INSTITUT ROUSSEAU

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ROAD TO NET ZERO

BRIDGING THE GREEN INVESTMENT GAP

January 2024

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About Institut Rousseau

Institut Rousseau is a think tank gathering intellectuals, researchers, civil servants, and private sector workers committed to implementing the environmental transition and to strengthening democracy in all their economic, social and institutional aspects.

In March 2022, Institut Rousseau published the report '2% for 2°C', which estimated the public and private investment needed to set France on track to meet its net zero objective in 2050.

Since its creation in March 2020, Institut Rousseau has published more than 200 policy notes, mobilising the necessary expertise in relevant fields and influencing public debate by proposing innovative, concrete and operational public policies. These publications provide the material to invent and build the future, aiming to set a course by describing the means to achieve it.

Visit our website: institut-rousseau.fr

The institute is mostly funded by its members and donations: feel free to support us!

Acknowledgments

Institut Rousseau is very thankful to the Greens/EFA Group for their financial support in making this report a reality.

Special thanks to Philippe Lamberts and Léa Das Neves Bicho for their trust.

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The team is thankful to Nicolas Dufrêne, Director of Institut Rousseau, who co-initiated this project and supported the team in its realisation.

Images: Storyset.com/Freepik.com, Unsplash.com, TheNounProject.com, Rawpixel.com

Other contributors and volunteers from across Europe

This work stems from the efforts of a group of almost 150 individuals and experts who volunteered for a year and a half. We couldn't thank them enough.

Transport: Guillaume Zuffinetti, Antoine Veyre, Benoît Parent, Sami Belhalfaoui, Clément Bordet, Sydney Lame, Daphé Dumoutet, Guillaume Gualda, Caroline Franzen, Maria Grazia Ferri, Emilie Claeys, Nikhil Anand, Maria Periotto, Nuria Lastras, Adrien Blain, Loïs Miraux

Industry: Max Bendjaballah, Louis Dreano, Matis Veniant, Yannick Malot, Thomas Lebrun, Mathis Berthelot, Sébastien Frin, Charles Duchêne, Sébastien Baly, Dimitri Seguret, Marc Drieux, Jeremy Cérival, Aurélien Gaillard, Thibaut Bragé, Laura Chémali, Laura Curto, Vesela Deneva, Letizia Sormani, Beatrice Ferrari, Nicolas Brémond, Louis Vandermesen, Thibault Goessel, Erina Schwartzmann, Christopher A. Williams, Iker Rivero, Nikitas Kitsantas, Tim Cayanga, Yasser Rahim, Mauro Och, Emilia Kim, Miguel Flor, Adam Michel, Arindam Ritam

Agriculture: Martin Jego, Maud Anjuere, Mathieu Fantino, Alice Valour, Julien Chevalier, Benjamin Thomas, Raphael Cousin, Laurent Dicale, Lolita Augay, Zoe Roussel, Teona Micevka

Buildings: Olivier Sidler, Louis Vandermessen, Geneviève Littot

Energy: Tim de Bree, Lucas Welin, Jérémy Cérival, Alexia Meynier, Pablo Esteban Aldama, Alexandre Périn, Barthélémy Martin, Samuel Assiga, Norbert Gravellier, Julien Bolard, Louis Cluzel, Olivier Saut, Jérémy Tessier, Pierre-Olivier Descamps

Waste: Marie Arcadias, Jérome Sagne, Jean-Thomas Pénet, Lilian Roux, Matis Veniant

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Cross-sector levers: Clotilde Naulet, Caroline Franzen, Gabrielle Sergent

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Other contributors: Inès Pitavy, Els Duffhues, Giulia Macchia, Jacob Wang, Stefan Van Den Heuvel, Abdul Hameed Raji, Benoit Larrouturou, Christian Nicol, Gaspard Chameroy

External partners & reviewers

Finally, we extend our gratitude to experts from 20+ partner organisations, businesses, administrations, and NGOs who generously helped to enhance the data we constructed and review this report.

We are grateful to the following organisations, with whom the discussions and exchanges helped us to improve the content of the report:

IEECP Institute for European Energy and Climate Policy
eco-union
Transport & Environment
Bioenergy Europe
Polski Instytut Ekonomiczny
ECCO The Italian Climate Change Think Tank
Clever
Association négaWatt
ASCA
Greifswald Mire Centre
UVa
geeds
Locomotion
Real Instituto Elcano Royal Institute
éclaircies

Similarly, we extend our thanks to the following people and organisations for the fruitful discussions conducted with them:

- European Environmental Agency
- Swedish Climate Policy Council and the editorial team of panorama-sverige.se
- Frans Rooijers (CE Delft)
- Stefan Thomas (Energy, Transport and Climate Policy, Wuppertal Institute)
- Aurélien Bigo (Chair Energy & Prosperity, Institut Louis Bachelier)
- David Bardina (Métron)
- Ignace de Franqueville (Métron)
- Nic Lampkin (Organic agriculture policy, business and research consultancy)
- Patrick Veysset (INRAE)
- Gilles Martel (INRAE)
- Vincent Feuillette (Buildings renovation expert)
- Benoît Esnault (French Energy Regulatory Commission)
- Ivan Faucheux (French Energy Regulatory Commission)
- Nicolas Goldberg (Energy expert)
- Alexandra Barthelmes (Greifswald Mire Centre)
- Matthieu Combaud (INRAE)
- Corentin Riet (The Shift Project)
- Mélanie Juillard (CITEPA)
- Quentin Bedrune (CITEPA)

Summary

Summary

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Summary

Introduction

Greenhouse gas levels are record-high. Global temperatures are record-high. Sea level rise is record-high. Antarctic sea ice is record-low. It's a deafening cacophony of broken records.

Professor Petteri Taalas, Secretary General of the World Meteorological Organisation, 2023

In a press release from 29 November 2023, the World Meteorological Organisation confirmed that 2023 was set to be the warmest year on record, emphasising the need to act now to limit the risks of an increasingly inhospitable climate in this century.

Over the past three decades, the European Union has positioned itself as a guardian of a relatively steady improvement in environmental and public health preservation. This has been achieved by implementing common standards and integrating numerous instruments for the protection of nature and public health into national laws.

Even though these advances have sometimes been slow, and occasionally perceived as contradictory to certain other EU policies (such as free trade agreements or the Common Agricultural Policy), or caused tensions within the Parliament's changing political landscape, the environmental protection goal has more or less prevailed.

In the past 2 years, the European Union embarked on a legislative sprint to implement the Green Deal and align itself with the Paris Agreement. It adopted 32 policies – spanning from the phasing out of internal combustion engines by 2035 to the introduction of a carbon border adjustment mechanism – to reduce CO_2-eq emissions by 55% by 2030 compared to 1990 (the 'Fit for 55' package) and achieve carbon neutrality by 2050.

Yet, tangible emission reductions are still lagging behind and the progress of European environmental policies relies on a delicate political balance. Struggles over the nature restoration project, postponing chemical regulation reform indefinitely, re-authorising glyphosate for a decade, and rejecting pesticide use regulation, are only a few examples of this. Furthermore, in June 2023, certain European heads of state endorsed a declaration calling for a 'regulatory pause' on the Green Deal[1].

Meanwhile, in a recent assessment of the effort-sharing legislation (which covers the 62% of UE-27 total GHG emissions that are not included in the EU Emission Trading System, or ETS), the European Environment Agency assessed that **no EU-27 country, except for Greece, was on track to meet its national 2030 emission reduction targets**[2]. In a recently published report addressing the necessity of sustaining current habitability conditions on Earth, the Club of Rome deemed current transition policies 'Too Little, Too Late.'[3] Their analysis underlines that the excessively slow reduction of greenhouse gas emissions and the continued collapse of biodiversity are propelling humanity toward a precipice.

Given increasing resistance to climate policies within the EU, and the inability to meet medium-term emissions reduction targets, committing to net zero transition is ever more vital. These commitments should build on a sound and objective assessment of the current policy trends across the EU.

The discrepancy between the EU's ambitious goals and its limited policies, both at the EU and member state levels, is mostly due to financial obstacles. In addition to inconsistent pro-fossil policies, the current economic climate, particularly European budgetary rules, has constrained States in their ability to deliver the investment required to implement transition policies. Therefore, public and private investments are both the primary hindrance to realising these poli-

cies and the most accurate lens to measure the commitment levels of European and national authorities.

Building on these considerations, Institut Rousseau has created this comprehensive report to quantify the existing gap with a disaggregated sectoral and country-level view. The collective extra-investment required to implement all decarbonisation measures needed to reach net zero by 2050 is estimated at €10 trillion, or an average of €360 billion per year. This investment represents around 2.3% of the current EU-27 GDP. These estimations cover the financial needs to fund the targeted sectoral emission reductions across all activities to reach 519 million tons of CO_2-eq per year by 2050 (-85% reduction, compensated by carbon sinks for net neutrality). This detailed assessment covers the required extra investment compared to a business-as-usual (BaU) scenario. It is both country- and sector-specific with estimates of the cumulative investment, as well as the annual average until 2050. **Additionally, the report provides a clear roadmap to bridge the investment gap, highlighting actionable measures balanced between public and private funding, depending on the investment.**

This report is the result of extensive work conducted by Institut Rousseau, a French think-tank specialising in public transition policies, in close dialogue with Member States' administrations, companies and NGOs with expertise in the studied sectors and countries. By addressing this critical aspect, this study aims to contribute to ongoing debates within the EU regarding the efforts required to reach our common environmental targets, a few months before the European elections. It calls for urgent actions in support of drastic emission reductions, to achieve our shared environmental goals.

Notes

1. European's People Party, 29 June 2023, EEP Summit Statement.
2. European Environment Agency, 2023, Climate and Energy in the EU.
3. Club of Rome, 2023, Earth for All: A Survival Guide for Humanity.

Study scope, key definitions and main limitations

1 Main questions addressed by this report

1. **Which public and private investments are needed** to achieve the transition to carbon neutrality in Europe by 2050?

2. **How do these investment amounts compare to the existing planned investments** in a business-as-usual scenario of similar scope?

3. **What measures can the public sector employ to guide, support and accelerate this transition? What would be their cost for public finances?**

A 3-step methodology was used to answer these questions. For further insights into the underlying approach and assumptions, please refer to the Methodological Appendix.

Fig. 1.1 3-step methodology used for the Road to Net Zero (RtoNZ) project

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1 List the decarbonisation levers required for each sector

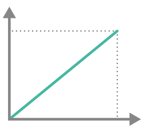
✔ Convert vehicles to low-carbon technologies
✔ Efficiently renovate housing
✔ Increase material efficiency in the industry
Etc.

× 37

2 Establish a Business-as-Usual scenario and a Transition scenario, then calculate their respective costs

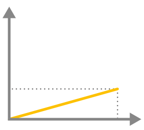
Transition scenario

Number of vehicles, % of electric
Number of buildings renovated
% of raw materials recycled
Etc.



→ € TRANSITION

Business-as-usual scenario (BaU)



→ € BaU

€ Transition – € BaU = € Extra Invest.

3 Define public measures for each lever in the 2 scenarios and compute their costs

Convert vehicles to low-carbon technologies → Reinforce conversion subsidies
Renovate buildings → Reinforce renovation subsidies
Etc. Etc.

37 LEVERS → 70+ PUBLIC MEASURES

€ Transition, Public – € BaU, Public = € Extra Public Invest.

This study is informed by a transition scenario aiming for carbon neutrality by 2050, in contrast to a baseline scenario (or business-as-usual scenario, extending current trends and policies). While the scenarios described are primarily physical ('what ought to be materially transformed for our society to be carbon-neutral?'), the present study is essentially economic, focusing on financing the described transformations.

Seven major countries are studied in detail: France, Germany, Italy, Spain, the Netherlands, Poland and Sweden. These countries represent approximately 77% of EU-27 GDP and 73% of domestic emissions. For each of the 37 decarbonisation levers and 70+ public policies, all modelling outputs (emissions reductions, public and private investments and extra-investments) are computed both at the country scale (for each of the 7 countries) and at the EU-27 scale.

Two additional questions will be addressed by future Institut Rousseau reports:

4. **How can the private and public sectors finance these investments?**

5. **What are the advantages of undertaking this ecological transition, and how do the benefits, including economic gains, offset the associated investments?**

2 Key definitions to understand the methodology

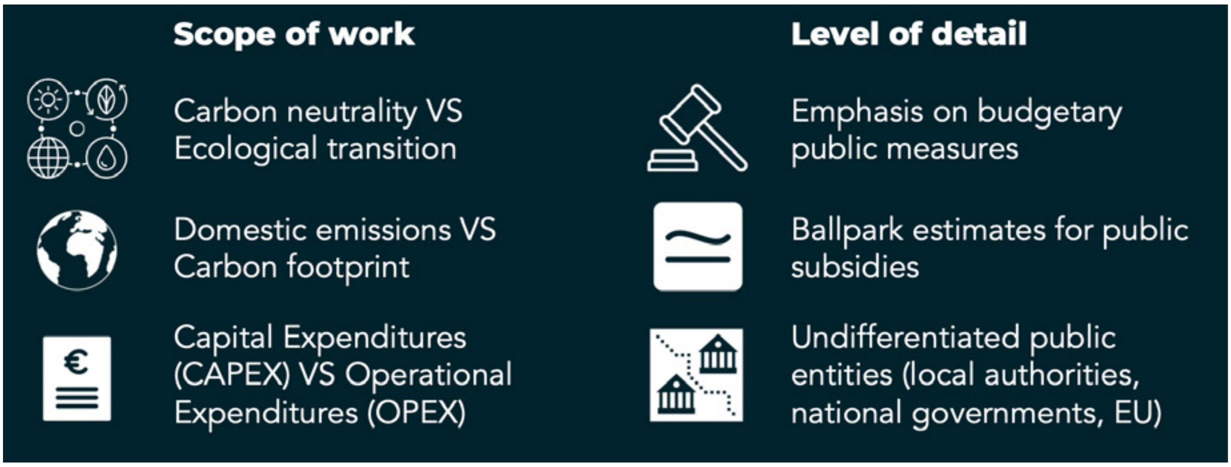
- **Investments**: The definition of 'investments' used here is broad, based on the notion of 'investment costs' in a project or asset. It refers to initial costs to implement a change (capital expenditure or CAPEX) and excludes so-called 'operational' or 'operating' costs that arise during the project (operational expenditure or OPEX). This definition is not constrained to a purely accounting perspective and will designate, for simplicity's sake, subjects and types of economic flows that are considerably broader and more heterogeneous, especially in the public sphere: direct public expenditures (e.g., investments in public transportation, renovation of public buildings) or indirect public assistance for private investments (e.g., subsidies, automotive conversion incentives), transfer mechanisms between private actors passing through public accounts (e.g., guaranteed selling prices for renewable energy producers), decreases in tax revenues, etc. For ease of language, the terms 'cost' or 'extra cost' compared to the trend are sometimes used to designate these same investments. Values are given in euros for 2022.

- **Net zero or net carbon neutrality**: The current objective set by most political institutions, including the European Union, is a 'net' objective, meaning it does not aim to completely stop emitting greenhouse gases by 2050 but rather to minimise emissions and absorb what cannot be reduced through carbon sinks (especially forests, which absorb atmospheric CO_2 during their growth). This study adopts the same logic, but aims to leverage carbon sinks (which have their own limitations) only as a last resort, after effectively decarbonising everything possible.

Additionally, the net zero objective must align with the 'carbon budget', indicating the allowable cumulative GHG emissions to stay within the Paris Agreement's temperature goals. Achieving net zero thus requires consistent efforts starting now, with particular emphasis on substantial emissions reduction before 2030.

3 Main limitations of this exercise

Fig. 1.2 **Main limits of the present study**



- **The cost of the entire ecological transition is not quantified here**; only the cost of achieving carbon neutrality by 2050 is considered. Other environmental issues, such as biodiversity preservation (addressing the ongoing sixth mass extinction), water management, chemical soil and process decontamination, etc., require equally important attention (cf. Appendix A.1. regarding biodiversity). Investments in these areas are justified and necessary but for methodological reasons, they are not directly included in this study, although several proposed investments also contribute to addressing these issues. **The amounts provided in our study thus represent a baseline for achieving carbon neutrality but should be significantly revised upwards by incorporating other ecological challenges.** This will be the subject of future work. Additionally, as explained earlier, operational costs are not directly accounted for in the totals, such as the VAT reductions recommended for transportation, food, or a portion of production subsidies in energy. For all these reasons, the extra cost for the public authority given here constitutes a baseline based on very cautious estimates.

- **The same applies to investments needed for Europe to adapt to climate change consequences.**

- **The greenhouse gas emissions considered here are solely territorial, i.e., emitted on European soil**, to align with the Green Deal. However, Europe's carbon footprint, accounting for the carbon impact of all imported products, is much broader. While these aspects are addressed whenever possible (emissions related to international aviation, management of carbon leakage through a carbon border adjustment mechanism for Europe, etc.), the associated costs are not quantified in the study. This also applies to Member States ' contributions to the UN Green Fund, an investment known to be necessary but aimed at supporting the decarbonisation of other countries.

- **The intrinsic economic or financial profitability of investments** and their impact on economic actors (production costs, household budgets) **is not systematically studied**, except in specific cases.

- **The suggested public support measures concentrate on those with substantial budgetary or fiscal allocations.** The approach followed in this report is fiscal rather than regulatory; we do not systematically address the legislative and regulatory measures that will inevitably accompany investment deployment. Nevertheless, the most pivotal regulatory measures or those serving as prerequisites for investments are outlined. Furthermore, this study acknowledges the operational complexity in implementing this transition, and does not systematically describe all the conditions essential to successfully execute the quantified action plan.

- **Public support is sized only by an order of magnitude.** A specific modelling of case studies, measure by measure, would be necessary to determine the subsidy required to balance incentive for private actors and windfall effects or abuse resulting from an overestimation of needs. Similarly, while general guidance is given on the distribution of public support based on social or economic criteria (e.g., higher coverage rates for low-income households, prioritisation of SMEs with limited investment leeway, etc.), the exact scales of the schemes are not detailed.

- **Public investments do not distinguish between costs that will be borne by the Member States and those that will be borne by European or local authorities.** Determining distribution between national and infra-national levels is contingent upon the governance structure of each Member State. However, this distinction is deemed inconsequential due to the overarching nature of public investment in both cases. Similarly, the allocation between the European and national levels is recognised as a matter of policy and political choices, with the responsibility for decision-making belonging to the Parliament.

- **Finally, investments are considered to start in early 2024 and end in late 2050, spanning 27 years.** The reference for current emissions, from the European Environment Agency[1], is 2021, as official 2022 and 2023 emissions were not yet available at the time this report was drafted. The emission variations of Europe between 2021 and 2023 are thus not factored into this study.

Box 1.1

Integration of biodiversity and broader nature-related considerations

This report focuses on reducing GHG emissions and does not address broader human impacts on nature. Consequently, the investments linked to the Road to Net Zero scenario should be considered as a baseline for initiating a comprehensive ecological transition.

However, since climate change significantly influences various environmental challenges, adopting the RtoNZ scenario would effectively mitigate other environmental pressures. Notably, transitioning to agroecology and investing in safeguarding and expanding natural ecosystems within the LULUCF sector substantially contribute to preventing biodiversity loss and adapting to climate change.

More details are provided in Appendix A.1.

Box 1.2

Impact of this scenario on critical material resource use

Concerns about potential bottlenecks in procuring materials critical to the transition are regularly raised.

To assess this risk, the critical raw material[2] requirements of the Road to Net Zero transition scenario were assessed and compared with the available reserves and resources[3] (reserves are economically viable deposits with current technologies, while resources encompass all known deposits, whether economically extractable or not). This showed that the transition scenario is associated with significant tensions over four products (nickel, lithium, copper and cobalt), despite significant sufficiency measures aimed at reducing such resource use. **Further research and policy proposals need to be considered beyond what is proposed in this report to soothe such tensions, with the ambition to achieve (and not just proclaim) global environmental justice.**

Detailed results are presented in Appendix A.2. A discussion of the geopolitical, environmental and social risks associated with mining is given in Appendix A.3.

Notes

1. European Environment Agency, 2023, 'Emissions data viewer'.

2. The definition of critical raw materials adopted here is that of the EU Raw Materials Information System (RMIS).

3. The estimates for reserves and resources are taken from the Energy Transitions Commission (ETC), 2023, Material and Resource Requirements for the Energy Transition.

Multi-sector synthesis

1 What levels of public and private investment are needed to meet the challenges?

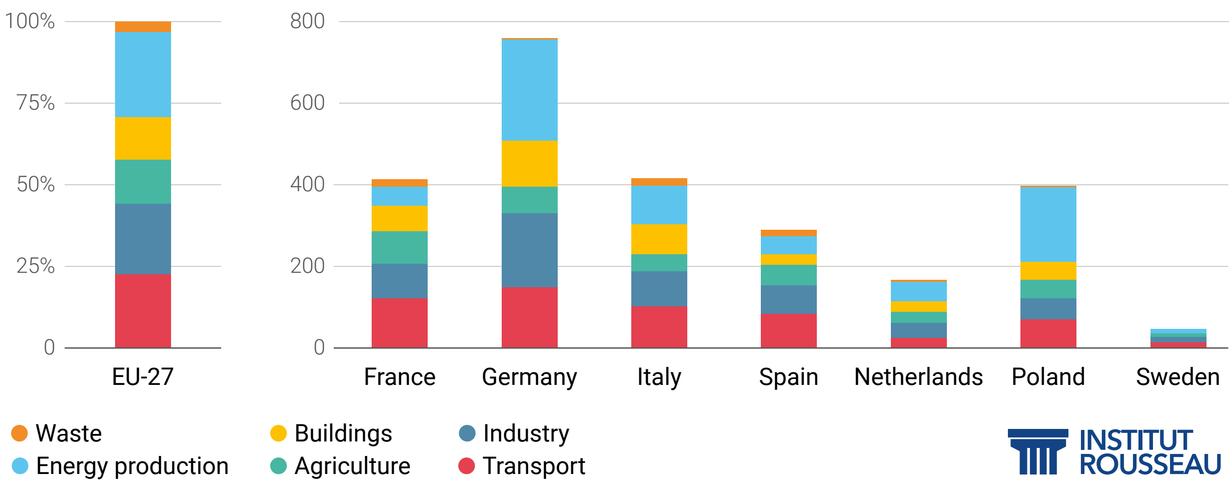
This section covers a synopsis of targeted sectoral emission reductions across all activities, a concise outline of total and sector-specific required investments, a comparative analysis with existing literature, and a discussion around the 2030 Fit-for-55 objective[1].

1.1 What emissions are considered here? What levels of decarbonisation can be expected? What tools are available to attain these?

Every essential aspect of our personal and collective existence is currently associated with greenhouse gas emissions. This encompasses transportation, nutrition, housing, lighting, heating, and the acquisition of various commodities.

Figure 2.1. below illustrates the distribution of these emissions across the sectors of the European (and main countries) economy responsible for delivering these diverse services.

Fig. 2.1 Sectoral breakdown of EU-27 current territorial emissions (2021) (in $MtCO_2$-eq per year)[2]



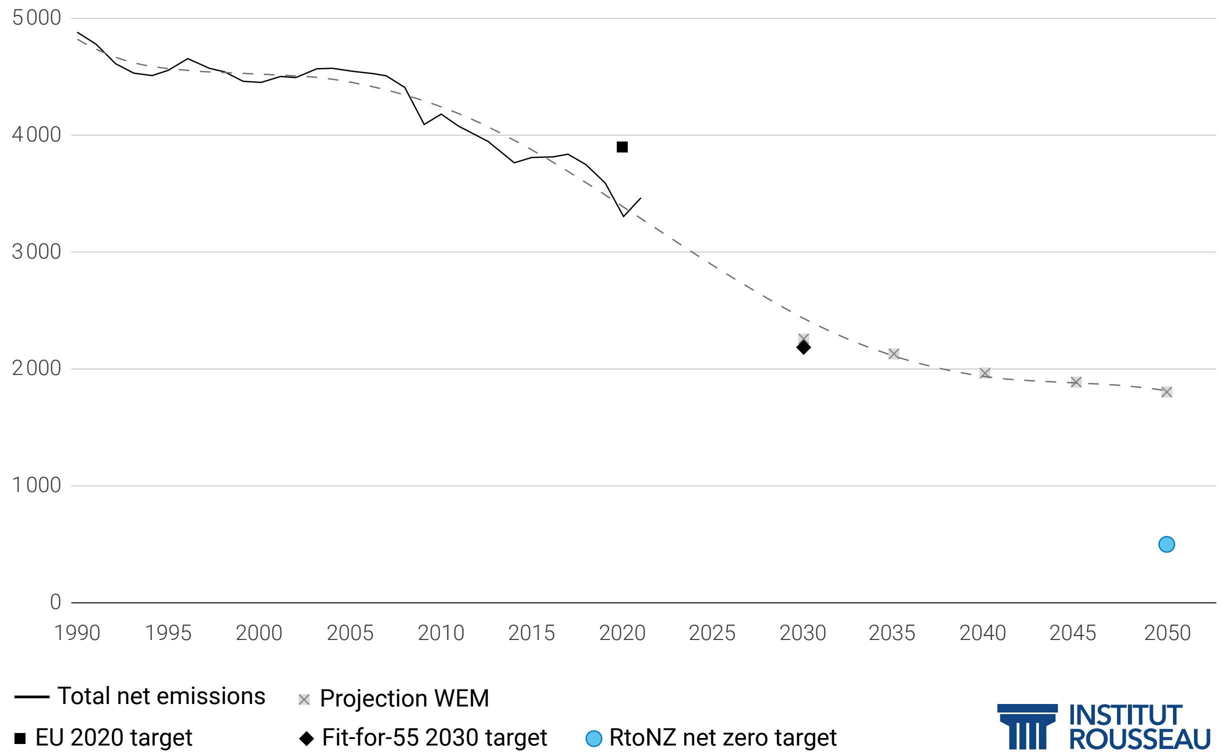
Europe's territorial emissions are primarily due to energy production (26%), the transport of goods and people (23%) and industry (22%). Agriculture and buildings (which consume energy for heating, lighting, cooking, ventilation, etc.) **follow in relatively equal proportions (around 13% each).** Waste management constitutes the remaining 3%, primarily attributed to methane emissions resulting from the natural decomposition of organic waste in landfills.

Each sector has the potential for significant or complete emissions reduction through targeted actions. Our simulated transition scenario achieves a stringent **86% reduction** in the EU's annual emissions compared to 2021, resulting in a residual of 519 million tons of CO_2-eq in 2050. **While Europe met its 2020 target, it is currently not on track to meet this 2050 objective, nor its Fit-for-55 2030 target**, as shown in Figure 2.2.

The European Climate Law set binding targets to achieve climate neutrality by 2050 and reduce net GHG emissions by at least 55% in 2030 compared to 1990. In 2021, emissions had dropped by 30% compared to 1990, with a further 1.9% estimated reduction between 2021 and 2022, mainly due to the energy crisis[3].

To meet the 2030 climate target, the average annual rate of absolute GHG emission reductions must triple compared to the past decade. Current and planned EU policies are expected to support this acceleration, with Member States projecting a 43% reduction in net emissions by 2030 (compared to 1990) based on existing policies. Factoring in planned additional measures could increase the projected reduction to 48%. This **leaves a 7 to 20 percentage point gap to the 2030 target, which requires swift action**.

Fig. 2.2 **Past UE-27 domestic emissions ($MtCO_2$-eq per year) and progress towards achieving 2030 and 2050 targets, in million tons of CO_2 equivalent ($MtCO_2e$).[4]**

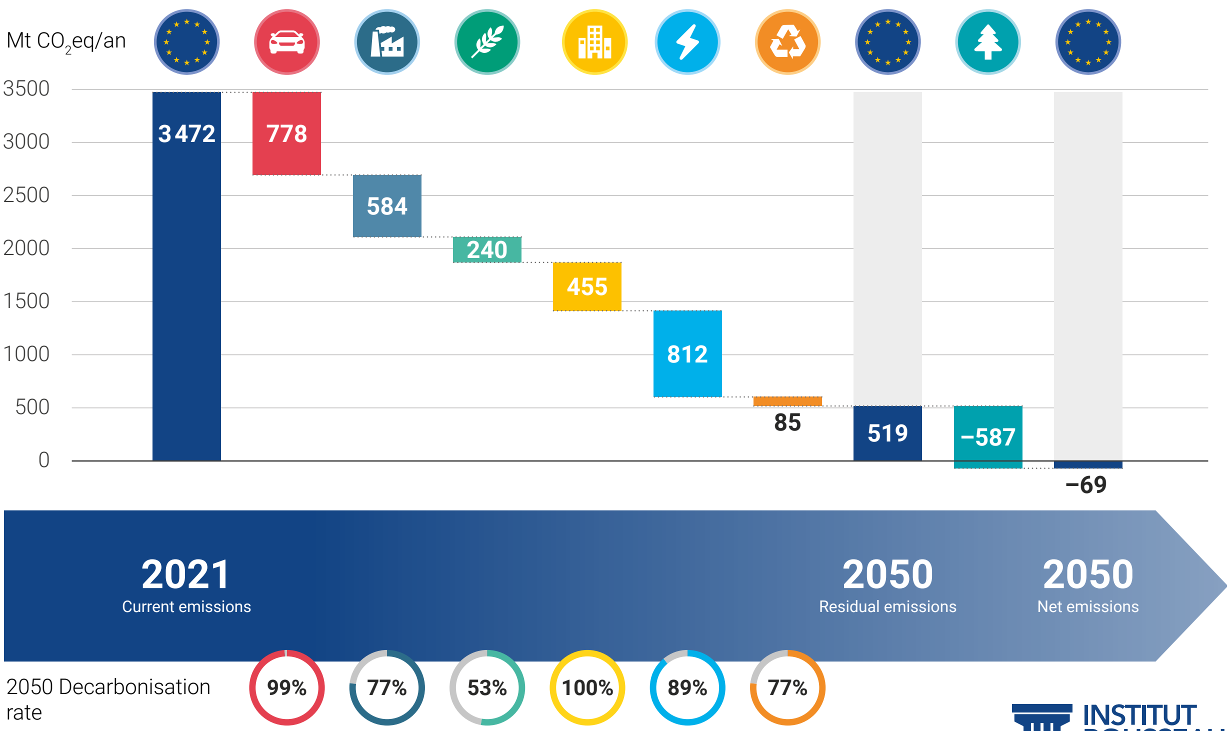


WEM: With Existing Measures.

Beyond 2030, the gap widens, with current and planned measures projecting a 60% reduction by 2040 and 64% by 2050, indicating the need for transformative policies across all sectors to achieve climate neutrality.

The 2050 net zero target can be achieved through the radical reduction of emissions in every sector, as shown in Figure 2.3.

Fig. 2.3 RtoNZ modelled emission reductions by 2050 and degrees of decarbonisation by sector



Achieving such low emissions necessitates a complete phasing out of fossil fuels (gas, oil, and coal), resulting in a near-total decarbonisation in energy production, as well as the transportation and construction sectors. The most challenging sectors to decarbonise include:

- **Agriculture (-53%)**: challenges arise from methane emissions linked to ruminant livestock (correlated with herd size and ultimately meat consumption in the EU) and the use of nitrogen fertilisers, leading to nitrous oxide (N_2O) emissions.
- **Industry (-77%)**: industrial activities generate diffuse emissions that are challenging to capture.
- **Waste (-77%)**: challenging-to-eliminate emissions associated with wastewater treatment, incineration of hard-to-recycle-or-reduce fossil waste, and the storage of certain wastes (final waste).

The remaining emissions primarily originate from these two sectors (216 and 173 million tons per year, respectively). Some flexibility remains in our model regarding carbon sinks (with a 6% sequestration potential buffer). However, due to the considerable uncertainties surrounding climate change's impact on European forests and their CO_2 storage capacity, this additional margin is both imperative and relative.

To meet these targets, it is necessary to activate multiple levers. There are 37 decarbonisation levers in total, outlined in Figure 2.4. Key decarbonisation levers with significant emission reduction potential involve energy (power production), transport (cars, trucks) and building renovations. But **there is no single solution for instantly decarbonising the European economy. All listed levers, regardless of the scale, must be engaged** to reach the goal of carbon neutrality.

