switch and electrification
	Other industries	3. Fuel switch and electrification
	Carbon Capture & Storage	
	Steel	5. CCS/BECCS
	Chemical	5. CCS/BECCS
	Cement	5. CCS/BECCS
	Other industries	5. CCS/BECCS

POWER	EU coal phase out	4. Zero-carbon power production
	EU nuclear context	4. Zero-carbon power production
	vRES framework	4. Zero-carbon power production
	Zero-carbon flexibility options	4. Zero-carbon power production
	Biomass contribution	3. Fuel switch and electrification
	Natural gas to H2	3. Fuel switch and electrification
	Carbon Capture & Storage	5. CCS/BECCS
AFOLU		
DIET	Calories consumed	1.a Social patterns
	Quantity of meat	1.a Social patterns
	Type of meat	1.a Social patterns
EFFICIENCY	Crop yields	2. Process improvements and energy efficiency
	Livestock intensification(grains/residues fed)	2. Process improvements and energy efficiency
	Livestock (pasture fed)	2. Process improvements and energy efficiency
	Bioenergy yields	2. Process improvements and energy efficiency
	Wastes and residues	2. Process improvements and energy efficiency
LAND	Solid or liquid	3. Fuel switch and electrification
	Surplus land (forest & bioenergy)	6. Land use sinks
	Land multiuse	6. Land use sinks
	Land degradation	6. Land use sinks
	EU self-sufficiency in food	1.b Societal organisation
	EU self-sufficiency in meat	1.b Societal organisation
	Add dedicated energy crops ?	6. Land use sinks
	Forestry intensity	6. Land use sinks

ABOUT THE PROJECT

PROCESS

This paper is the outcome of a year-long effort of deep analytical work and active stakeholder engagement. It builds on the model developed as part of the Carbon Transparency Initiative (CTI) by the *ClimateWorks Foundation* and has been extended and upgraded for Europe with the support of the *European Climate Foundation* (ECF), in consultation with other experts in the field. This consultative process took place between September 2017 and September 2018, and was concluded over the summer of 2018 with the testing of the model by a range of experts who have developed their own low-carbon scenarios to explore and develop the policy options under consideration.

ClimateWorks FOUNDATION

European Climate Foundation

OUTPUTS

The CTI 2050 Roadmap Tool project has two major outputs:

This Report and Summary for Policy Makers, which provide a perspective on the feasibility and the implications of reaching net-zero emissions by 2050 at the latest. It describes the key changes required and highlights potential net-zero trajectories and their implications in terms of both costs and co-benefits. This is intended as an input to the preparation of the European Union (EU)'s Long Term Strategy, as required under Article 14 of the Paris Agreement. It also gives a perspective on near-term actions needed to get on track to net-zero, which has relevance for ongoing discussions on EU Member States' National Energy and Climate Plans required under the EU Governance Regulation, and the EU's Nationally Determined Contribution (NDC) under the Paris Agreement.

A webtool version of the model featuring:

- A range of scenarios that online users can explore to better understand the results.
- An option to switch to a live version of the webtool, which stakeholders are invited to use to explore, design, and propose their own pathways.
- These are available at: *https://stakeholder.netzero2050.eu*
- Sectoral presentations to explain the assumptions and model logic in more detail.
- These can be found at: *https://europeanclimate.org/net-zero-2050/*

ENDNOTES

1. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
2. Including: Denmark, Finland, France, Iceland, Luxembourg, Sweden, New Zealand, Norway, and Portugal. Brazil, Colombia, Costa Rica, Ethiopia, Finland, France, Germany, Iceland, Luxembourg, Marshall Islands, Mexico, Netherlands, New Zealand, and Portugal – as well as thirty-two cities – have signed up to a statement to develop long-term pathways to transition to net-zero emissions as part of the carbon neutrality coalition.
3. Note on innovation: According to formal definitions, the points discussed above – scaling up deployment of existing commercially available solutions and increasing the uptake and technology readiness of other known solutions – can be referred to as 'innovation', and as requiring 'innovation support'. An informal understanding of the word 'innovation' may however risk misinterpretation that the solutions required to reach net-zero are as yet unknown. Our research finds that this is not the case. To avoid possible confusion, the concept of innovation is not used extensively in the Executive Summary but detailed further in the body of the text. We refer readers to the text around Figure 13 p21 where there is a more thorough and precise discussion of what is implied.
4. See the details of the EU Reference Scenario 2016 and the EUCO scenarios at https://ec.europa.eu/energy/en/data-analysis/energy-modelling, and the non-paper on increased energy efficiency and renewables targets as summarised and downloadable in the following Euractiv article https://www.euractiv.com/section/energy/news/leaked-eu-analysis-makes-case-for-higher-renewables-energy-saving-goals/
5. In this report, 'no-regret actions' are defined as emissions reduction actions that are common to all our net-zero scenarios and hence appear as "must do" irrespective of chosen pathway. This definition may differ from other studies where "no-regret" means having a short financial payback or a negative marginal abatement cost.
6. Afforestation/reforestation being based on a mix of species guaranteeing high biodiversity. New forests must also not lower the albedo of the land in order to avoid a negative net climate impact.
7. Article 3, Treaty of Lisbon: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:12016M/TXT&from=EN
8. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
9. Including: Denmark, Finland, France, Iceland, Luxembourg, Sweden, New Zealand, Norway, and Portugal. Brazil, Colombia, Costa Rica, Ethiopia, Finland, France, Germany, Iceland, Luxembourg, Marshall Islands, Mexico, Netherlands, New Zealand, and Portugal – as well as thirty-two cities – have signed up to a statement to develop long-term pathways to transition to net-zero emissions as part of the carbon neutrality coalition.
10. Exponential climate action roadmap : http://exponentialroadmap.futureearth.org/report/
11. Afforestation/reforestation being based on a mix of species guaranteeing high biodiversity. New forests must also not lower the albedo of the land in order to avoid a negative net climate impact.
12. It is worth mentioning here that the Calculating and Operationalising the Multiple Benefits of Energy Efficiency in Europe (COMBI) project was focused on energy efficiency, which means it is a conservative estimate of the co-benefits that the full low-carbon scenarios would lead to.
13. From McKinsey, Europe's circular economy opportunity, September 2015. The EU Commission also published a report on "The Circular Economy, a win-win situation" highlighting savings of €600 billion for EU businesses, equivalent to 8% of their annual turnover, creation of 580,000 jobs, and reduction of EU carbon emissions by 450 million tonnes by 2030.
14. Wageningen University, Business performance in the Dutch Circular Economy, 2017
15. Interface is a carpet manufacturer. Carpets were originally made from fossil fuel plastics and generated a large amount of waste. Source: Ellen McArthur, Interface

https://europeanclimate.org/net-zero-2050/
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