Fig. 2.4 Decarbonisation levers proposed and modelled in this study, by sector

TRANSPORT

1. Reduce the number of vehicles and convert them to low-carbon technologies
2. Develop public transportation
3. Develop soft mobility
4. Reduce air traffic and switch to Sustainable Aviation Fuels
5. Transition to zero carbon navigation

INDUSTRY

1. Reduce industrial production through end-use sufficiency
2. Increase material efficiency
3. Increase energy efficiency
4. Decarbonize industrial energy mix
5. Develop low-carbon innovative processes
6. On-site Carbon Capture, Utilisation and Storage
7. Develop EU strategic industrial sectors for the transition

AGRICULTURE

1. Reduce herd size and adapt breeding practices
2. Convert crop systems to agroecology
3. Convert tractors to low-carbon technologies

BUILDINGS

1. Efficient renovation of housing
2. Efficient renovation of public tertiary buildings
3. Efficient renovation of private tertiary buildings

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ENERGY PRODUCTION AND INFRASTRUCTURE

1. Decarbonize and adapt the power system
2. Switch from fossil gas to biogas and other "green" gases
3. Phase coal and oil out, end conventional refining activities
4. Decarbonize heat production for district heating

WASTE MANAGEMENT

1. Separately collect and recover biowaste
2. Reduce plastic use, increase plastic recycling and substitution with other materials
3. Reduce wastewater treatment emissions through process adaptation
4. Produce biogas from waste and sludge

CARBON SINKS (LULUCF)

1. Improve forest management
2. Revitalise degraded ecosystems
3. Support wood industry adaptation
4. Increase forest area
5. Turn grasslands back to net sinks
6. Plant hedgerows and field trees
7. Protect wetlands and peatlands
8. Reach net zero artificialisation

CROSS-SECTOR LEVERS

1. Enhance Research & Development in transition solutions
2. Foster public awareness of environmental issues
3. Boost the Fair Transition Fund to support professional transitions

1.2 Investment for decarbonisation: how much is needed and what's the extra cost compared to the current trend?

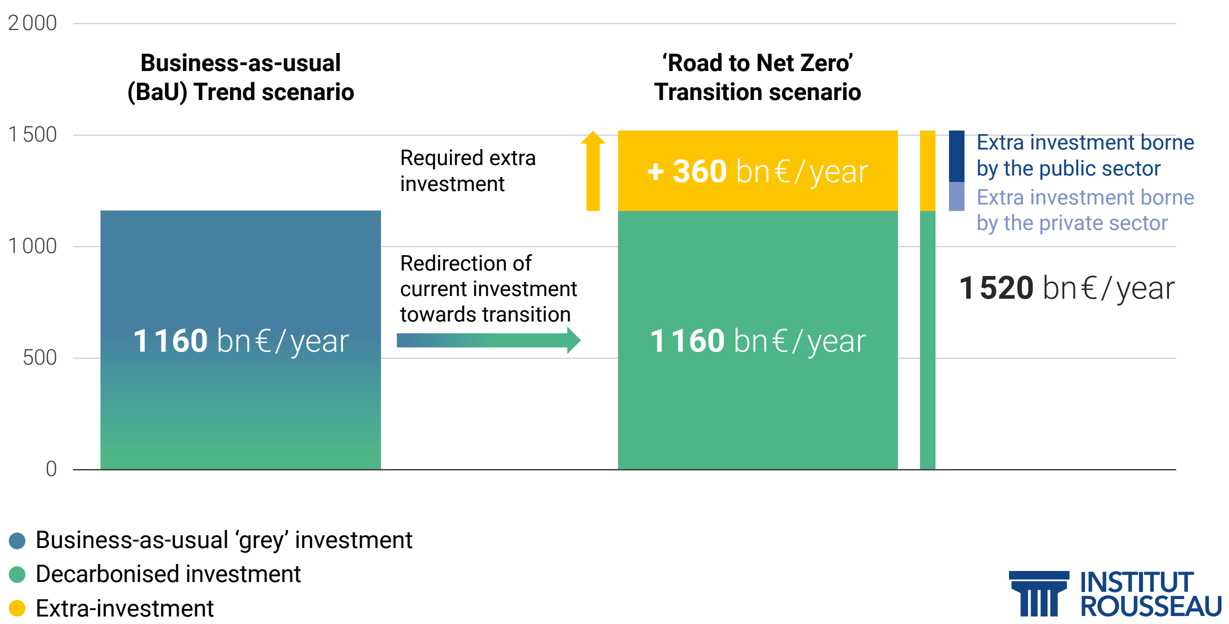
1.2.1 Total investment needed to achieve net zero by 2050

The collective investment required to activate all decarbonisation measures listed in 1.1 is estimated at €40 trillion by 2050, averaging €1,520 billion yearly. This equals almost 10% of current EU-27 GDP. This contrasts with the ongoing business-as-usual (BaU) scenario, estimated at around €30 trillion between now and 2050, averaging €1.160 billion per year (7,3% of current EU-27 GDP).

The difference, about €10 trillion or an average of €360 billion per year, represents the 'extra investment' needed for carbon neutrality. This extra investment represents a **31% increase compared to the baseline scenario and around 2,3% of current EU-27 GDP.**

These estimates are correct only under the express condition that all BaU investments are actively redirected towards the transition by 2050. This implies a massive divestment from sectors that have become partially to completely obsolete (internal combustion engine cars, fossil fuel exploration and production, the production of chemical agricultural inputs, the construction of highways and airports, etc.) and a significant investment in essential sectors (development of public transportation infrastructure, building renovation, production and recycling chains for renewable energy production and storage, etc.). The activities that are negatively impacted will need to be accompanied by social measures (cf. Just Transition Fund, section 10.1.3.). **Without this active shift, not only will carbon neutrality not be achieved, the above-mentioned extra cost will also be higher.**

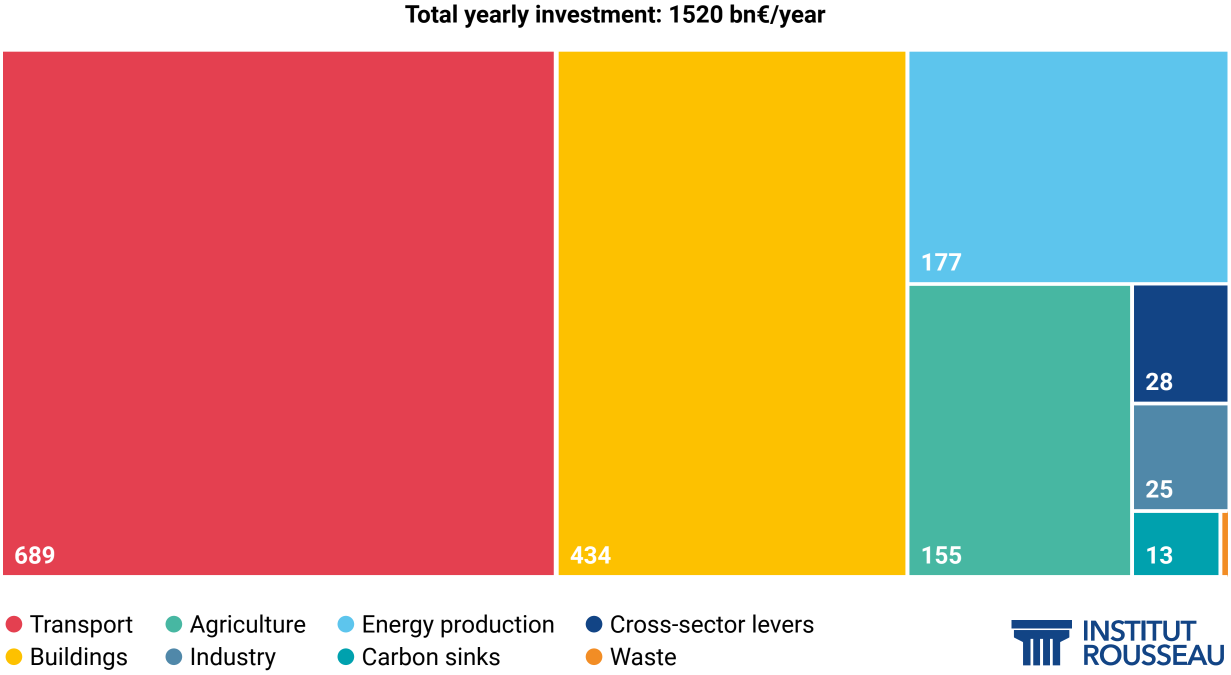
Fig. 2.5 Concepts and amounts of total EU-27 investment required for the transition and of extra investment compared with a business-as-usual scenario (in €billion per year)



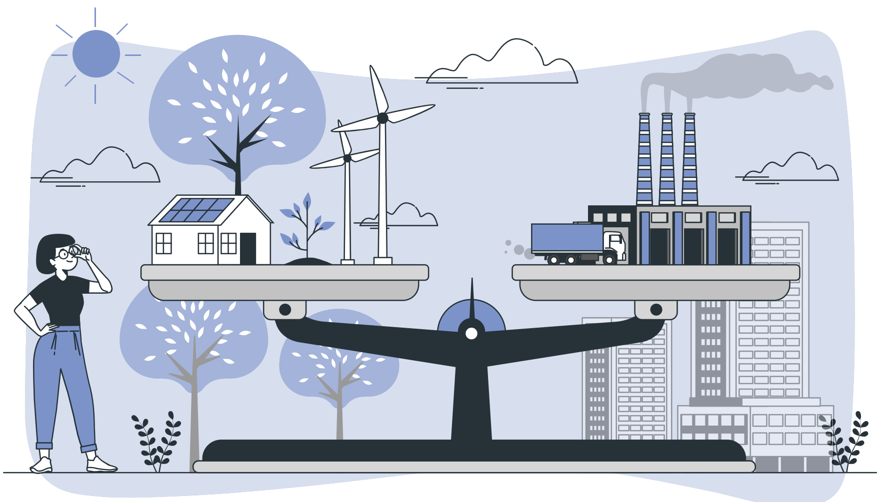
This section examines the distribution of investment and extra investment among various sectors, as illustrated in Figures 2.6. and 2.7.

In terms of overall investment, approximately 75% is concentrated in two sectors: transport (45% of overall investment, €689 billion annually) and buildings (29%, €434 billion annually). This is due to the large-scale nature of these sectors, which invest in tens of millions of vehicles and buildings. These sectors are **followed by and energy production and infrastructure (12%, €177 billion annually) and agriculture (10%, €155 billion annually).** Industry (€25 billion annually), cross-sector measures (€28 billion annually), carbon sinks (€13 billion annually) and waste management are significantly less, accounting for a combined 4% of investment.

Fig. 2.6 **Yearly investment needed by sector (in €billion per year)**



These overall investments exhibit a proportional trend relative to each country's GDP, hovering at approximately 10% (France, Italy, Sweden, and the average of the 7 countries[5]). This range extends from about 8% (Germany, Netherlands) to approximately 11% (Spain), with a notable exception being Poland at 13.6%.



1.2.2 Extra investment needed to achieve net zero by 2050, compared to business-as-usual

When considering extra investment compared to the business-as-usual trend (Figure 2.7.), the top three sectors remain the same, but the buildings and energy production sectors require the most substantial extra effort, requiring respectively 39% (€142 billion per year) and 22% (€79 billion per year) of the total extra investment. In the building sector, this is attributed to the need for an accelerated renovation pace and a shift towards comprehensive renovations, which are individually more expensive. On the energy side, the assumption of strong electrification and power-to-gas development in the transition scenario would double electricity consumption compared to the trend scenario. The transport sector's decrease in extra investment ranking is primarily attributed to two factors. Firstly, the extra investment linked to the cost difference between low-carbon and internal combustion vehicles diminishes over time, reaching zero with the enforcement of bans (e.g., ICE ban scheduled for private cars in 2035[6]) or achieving cost parity (e.g., in 2030 for trucks). Secondly, a 23% reduction in the private car fleet in the transition scenario, coupled with the growth of rail and public transport, results in a negative extra cost (more cars are purchased in the business-as-usual scenario). This reduction offsets other extra costs in the sector, such as the development of public transport and improvements to the railway system.

Fig. 2.7 **Extra investment needed by sector (in € billion per year)**

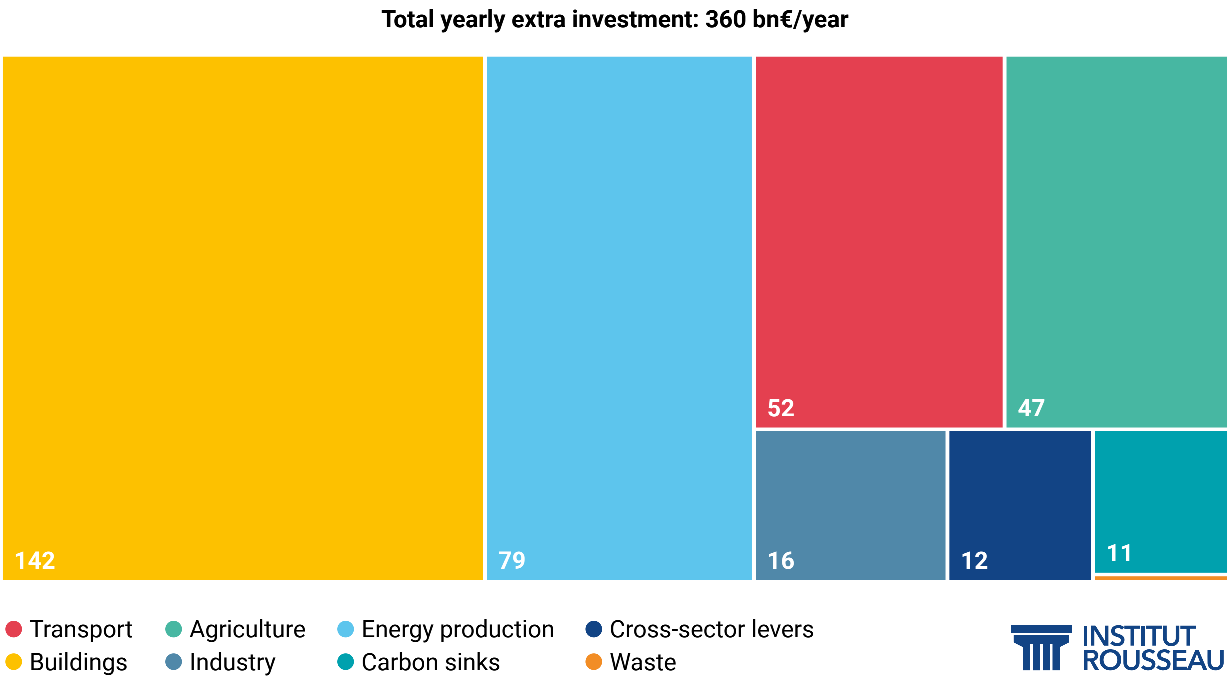
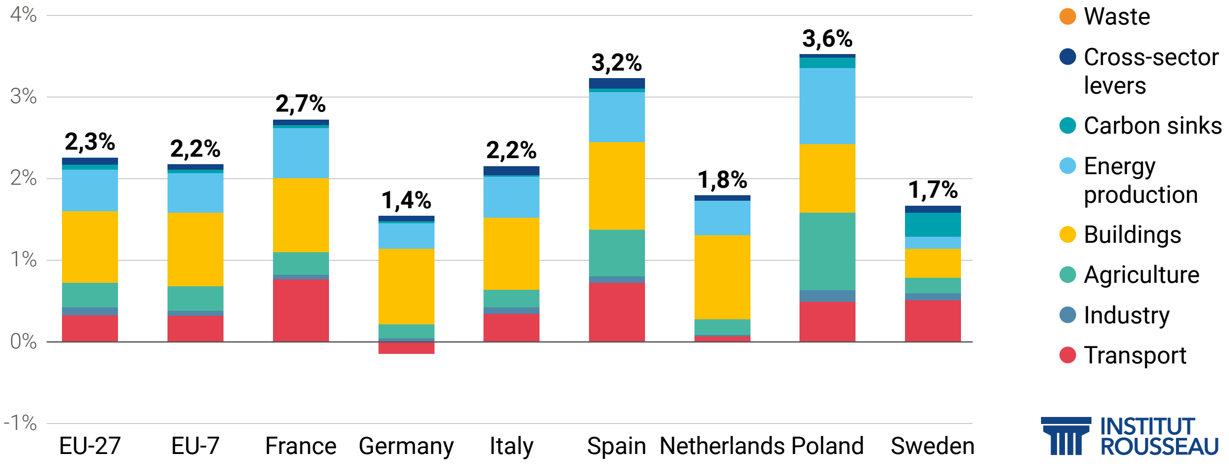


Figure 2.8 shows how these extra investments may vary from one country to another in % of their GDP.

Fig. 2.8 **Yearly extra investment needed by sector per country (in % of GDP 2022)**

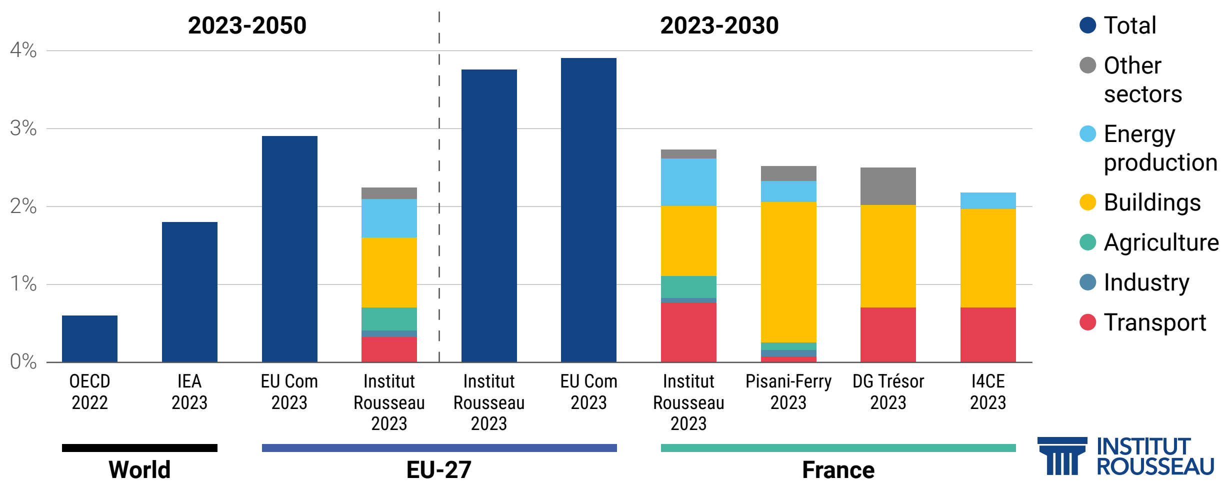


The divergences in the sectoral breakdown are mainly explained by the relative level of carbon intensity between each sector and country. For Germany and the Netherlands, the weight of transport investments is limited due to well-established public transport infrastructure and greater opportunities for reducing road transport costs (through fleet size reduction and average vehicle size), while for France and Spain, substantial efforts are needed to extend railway network and soft mobility infrastructure. Poland shows a comparatively higher level of extra investment needs, mostly due to the strong carbon intensity of its current energy mix and a very high agricultural area/GDP ratio.

1.2.3 How does it compare to existing benchmarks?

The figures presented above are comparable to existing benchmarks in the field. Figure 2.9 recaps estimates from various studies.

Fig. 2.9 **Comparing average yearly transition investment and extra investment as a percentage of GDP[7], according to various studies for the world, EU-27 and the illustration of France**



In terms of magnitude, the results align with international work by reputable institutions such as the International Energy Agency, the OECD and the European Commission. While not depicted in this graph, these studies mask significant variations in the required distribution of these investment levels across different economic sectors. **The study's significant strengths include a precise and well-substantiated breakdown of sector-specific investment needs, addressing each decarbonisation lever. Additionally, it goes beyond total investments, offering detailed insights into public expenditures for over 70 specific measures – an aspect overlooked in other studies.**

Box 2.1

Carbon efficiency of the proposed investments

This study reveals varying effectiveness in investment and extra investment across sectors. This 'carbon efficiency of investments' aligns with the concept of abatement cost, categorising investments based on emission reductions. Although similar, the distinct scope and calculation methods prevent their direct combination. This data helps to prioritise investments over time toward the most effective strategies and measures to minimise CO_2-eq emissions from now until 2050.

However, this study avoids establishing a carbon efficiency priority order and advocates that all of the investments presented are necessary for climate objectives, emphasising simultaneous and swift execution. Compliance with the Paris Agreement, Europe's resilience, and energy independence, are crucial. A transition guided solely by cost efficiency, risking insufficient emission reduction, would undermine the fight against the ongoing catastrophe. Weak action leads to predicted disasters, and governments, including European, have demonstrated the capacity to allocate resources for what they considered to be major threats (the financial crisis of 2009, COVID-19, the current energy crisis). **The focus should not be on choosing between sectoral transitions but on finding means to pursue all of them.**

2 How can public authorities promote and facilitate this transition? What extra costs might the public incur?

After clarifying the required investment for Europe's net zero goal, attention turns to the role and potential costs for public authorities in supporting this transition. The Member States have a dual duty: safeguarding current and future generations from climate and environmental challenges, and playing a pivotal role in formulating and implementing long-term strategies. **This study outlines 73 policy proposals categorised for each of the 37 decarbonisation levers.** Detailed explanations of these measures can be found in the relevant sections on sector-specific investment requirements.

Trend public investment should double from €250 billion to €510 billion per year.

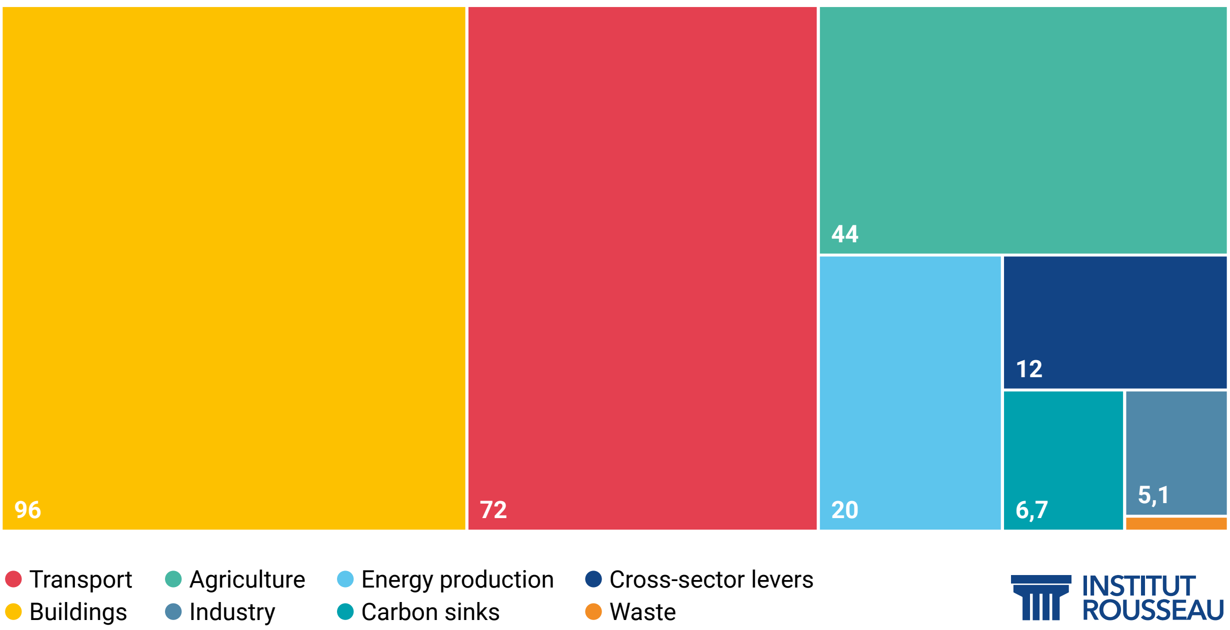
The sectoral breakdown of the €510 billion investment reveals that two sectors, buildings (35%) and transport (27%), account for two thirds of the required public investment. When agriculture is included (21%), said three sectors amount to a total of 84% of essential public investments. Logically, the first two include both mass sectors, where public intervention is required for change to take place. The strong variation between sectors can be summed up in three distinct groups:

- **Four sectors heavily reliant on public investment for decarbonisation**, including waste (primarily requiring investment in selective collection), cross-sector public measures (public by definition), and agriculture and carbon sinks. Both latter sectors intentionally emphasise public costs as a proxy for total investments.
- **The industry and buildings sectors demonstrate a fairly balanced distribution of efforts** between the public and private sectors, with a 40-45% ratio.
- **The transport and energy sectors require a lower rate of public intervention**, hovering at around 20%. This is due to the relatively greater maturity of the decarbonisation levers and their higher profitability for the private sector.

These ratios should be treated with caution and are maximum figures as all the investments made by private players (in particular farmers and private forest owners) have not always been fully assessed.

The rankings and relative shares remain mostly the same when considering the €260 billion per year of extra public investment (Figure 2.10), with the same two sectors alone accounting for two third of extra public investment needs: buildings (38%) and transport (28%). Agriculture (17%), energy production and infrastructure (8%) and cross-sector measures (5%) come next. The ranking remains consistent with total public investment needs, since public support allocations are generally calculated within the same scope between the transition and reference scenarios. The proportions between items representing significant public investment (such as vehicle conversion premiums, aid for building renovation, support under pillar 1 of the Common Agricultural Policy, and public R&D budgets) and those requiring more moderate investment are broadly maintained from one trajectory to the next.

Fig. 2.10 **Yearly extra public investment to be released by sector (in €billion per year)**[8]



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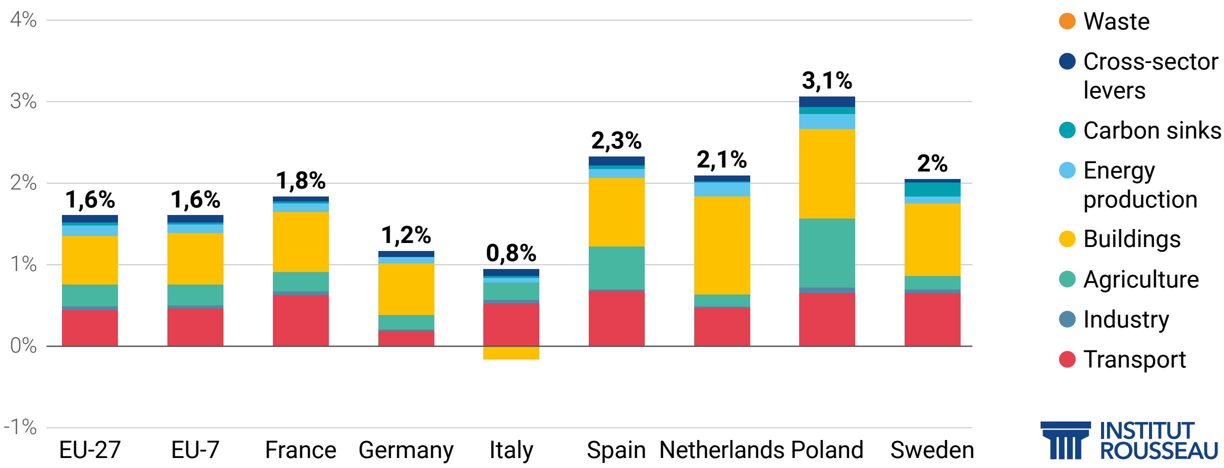
The gap between the total extra investment and the public extra investment needed is driven by factors relative to each sector. Firstly, while energy production was the second sector in terms of extra investment needs, its weight in extra public investment is diminished due to renewable power capacity requiring decreasing public support in a context of improved maturity and rising market prices. The building sector represents the main bulk of extra public investment needs, due to a need to at least quadruple the current pace of efficient renovations which are most often only carried out provided significant public support. Furthermore, the extra public investment needs for the agriculture sector and cross-sectoral levers are equal to the extra investment needs, as these two sectors mainly use public expenditures as proxy for total investments.

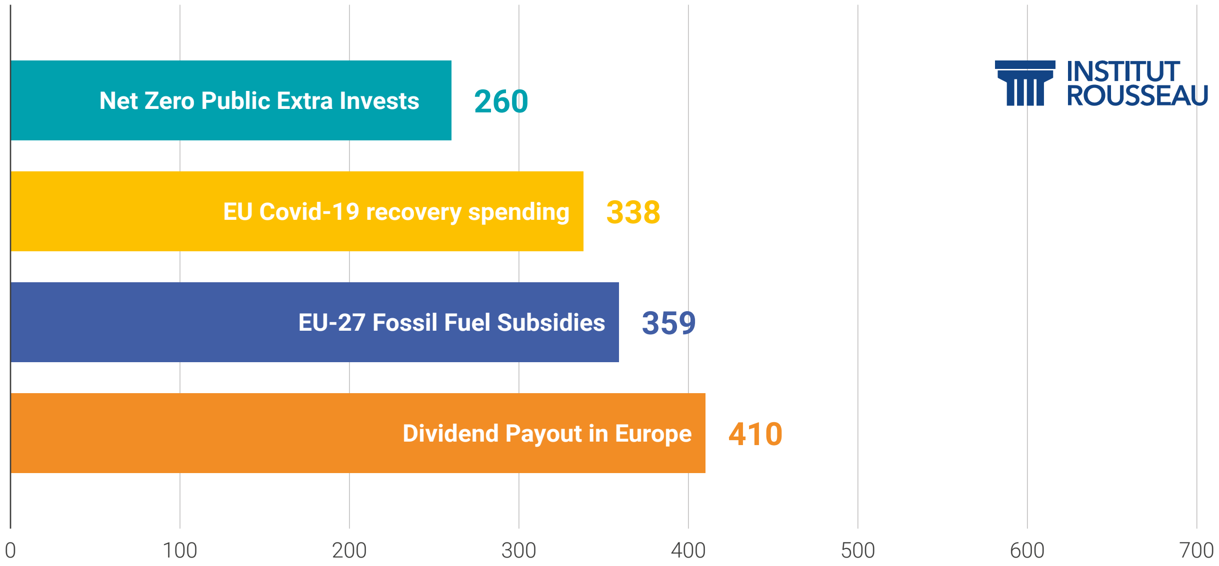
Fig. 2.11 **Yearly public extra investment needed by sector per country (in % of GDP 2022)**



Germany requires relatively modest additional public investments, thanks to its already substantial current spending on existing public transport infrastructure and a comparatively low ratio of agricultural area to GDP. In contrast, Poland exhibits a much higher level of additional public investment needs, driven primarily by a substantial ratio of agricultural area to GDP and, secondarily, a significant proportion of energy-intensive buildings necessitating renovation (with both the agriculture and buildings sectors demanding substantial public support). Italy's 'negative' additional public cost for buildings is attributed to the 2020 launch of the 'Superbonus 110%', resulting in extensive and uncontrolled tax credit commitments. Excluding this specific factor, Italy's additional public investment needs would align with the EU-27 average.

Contextualising the proposed €260 billion per year is crucial. This amount, allocated to empower public authorities in stimulating, encouraging, and overseeing all stakeholders while setting the necessary pace to meet the European Union's climate objectives, must be viewed in perspective.

Fig. 2.12 **Contrasting extra public investment with known yearly budget**



These amounts compare to the potential **cost of inaction which could reach €120 billion per year in a 2°C scenario to €190 billion per year in a 3°C scenario**[9].

3 What levels of investment are needed between now and 2030 to bring Europe into line with Fit-for-55 European targets?

Although this study focuses on achieving carbon neutrality by 2050, the impact of the Fit-for-55 objective on sectoral change and investment needs between now and 2030 can be assessed. Europe's impact on climate change will depend on the cumulated volume of GHG emitted between now and 2050. **A front-loaded effort in the early years can significantly influence the outcome from a climate perspective**.

Meeting the Fit-for-55 2030 objective means that 43% of total GHG reductions needed by 2050 must be achieved within the next 7 years. This means a +70% increase in the GHG yearly reduction pace compared to the 2050 target[10] (-183 versus -110 $MtCO_2$-eq/year). It is also three times higher than what has been observed in the last decade and four times higher than the reduction pace observed since 1990.

These ambitious targets necessitate accelerated decarbonisation across all sectors before 2030. As shown on Figure 2.9, extrapolating necessary investments to this accelerated pace leads to a rise in yearly average extra-investment from 2,3% to 3,8% of current EU-27 GDP, from ~ €1500 to ~ €2500 billion per year.

Pre-2030 emissions reduction could be maximised by efficiently prioritising decarbonisation efforts. This doesn't mean investing only in most efficient levers but immediately and massively deploying mature solutions while prioritising most carbon-efficient uses of maturing technologies. In the building sector, initial investment should focus on renovating poorly performing buildings. In energy production, the priority lies in deploying low-carbon production capacity and adapting the network for closing fossil-fired power stations. Green gas production until 2030 should mainly serve industrial uses with limited alternatives. For industry, activating mature decarbonisation levers (circular economy, energy efficiency) is crucial to compensate for less mature solutions.

However, with a constrained time frame until 2030 and practical hurdles in deploying certain solutions (e.g., efficient building renovations), coupled with regulatory renegotiation periods (e.g., the Common Agricultural Policy already set for 2023-2027), **achieving the Fit-for-55 objective is very doubtful without prompt and decisive actions, akin to a wartime economy**. Missing the target would necessitate an intensified decarbonisation effort post-2030 to align with the allocated carbon budget.

Notes

1. European Commission, 'Fit for 55': delivering on the proposals.

2. European Environmental Agency (EEA), GHG data viewer, visited in November 2023.

3. Rising gas prices prompted energy savings in the buildings sector, while output decreases in energy-intensive industries led to a significant emission reduction. However, emissions in the power sector increased due to a partial shift to more carbon-intensive coal generation. For more details about the French case, see Éclaircies, 'L'Affaire du Siècle, l'Etat a-t-il réparé le préjudice écologique ? Analyse des causes conjoncturelles et structurelles des baisses d'émissions 2021-2022', 2023.

4. European Environment Agency, 2023, 'Total net greenhouse gas emission trends and projections in Europe'.

5. National 2022 GDP, Eurostat, 2023.

6. European Parliament, 'EU ban on the sale of new petrol and diesel cars from 2035 explained', 2022.

7. 2021 GDP was used for Institut Rousseau's results.

8. These costs, borne by the EU, the Member States and, in several instances, local authorities, are not addressed individually.

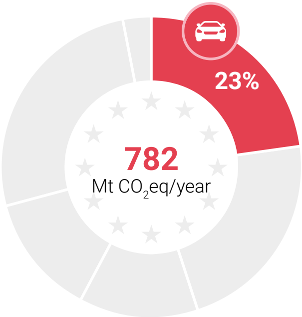
9. Joint Research Center, 2014, Climate Impacts in Europe.

10. I.e. a -85% gross emissions reduction compared to 1990, in RtoNZ transition scenario.

Investments in the transport sector

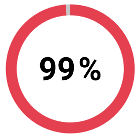
Developing an alternative to the all-car fossil-based transportation model

Current emissions and reduction potential



Decarbonisation levers to mobilise:

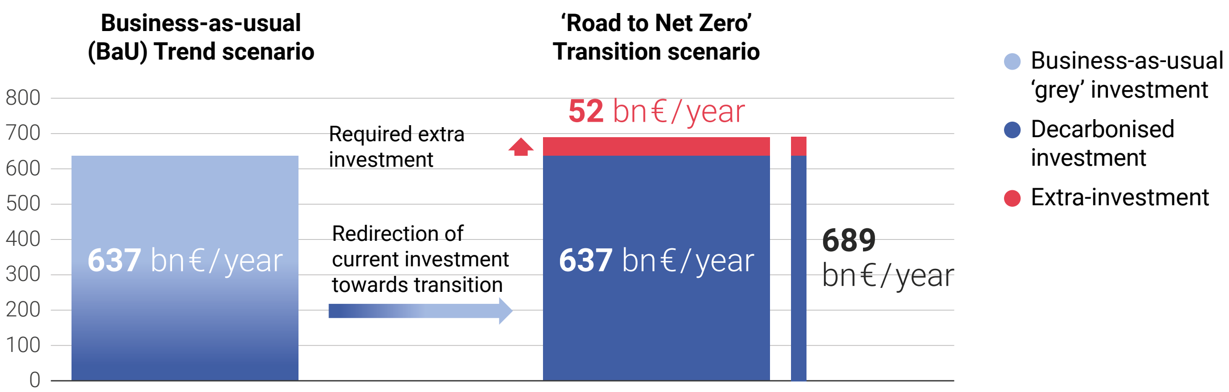
1. Reduce the number of vehicles and convert them to low-carbon technologies
2. Develop public transportation
3. Develop soft mobility
4. Reduce air traffic and switch and Sustainable Aviation Fuels
5. Transition to zero carbon navigation



2050 decarbonisation potential

Global investment needs

UE-27 global investment and extra-investment



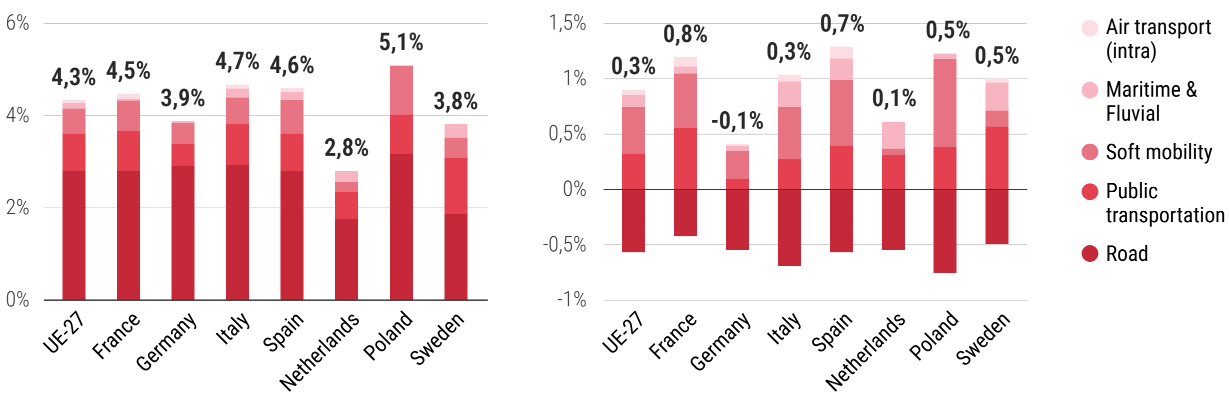
Global investment and extra-investment per lever, per country (in % of GDP):

Total investment

4,3%

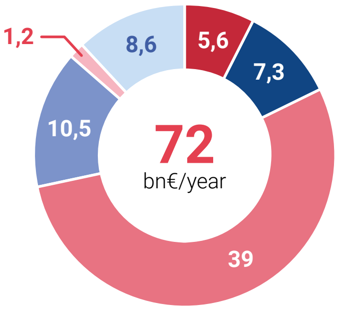
Total extra-investment

0,3%



Public investment needs

Total public investment in proposed public policies	Public share in total investment	Public extra-investment in % GDP
140 bn€/year	20%	0,45%



Total extra public investment in proposed public policies : 72 bn€/year

- Conversion bonus
- Charging network
- Rail and bus infrastructure
- Bike plan
- Air transport
- Maritime & fluvial

Complementary measures:

+ Tax measures to lower public transportation cost
+ Eliminate tax incentives for aviation and reinforcing truck tolls
+ Ban flights with modal alternatives < 4h30 ; Moratorium on new airport infrastructure
+ Imposing quotas for the incorporation of Sustainable Aviation Fuels in aeroplanes

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT	
TOTAL	EXTRA	TOTAL	EXTRA
45%	14%	27%	28%

Key takeaways

- **The transport sector necessitates the highest total investment at €689 billion per year, with a relatively modest additional cost of +8%.**
- **Public expenditures must double, constituting ~20% of the total investment.**
- **Through those strategic investments, a complete decarbonisation is possible.**
- **Road transport requires 65% of transport investments, at €447 billion per year, while public transport stands as the primary contributor to public expenditures at €82 billion per year.**
- **There is no silver bullet to replace cars. If an ambitious modal shift development policy is crucial, with €50 billion per year, an integrated transportation system must also include new intermediate vehicles, sharing services and a new approach to urbanisation.**
- **On top of investment in infrastructure, fiscal measures are imperative to enhance the economic competitiveness of trains.**
- **The unrestrained increase in air traffic must be halted and a democratic debate should determine the appropriate level of sufficiency.**

The transport sector necessitates the highest total investment at €689 billion per year, with a relatively modest additional cost of +8%.

The transport sector is the second greenhouse gas emitter in Europe (after energy production). It contributed 782 million tons of CO_2-eq in 2021 (Figure 3.1.), nearly a quarter of the European Union's emissions. The estimated total investment required to fully decarbonise the sector is €689 billion annually, but represents a proportionally limited €52 billion extra cost compared to the business-as-usual scenario (+8%).

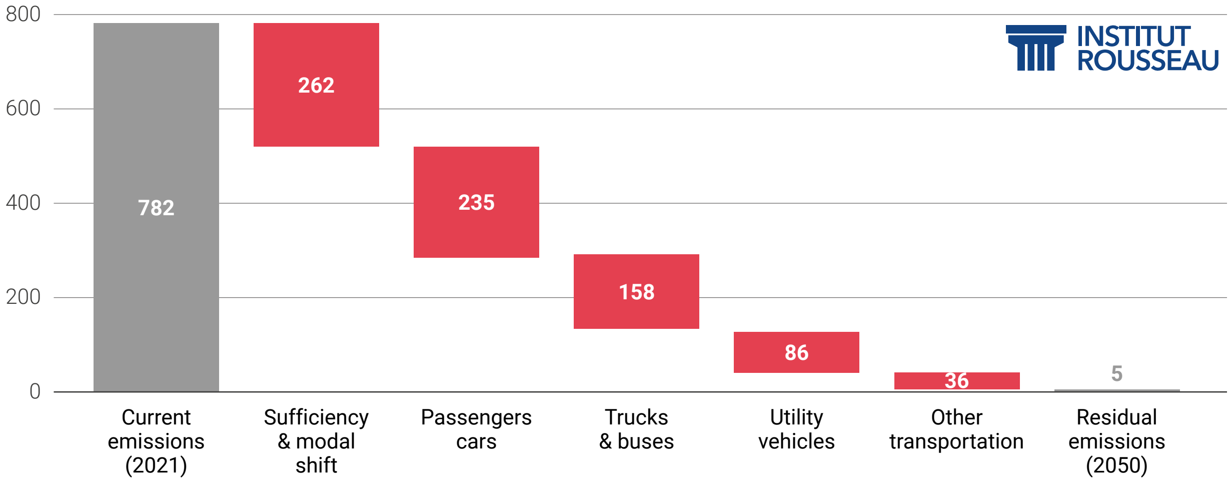
Public expenditures must double, to amount to ~20% of the total investment.

The required public investment for the transition reaches €140 billion annually, representing 20% of the total required investment. This includes an extra €72 billion compared to the business-as-usual scenario (+105%).

Such investments would enable the near-complete decarbonisation of the sector by 2050, through the implementation of the two following complementary measures:

- **The facilitation and acceleration of sufficiency and modal shift** from highly polluting transport modes to less polluting alternatives (e.g., from planes to trains, cars to public transportation, and bicycles), which would result in **a 34% emission reduction**.
- **The conversion of all remaining vehicles into low-carbon alternatives**, including 326 million vehicles (76% passenger cars, 13% powered two-wheelers, 9% utility vehicles, and 2% heavy-duty trucks, excluding boats and planes), which would result in **an 65% reduction in the sector's emissions**.

Fig. 3.1 Emissions reduction scenario in transportation (in $MtCO_2eq$)



A new sufficiency-based transportation system is not only about moving towards more fuel-efficient vehicles, nor only about trains and bikes. It must be approached in an integrated manner, combining various solutions:

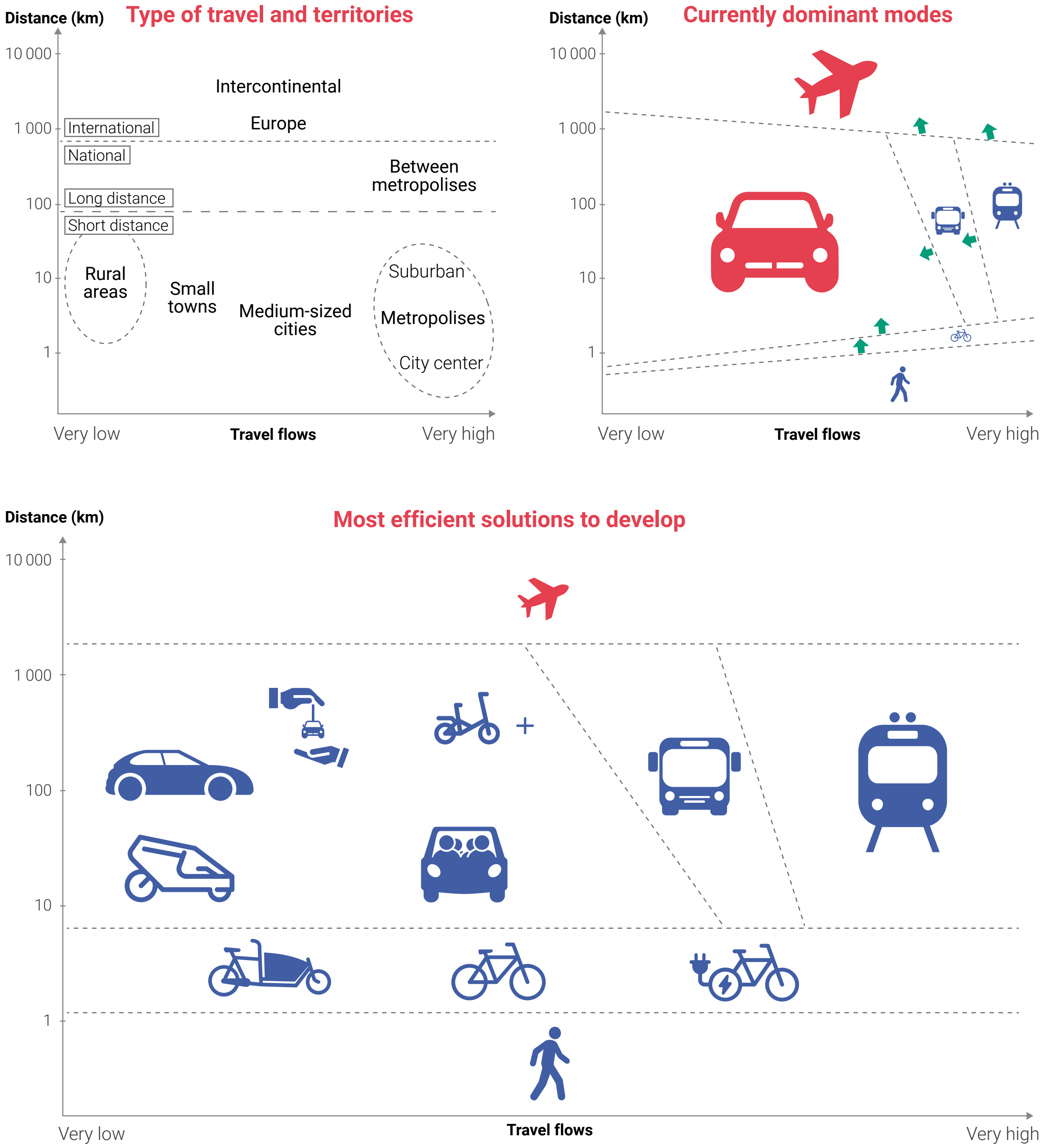
There is no magic solution to replace cars. A combination of several modes and vehicles is necessary to address the specific needs of various households, regions, and types of journeys, as illustrated in Figure 3.2. These include:

- **Reducing car and battery sizes;**
- **Developing intermediate vehicles**[1] between bikes and cars, with significant potential for transitioning from traditional cars. This is especially relevant in cases of oversizing such as solo commuting, which affects 64% of home-to-work trips, single-person households, secondary vehicles for multi-mo-

torised households, low and medium-density areas with a strong car dependence and limited alternatives;

- **Developing carpooling and car-sharing** services;
- **Implementing aviation sufficiency** (see 3.2.3);
- **Revising the conventional approach to urbanism**, by reconfiguring activities (housing, work, commerce) so that they mix at all scales and by decentralising territorial planning, etc;
- **Divesting from conventional solutions**: road infrastructure, airport expansions, urban sprawl, large vehicles.

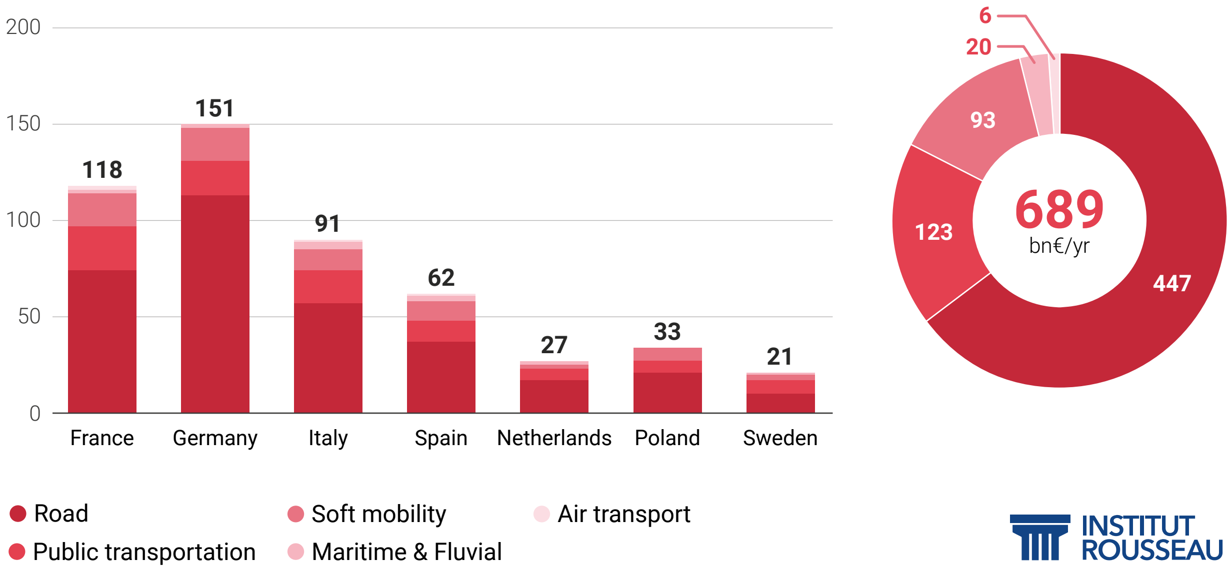
Fig. 3.2 **The future of transport: sufficiency and multi-modality**[2]



Source: adapted from Aurélien Bigo.

Road transport requires 65% of transport investments, at €447 billion per year, while public transport stands as the primary contributor to public expenditures at €82 billion per year.

Fig. 3.3 Annual investment required to decarbonise transportation (in €billion per year), by country



Investment varies between countries according to the vehicles requiring conversion and the current state of alternative transport infrastructure development (charging stations, railway extensions, soft mobility initiatives).

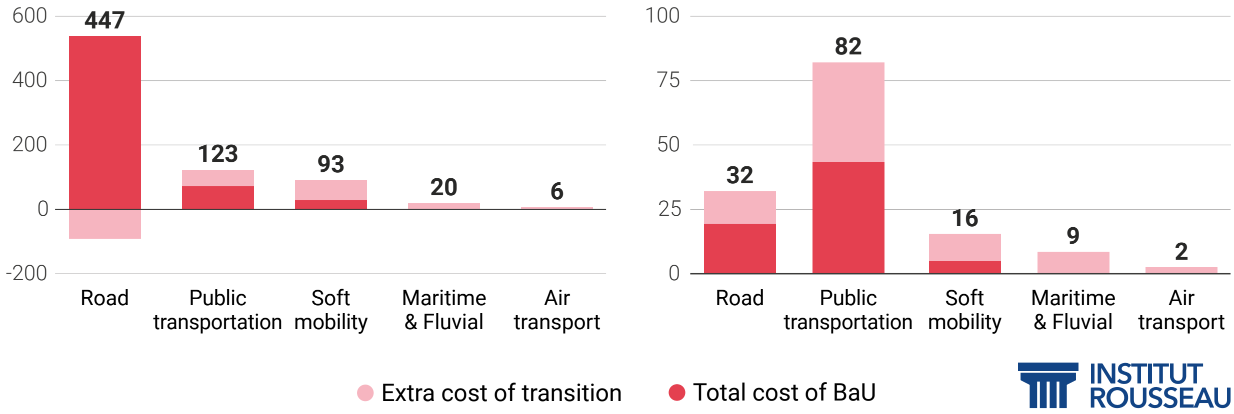
Renewing the vehicle fleet would cost €447 billion per year, representing 65% of the sector's total investments. This means saving €92 billion per year (-17%) compared to the business-as-usual scenario. This would be mainly due to the 14% reduction in fleet size by 2050, through sufficiency and the modal shift to public transport, rail and soft mobility. Conversely, public support for the complete decarbonisation of vehicle fleets by 2050 (through low-carbon vehicle purchase bonus for both individuals and businesses, as well as for charging station installations) requires an increase of €13 billion annually (+66%), totaling €32 billion per year and accounting for 23% of the sector's overall public costs.

Developing public transport and rail has the second highest cost for the transition, at €123 billion per year, representing a €52 billion extra cost compared to the business-as-usual scenario (+74%) and for 18% of the sector's total investments. The high public share of these investments (67%) supports the development of rail, trams, metros, and buses. This investment amounts to €82 billion per year and represents an annual extra cost of €39 billion (+89%) compared to the business-as-usual scenario. **It would represent the largest portion (58%) of the sector's total public costs.**

This is followed by **soft mobility** at €93 billion per year, representing an extra cost of €66 billion (+241%) compared to the business-as-usual scenario. Public investments totaling €16 billion per year (+206% compared to the BaU scenario) primarily focus on the expansion of cycling lanes and bike parking facilities, as well as support for bicycle purchases.

The extra costs to decarbonise **inland navigation and internal domestic aviation** are estimated at €20 billion and €6 billion per year, respectively.

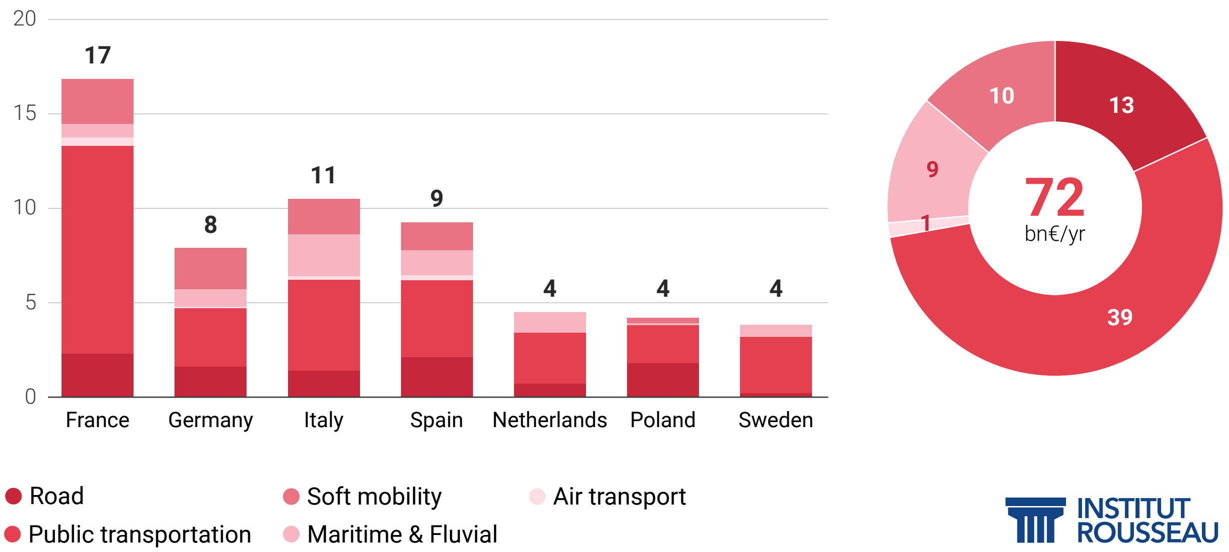
Fig. 3.4 **EU-27 Total (left) and Public (right) annual investment and extra-investment required to decarbonise the transport sector (in €billion per year), per sub-sector**



Decarbonising the transport sector requires €72 billion per year in extra public investments, distributed unevenly among countries.

The required extra public investments vary greatly between countries (Figure 3.5.), mainly due to the gap between required vs. current public transportation investments. Specifically, the expansion of rail transport heavily relies on the quality of the existing rail network and the necessary extensions and interconnections to enable an effective modal shift (both passengers and freight) across all European Union countries. For instance, France needs to expand its rail network substantially but so far has announced very low investments in the sector. In contrast, Germany, with lower expansion requirements, already invests significantly, bolstered by robust public support.

Fig. 3.5 **Public extra-investments by country for decarbonising the transportation sector (in €billion per year)**

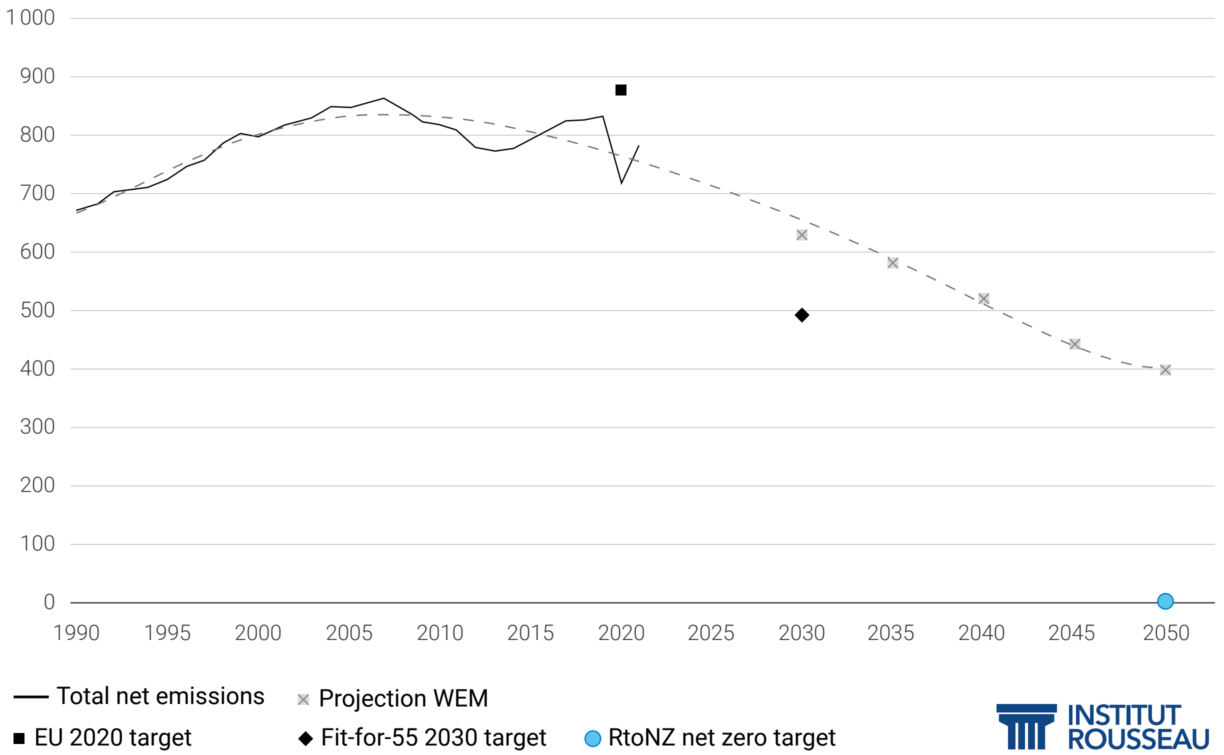


1 Emissions of the sector

Transport emissions account for 22,5% of total emissions, ranking second after energy production. It is the only sector in which emissions have increased since the 1990s.

In 2021, transport emissions totaled 782 $MtCO_2$-eq, a 16% increase from 1990, making it the only sector with rising emissions over that period. **Despite a 14% reduction in emissions in 2020 due to the pandemic, there was an 8.6% rebound in 2021 (followed by a 2.7% increase in 2022[3]). To meet the 2050 target, the average reduction rate observed in the last decade must be multiplied by 10.** Projections based on existing policy measures indicate that meeting either of 2030 and 2050 targets is currently extremely unlikely, as illustrated in Figure 3.6.

Fig. 3.5 Transport past UE-27 domestic emissions and progress towards achieving 2030 and 2050 targets, in million tons of CO$_2$ equivalent ($MtCO_2e$).[3]



WEM: With Existing Measures.

2 How to decarbonise the sector and how much investment does it require?

2.1 Reduce the number of vehicles and convert them to low-carbon technologies

With 325 million vehicles, of which 248 million of private cars, road transport accounts for over 90% of emissions from intra-European transport.

These exclude buses and coaches, treated in Subsection 3.2.2. Consequently, decarbonising vehicle fleets is crucial to achieve the European Union's 2050 Net Zero carbon goals. It is achieved through:

- **an overall reduction in the number of vehicles in circulation**, mainly enabled by increased occupancy rates, car pooling and sharing, and modal shift to public transportation;
- **the replacement of remaining vehicles with low-carbon vehicles** (electric, hydrogen, or bioCNG-powered).

A reduction in the average size and weight of vehicles is also needed, as switching to these technologies entails a significant increase in the consumption of metals and resources, especially for batteries (cf. Appendix A.2).

The rapid uptake of low-carbon vehicles by 2035 relies on both expected cost parity between traditional and electric vehicles to be reached before 2030, and regulatory bans of thermal vehicles.

With an average vehicle lifespan of 15 years, the proposed transition scenarios (Figure 3.7.) marks 2035 as the deadline to stop selling thermal vehicles (including hybrids) in order to guarantee a decarbonised fleet by 2050.

Price parity is assumed in terms of purchase prices or total cost of ownership (TCO), depending on the vehicle type, as shown on Figure 3.7. The ban of conventional Internal Combustion Engines (ICE) sales by 2035 has already been voted on for private cars and Light Commercial Vehicles. A similar ban is recommended and considered for trucks by 2037 in the transition scenario.

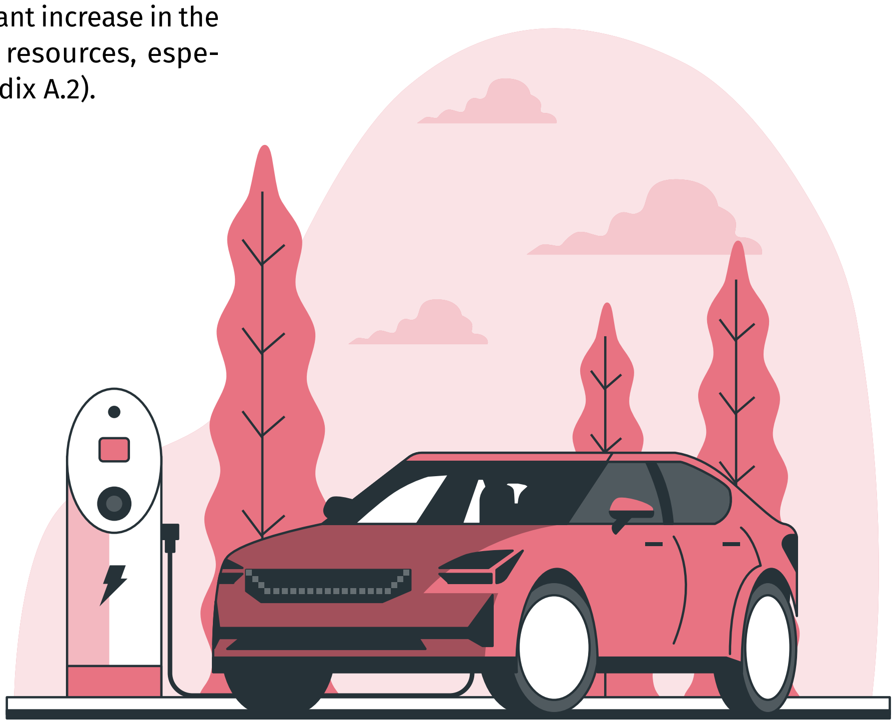


Fig. 3.7 **Key milestones considered for the decarbonisation of vehicle fleets**

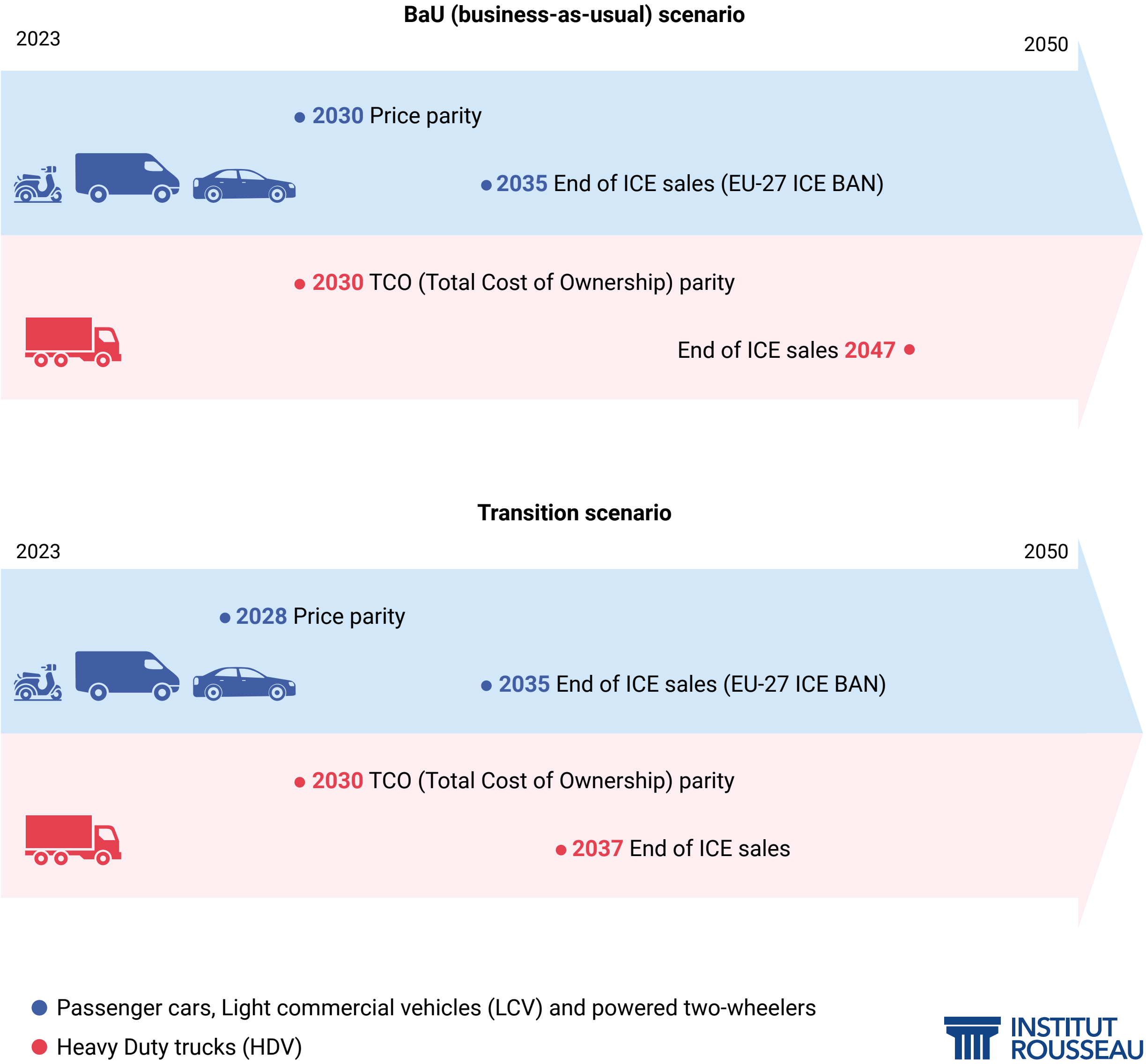
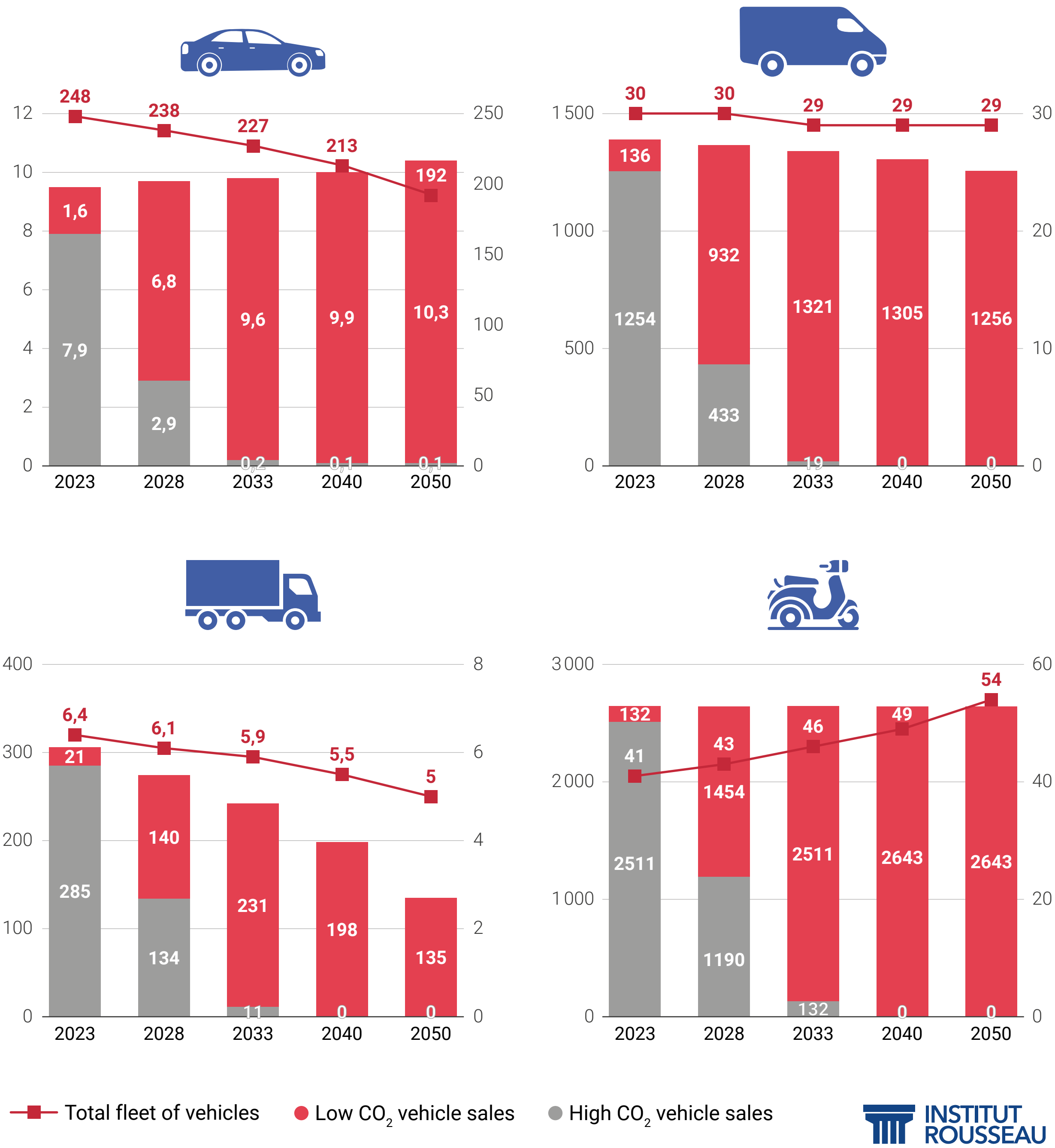


Figure 3.8. illustrates the outcomes of these milestones in terms of sales for conventional versus low-carbon vehicles and the overall fleet sizes in the transition scenario.

Fig. 3.8 **Transition scenarios fleet sizes and yearly sales, per vehicle type**



Implementing such measures (with a total cost of €417 billion per year) yields a 19% cost saving (- €95 billion per year) compared to the business-as-usual trend.

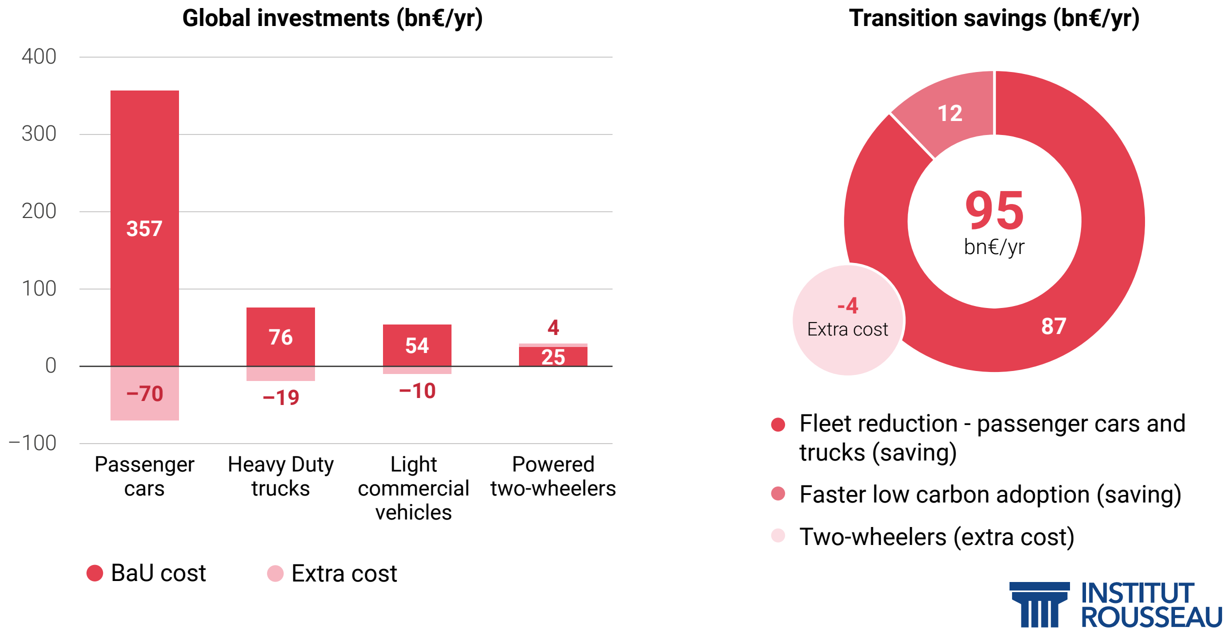
This substantial saving, coupled with its significant greenhouse gas emission reductions, underscores the urgency of prompt implementation. This cost reduction primarily stems from:

- **A significant decrease in vehicle fleets** (-23% passenger cars, -21% heavy-duty trucks, -3% light commercial vehicles) achieved through modal shift to public transportation, particularly trains, resulting in a yearly savings of - €87 billion per year.

- **Faster adoption of electric vehicles**, further reducing prices, especially for batteries, and achieving earlier price parity. It would also include making smaller batteries **for equivalent models** (facilitated by technological advancements) (- €12 billion per year), rather than an increase in power/autonomy.

- Partly offset by a 31% increase in the fleet size of two-wheelers (+ €4 billion per year).

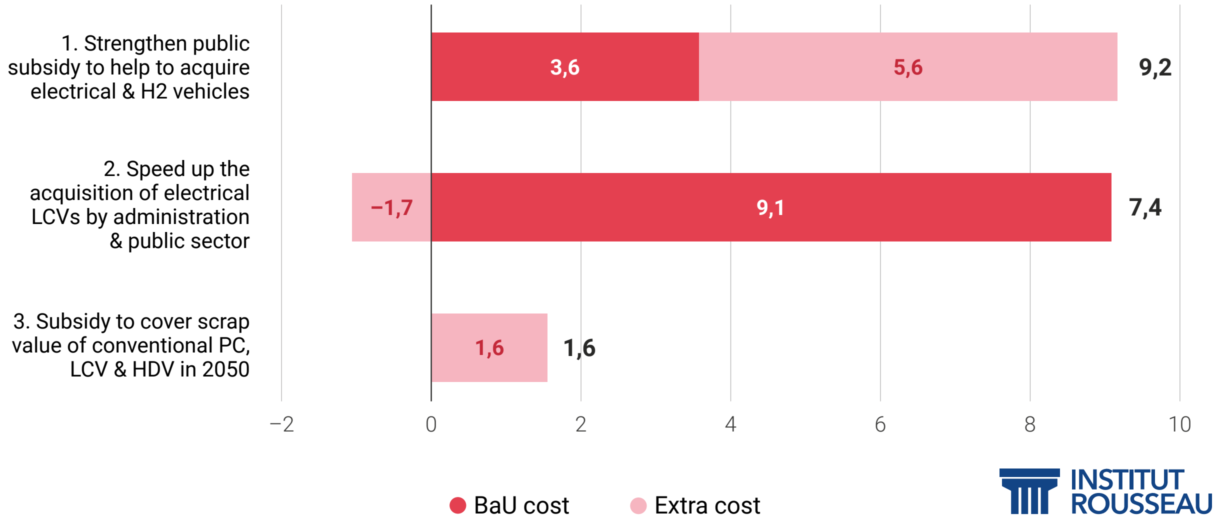
Fig. 3.9 **Annual investment and extra-investment required for the decarbonisation of road transport (in € billion per year)**



Implementing this transition scenario necessitates a public investment of €18.2 billion per year, with an additional cost of €5.5 billion.

This involves three complementary public measures (Figure 3.10): strengthening conversion premiums, converting public Light Commercial Vehicles fleets to low-carbon technologies, and introducing a scrappage incentive for thermal vehicles still in circulation by 2050.

Fig. 3.10 **Annual public investment and extra-investment to support the transition of road transport (in € billion per year)**



To maximise CO_2 reduction, incentives are focused exclusively on electric and H2 vehicles, with the aim to phase out hybrids by 2035. Subsidy programs will adjust to cover 80% of the price gap[5] for passenger cars, light commercial vehicles and powered two-wheelers (PC, LCV, PTW) and 100% of TCO gap for heavy-duty vehicles (HDV)[6]. This adaptability considers market dynamics and expected price reductions for low-carbon vehicles. Assuming current conditions, these programs should be phased out once price parity is reached, estimated between 2028 and 2031 for PC, LCV & PTW. For HDVs, with TCO uncertainties in mind, the subsidy program should end in 2037, aligning with the proposed ban on conventional HDV sales. Implementation prioritises targeted subsidies to low-income and large families, to SMEs (as opposed to large corporations), and for light weight vehicle purchases.

Measure 3.1

Enhance Eco Conversion Bonus/Subsidy for incentivising low-carbon vehicle purchases

Public cost
€9.2 billion per year
Public extra-cost
€5.6 billion per year, primarily allocated by 2035[6]

The LCV Fleets owned by public administrations comprises 10% to 25% of the overall LCV fleet, depending on countries. Governments should conduct tenders with criteria promoting rapid transition from carbon-intensive to electric and hydrogen fleets, incorporating necessary fleet reduction measures.

Measure 3.2

Accelerate the decarbonisation of LCV Fleets owned by public administrations

Public cost
€7.4 billion per year
Public extra-cost
€-1.7 billion per year

To ensure the complete decarbonisation of the rolling vehicle segment in the long term, it is also proposed to buy back the residual fleets of conventional vehicles from households and businesses, at approximately 10% of their purchase price.

Measure 3.3

Provision of public funds for the long-term buyback (by 2050) of the Remaining Conventional Vehicle Fleets

Public extra-cost
€1.6 billion per year

Complementary tax measures (CO_2 malus and weight tax) could accelerate the fleet decarbonisation and fund the corresponding public extra costs.

+ €1.2 billion per year[8]: tax on Conventional PC/HDV: based on an average 9 €/g CO_2/km penalty (~ €1200 average penalty per vehicle). The tax should be progressive, targeting high-emission vehicles like SUVs.

+ €13.7 billion per year: Implementation of a weight tax on the acquisition of any new PC at €10/kg commencing at 1300 kg for conventional vehicles and 1600 kg for zero-carbon ones (hydrogen, electric)[9]

Best Practices

The Netherlands boasts one of the EU's highest acquisition taxation systems (BPM[9]) for high-emission personal cars. With a low taxation threshold (86 gCO_2/km) and a progressive structure targeting such vehicles, a typical conventional SUV emitting 150 gCO_2/km faces an €8,700 acquisition tax, translating to a nearly 25% increase in the vehicle's pre-tax cost. This taxation level significantly surpasses that of most other EU countries.

A rapid and substantial increase in the installation of electric vehicle charging stations and hydrogen infrastructure is essential in the upcoming years.

Investments in electric charging stations (CS) need to increase substantially to reach €24 billion per year. Simultaneously, investment in deploying hydrogen infrastructure, which is virtually non existent today, must reach €7 billion annually on average by 2050. These averages cover the period from now until 2050, with a notable concentration of electric infrastructure investments expected in the current decade. Hydrogen infrastructure is anticipated to see more significant development between 2030 and 2040, considering the technology's current limited deployment.

Measure 3.4

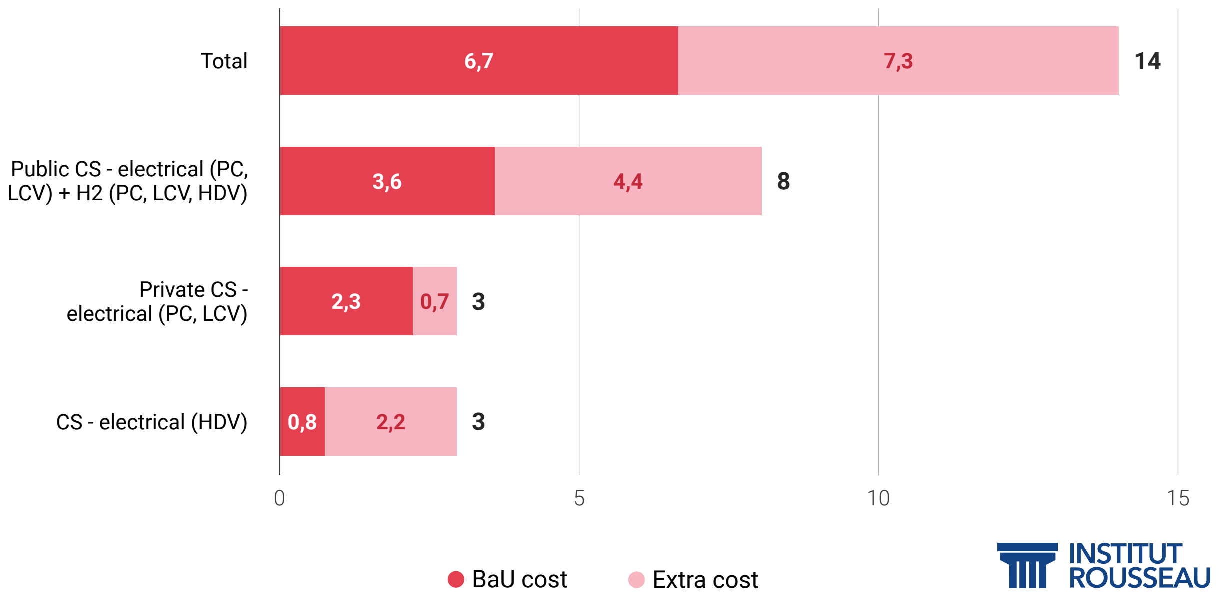
Scale up electric and hydrogen charging infrastructures

Public cost
€14 billion per year
Public extra-cost
€7.3 billion per year

The proposed public investment to support the fast expansion of charging stations is broken down as follows:

1. **Strengthen public investment coverage for the deployment costs of public charging stations**, incurring an extra public cost of €4.4 billion per year (Figure 3.11.) Considering the uncertainty regarding the economic viability of publicly available CS[11], an average subsidy rate of 50% of purchase cost is recommended to attract private investment.

Fig. 3.11 **Annual public investment and extra-investment required for charging stations (in €billion per year)**

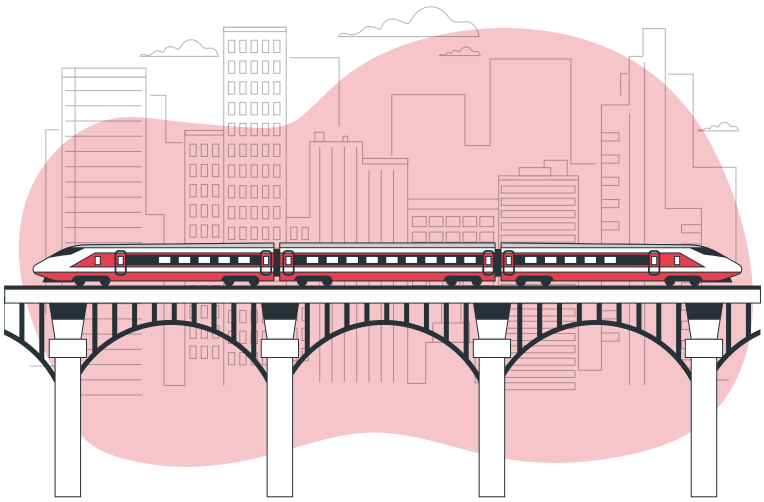


However, to prevent the abuses observed in several countries (opaque and prohibitive pricing of electricity charged to consumers during their vehicle charging[12]), **public authorities and private operators should contractually approve tariffs** before receiving public support. Furthermore, there should be a **comprehensive strategy for implementing charging stations across the EU to avoid creating 'white zones'** in less profitable areas.

2. **Increase grants for the acquisition of private electric charging stations** (households, condominiums, businesses) to cover 50% of the purchase costs on average, resulting in an extra public cost of €0.7 billion per year.

3. **Significantly expand aid programs aimed at electric charging stations for trucks (HDVs)**, targeting a coverage rate of at least 50% (some countries like Sweden and Germany have launched programs covering up to 80% of the costs[13]) for an extra public cost of €2.2 billion per year.

2.2 Develop public transportation



An ambitious public transport development policy is crucial to successfully decarbonise the transportation sector. Through modal shifts, it enables the reduction of the overall number of vehicles in circulation. This, in turn, helps limit the use of resources and metals required to manufacture batteries and charging stations.

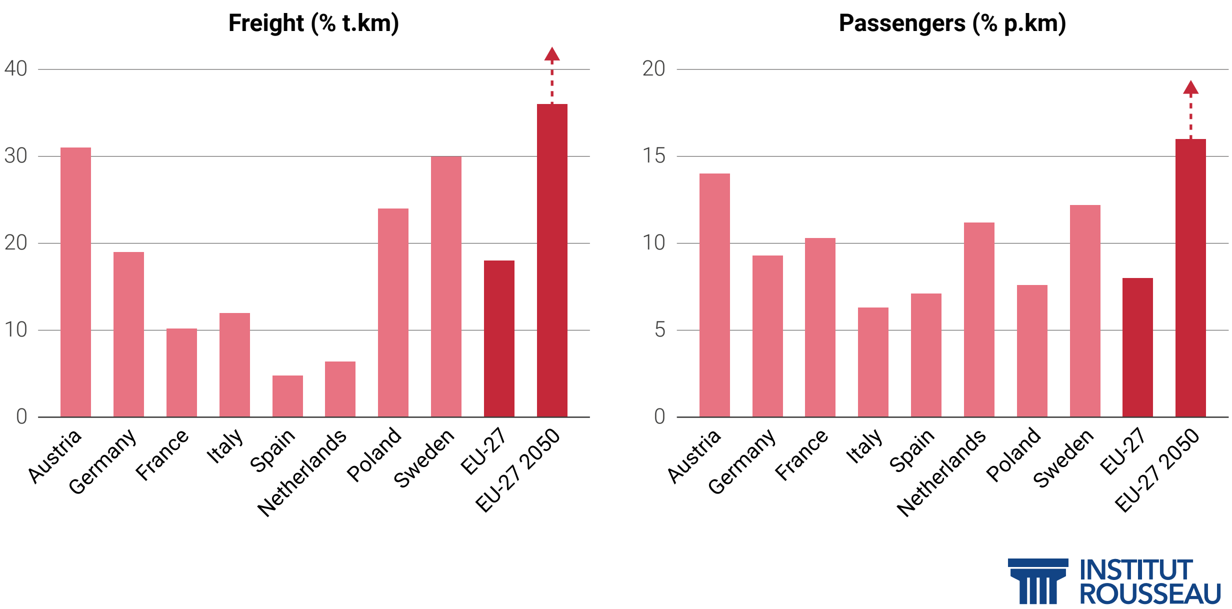
2.2.1 Fully decarbonise the railway and increase railway traffic

Current rail modal shares must at least double by 2050[14], as already targeted by most studied countries.

Trains are crucial to decarbonise challenging segments like medium-distance (air) travel and medium- and long-distance road freight. They offer significant benefits, such as a drastic reduction in energy consumption (75-90% less per km[15]), and help to reduce air and noise pollution. Investing in a more attractive rail network will also reduce maintenance costs (up to -40%[16]) as well as truck fleet conversion costs (see above).

The needed investments for this modal shift are derived from a benchmark mix of top-performing countries, with Austria excelling in both passenger and rail freight efficiency, along with Germany's notable performance in rail freight (Figure 3.12, Box 3.1).[17]

Fig. 3.12 Modal share of train in Europe (2019 and 2050 target)



Best Practices

Reference countries for rail transition scenarios

Austria's high performance in terms of rail is based on an already very developed network (620 km of lines/M of inhabitants vs. 460 km/M of inhabitants on EU average) and massive development and renewal/modernisation investment expenditure (€310/inhabitant/year including 43% for the current network excluding maintenance[17] vs. +- €100/inhabitant/year in UE), 80% supported by public funds (vs. +- 60% on EU average[18]).

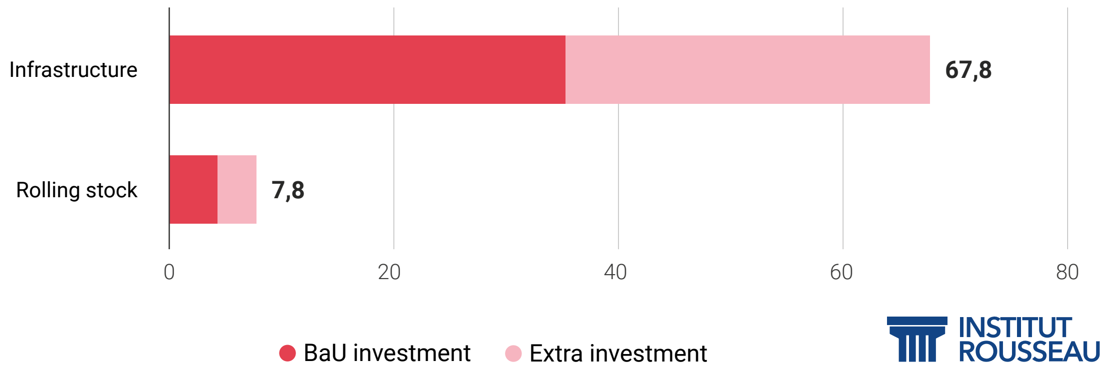
In addition, **Germany** has an expansive rail freight network in relation to its surface area (11 km/100 km^2) and spends €200,000/km to renew and modernise its network. However, Germany is less efficient for long-distance travel and development investments, which are currently limited[19].

For most countries, 'transition' network development is based on a mix of new lines and extensions of existing lines (e.g. doubling of tracks), in order to make possible a doubling of tons and passengers.km[21]. Costs per km are aligned with GDP/inhabitant for renewal/upgrade investments and with the actual costs of ongoing projects for network development. These investments are subsidised by an average 80% public fund support, mirroring high-performing countries. New investments are also considered for rolling stock.

Despite indications in recovery plans signalling a commitment to rail sector development, current investments remain largely insufficient and must double to approach the stated objectives.

At the EU-27 level, public investment for this transition is estimated at €76 billion per year, accounting for roughly 69% of the total required investments and surpassing current sectoral public spending by €36 billion.

Fig. 3.13 **Annual public investment and extra-investment required in rail (in € billion per year)**



Measure 3.5

Double current rail's modal share by 2050

Public cost
€76 billion per year
Public extra-cost
€36 billion per year

Fiscal measures are imperative to enhance the economic competitiveness of trains.

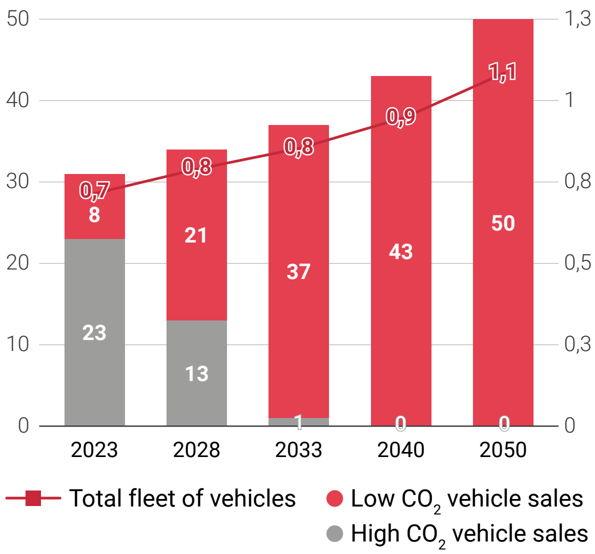
Austria, Switzerland and Germany's rail freight success notably underscores **the critical role of reinforcing truck tolls**[22]**, which should be increased proportionally with the trucks' weight,** especially when a viable rail alternative exists. Additionally, **ceasing tax breaks on kerosene and VAT** could curb air travel support, particularly in medium distances where rail could offer a feasible alternative, with the reinforcement of new night train lines connecting European cities.

2.2.2 Increase and fully decarbonise public transportation by bus and coach

To promote the shift from individual to collective transportation, bus and coach numbers are steadily increasing, set to surpass one million by 2050 (a +48% increase).

The current fleet (accounting for 4% of current intra-EU transport emissions) is swiftly decarbonising, marked by stopping new combustion engine vehicles from entering service by 2027 for buses and 2035 for coaches.

Fig. 3.14 **Transition scenario for buses & coaches (fleet right axis, million vehicles - sales left axis, thousand vehicles)**



Measure 3.6

Increase public investment in buses & coaches

Public cost
€6.5 billion per year
Public extra-cost
€2.6 billion per year

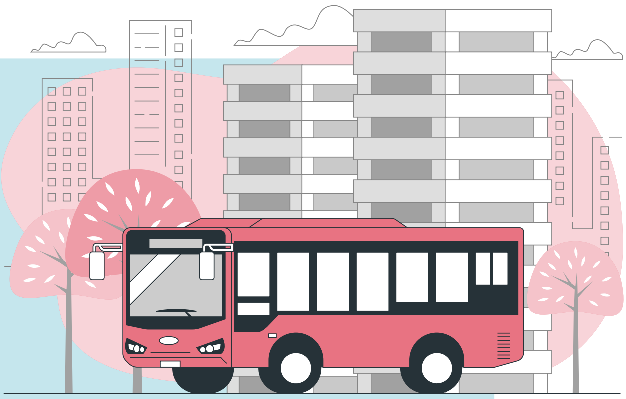
The proposed public investment to support the high expansion of the bus and coach fleet is broken down as follows (Figure 3.15):

- **Public fleet renewal**: €4.4 billion per year, of which an extra €1 billion cost compared to the BaU trend. Public fleets represent between 23% and 50% of national bus and coach fleets, depending on the country considered[23].

- **Additional subsidy programs to convert private fleets to low-carbon vehicles**: €2 billion per year, of which an €1.6 billion extra cost compared to the BaU trend. This program aims to cover approximately 24% of the acquisition costs for low-carbon buses by private actors, drawing inspiration from the policy implemented in Germany.

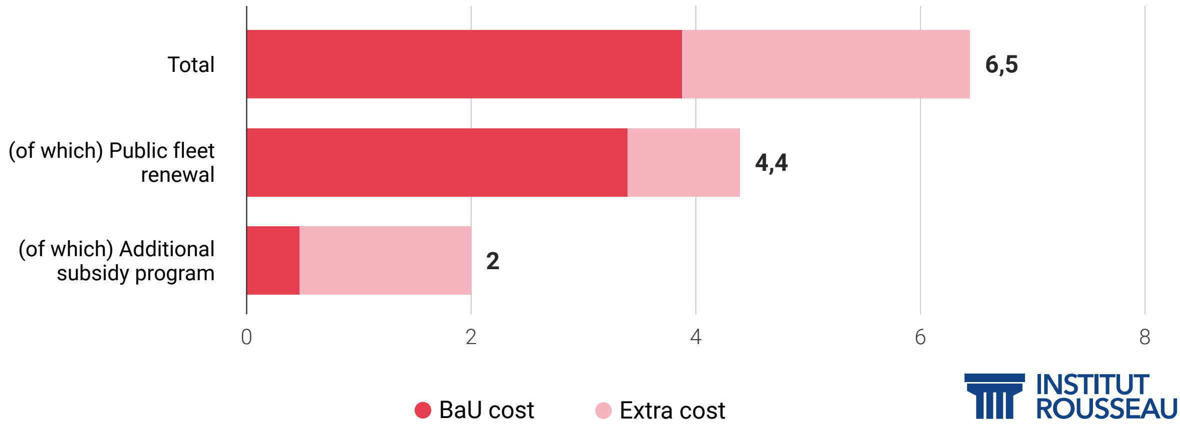
Best Practices

Germany[23] boasts one of the highest dedicated subsidy programs for low-carbon buses in the EU.



- €600 million spent in 2022[24] and €270 million in 2023[25], financing 2,800 low-carbon buses (€310k per vehicle, covering 48% of total average investment cost).
- €1.25 billion committed over 2021-2024 (€417 million per year) for procuring around 3,000 additional buses[26] and associated charging/refuelling infrastructure.

Fig. 3.15 **Annual public investment and extra-investment required in buses and coaches (in €billion per year)**



2.3 Reduce air traffic and switch to Sustainable Aviation Fuels

Global air transport emissions more than doubled over the past 20 years and business-as-usual traffic is expected to triple again by 2050[28]. European traffic is planned to 'only' double.

Fueled by a record growth in traffic, attributed to a substantial rise in passenger numbers and commercial exchange volumes, CO_2-eq emissions from international aviation more than doubled over the past 20 years, increasing by 130% to reach 2.4% of global emissions in pre-COVID 2018.[29, 30]

In this study, only EU domestic emissions are tackled. Thus, only domestic and intra-EU flights are targeted here. In 2019, those flights accounted for 62 tons of CO_2-eq[31], representing 7% of the transport sector and 2% of EU-27 territorial emissions.

Despite having become a symbol of freedom of movement in a globalised world, air travel is, in reality, used by only a tiny minority with the highest incomes.

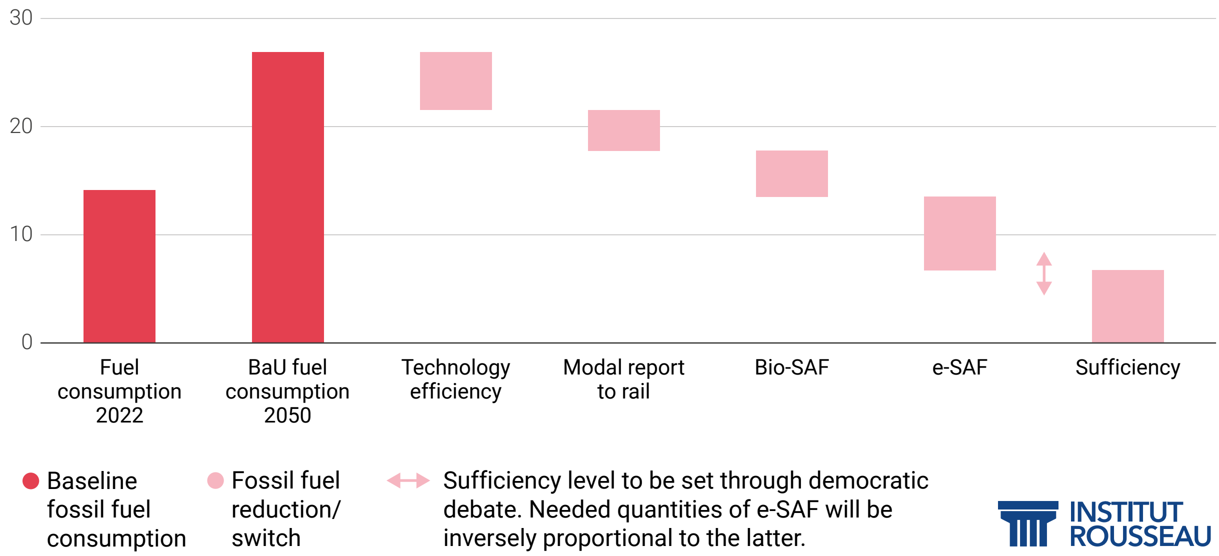
The airplane, as the most emitting mode of transport per km travelled per passenger (with cars), frequently becomes the focal point of debates. This is also because these emissions are highly concentrated within a limited segment of the population: 50% of journeys are undertaken by the top 1% with the highest incomes per consumption unit, and 50% of emissions originate from the 5% of individuals who travel the most.[32]

To reduce emissions from domestic aviation, two primary strategies are essential:

1. **Halt the unrestrained increase in traffic and, on the contrary, decrease the number of flights**, through sufficiency (e.g. travelling closer for holidays) and the mandatory use of trains for all travel durations below a specific threshold.

2. **Mitigate the impact of remaining flights**, primarily by ensuring they operate using Sustainable Aviation Fuels (SAF), i.e. biofuels or synthetic fuels. To a non negligible extent (20%), by continuously enhancing technological and operational efficiency[33].

Fig. 3.16 Kerosene consumption reduction and decarbonisation scenario (in Mt/year)



Modal shift to trains is projected to account for 14% of the overall decarbonisation efforts within aviation, reducing 13 million tons of CO_2-eq.

A reduction of 12% of intra-EU aviation and 4% of total EU aviation emissions can be done by technically improving the European train offer, i.e. day train speed and services.[34,35] Developing EU night trains over 1000 km would result in an additional 2% GHG reduction.[36]

To achieve this modal shift, a combination of regulatory, fiscal measures to improve train competitiveness, and essential investments in rail infrastructure is required.

Necessary investments to substantially expand train and long-distance public transport offerings are detailed in Subsection 3.2.2.

To limit air traffic's rapid increase and ensure an effective modal switch, **two regulatory measures are proposed: a moratorium on the construction of new airports** and, building upon the proposals of the French Citizens' Climate Convention, **a progressive ban threshold is proposed for domestic flights when there is a train alternative** of less than 4h30 (starting at 2h and progressively increasing the threshold with time).

Measure 3.7

Gradually organise, by 2030, the cessation of domestic air traffic on routes where a train alternative exists within less than 4h30

Measure 3.8

Moratorium on all airport extensions and on the construction of any new airport in the EU

To ensure modal report, it is also mandatory to **make trains economically more attractive** than planes, and to end current distorsive support for air transport. **Three fiscal measures are proposed and assessed to make trains more competitive than planes**, based on T&E propositions[37]:

Measure 3.9

Set of fiscal measures 3.9 to end the preferential treatment of air transport over rail and enhance rail travel's competitiveness:

→ End fossil kerosene tax exemptions and apply a 0,38 €/L tax

→ End VAT exemptions on plane tickets and apply 20% in all EU (current average of 1,1%)

→ Increase average CO_2 price paid by airline companies, from 45 €/tCO_2 to 85 €/tCO_2

Estimated revenues from fiscal measures

€28 billion per year on average
starting from €570 billion in 2025 down to almost zero in 2050

In response to these measures, airlines may be tempted to raise ticket prices, which could further exacerbate social inequalities related to air travel. Another way (or complementary measure) to reduce aviation emissions while addressing associated social injustices would be to **introduce quotas on the number of flights or km travelled by plane, per person, within a given period.**

To mitigate the impact of remaining flights, transition to Sustainable Aviation Fuels (bio- and e-SAF) should be facilitated by increasing mandates.

To address the emissions from residual flights, **bio-SAF can be used in priority and yield a potential 16% reduction in intra-EU GHG emissions**[38]. The potential for incorporating bio-SAF is however constrained by the availability of biomass resources.

Once all these levers are applied (technological and operational efficiency, modal shift, bio-SAF incorporation), the **remaining emissions can be further reduced by utilising e-SAF** (synthetic fuels produced from electricity and CO_2) as jet fuel.

Measure 3.10

Enforce and gradually increase incorporation mandates for biofuels and synthetic fuels in aircraft, reaching 100% by 2050

The needed quantities of e-SAF will be inversely proportional to the level of sufficiency achieved. Despite being more expensive, a full technological solution can technically address remaining intra-EU emissions.

With no sufficiency measures, the production of up to 13.4 million tons of e-SAF per year will be needed in 2050, requiring an average investment of €6.4 billion per year by 2050. This production would require 140 gigawatts (GWe) of renewable energy capacity and 328 TWh of electricity by 2050, representing 12% of the current EU-27 power consumption. This estimation is twice the coverage anticipated by energy scenarios like TYNDP.

Considering the same public support ratio used in the energy sector for low-carbon electricity production assets, and including only extra capacities compared to those already considered in the energy section (€3.1 billion euros per year), this would represent a maximum of €1.2 billion of additional public expenditures.

Measure 3.11

Support the installation of additional EnR capacity for intra-EU e-SAF production

Public extra-cost
€1.2 billion per year

Sufficiency is however non-negotiable when it comes to mitigating emissions from international air transport. The optimal balance between sufficiency and e-SAF production should be democratically determined.

In the context of international transport (all flights departing from EU airports), a 0% sufficiency / 100% e-fuel ratio would result in impractical requirements: e-SAF 2050 production would need to triple to over 40 million tons, necessitating 405 GWe of low-carbon electricity production assets (equivalent to 20 times the current Belgian production capacity) and a +34% increase in current electricity consumption solely to meet aviation demands (considering the already challenging task of doubling electricity production for other purposes, as detailed in the energy section). In contrast, excessively high or rapidly imposed sufficiency levels (via increased ticket prices or quotas) could be resisted by the public. Between these challenging extremes, there are a range of options (cf. Figure 3.17) that should be democratically determined by the EU population.

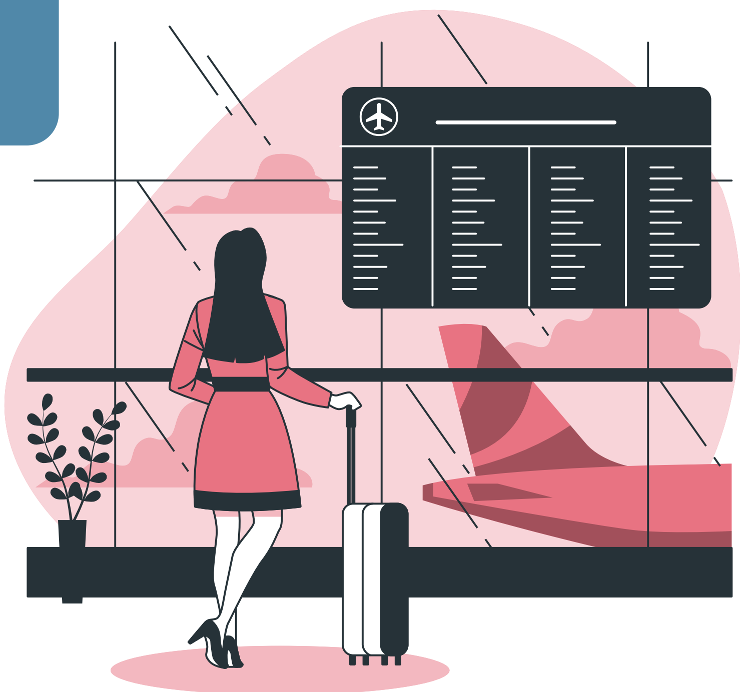
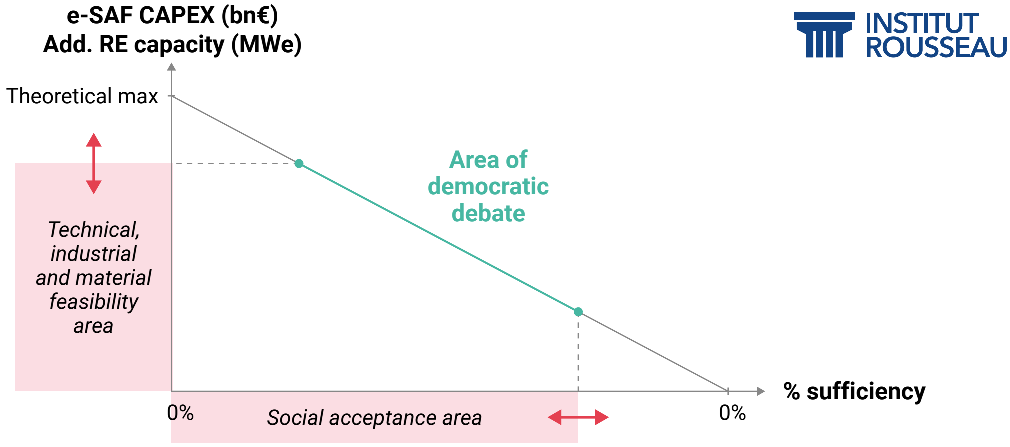


Fig. 3.17 **Area of democratic debate between sufficiency (social acceptance) and e-SAF production (technical feasibility and additional cost)**



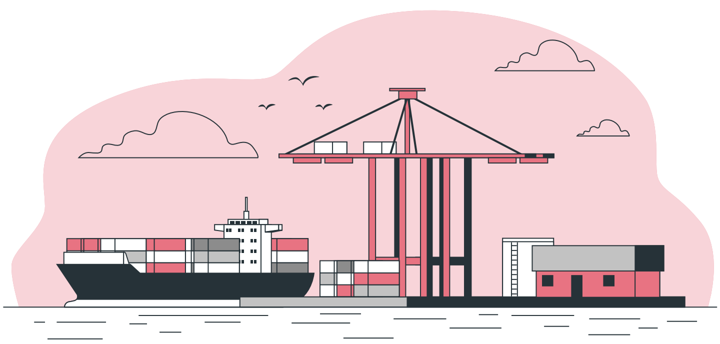
2.4 Transition to zero carbon navigation

Boats must also transition to low-carbon propulsion methods to mitigate their emissions (16 million tons of CO_2-eq in 2021). The objective is a complete decarbonisation of both maritime and inland waterway transportation, shifting by 2050 to propulsion systems primarily powered by electricity, biogas, or ammonia depending on the weight and type of vessel.

The investment required to transition the maritime and fluvial sector is approximately €536 billion by 2050, averaging around €20 billion annually.

This encompasses the shift to electric propulsion systems for small fishing and leisure boats and, in the case of the merchant fleet, extra cost for adapting port infrastructure and switching onboard engine to low carbon propulsion systems (biofuels, electrofuels and blue fuels)[39]. **Establishing alternative fuel infrastructure (including fuel production and storage capacity, and port adaptation) entails a substantial investment, accounting for approximately 90% of the total required investment.**

To smooth the transition, a state support for eco-converting boats is proposed, which would mirror the existing automobile conversion subsidy.



Support would vary based on vessel type and stakeholder capacities. Estimated annual costs for onboard technologies and infrastructure subsidies are approximately €8.6 billion annually until 2050, marking a new fiscal commitment in the absence of existing support.

Measure 3.12

Support the switch to a low-carbon navigation fleet

Public extra-cost
€8.6 billion per year

2.5 Develop soft mobility and encourage modal shift

A large proportion of passenger-kilometres travelled involves journeys of less than 10 km that could be made by bicycle or electric bike (e.g. 62% in France[40]).

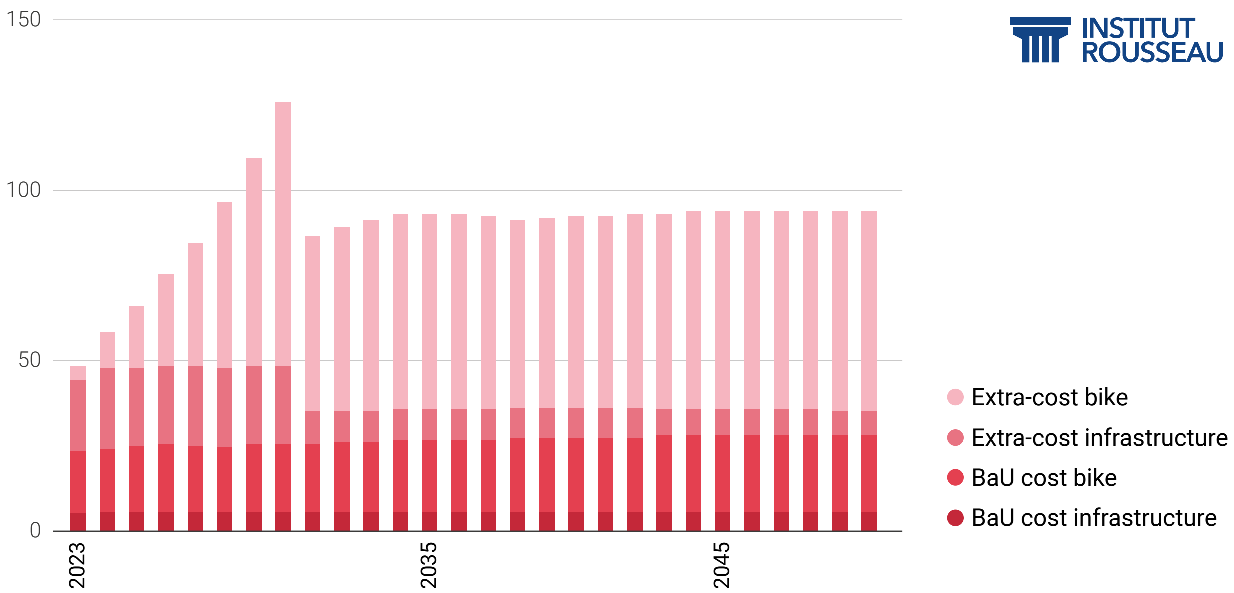
Along with trains, 'light' modes of transportation such as bicycles must be promoted as an alternative to cars. The promotion of these mobility options, along with the expansion of public transportation, enables the anticipated 23% reduction in the number of passenger cars outlined in section 3.2.1.

Cycling infrastructure must be developed and financial support must increase to ensure that every European has access to a bike.

A target ratio of 1.1 bicycles per person in Europe by 2030 is recommended by ADEME[41] (the French ecological transition agency), encompassing all types of bikes[42], for both private and commercial uses.

Facilitating the rapid advancement of active mobility depends on secure and efficient infrastructures for 'light' transportation modes, such as cycle lanes and parking stations. Denmark can serve as a benchmark for modelling transition scenarios in other nations[43]. **The strategic imperative lies in developing these infrastructure facilities rapidly by 2030, with a smoother continual expansion trajectory until 2050.**

Fig. 3.18 Annual investment required in bikes and biking infrastructure (in € billion per year)



To ensure the accurate tracking of both bicycle numbers and associated infrastructures, it is imperative to **improve the quality of data collection**, given the current challenges in obtaining robust information on these matters.

Soft mobility public expenditures must triple, mostly before 2030.

Considering both new infrastructures and bicycle subsidies, public investment at the EU-27 level for the transition of this sector is estimated at €15.5 billion per year (of which €10.5 billion are additional to the BaU trend)[44]. This constitutes approximately 17% of the total required investments. The public investment equates to about € 34 per capita per year, which can be contrasted with the €30 per capita per year goal suggested in the latest German National Cycling Plan[45]. This funding aims to attain the 2050 objective of 4.6 metres of bike lanes and green paths per inhabitant, mirroring Denmark's 2022 achievement[46].

Measure 3.13

Increase Support for Active Mobility

Public cost
€15.5 billion per year
Public extra-cost
€10.5 billion per year

Notes

1. Bon pote, Les véhicules intermédiaires : l'avenir de la mobilité ?, 2023.
2. Aurélien Bigo, 2023.
3. European Environment Agency, Transport and mobility, 2024.
4. Past data is sourced from the EEA Dataviewer. Targets for 2020 and 2030 reflect the EU's overall emission reduction goals of -20% and -55% from 1990 levels, distributed proportionally according to each sector's 2021 emission share. The 2050 target aligns with residual emissions in the RtoNZ transition scenario. WEM (With Existing Measures) projections, utilising EEA & Climact data, estimate future emissions considering measures already implemented by the EU and its Member States.
5. Net of malus/acquisition tax applicable on conventional PC/LCV/PTW.
6. T&E and BCG, 2023, Impact Assessment of the Transition to Zero-Emission Trucks in Europe.
7. Around €13.9 billion per year until 2035.
8. Until achieving price parity in 2028, totaling an estimated €6 billion.
9. Réseau Action Climat, 2020, Aides à l'achat de véhicules Propositions de réformes pour un meilleur impact écologique et social.
10. Belastingdienst, 2023, Bpm tariff passenger car.
11. Transport & Environment, April 2022, Charging for phase out.
12. UFC Que Choisir, November 2023, 'Accelerating the network deployment, halting tariff overruns'.
13. Transport & Environment, 2022, How to buy an electric truck.
14. Note that with certain measures proposed in other sectors, in particular the relocation of agriculture, a doubling of the volume of rail freight will make it possible to go beyond a doubling of its modal share (36% vs. 18%).
15. IEA, 2019, Energy-intensity of transport modes and DB, 2022, Integrated Report p. 72.
16. ART, 2023, Scénarios de long terme pour le réseau ferroviaire.
17. These necessary levels of network development to double current modal shares are confirmed by several detailed national assessments (e.g. ART, Scénarios de long terme pour le réseau ferroviaire, 2023 or DB, 'Strong rail strategy' in 2021 Integrated report). These assessments highlight that renewal investments are certainly necessary to avoid a progressive reduction of potential train.km, but that it is impossible to approach a doubling of rail without developing new lines or tracks, both on routes that are already saturated and on those without an alternative to road or planes.
18. For 2022: Parlament Österreich, 2021, ÖBB - Rahmenplan 2022 – 2027.

19. Page 39: Direction Générale des politiques internes, 2015, Les résultats et l'efficacité du financement des infrastructures dans l'Union.

20. IRG-Rail, 2023, Eleventh Annual Market Monitoring Report.

21. For example, from 6000 to 8000 km of new lines combined with 4000 to 6000 km of extensions are required for Italy, Spain and France, in order to approach the capacities of the reference networks, while remaining consistent with the volume of potential projects listed in their national planning documents (e.g.MIT, Documento strategico ferroviaria 2021 for Italy or COI, Investir plus et mieux dans les mobilités 2022 for France, cf. Methodological Appendix for more details).

22. €7 billion per year in Germany in 2022: L'Officiel des Transporteurs, 2023 Péage autoroutier allemand, jackpot pour les caisses publiques.

23. M. Poliak, S. Semanová, M. Mrníková, L. Komačková, P. Šimurková (2017), Financing public transport services from public funds.

24. BMVI: German Federal Ministry of Digital Affairs and Transport.

25. Electrive, 2022, Germany issues first grants to decarbonise urban bus fleets.

26. Electrive, 2023, Germany releases funding for another 1,000 electric buses.

27. Electrive, 2022, Funding granted for 1,200 low- and zero-emission buses in Germany.

28. International Civil Aviation Organization, 2020, The World of Air Transport; Air Transport Action Group, 2021, Waypoint 2050.

29. European Parliament News, 2023, Émissions de CO_2 des avions et des navires : faits et chiffres (infographie).

30. 2% in 2022 according to IEA, rebounding quickly after a sharp COVID-related drop.

31. Transport & Environment, 2020, Maximising Air to Rail Journeys.

32. French example – Shift Project, 2021, Pouvoir voler en 2050 : quelle aviation dans un monde contraint.

33. Average value between T&E, 2022, Roadmap to climate neutral aviation in Europe and Air Transport Action Group, 2021, Waypoint 2050 hypothesis.

34. Transport & Environment, 2020, Maximising Air to Rail Journeys.

35. This switch potential is purely technical and does not include the modal shift potential from changing price signals through application of a kerosene tax, for example.

36. Back-on-track EU, 2022, The Global Warming Reduction Potential of Night Trains.

37. Transport & Environment, 2023, Aviation tax gap report.

38. In-house assessment based on negaWatt, 2022, Agriculture, forestry, other land-use changes and bioenergy (AFOLUB) and others.

39. DNV, 2022, Maritime Forecast to 2050.

40. This data pertains to weekday local mobility according to: Ministère de la Transition Écologique et des Territoires, 2019, Enquête « Mobilité des personnes ».

41. ADEME, 2020, Impact économique et potentiel de développement des usages du vélo en France, pp. 283-284.

42. Conventional bicycles, E-bikes, folding bicycles, tricycles, sidecars, multi-seater bicycles for transporting children, and cargo bicycles for goods.

43. If the Netherlands and Sweden also exhibit strong soft mobility, their unique geography makes them unsuitable benchmarks.

44. While countries like the Netherlands, Sweden, and Germany may no longer require subsidies for their already robust bicycle markets, it is necessary to increase subsidies for bicycles, including conventional and E-(cargo) bikes, in other countries until 2030. ECF, 2023, Money for bikes: Tax incentives and purchase premiums for cycling in Europe.

45. Federal Ministry for Digital and Transport, 2023, National Cycling Plan 3.0.

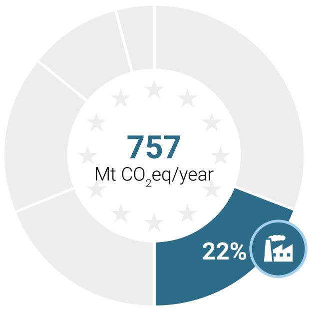
46. Data for December 2022. GeoVelo, 2023, Aménagement cyclable par GeoVelo.

Investments in the industry sector

Sufficiency, circularity, transformation

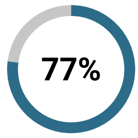
INSTITUT ROUSSEAU

Current emissions and reduction potential



Decarbonisation levers to mobilise:

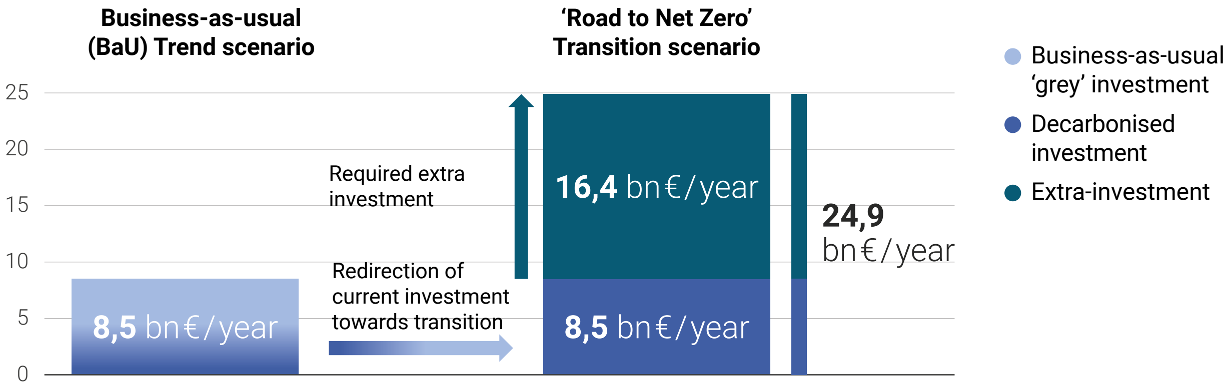
1. Reduce industrial production through end-use sufficiency
2. Increase material efficiency
3. Increase energy efficiency
4. Decarbonise industrial energy mix
5. Develop low-carbon innovative processes
6. On-site Carbon Capture, Utilisation and Storage
7. Develop EU strategic industrial sectors for the transition



2050 decarbonisation potential

Global investment needs

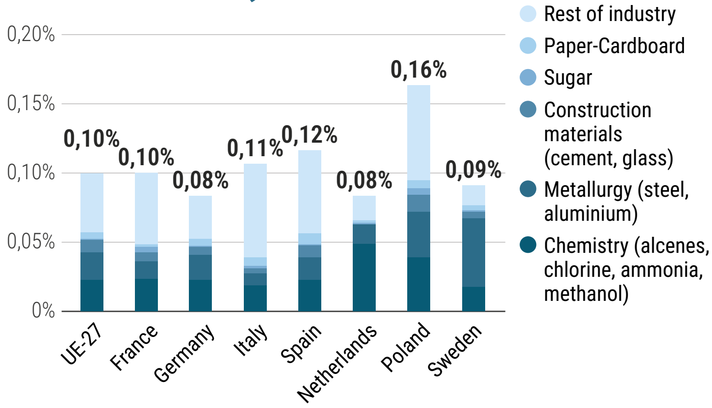
UE-27 global investment and extra-investment



Global investment and extra-investment per lever, per country (in % of GDP):

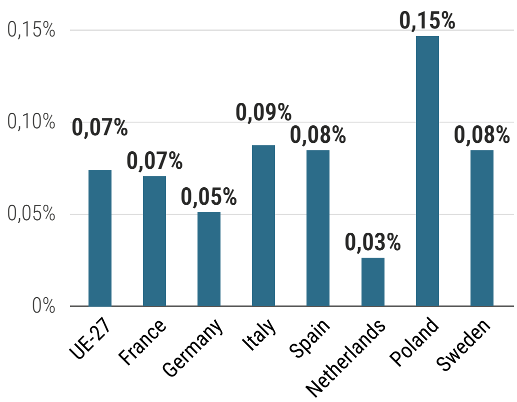
Total investment

0,1%



Total extra-investment

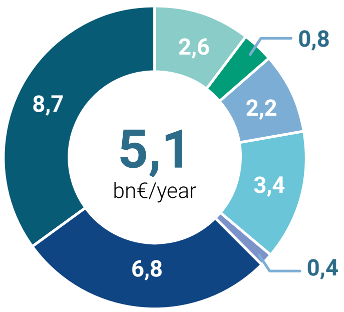
0,07%



Public investment needs

Total public investment in proposed public policies	Public share in total investment	Public extra-investment in % GDP
7 bn€/year	**43%**	**0,03%**

Total extra public investment in proposed public policies: 5,1 bn€/year



- Increase material efficiency
- Increase energy efficiency
- Decarbonise industrial energy mix
- Develop low-carbon innovative processes
- On-site Carbon Capture, Utilisation and Storage
- Extrapolation to the rest of industry
- Develop EU strategic sectors

Complementary measures:

+ Set long-term targets for CO_2 emission standards in heavy industry and bans on certain high-carbon processes
+ Extend Temporary Crisis and Transition Framework (TCTF) after 2025
+ Strengthen Carbon Border Adjustment Mechanism (CBAM) ambition
+ Strengthen Net-Zero Industry Act (NZIA) tools with financial and technical support

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT*	
TOTAL	EXTRA	TOTAL	EXTRA
1,6%	4,6%	1,4%	2%

Key takeaways

- **The challenge for the industrial sector is twofold: decarbonising its emissions and developing strategic transition sectors on EU soil, such as the manufacture of solar panels, electric battery production and recycling facilities, etc.**
- **The GHG emissions of the EU industrial sector – standing at 757 million tons of CO_2-eq in 2021 – can be decreased by 75-80% by 2050.**
- **To achieve such a decarbonisation, an investment of approximately €670 billion is needed, averaging €25 billion annually. This would mean tripling the €230 billion already earmarked for investment.**
- **Of this amount, €440 billion (€16.5 billion per year) is required to decarbonise the European industry. Based on current subsidy schemes for industrial decarbonisation, about €190 billion should be taken up by the public sector. This means an additional public investment – compared to business-as-usual – of €140 billion until 2050.**
- **In addition, €235 billion (8.5 billion per year) of both public and private investments are needed to scale up strategic sectors of the transition. This means an extra investment – compared to business-as-usual – of €120 billion until 2050.**

* Only public investments for decarbonising the industry have been estimated, and not public investments to scale up strategic transition sectors (production of solar panels, batteries, etc.) (see below)

In 2021, the European industrial sector emitted 757 million tons of CO_2-eq, ranking as the third-highest emitting sector, but with the second-lowest decarbonisation investment requirement.

This study focuses on the nine most energy-intensive activities (steel, cement, hydrocarbons, glass, paper-cardboard, ammonia, sugar, aluminium, chlorine) and methanol, which constitute 60% of the sector's emissions. The rest is extrapolated.

To decarbonise the European industrial sector by 2050, an investment of approximately €670 billion is needed, averaging €25 billion annually.

Of this investment, 38% is needed to decarbonise the ten sub-sectors of focus, 27% will be used to decarbonise the rest of industry, and 35% will serve to scale up strategic sub-sectors (production of solar panels, wind turbines, batteries...). **This would mean tripling the €230 billion already earmarked for investment**.

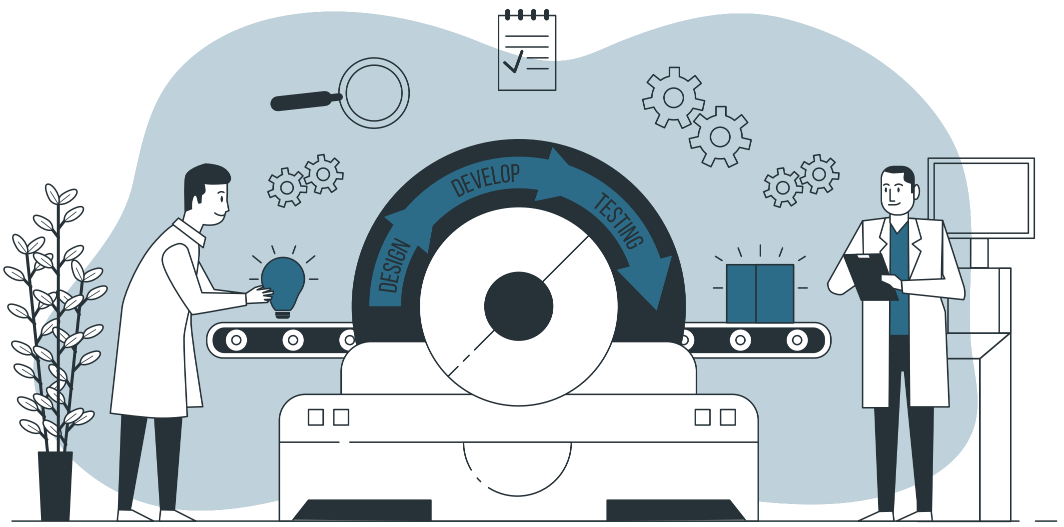
Building a competitive low-carbon industry is challenging, which is why significant public support is needed.

Indeed, climate-friendly production is significantly more expensive than traditional production (e.g. +0-20% for steel, +20-43% for plastics, +70-115% for cement[1]). **Public support is crucial for the EU to remain competitive. The transition requires support that is both financial** (to attract industrialists, mitigate rising energy costs, compensate for higher wages compared to economies such as China or India) **and regulatory** (ensuring material supply, providing long-term outlooks, protecting the EU market). A proactive approach from the EU and Member States is needed for industrialists to anticipate market conditions and make informed investment decisions in this capital-intensive sector.

This transition would require around €190 billion of public funds, covering approximately 43% of the total investment. To sufficiently scale up strategic sectors, €234 billion of both public and private investment is needed.

Industrial activity is impacting the environment, and will soon face reciprocal consequences.

Like many other sectors, industry is responsible for putting pressure on ecosystems, through pollution and disturbance of natural habitats. Environmental changes will also impact industries. Industrial actors need to start preparing for significant fluctuations caused by climate change and biodiversity collapse. The physical risks associated include storms, floods, fires, rising temperatures, decreasing productivity, and pandemics. These risks can be direct (and endanger the assets owned by the industrial player) and/or indirect (raw materials supply issues, systemic crisis). Fostering resilience should thus be a priority.



1 Emissions of the sector

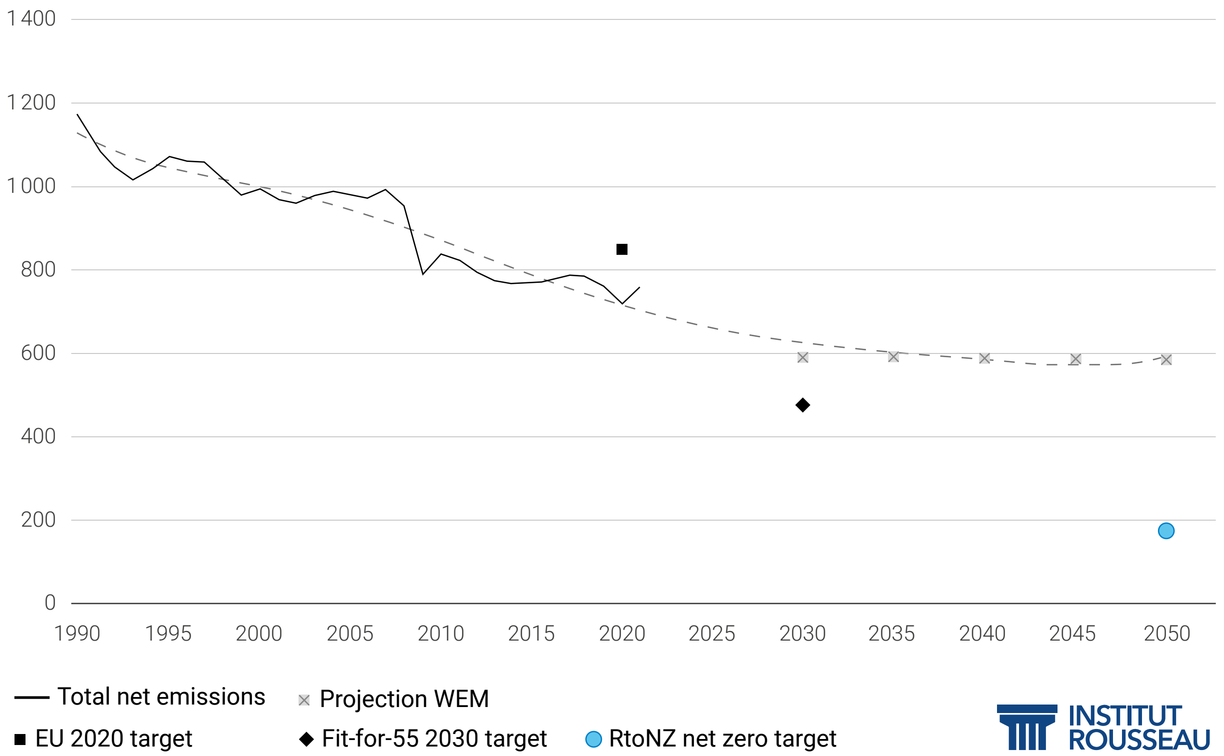
Industry is the third most emitting sector in Europe, with 22% of total emissions.

The **European industrial sector emitted 757 million tons of GHGs in 2021** (scope 1), comprising **22% of the EU's net GHG emissions and ranking third** after energy production and transport. Emissions in the EU-27 decreased from 1,174 million tons in 1990 to 757 million tons in 2021, a **33% reduction or 13 million tons per year on average**. All countries under study achieved reductions of 27% to 38% during this period, except Poland, where a 15% reduction was observed.

To achieve the 'Fit-for-55' 2030 target aligned with the sector's current share, the historical emissions reduction pace would need to triple. To achieve the 2050 target, the pace would need to increase by 50%.

Projections based on existing policy measures indicate that meeting the 2030 and 2050 targets is - under current conditions – extremely unlikely, as illustrated in Figure 4.1. For the 2050 target to be reached, **yearly decarbonisation efforts must increase from an average of -13 to -20 million tons of CO_2-eq per year**. This is a significant increase, especially considering that past emissions reductions were strongly linked to European deindustrialisation[2]. Europe needs to reverse this trend and thus reduce its carbon footprint, create local jobs, and improve its commercial balance and geopolitical independence. In particular, Europe must develop key sectors for the low-carbon transition (solar panels, batteries, and heat pumps) within its own borders.

Fig. 4.1 **Industry past UE-27 domestic emissions and progress towards achieving 2030 and 2050 targets, in million tons of CO_2 equivalent ($MtCO_2e$).[3]**

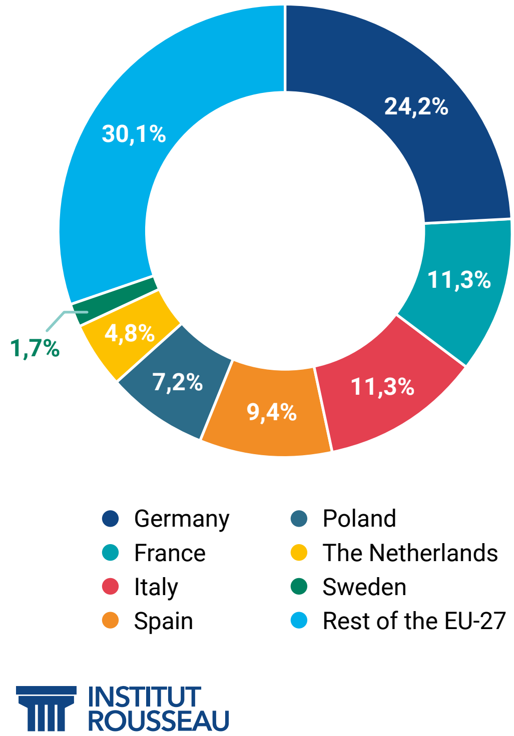


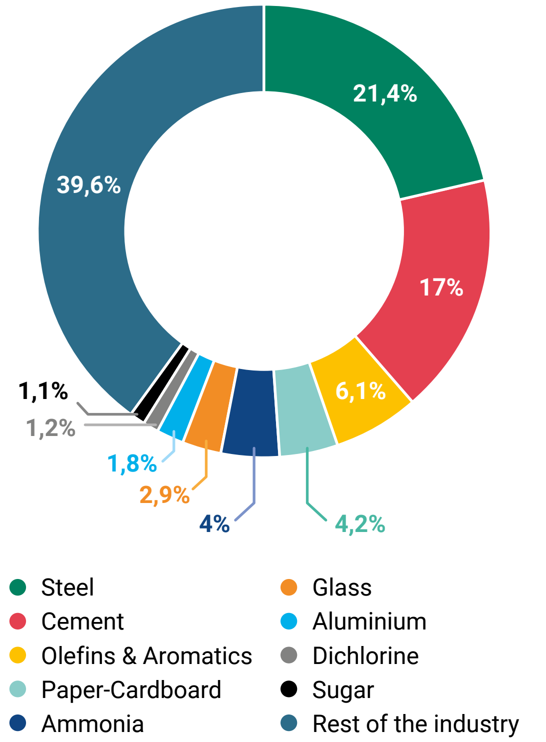
WEM: With Existing Measures.

The seven countries scrutinised in this report[4] represent 70% of EU-27 industrial emissions, with Germany contributing to 25%.

The industrial sector encompasses a **wide variety of sub-sectors, preventing an exhaustive bottom-up analysis.** Instead, the nine most energy-intensive industries were assessed – which, by order of emissions, are steel, cement, pulp & paper, olefins & aromatics, ammonia, glass, aluminium, chlorine, sugar – to which was added methanol production[5]. Together, they represent **60% of the industry's scope 1 GHG emissions** (Figure 4.2.)

Fig. 4.2 Share of EU countries (left) and industrial sub-sectors (right) in EU industrial GHG emissions





2 How to decarbonise the sector?

A 75-80% reduction in industry GHG emissions can be achieved by 2050.

A 75-80% reduction of GHG emissions can be achieved by 2050 across the ten sectors studied. A parallel reduction in non-covered sectors is assumed. The emissions transition for each sector is depicted in Figure 4.3.

This reduction is attained through five types of levers:

1. **Sufficiency**: reducing the production of certain industrial products through policies and practices curbing consumption needs.

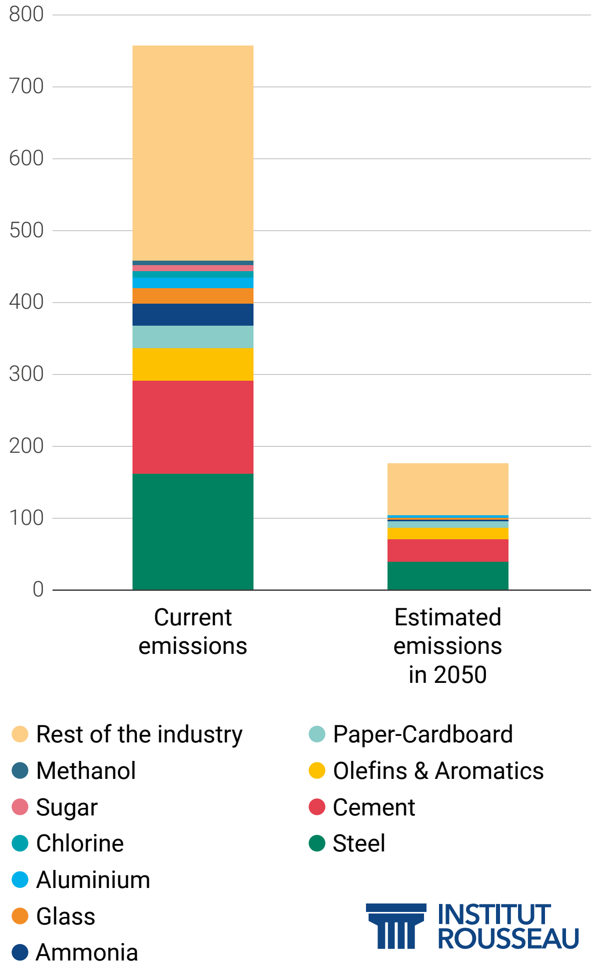
2. **Material efficiency**: expanding and enhancing recycling, reusing products, and minimising material losses or usage in industrial processes. Direct product reuse reduces production needs, and recycling usually consumes less energy than raw material production.

3. **Energy efficiency**: reducing energy needs per material unit of production while maintaining the production process and energy mix.

4. **Process Change**: overhauling or significantly altering the production process of specific materials to decarbonise, such as using inert anodes in aluminium production or adopting direct reduction of iron in the steel sector.

5. **On-site Carbon Capture, Utilisation and Storage (CCUS)**: capturing concentrated CO_2 emissions from industrial flue gases and either converting it into new products (chemicals of e-fuels) or storing it underground. Used only where no other solution is foreseen to enable a significant reduction in GHG emissions.

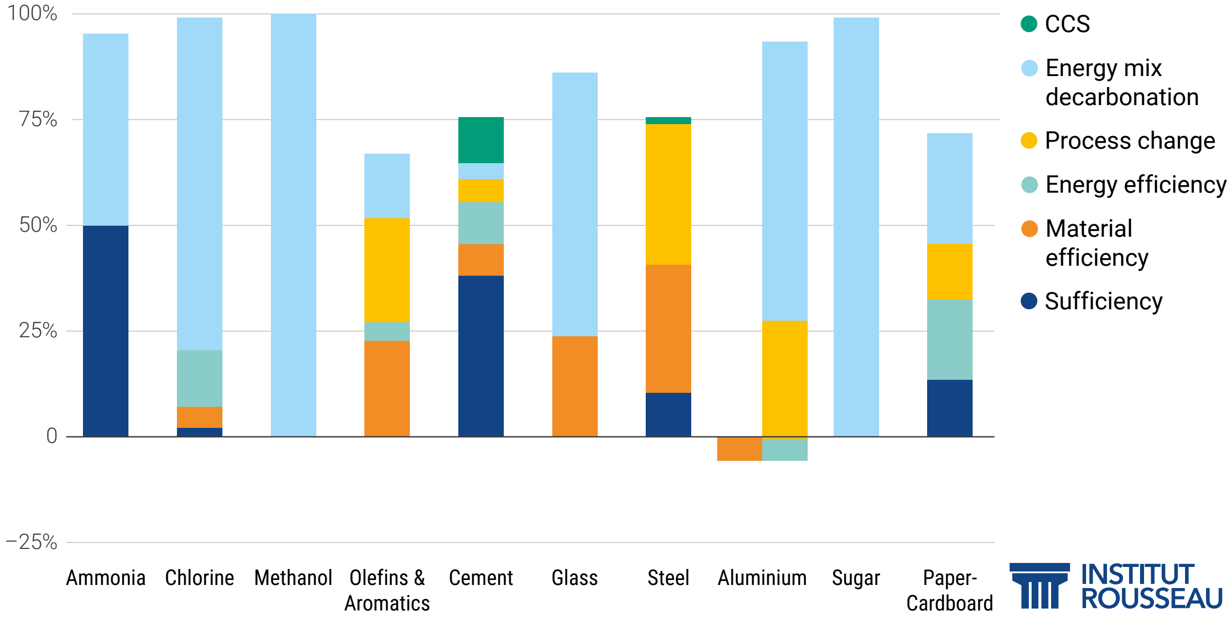
Fig. 4.3 **EU industrial GHG emissions in 2022 and in 2050 as per the RtoNZ scenario (in $MtCO_2eq.$ per year)**



Classifying levers within these categories is somewhat arbitrary. For example, electrifying industrial processes is categorised as energy mix decarbonisation but often results in significant energy efficiency gains.

These levers contribute uniquely to sector decarbonisation. Figure 4.4. illustrates each lever's contribution to decarbonising the sectors covered by 2050, reflecting both scenario orientations and varying difficulty in decarbonising certain productions.

Fig. 4.4 Overall decarbonisation reached for the 10 studied sub-sectors, and share of each lever type in this decarbonisation[6]



Sufficiency is crucial for certain sectors, particularly for ammonia production, for which a full transition towards agroecology results in the end of the use of nitrogen fertilisers, thus significantly reducing ammonia demand. Less demand for cement stems from demographic changes, higher average dwelling occupancy, wood substitution, decreased public works, and smarter design. This also contributes to lowering the demand for steel. **Sufficiency levers drive a 19% overall GHG emissions reduction, underscoring the role of limiting consumption for decarbonisation.** Our assessment, guided by the CLEVER scenario, aligns with industrial transitions that are based on ambitious sufficiency principles. These principles are inspired by the 'doughnut' economy approach (cf. Box 4.1.)

Material efficiency is key to decarbonise the production of plastics (via chemical and mechanical recycling - olefins & aromatics), steel (scrap-based production), and glass (increased use of glass cullets in furnaces). Although not reflected in Figure 4.4. (cf. Footnote 6), significant growth in recycled aluminium production reduces emissions from emissive primary production and curtails steel use. **Material efficiency levers achieve a 15% overall GHG emissions reduction, emphasising the role of circular economy in decarbonisation.**

Process changes are pivotal for olefins & aromatics (shifting to the Methanol-to-olefins route), steel (moving from blast furnace to direct reduction of iron), aluminium (using an inert anode), and paper-cardboard, **achieving an 18% emissions reduction.**

Energy mix decarbonisation, through electrification (e.g., olefins sector crackers), low-carbon hydrogen use (e.g., ammonia production), or biogas and biomass utilisation (e.g., methanol, sugar, glass), **accounts for a 17% emissions reduction.**

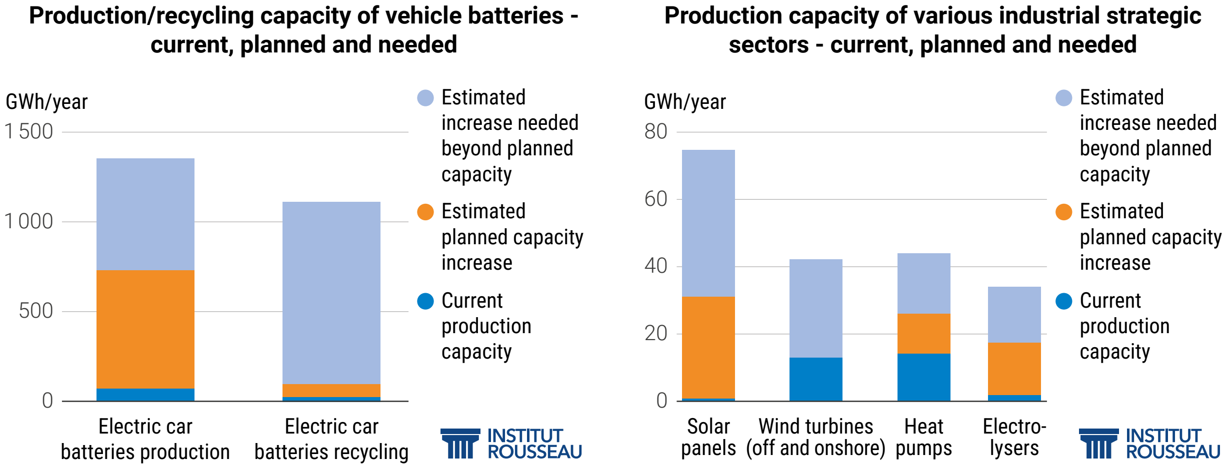
Enhanced **energy efficiency** is notable in the chlorine sector (with oxygen depolarised cathodes), cement, and paper-cardboard sectors (utilising best available techniques), **resulting in a 5% emissions reduction.**

Caution is warranted concerning **CCS technology** uncertainties. In this model, it is considered only for the cement sector and a limited share of steel production in Sweden, contributing to a mere **4% emissions reduction.**

Along with reducing industrial emissions, increasing certain industrial productions plays a crucial role in enabling the decarbonisation of other sectors (e.g. transport, buildings, etc.) and must be scaled up to meet EU demand.

Figure 4.5 depicts current, planned, and required capacities for strategic industrial technologies. By 2050, substantial new capacity is essential, especially if planned increases fail to materialise, as could be the case for solar panels (due to current industry challenges).

Fig. 4.5 Production capacity of various industrial sectors (left), production and recycling capacity of electric vehicle batteries (right) (in GWh per year)



Box 4.1

The CLEVER scenario (Collaborative Low Energy Vision for the European Region)

RtoNZ industrial transition scenario is based on the CLEVER scenario, crafted in 2022-2023 by a network of European organisations led by the French think tank negaWatt. This scenario outlines a detailed decarbonisation path for Europe and, unlike many scenarios, a detailed decarbonisation path for Europe. Unlike many scenarios, it offers comprehensive insights into transforming industrial product consumption and production, and their associated energy use. Notably, the CLEVER scenario places demand management at the forefront of the low-carbon transition, emphasising sufficiency as a reliable method for greenhouse gas (GHG) reduction. This approach stands out against doubts surrounding the effectiveness of technological switches in achieving substantial emissions reductions while maintaining (or even increasing) material consumption and waste.

Moreover, the CLEVER scenario prioritises security and resilience by diminishing Europe's reliance on critical material imports, presenting additional advantages from biodiversity and resources management standpoints. Specifically in the industrial sector, the scenario demonstrates the feasibility of significantly reducing the production of high-emission products through rationalised needs and improved material efficiency[7].

3 How much investment does it require?

We project that the transition of the EU industry requires a total investment of €670 billion by 2050, averaging €25 billion annually[8].

Decarbonising the ten sectors requires around €255 billion (€9.5 billion per year), with an extra €180 billion (€7 billion per year) estimated for the rest of the industry. To scale up strategic industrial sectors, €234 billion (€8.5 billion per year) is required.

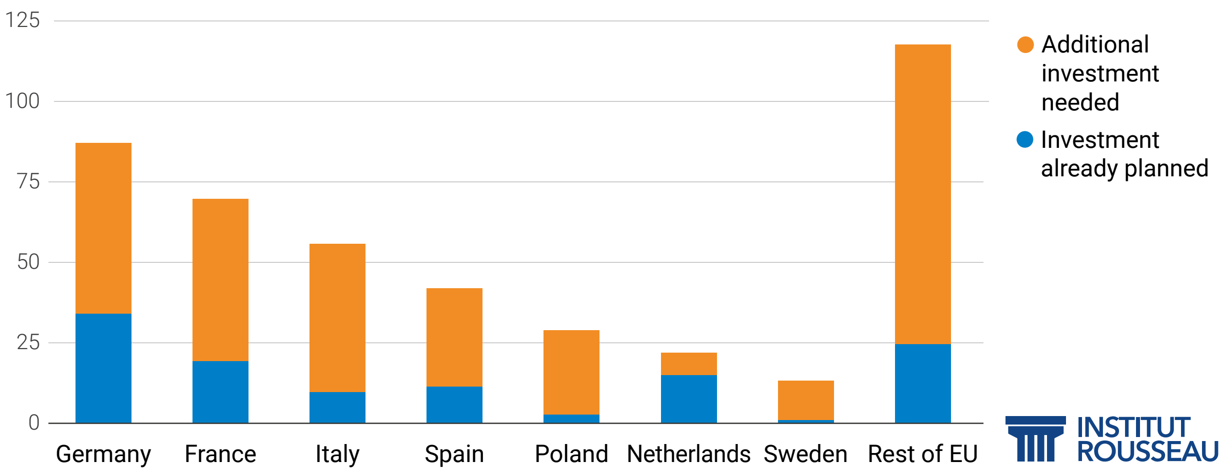
This would mean tripling the €230 billion already earmarked for investment.

This €230 billion figure is likely a conservative figure[9] and does not include business-as-usual investment in renewing conventional industrial capacities. Specifically, €120 billion is designated for the decarbonisation of the EU industry, and an extra €110 billion is planned for strategic sector development.

Further breakdowns by country, sector, and lever are provided below.

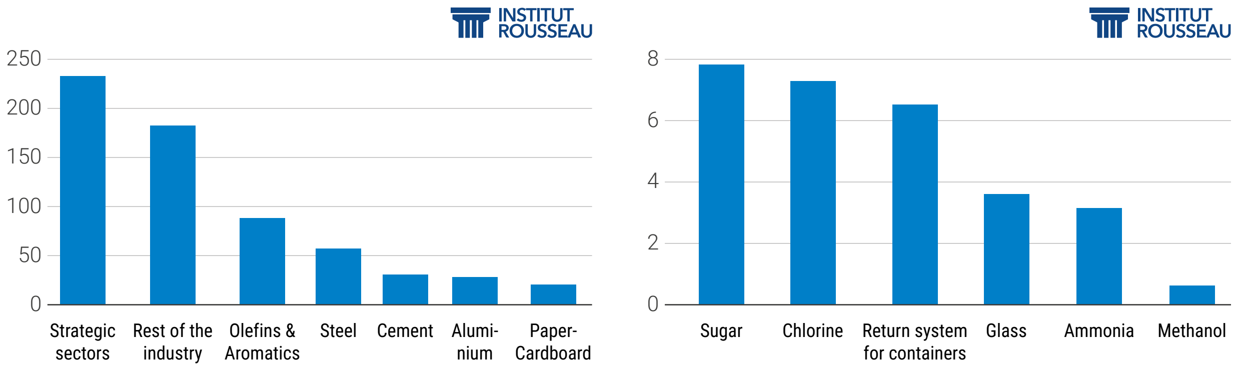
- **Figure 4.6. presents a country ranking based on investment needs for decarbonisation, which proves similar to industrial GHG emissions**. Notably, Italy needs fewer investments than France, mainly due to less planned production of low-carbon primary steel in 2050. The Netherlands stands out for its extensive decarbonisation investments, primarily fueled by significant commitments from the carbon contracts for difference (SDE++) program with planned investments extending until 2038.

Fig. 4.6 Total investment and extra-investment needed to decarbonise industry, per country (€billion)



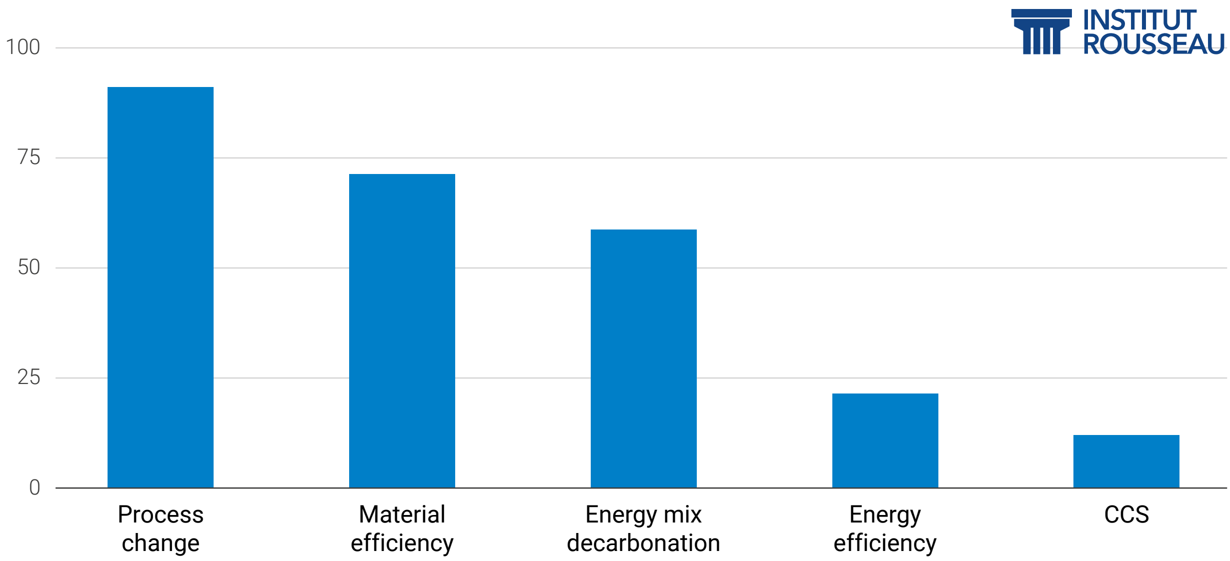
- **Figure 4.7 illustrates the varying investment needs across EU sectors, with Olefins & Aromatics and Steel ranking first**. Substantial investments are imperative for decarbonising olefins & aromatics due to adopting the Methanol-To-Olefins (MTO) process. This requires a complete process overhaul and new methanol production capacities, entailing considerable costs. Similarly, the steel sector needs high investments to replace blast furnaces with direct reduction units and electric arc furnaces. In contrast, cement's significant decarbonisation investments are tempered by a strong emphasis on demand reduction in the transition scenario, aligning with demographic shifts, enhanced co-living, and decreased public works.

Fig. 4.7 Total investment needs per industrial sub-sector (in € billion)



- **Analysing decarbonisation levers, investments in process change and material efficiency predominate** (Figure 4.8.), encompassing costly technologies like chemical recycling, MTO, and direct reduction of iron in the steel sector. Relatively modest investment needs in energy mix decarbonisation stem from significant energy sector investments addressing industrial energy consumption. Lower investment requirements for CCS result from a deliberate effort to minimise its use.

Fig. 4.8 Total investment needs per decarbonisation lever (in €billion)

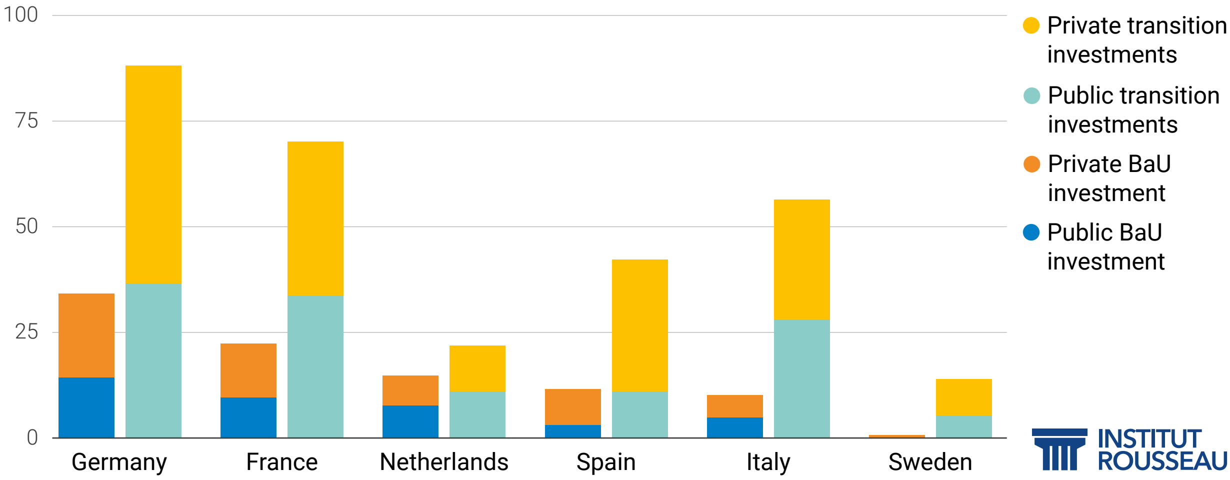


4 How can public authorities promote and facilitate this transition? What extra investments might the public incur?

4.1 Scaling up public investment at country level

To mobilise necessary funds for industrial decarbonisation, it is suggested to amplify current public investment mechanisms. Existing subsidy programs in the studied countries (excluding Poland due to data limitations) currently subsidise around 43% of industrial decarbonisation investments (weighted average). It is assumed that this average support rate will persist throughout the low-carbon transition, leading to a public-private investment breakdown as depicted in Figure 4.9.

Fig. 4.9 **Public and private decarbonisation investment and extra-investment per country (in €billion)**



Required public investment and extra-investment in industry decarbonisation are presented in total amounts until 2050 rather than in yearly amounts, as is done for other sectors. This stems from a required extra-investment significantly lower before 2030 than after 2030. Therefore, presenting an average extra-investment over the 2023-2050 period would be misleading.

Measure 4.1

Increase public support to industrial decarbonisation investments

Public cost	Public extra-cost
€190 billion per year - 7 billion per year	**€139 billion per year**

4.2 Sufficiency in the industry sector: a concept for further refinement

The European Commission advocates expanding the integration of the sufficiency concept into European policies[10]. Reducing demand for various goods will decrease the manufacturing needs, and therefore industrial demand. For instance, reducing new constructions and car traffic could decrease steel demand by 15% by 2050 compared to 2015[11]. Additionally, sufficiency is crucial in preventing typical rebound effects that may follow the implementation of the energy efficiency measures outlined below.

Sufficiency in the industry hinges on policies that decrease demand for manufactured products, targeting broader sectors than just the primary sector. The EU or EU countries should consider the following policy measures:

Measure 4.2

Set of measures 4.2[12] to decrease demand for manufactured products

- **Extend warranty duration** for electronic products (laptops, phones) at 5 years and 10 years for heavy household appliances. Accompany this extension with a **prohibition of software obsolescence**, particularly for smartphones and electronic tools.
- **Implement stringent weight and size limits** on key durable goods such as cars (average SUVs are 40% heavier than average cars). cf. Transport section.
- **Encourage shared use** of vehicles and buildings through initiatives like high occupancy vehicle lanes or higher taxes for low occupancy levels in homes.
- **Tax second home ownership** through strong and progressive taxes on second home ownership to limit construction needs. cf. Buildings section.
- **Increase the regulation on advertisements**, especially on products with a high-carbon footprint
- **Launch communication campaigns targeted at the general public** to promote sufficiency, for instance during high consumption periods (Black Friday[13], Christmas...)

4.3 Energy efficiency and process change

Energy efficiency and process changes are vital for industrial decarbonisation, and Europe uses several tools to leverage this potential:

- **Energy Efficiency Directive**: Established in 2012 and updated in 2018 and 2023, this directive aims for an 11.7% reduction in energy consumption compared to 2020 projections[14]. It mandates regular energy audits for major consumers and requires large companies to implement an energy management system (EMS).
- **Ecodesign Directive**: This directive sets performance criteria for manufacturers, covering products like air conditioning, heating, and industrial furnaces. With 31 product groups and an estimated €120 billion energy bill impact, it targets a 10% annual energy consumption reduction, with a revision underway[15].
- **Emission Trading Scheme (ETS)**: Applicable to electricity and industry, the ETS was reformed due to oversupply and free allowances issues[16]. Although the too-low carbon price historically deterred few emissions, it reached an average of €80/tCO_2-eq in 2022.
- **The Carbon Contracts for Difference (CCfD)**, which allow for companies engaged in the decarbonisation of their production to be compensated by 15-year agreements covering for their extra costs required to convert their production[17].

In the current European geopolitical context leading to an increase in energy prices as well as a high volatility of these prices (namely for natural gas and as a consequence electricity), **energy efficiency measures enable industrial players to better manage their OPEX costs**. It is a major co-benefit and might even be a question of survival for some of them.

Despite these initiatives, energy demand often gets overlooked in industrial policies. The EU should consider the following policy measures:

Measure 4.3

Set of Measures 4.3 to improve industrial energy efficiency and foster process change

- **Include demand-side technologies in NZIA** and align it with the Green Deal. Support energy efficiency and technological substitution in major industry sectors like steel, cement, and chemicals and endorse the Energy Efficiency Directive[18].
- **Promote innovative tools** like energy consumption monitoring software and train new qualified workers, such as energy auditors or managers[19].
- **Set long-term targets** for CO_2 emission standards in heavy industrial productions and bans on certain high-carbon processes. This enables industrialists to anticipate and plan necessary investments for regulatory compliance.
- **At the country level, assess the relevance of setting CCfD programmes**, as Germany and the Netherlands have done. These prove efficient in reducing or eliminating uncertainty related to the competitiveness of low-carbon production techniques, and therefore facilitate associated heavy investment decisions.

4.4 Material efficiency and circular economy

Under the Green Deal, the 2020 **Circular Economy Action Plan (CEAP) introduced measures** for sustainable products, consumer empowerment, and reviews of construction regulations and sustainable textiles[20]. The EU Parliament set 2030 targets for sectors like plastics, textiles, electronics, food, water, packaging, batteries, and construction[21]. Current revisions of circular economy regulations aim to decrease new product demand and foster key raw material reuse, reducing reliance on foreign supply chains and critical materials. **However, progress is slow, notably in the Electrical and Electronic Equipment (EEE) and plastic industries**. The 2012 WEEE directive fell short of its 65% minimum EEE[22] collection goal in 2018, with 4.7 million tons left unprocessed[23]. Regarding plastics, the 2015 goal of recycling 55% of plastic packaging by 2025 faces challenges. The 2018 CEAP strategy aims for all plastics and packaging to be reusable or easily recyclable by 2030, with a goal of recycling ten million tons of plastic by 2025. However, only 14% of waste was collected in 2021, leaving governments off track for the 2025 target.

To meet EU objectives, **efforts should focus on reinforcing regulations for product reparability, recyclability, and reusability**:

Measure 4.4

Set of Measures 4.4 to promote material efficiency and circular economy

- **Strengthen standards** regarding reparability, recyclability and reusability of products;
- **Set up refundable return schemes** to reuse and recycle plastics, glass and aluminium containers, in order to maximise collection rates;
- **Encourage innovative business models**, including financially supporting the adoption of the circular economy (e.g. service-based models)[24].
- **Promote a circular economy in education, awareness, and training.**

4.5 Industry energy supply: energy mix decarbonisation, electrification, and CCS

In 2020, the EU adopted a comprehensive hydrogen strategy, to support investment, assist production and demand, create a new hydrogen market, encourage research and cooperation, and strengthen international collaboration. Following the war in Ukraine, a new goal of 10 million tons of renewable hydrogen production and imports has been set for 2030. However, current estimations project demand at 8.5 million tons, falling short of the Commission targets. New laws, including green labels for electrolyzers and the NZIA's Hydrogen bank, are being formulated to attract industrial consumers[25].

CCS is part of the NZIA proposal, targeting 50 million tons of annual CO_2 injection by 2030 to mitigate emissions from hydrogen production. EU-wide CCS projects face challenges, including storage site availability, capture performance issues, social acceptance and long-term governance uncertainties[26].

To go further, the following measures could be taken:

Measure 4.5

Set of Measures 4.5 to scale up the decarbonisation of the energy mix of EU industries

- **Implement widespread deployment of heat pumps** for low to medium heat requirements in the industry, alongside electric boilers and other electric processes for medium to high temperatures.
- **Further encourage the use of green hydrogen in industrial processes** like steel, olefins, and ammonia, for instance through the Hydrogen Bank.

4.6 The challenge of scaling up strategic sectors

The European Commission's proposed Net Zero Industry Act (NZIA) is a response to competition, particularly from the US Inflation Reduction Act (IRA), as outlined in Box 4.2[27]. The NZIA, part of the Green Deal, seeks to enhance Europe's decarbonisation capabilities, covering 40% of local needs by 2030, and also to achieve geostrategic independence and industrial resilience[28]. With a variety of proposed measures[29], the NZIA aligns with the Temporary Crisis and Transition Framework (TCTF)[30], which permits Member States to support decarbonisation activities. As of September 2023, the TCTF had secured €742 billion, mainly from Germany and France[31]. Additional initiatives include the Strategic Technologies for Europe Platform (STEP), offering €10 billion for various technologies, presented in June 2023[32].

Box 4.2

Introducing the US Inflation Reduction Act (IRA)

The IRA was implemented in the USA in August 2022 and was hailed as a major policy of the Biden presidency. The IRA 'aims to catalyse investments in domestic manufacturing capacity, encourage procurement of critical supplies domestically or from free-trade partners, and jump-start R&D and commercialisation of leading-edge technologies such as carbon capture and storage and clean hydrogen'. Valued at USD 500 billion of subsidies (spending and tax breaks), it targets clean energy and healthcare sectors[33]. More specifically, the IRA aims to lower energy costs for individuals, increase the country's energy independence (and reduce its reliance on China), invest in innovative decarbonisation solutions, and prioritise investments for disadvantaged and rural communities[34]. The IRA faces challenges, particularly from the Republican Party[35], and struggles with some sectors, such as offshore wind[36]. So far, it has been unable to slow down oil production, which broke a new record in October 2023, reaching 13.2 million barrels per day[37].

While the NZIA may seem modest compared to the IRA, it aligns with broader European climate policies. The IRA allocates USD 269 billion (€337 billion) to climate and industry, with an investment that could total USD 1 trillion with private sector support. International competition is intense, with China leading in solar panels, batteries, and electric vehicles[38]. To address this, the EU should consider further measures to strengthen the NZIA and compete globally, given the rising influence of countries like India and its Production Linked Incentives (PLI) subsidy programme[39], Malaysia, and Vietnam.

Measure 4.6

Strengthen the NZIA and TCTF to develop transition-related European production assets despite international fierce competition

Possible sub-measures include:

- **Expanding the support** under the NZIA and the TCTF to regions, OPEX, and energy efficiency technologies
- **Extending the TCTF after 2025**
- **Setting rules so that the TCTF does not generate a subsidy race** that the largest economies would eventually win
- **Working with the different Member States so they adopt local production criteria** in their tenders
- **Allowing for emergency support packages** to support industries that may suffer from unfair competition from abroad

4.7 Strengthen the ambition of the Carbon Border Adjustment Mechanism

The Carbon Border Adjustment Mechanism (CBAM), to be effective in 2026, aims to protect the European market against climate dumping. Covering the cement, iron and steel, aluminium, fertiliser, and electricity sectors, it requires importers to purchase certificates on the European carbon market. The proposal envisions a gradual phase-out (2026-2035) of the current distribution of free quotas on the European carbon market. Although welcomed, it has some pitfalls and uncertainties that may limit its impact. The EU should consider the following CBAM revisions:

Measure 4.7

Set of Measures 4.7 to reinforce the Carbon Border Adjustment Mechanism

- **Accompany CBAM by ending the free allocation of quotas, instead of implementing a gradual phase-out.** Extending CBAM without ending free allocation would impose a higher carbon cost on imported products than on market-manufactured products, which does not constitute an incentive to decarbonise.
- **Extend CBAM to other products** and manufactured goods to avoid substitution of covered basic products with downstream products not covered by the mechanism (e.g., substituting steel and aluminium imports with packaging containing these materials).

Notes

1. Material Economics, 2019, Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry.

2. Yamano N., Guilhoto J.J.M. (2020) Emissions Embodied in International Trade and Domestic Final Demand, Using the OECD Inter-Country Input-Output Database. Methodology and Results *CO2*, Paris: OECD, 55 pp.

3. Past data is sourced from the EEA Dataviewer. Targets for 2020 and 2030 reflect the EU's overall emission reduction goals of -20% and -55% from 1990 levels, distributed proportionally according to each sector's 2021 emission share. The 2050 target aligns with residual emissions in the RtoNZ transition scenario. WEM (With Existing Measures) projections, utilising EEA & Climact data, estimate future emissions considering measures already implemented by the EU and its Member States.

4. Germany, France, Italy, Spain, the Netherlands, Poland, Sweden.

5. Only methanol production in Germany is covered, which represents about two thirds of the EU's methanol production.

6. The material efficiency levers of the olefins & aromatics sectors also include sufficiency, but it has not been possible to disentangle the share of the two. Moreover, the emissions increase associated to the material efficiency lever for aluminium reflects a strong increase in recycled production, leading to an overall increase in aluminium production by 2050. Despite being a lot less emissive than primary production of aluminium, the strong increase in secondary production leads to an overall increase in emissions (before applying other levers).

7. Bourgeois, S. *et al.*, 2023, CLEVER Final Report. Climate neutrality, Energy Security and Sustainability: A pathway to bridge the gap through Sufficiency, Efficiency and Renewables.

8. These figures do not take into account losses on past investments in assets which will become stranded because of the low-carbon transition.

9. To determine planned investment into industry decarbonisation (€120 billion), an assessment performed, in each of the countries

covered except in Poland (because of a lack of data), of the public subsidies to decarbonisation investments into industry, and of the private investments to which these subsidies were associated. This therefore leaves aside any decarbonisation investment which would be implemented without public support. Such investments are however likely to be low, considering the lack of business case for many low-carbon industrial investments.

10. Euractiv, 5 June 2023, '[Energy sufficiency, a French political concept still misunderstood in Europe]', *Euractiv*.

11. *Ibid*.

12. These are strongly inspired from the CLEVER scenario. Toledano, A. *et al.*, 2023, [Clever - Establishment of energy consumption convergence corridors to 2050 - Industrial sector].

13. For instance, Ademe, the French agency for ecological transition, launched an advertisement campaign promoting sufficiency ahead of Black Friday 2023.

14. European Parliament and Council, 2023, '[Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending regulations (EU) 2023/9455 (recast=)]' September 13, Eur-Lex.

15. European Commission, '[Ecodesign for Sustainable Products Regulation]', consulted in December 2023.

16. Carbon Market Watch, March 2022, '[EU ETS 101 A beginner's guide to the EU's Emissions Trading System]'.

17. '[Carbon Contracts for Difference (CCfD) program for energy-intensive industries]', IEA, iea.org.

18. As recommended by many NGOs and think tanks. Bourgeois, S. et al., 2023, *CLEVER Final Report*, op. cit., p. 55. E3G, 5 February 2023, '[EU Green Deal Industrial Plan 'can-do energy' with some gaps]'. Climate Action Network Europe, European Environmental Bureau, WWF, 28 June 2023, [Joint NGO Statement on Net-Zero Industry Act (NZIA)].

19. These measures also appear in Cleantech for Europe, 10 February 2022, '[Supercharging EU Energy Efficiency: Nine Policy Proposals from the Innovation Community]'.

20. European Commission, March 2020, '[Circular economy action plan]'.

21. European Parliament News, 15 November 2023, '[How the EU wants to achieve a circular economy by 2050]'.

22. European Parliament and Council (2012, revised in 2019) '[Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)]', consulted on 4 July 2023 via Eur-lex.

23. As per a recent study financed by the EU and focusing on the European countries, as well as the UK, Norway, and Switzerland: Habib H, Wagener M., Baldé C. P. et al. (2022) '[What gets measured gets managed – does it? Uncovering the waste electrical and electronic equipment flows in the European Union]', *Resources, Conservation and Recycling*, volume 181, June.

24. For more information, see, Institut national de l'économie circulaire and Orée, April 2020, '[Major Circular Economy Networks in Europe]'.

25. Euractiv, September 2023, '[EU's hydrogen economy struggles to pick up pace]'.

26. Euractiv, 17 March 2023, '[EU sets world's first target for underground CO_2 storage capacity]'. European Environmental Bureau, 21 November 2023, '[European Parliament unravels net-zero industrial policy with costly giveaways and a new attack on nature]'.

27. European Commission, 2023, '[Net-Zero Industry Act]'.

28. These include: solar photovoltaic and solar thermal, electrolysers and fuel cells, onshore wind and offshore renewables, sustainable biogas and biomethane, batteries and storage, carbon capture and storage, heat pumps and geothermal energy, and grid technologies. To these, the Parliament added other technologies, including all types of nuclear fission and fusion, sustainable fuels, and biogas. Euractiv, 25 October 2023, '[Parliament adds nuclear to EU's net-zero industry shortlist]'.

29. Such as the identification of Net-zero Strategic Projects, the lowering of administrative burden, support to carbon capture and storage projects (see below), the establishment of a Net-Zero Europe Platform and the European Hydrogen Bank to attract investments, the implementation of sustainability and resilience criteria in procurement procedures and auctions to boost the renewable energy market, the establishment of regulatory sandboxes, and the creation of Net-Zero Industry Academies, with the support and oversight of the Net-Zero Europe Platform; 'Net-Zero Industry Act', *European Commission*, op. cit.

30. European Commission, Press Corner, 9 March 2023, '[State aid: Commission adopts Temporary Crisis and Transition Framework to further support transition towards net-zero economy]'.

31. Euractiv, 12 September (updated 8 November) 2023, '[Analysis: EU subsidy race is on – and Germany is winning it]'.

32. European Commission, 2022, '[Strategic Technologies Europe Platform]'.

33. McKinsey & Company, October 2022, '[The Inflation Reduction Act: Here's what's in it]'.

34. Senate Democrats, 2022, '[Summary of the Energy Security and Climate Change Investments in the Inflation Reduction Act of 2022]'.

35. It has made it clear that support for renewables would be scrapped if it comes back to power after the next election. McNamee B. L., 2023, '[Department of Energy and Related Commissions]' in *Project 2025*, Republican Party. In addition, Republic States are refusing to transition to electric vehicles. Bloomberg, 9 November 2023, '[Red State Drivers Turn Up Their Noses at EVs Despite Incentives]'.

36. Le Monde, 9 October 2023, '[Aux États-Unis, la bulle des énergies renouvelables explose]'.

37. AP News, 13 October 2023, '[US oil production hits all-time high, conflicting with efforts to cut heat-trapping pollution]'.

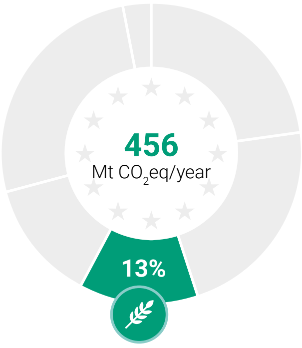
38. China Dialogue, 7 November 2023, '[The 'new three': How China came to lead solar cell, lithium battery and EV manufacturing]'.

39. InvestIndia, [Production Linked Incentive (PLI) Schemes in India], consulted in December 2023.

Investments in the agriculture sector

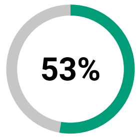
Extensify, despecialise, re-territorialise and transition to agroecology

Current emissions and reduction potential



Action levers to mobilise:

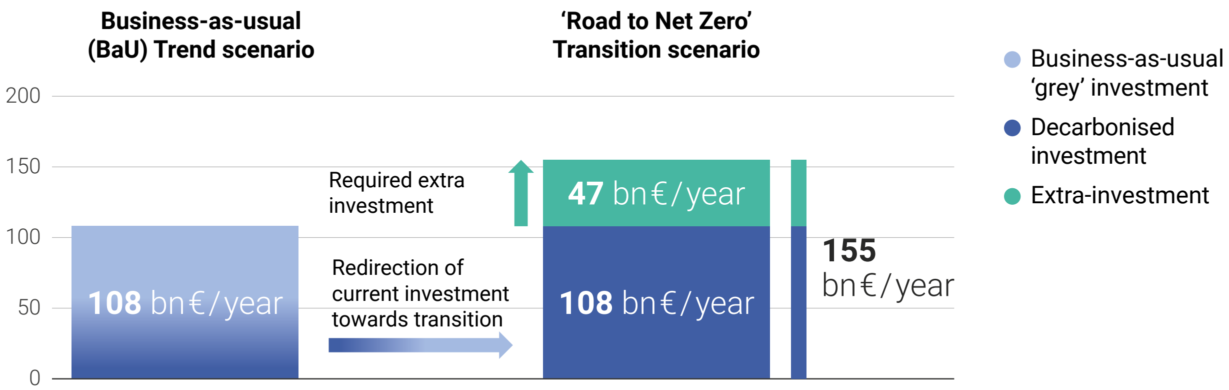
1. Reduce herd size and adapt breeding practices
2. Convert crop systems to agroecology
3. Convert tractors to low-carbon technologies



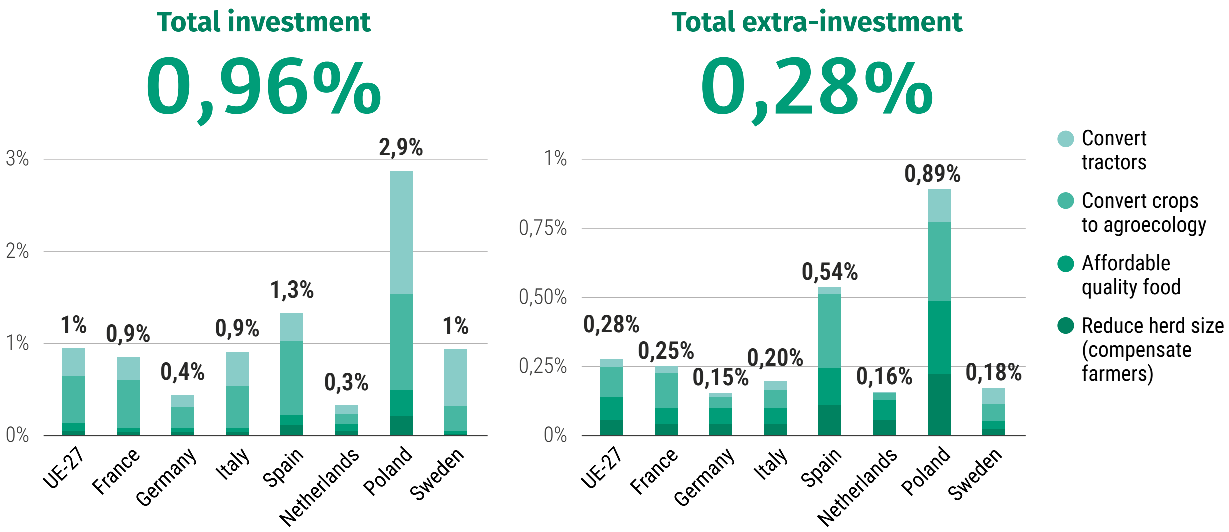
2050 decarbonisation potential

Global investment needs

UE-27 global investment and extra-investment



Global investment and extra-investment per lever, per country (in % of GDP):



Public investment needs

Total public investment in proposed public policies

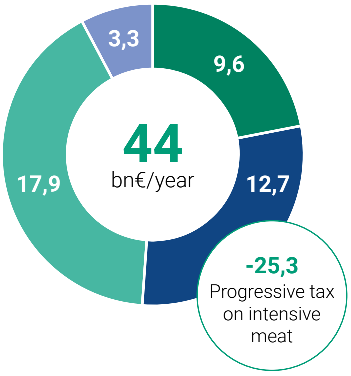
108 bn€/year

Public share in total investment

70%

Public extra-investment in % GDP

0,27%



Total extra public investment in proposed public policies: 44 bn€/year

- Support fund for the transition of the meat industry
- Support to affordable quality food
- Support to organic farming and agro-ecology (conversion, maintenance, setup)
- Tractor conversion premium

Complementary measures:

+ Conditioning CAP subsidies based on the amount of labour rather than land area
+ Promoting functional integrated crop-livestock management systems

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT	
TOTAL	EXTRA	TOTAL	EXTRA
10%	13%	21%	17%

Key takeaways

- **When it comes to agriculture, the objective of climate mitigation must be put in the broader perspective of transitioning towards a sustainable food system.**
- **Europe's Common Agricultural Policy (CAP) historically prioritised a productivity-driven approach to ensure food self-sufficiency. This model is outdated and detrimental to soil health, biodiversity, water resources, the climate, and human health.**
- **Agroecological practices must replace the current chemical-intensive productivity-driven agriculture approach. To do so, a rise of ~25% in current CAP subsidies is necessary to align with levels provided by EU countries or regions with exemplary historical conversion rates.**
- **Livestock accounts for a significant part of agricultural emissions. To cut these emissions, producers need to reduce their herds and consumers need to eat less meat.**
- **Tax policies can help to transform the agricultural sector. To guarantee a fair transition, the tax revenues should be redistributed to compensate farmers' losses and support efforts toward affordable quality food.**
- **Direct CO_2 emissions, primarily related to greenhouse heating and the combustion of fossil fuels in tractor engines, can be mostly eliminated by switching to low-carbon energy sources.**

For climate mitigation, agricultural sector should aim to transition towards a sustainable food system, which prioritises human health, conserves natural resources and biodiversity, and is adaptable to climate change.

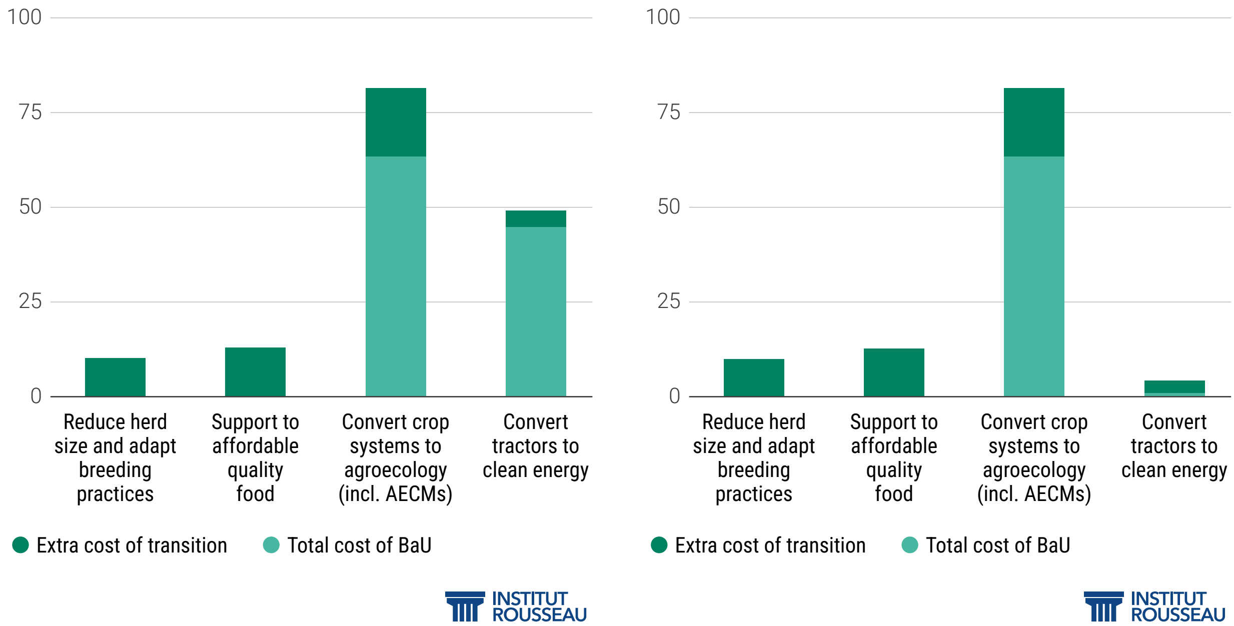
Agroecological practices must replace chemical-intensive productivity-driven industrial agriculture.

Europe's agricultural policy, defined under **the Common Agricultural Policy (CAP), initially focused on post-war food self-sufficiency, prioritising a productivity-driven approach. This model is outdated, as it pollutes soils and clean water, threatens biodiversity and the climate, and is detrimental to safe employment and human health.** In response, innovative agricultural practices, collectively termed 'agroecology', are emerging. Agroecological practices view agrosystems holistically as ecosystems, emphasising intricate interactions between soil and living organisms. Unlike traditional productivity-centric approaches, agroecology prioritises the multitude of ecosystem services provided by agricultural systems and highlights soil as a primary production factor, often involving minimal soil disturbance. In the absence of an agroecology label, agroecology is mainly represented (and approximated here) by the 'organic'[1] label, sometimes supplemented by other agro-environmental measures. Organic farming represents around 9% of Europe's Useful Agricultural Area (UAA) in 2020[2].

This report outlines measures to decarbonise the European agricultural sector and transition to a resilient, environmentally friendly model. **This vision of the 2050 food system is based on the TYFA-GHG scenario** developed by IDDRI and AScA[3]. While some measures are technical, most aim at systemic change, departing from dominant forms of agriculture. Several measures also aim to diversify and enhance farmers' income sources, transforming the economic model by rewarding environmental contributions through the combination of market redesign and public policy support.

The estimated annual investment required to reduce EU-27 agricultural emissions by 53% from now until 2050 is €155 billion, requiring an extra annual public investment of €44 billion.

Fig. 5.1 **Total (left) and public (right) investments and extra-investments required for agriculture, per decarbonisation lever (in €billion per year)**



Box 5.1

Agro-ecology benefits expand far beyond emissions reduction

Shifting towards agro-ecology include significant co-benefits on top of emissions reduction, including:

Biodiversity and biogeochemical improvements

- Phasing out agrochemicals promotes healthier soil and agroecosystems.
- Agroecological infrastructures (AEI) like permanent grasslands and hedges enhance ecological structure (cf. Carbon sinks section).
- Agricultural practices, such as permanent soil cover, boost organic matter and biological activity.

Farming efficiency and employment

- Reduced reliance on inputs and capital creates (better-paid) jobs.
- Diversified farming systems increase resilience to unpredictable weather patterns.
- While the yields of agroecology may be lower than present-day conventional farming, they are more resilient. Yields of high-input farming are stagnating and are becoming more and more variable and might decrease in the short future. Thus, it is socially and economically risky continue with highly productive farming.

Health Benefits

- Eliminating agrochemicals enhances working conditions for agricultural workers.
- Promotes a healthier diet for the entire population.

Trade balance

- Enhancing Europe's trade balance by gradually phasing out imports of chemical fertilisers, amounting to €6.7 billion[4], and soybean, amounting €8.8 billion in 2022[5].

Land-use impact and carbon sequestration (cf. Carbon sinks section)

- Suspending soybean/plant protein imports for animal feed prevents deforestation in exporting countries[6].
- Carbon sequestration[7] is enhanced through composted inputs, crop rotation with legumes, cover crop use, extensification, and organic conversion.

Climate adaptation

- Addresses issues like pest/disease outbreaks through increased biodiversity (natural control).
- Agroecological infrastructures act as barriers against extreme climatic events.
- Improved soil structure aids water absorption during floods and drought.
- These measures collectively contribute to a sustainable and resilient food system amid escalating climate challenges.

1 Emissions of the sector

The agricultural sector accounts for approximately 13% of Europe's domestic emissions, totaling 456 million tons of CO_2-eq in 2021.

These emissions are split as follows:

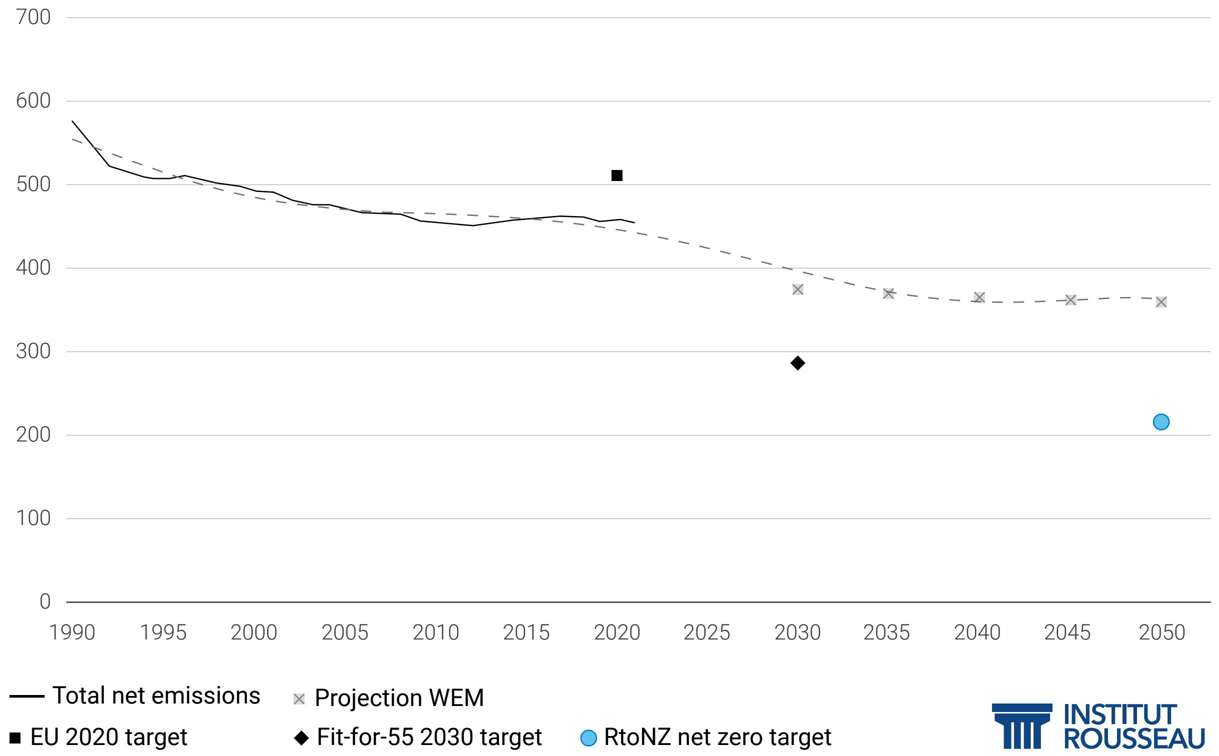
- **54% to livestock**, primarily from methane emissions, with 74% originating from enteric fermentation and 26% from the open-air decomposition of animal waste (manure, slurry).

- **26% to crop cultivation**, predominantly emitting nitrous oxide (N_2O) linked to nitrogen fertilizer use.

- **17% to energy consumption**, including machinery (mainly tractors) and greenhouse heating.

These emissions have remained constant over the past decade, and the current business-as-usual trend, considering existing policy measures, reveals a significant gap with the 2030 and 2050 targets, as shown in Figure 5.2.

Fig. 5.2 **Agriculture past UE-27 domestic emissions and progress towards achieving 2030 and 2050 targets, in million tons of CO_2 equivalent ($MtCO_2e$).[8]**



WEM: With Existing Measures.

A shift toward the agro-system described by the TYFA-GHG scenario would lead to 45% emission reductions[9] of the agricultural sector by 2050. This reduction is achieved through:

- **Ending chemical fertiliser use**: the biggest GHG reduction comes from significantly reducing N_2O and CO_2 emissions by no longer using or producing chemical fertilisers, particularly nitrogen (reduction from production is factored into the industry sector). TYFA GHG enables a reduction of -60%[10] on direct and indirect N_2O emissions for agricultural soils by 2050 compared to 2010.

- **Better manure management**: significantly reducing emissions in manure management comes from producing fewer animals and changing practices, especially in the bovine herd. This includes the shift away from liquid manure through increased use of straw and, to a limited extent, its collection for biogas production (through anaerobic digestion).

- **Reduction of enteric fermentation**: while enteric fermentation reductions are less significant due to the maintenance of a substantial cattle population valuing permanent grassland, efforts are made to reduce emissions by using feed additives to reduce enteric emissions from dairy and suckler cows; other ruminants like sheep and goats are taken into account but are less significant.

- **Improved energy consumption**: using fewer greenhouses that require heating, by producing more seasonal fruits and vegetables.

The RtoNZ model goes further to address energy-related CO_2 emissions. It involves **converting all tractors to low-carbon technologies**, primarily biomethane and electricity. Additionally, electricity consumption becomes decarbonised (cf. Energy production section), and the model **replaces fossil gas with biomethane** (and some low-carbon electricity) **for heating greenhouses. This comprehensive strategy results in a 53% reduction in current GHG emissions by 2050**.

2 What will the 2050 agro-system look like? A recap of TYFA-GHG

Agriculture projections are based on the TYFA-GHG[11] model developed by the Institute for Sustainable Development and International Relations (IDDRI) and AScA, using the ClimAgri tool.

Exploring various EU agricultural models for the 2050 transition, focus must extend beyond mere greenhouse gas (GHG) reductions. Recognising agriculture's pivotal role in the food system and society, a model that comprehensively addresses diverse environmental, social, and co-benefits is needed. Agriculture also requires reinforcement against current and anticipated climate challenges.

TYFA stands for Ten Years For Agroecology, and TYFA-GHG is an alternative scenario that maximises GHG reductions while equally prioritising critical issues in the food, agriculture, and land sectors. Beyond climate mitigation, TYFA tackles biodiversity conservation, natural resource preservation (especially water and soils), food security, and human health concerns linked to diets and agricultural chemical exposure. Moreover, TYFA emphasises enhancing adaptation capacity at both farm and landscape levels. TYFA employs a meticulous and conservative approach to systematically evaluate critical parameters, providing heightened relevance on various fronts. Examples include the ongoing decline in agricultural yields, the use of a modelling tool designed to simulate the dynamics of the European food system, and emphasis on fundamental constraints like the nitrogen cycle and feed-food balance.

Box 5.2

The TYFA-GHG model at a glance

Crop production and land-use

- **Optimising the nitrogen cycle management** at the most local level possible. This involves (i) phasing-out the use of synthetic fertilisers (ii) eliminating soybean/plant protein imports, (iii) reintegrating legumes into crop rotations, and (iv) localising livestock systems in cropland areas in order to maximise fertility transfers, including those from legume-rich permanent grassland to crops through composted manure.
- **Extensifying crop production towards agroecological practices** includes a gradual phasing out of pesticides and above-mentioned synthetic fertilisers, aligning with organic agriculture practices such as adopting year-round crop covers.
- **Diversifying the agricultural landscape** by allocating 10% of cropland to semi-natural vegetation as agroecological infrastructure. This strategy includes the strategic redeployment of natural/permanent grasslands across European territory.

Livestock production

- **Extensifying livestock production**, minimising feed / food competition, reducing granivore numbers, and moderately decreasing ruminant numbers, maintaining permanent and natural grasslands comparable to 2010 levels.
- **Widespread adoption of integrated crop-livestock farming systems**, reducing territorial agricultural specialisation and transferring fertility from livestock to crops. Consequently, bovine herd size is adjusted to maintain natural grasslands while overall decreasing grazing intensity.

Improving diets

- **Improving diets and aligning with nutritional recommendations** by reducing consumption of animal products (especially monogastric meat consumption, as ruminant livestock is less decreased) and prioritising plant proteins, fruits and vegetables.

Food, feed and fuel

- Prioritising agricultural resources ensures human food takes precedence, followed by animal feed and non-food uses, contributing to methanisation unit development for 189 TWh production in 2050 (mainly based on grassland and manure). While maintaining this logic, in order to loop energy needs, RtoNZ model considers a higher biogas production, up to 489 TWh per year.
- A wise use of ligneous semi-natural vegetation may also contribute to a significant amount of renewable local energy.

These transformations signify a shift to less input- and capital-dependent farming, emphasising agricultural labour (e.g., reintroducing legumes and re-territorialised animal manure eliminates the need for synthetic fertilisers).

Box 5.3

Will EU citizens face hunger in 2050 with agroecology's lower yields?

Although agroecology may indeed lead to lower yields in livestock production, the impact on crop production is becoming increasingly negligible, almost comparable to conventional methods[12]. Even considering very conservative yield assumptions, TYFA-GHG still ensures sufficient production to feed the entire EU population and meet key export needs in dairy and wheat.

Box 5.4

Why not prioritise a more significant reduction in beef production?

TYFA-GHG recommends a more substantial reduction in the production of climate-efficient animals like swine or poultry, while advocating for a comparatively lesser reduction in bovine production. This strategic choice is based on the understanding that, **despite ruminants and the maintenance of permanent grasslands posing challenges for climate mitigation, they play vital roles in fertility transfer at the territorial level** and make substantial and irreplaceable contributions to biodiversity and the conservation of natural resources. By consuming resources that are not edible for humans, they also contribute to the overall food balance in a rather efficient way[13].

3 How to decarbonise the sector and how much investment does it require?

Specific emission reduction strategies from the TYFA model were selected and corresponding measures for implementation, including taxes, modifications to the Common Agricultural Policy, and subsidies, were developed. **Due to the extreme variability in European farms and production systems**, estimating average private costs (i.e. total costs), such as those related to transitioning to agroecology or reducing meat consumption, is very challenging. Hence, **the public costs serve as approximations for the investments associated with various decarbonisation levers**.

Key policy measures include:

- **Support for gradual conversion to agroecological systems across the entire EU agricultural area.** This involves strengthening and restructuring CAP aid, protecting against cheaper imports, and reducing prices for organic and extensive foods for the majority of the population.

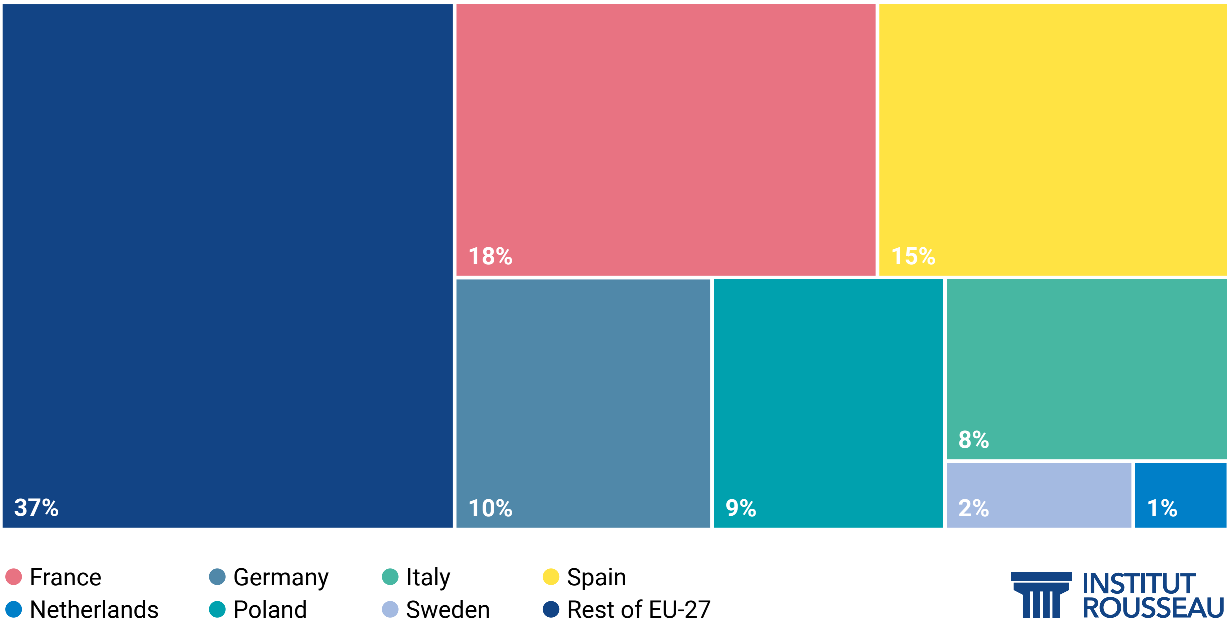
- **Support for reducing livestock through a tax on intensively produced meat**. This tax income would be used to 1) compensate affected breeders and 2) fund price reductions for organic and extensive food. Additionally, it is proposed to incentivise the use of feed additives (50%) used to reduce livestock enteric fermentation and CH_4 production.

- **Support conversion to low-carbon tractor fleet**, with public aid covering 100% of the acquisition extra-cost between conventional and low-carbon vehicles. Support for biogas production and low-carbon energy production is already included in the Energy production section.

3.1 Convert crop systems to agroecology

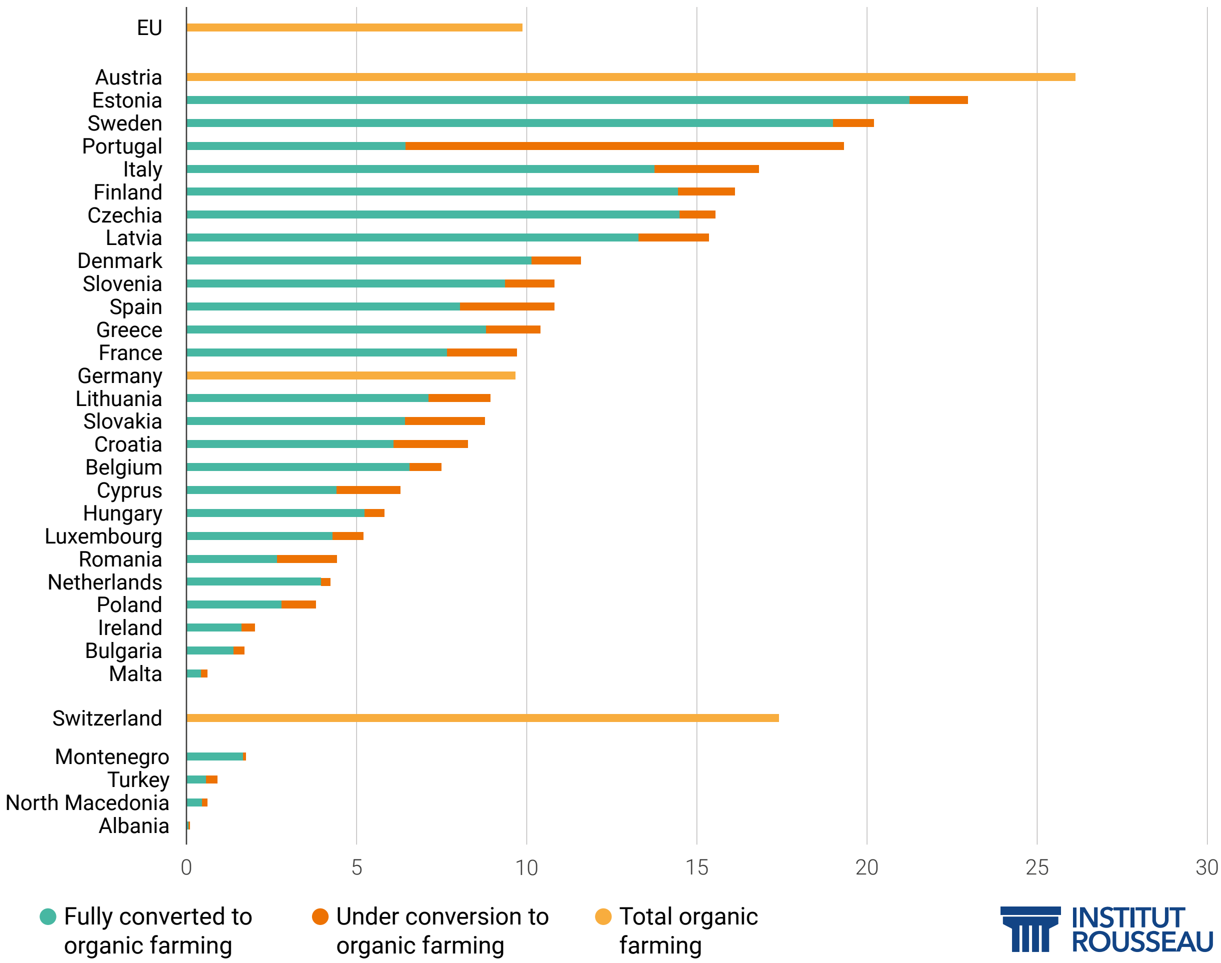
The key lever for reducing emissions in the EU's agricultural sector is the gradual conversion of crop systems to 100% agroecological systems, achieving a 25% reduction of emissions. Crop surfaces vary a lot from one country to another, as shown in Figure 5.3. The seven studied countries represent 63% of the European Utilised Agricultural Area (UAA), with France (18%) and Spain (15%) showing the highest surfaces.

Fig. 5.3 **Distribution of European Utilised Agricultural Area (UAA) by country**



Today, organic farming represents around 10% of EU agricultural areas (2022[14]), with a conversion rate slightly below +1% per year, coupled with stagnant areas under other agro-environmental measures. This trend indicates that, in a business-as-usual scenario, the majority of EU UAA will remain under intensive farming by 2050. This is exacerbated by current lower organic development rates due to high inflation of food prices[15].

Fig. 5.4 **Organic areas, in % share of total national Utilised Agricultural Area**[16]



Similar to the ongoing shift of farms to organic agriculture, this transition needs public support[17]. Ambitious measures are needed for conversion and maintenance support, income restructuring, protection against low-cost imports, and price reduction for agro-ecological food.

To ensure all farmers are certified organic or converting by 2050, current support for organic and other agro-environmental practices is notably inadequate[18] and must align to the historical EU best-in-class.

Increased conversion and maintenance support for organic and agro-ecological systems is needed to address (i) additional expenses, (ii) the learning curve, and (iii) potential risks without increasing prices. This support should encourage diversification (e.g., a bonus for legume production) and the development of agroecological infrastructure (hedges, ponds, intra-plot trees). **A gradual strategy could commence with support for 'integrated' farming** (allowing restricted use of fertilisers and pesticides), **then progressing towards a combination of organic farming, diversification, and agro-ecological infrastructure.**

- **To achieve conversion rates of 2.5% and then 4% per year, conversion support should align with levels provided by EU countries or regions with exemplary historical conversion rates,** especially in annual crops (60% of areas) and grassland (30% of areas). Notable examples are the Italian regions of Tuscany and Campania (with 35% and 20% organic UAA, respectively[19]) for arable lands, and Denmark for permanent grassland (21% organic UAA in 2019[20]).

These regions offer support approximately double the EU average, around €450/ha for field crops and €300/ha for grassland. For permanent crops (orchards and vineyards), where organic UAA progression is faster, an average support per hectare similar to the current one is recommended, i.e. approximately €800/ha[21]. The suggested support duration is an average of 5 years, covering both the conversion period (approximately 3 years) and the first years of organic certification.

- For **maintenance support**, the analysis of the top-performing EU country or region suggests a **prolonged support mechanism** (to prevent reversal) **comprising at least 50% of the conversion support** amount.

- **For the initial phase, sustaining the most ambitious agro-environmental and climate measures (AECM) is recommended** to offer an achievable first step before transitioning to organic practices. This could involve mixed crop and livestock systems with a declining pesticide ceiling over five years. Maintaining an average of 50% of the current AECM at the EU level during this period would amount to €2 billion per year.

The total estimated cost for complete sector conversion by 2050 is around €25 billion per year, with an extra public cost of approximately €18 billion per year between 2022 and 2050[22]. This constitutes a 30% increase over the existing €57 billion per year income support provided by the CAP.

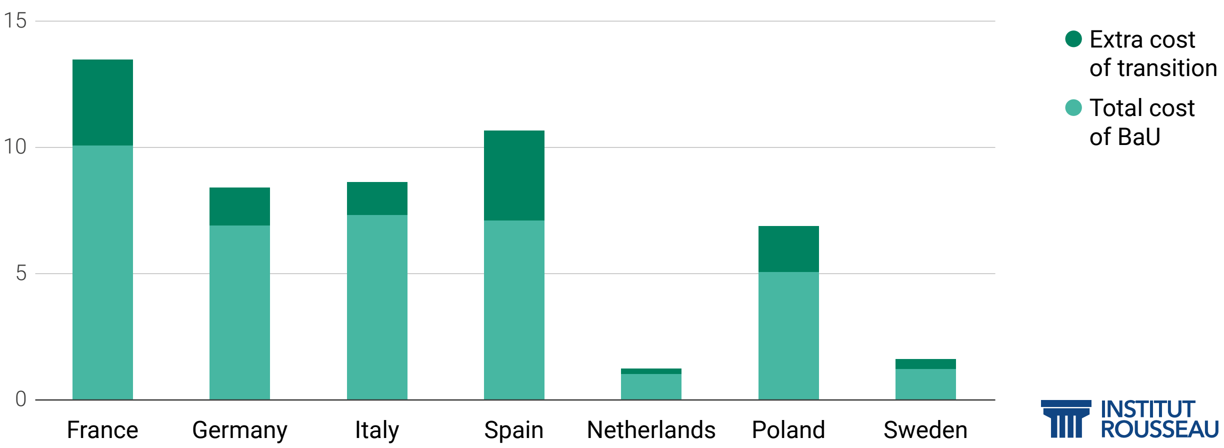
Measure 5.1

Double the average aid per hectare for organic farming and extend it to agro-ecological practices

Public cost
€25 billion per year
Public extra-cost
€18 billion per year

Extra public costs vary among countries (Figure 5.5.), with higher expenses in certain nations like France and Spain, attributed to their significant Utilised Agricultural Area (UAA) and relatively lower existing 'agro-environmental' public support. In contrast, Italy and Germany have less agricultural land and already possess relatively substantial public support for organic and other Agro-Environmental and Climate Measures (AECMs).

Fig. 5.5 **Annual public investment and extra-investment required to support EU agrosystem conversion to agroecology (in €billion per year)**



This financial support to agroecology should be complemented by the following policy measures:

1. **Ensuring organic, agroecology and/or extensive, local, quality foods remain accessible to everyone**, through targeted subsidies[23]. Today, organic foods are still largely inaccessible to the majority of the population, particularly due to excess margins of large manufacturers and distributors[24]. Therefore, alongside support measures for farmers, a substantial price reduction for end-consumers, proportionate to the economic vulnerability of the household, is essential without compromising farmers' income. To achieve this intricate goal, an **'agro-ecological food' voucher or social protection system could enhance the affordability of organic and agroecology food**. To prevent excessive margins by the agrifood industry and distributors linked to this support mechanism, strict regulation of the organic end-product price evolution is necessary. This price reduction will be **funded in particular[25] by a tax on intensive meats** of which 50% is dedicated to this mechanism (cf. 5.3.2).

2. **Preventing unfair competition from international intensive agriculture**, through 'safeguard clauses' (i.e. imposing same environmental and health standards for imports than local production) or a carbon tax at borders (cf. Measures 4.6 and 4.7 in Industry section)[26].

3. **Pivoting agricultural training and consulting towards agroecological systems and techniques**, aligning with the broader reorientation and overall increase in agricultural R&D. Additionally, as agro-ecological systems require more labour, a portion of the reconversion support will contribute to developing highly skilled agricultural professions (cf. Cross-sector section for more details on both topics).

Measure 5.2

Agro-ecological/quality food check or other social food protection

Public extra-cost
€12,7 billion per year
Financed by the tax on intensive meat (5.4)

In addition to agro-ecological support, it would be beneficial to transition from hectare-based income support (1st pillar of the CAP) to workforce-based support (in FTE/UTA). This shift will encourage labour-intensive agro-ecological practices, benefitting medium-sized farms that integrate well into their surroundings, thereby mitigating the concentration of agricultural production and long-distance food transport. The income support budget will remain constant (in euros 2023-2027) to avoid reducing the limited income of most current farmers (excluding cereal and wine sectors). Agro-ecological support, designed to cover

additional costs in organic farming, will mildly increase farmers' income, particularly with controlled prices. Consequently, the primary boost to the majority of farmers' (small and medium-sized) income will come from restructuring the CAP 1st pillar income support.

Measure 5.3

Switch from hectare-based income support to workforce-based support

Public cost
€57 billion per year
Public extra-cost
€0 billion per year

3.2 Reduce herd size and adapt breeding practices

Livestock accounted for 54% of agricultural emissions in 2021, comprising 40% from methane released during enteric fermentation and 14% from methane released during manure decomposition.

To cut these emissions, herd sizes must be decreased and meat consumption reduced. This can be done through a progressive tax on intensive meat. The tax revenue should be redistributed to compensate breeders and support efforts to make quality food affordable for all.

Current public measures, like the weekly vegetarian menu in collective catering introduced in France, (affecting only 7% of meals) are not ambitious enough. To accelerate the business-as-usual 0.6% annual decline in meat consumption since 1990, driven by health, environmental, and financial concerns, a progressive tax on intensive meat is recommended. The tax design, inspired by the True Animal Protein Price Coalition[27], has been adapted to fit to TYFA-GHG projections by type of animal (setting superior tax amount for pork and poultry compared to beef as explained in Box 5.4.) It starts at 10 cents per kg for beef and 20 ct€/kg for pork and poultry in the first year, rising to 35 cents /1.2 €/kg by 2030 and up to 1.5 / 4.5 €/kg in 2050. With an estimated average tax cost of €1.8 per kilogram from 2022-2050, **it would generate a €669 billion revenue on the total 2023-2050 period (i.e. a €24.8 billion annual average)**.

The tax on intensive meat seeks not to raise meat prices overall but specifically those from factory farms. This aims to curb their consumption while funding lower prices for meat and agro-ecological crops. Revenues of this tax would be redistributed as follows:

- **40% to compensate breeders** compelled to reduce their livestock due to the overall decline in meat consumption, especially for granivores
- **50% to support affordable quality food**, through agro-ecological food checks (or social food protection)
- **10% to support developing countries** in reducing their GHG emissions and adapt to climate change (this part of the reinvestment concerning extra-EU countries, they are not included in public investments here).

Measure 5.4

Tax on intensive meat, redistributed to compensate breeders (5.5) and subsidy organic and agroecological food products (5.2)

Average revenues
€24.8 billion per year

Measure 5.5

Providing financial assistance to farmers for the expansion of extensive farming practices and compensating for reductions in herd size

Public extra-cost
€9,6 billion per year
Financed by the tax on intensive meat (5.4)

The second policy measure is to reduce livestock emissions focuses on enteric fermentation (representing 74% of total livestock emissions). A **50% public subsidy to encourage innovative solutions targeting livestock methane production is suggested, such as feed additives**. Based on essential oils, these can reduce methane emissions by at least 20% by adjusting the bacterial flora in ruminants' digestive systems. The aim is to promote such solutions in the market, costing €11 per year per bovine in the cited example. This subsidy would cost approximately €184 million annually for an almost immediate emission reduction of 11 million tons of CO_2-eq.

Measure 5.6

Support to feed additives reducing livestock enteric fermentation and associated methane emissions

Public cost
€0.18 billion per year
Public extra-cost
€0.18 billion per year

3.3 Decarbonise the energy used in agriculture: tractor fleet and heated greenhouses

Direct carbon dioxide (CO_2) emissions from the agricultural sector, primarily related to greenhouse heating and the combustion of fossil fuels in tractor engines, can be mostly eliminated through a switch to low-carbon energy sources.

Greenhouses' boilers, currently primarily heated with fossil gas, can run on biomethane and require no extra investment for the switch to biomethane. **As for transitioning tractors to low-carbon fuels, a mix of biodiesel, electric, and biomethane (bioCNG[28]) is likely to replace current diesel use (while hydrogen is unlikely to be competitive[29])**. Considering a gradual conversion of all European tractors by 2050, a current average +25% extra-investment cost for alternative technologies compared to conventional tractors, and a price parity reached by 2050, the total extra-investment is estimated to be €118 billion for the period 2022-2050, i.e. €4,4 billion per year on average.

To support farmers in this transition, a tractor conversion incentive can be introduced, following a similar model to that for private vehicles (cf. Transport section). As is already the case in France, this incentive would cover 100% of the extra-investment and amount to a total **additional public expenditure of €89 billion between now and 2050, averaging €3,3 billion annually**.

Measure 5.7

Tractor conversion premium

Public cost
€4,4 billion per year
Public extra-cost
€3,3 billion per year

Notes

1. Emphasising chemical-free, non-GMO, and animal welfare-focused practices.
2. Eurostat, 2022, land fully organic or in conversion.
3. IDDRI, 2018, 'Ten Years for Agroecology in Europe (TYFA)'.
4. In average between 2019 and 2021; European Commission, Ensuring availability and affordability of fertilisers, consulted in December 2023.
5. TrendEconomy, Annual International Trade Statistics by Country (HS), consulted in November 2023.

6. As of today, one third of these imports are considered to cause deforestation.

7. Note: soil carbon sequestration is fundamentally a matter of fertility management, soil biological activity, biodiversity, and climate adaptation, rather than being primarily focused on climate mitigation.

8. Past data is sourced from the EEA Dataviewer. Targets for 2020 and 2030 reflect the EU's overall emission reduction goals of -20% and -55% from 1990 levels, distributed proportionally according to each sector's 2021 emission share. The 2050 target aligns with residual emissions in the RtoNZ transition scenario. WEM (With Existing Measures) projections, utilizing EEA & Climact data, estimate future emissions considering measures already implemented by the EU and its Member States.

9. TYFA-GHG explores more reduction levers than these 4 main ones, for instance it takes into account the reduction of deforestation abroad (from the phase out of protein imports like soybean) or the reduction of GHG due to the stop of synthetic fertiliser production (reported in the Industry section for this study). Hence, the % of GHG reduction has been recalculated here thanks to the Climagri tool provided by the TYFA-GHG research team.

10. These findings precede the IPCC update on organic and mineral nitrogen emission factors, with new values at 0.6% and 1.6%, respectively, compared to the previous average of 1%. Incorporating these updated IPCC values would enhance the emission reduction performance of the TYFA scenario.

11. TYFA-GHG is a variant of the first TYFA model, exploring stronger GHG reductions; Poux, X., Aubert, P.-M. (2018). An agroecological Europe in 2050: multifunctional agriculture for healthy eating. Findings from the Ten Years For Agroecology (TYFA) modelling exercise, Iddri-AScA, Study N°09/18, Paris, France, 74 p.; Aubert, P.M., Schwoob, M.H., Poux, X. (2019). Agroecology and carbon neutrality in Europe by 2050: what are the issues? Findings from the TYFA modelling exercise. IDDRI, Study N°02/19.

12. See for instance Perrot, T., Bretagnolle, V., Gaba, S. (2022). Environmentally-friendly landscape management improves oilseed rape yields by increasing pollinators and reducing pests. Journal of Applied Ecology. Inrae, 2022, Regulnat Expertise Report. Inrae, 2023, European chemical Pesticide-Free Agriculture in 2050.

13. Also see: Van Selm et al. (2022), 'Circularity in animal production requires a change in the EAT-Lancet diet in Europe', Nature Food, which comes to the same conclusions.

14. European Commission, Approved 28 CAP Strategic Plans (2023-2027) (2023): p. 76 for % organic UAA (certified or in conversion).

15. For the example of France, see Agence bio, 2023, Les chiffres du bio en 2022.

16. Eurostat, 2023, 'Development in organic farming'.

17. In the absence of specific support for agroecological practices or a comprehensive study on transition costs, public investment was estimated based on amounts allocated to support organic farming.

18. IFOAM, 2022, 'Evaluation of support for organic farming in draft CAP Strategic Plans (2023-2027)'.

19. For regional performances see Crea, 2022, Italian Agriculture in figures 2022. For support level per region and culture type, see Ministero dell'agricoltura, della sovranità alimentare e delle foreste, Piano Strategico Politica Agricola Comune 2023-2027.

20. IFOAM, 2021, Prospects & Developments for organic in national CAP strategic plan.

21. Even if the extra costs compensated differ according to the price level, the same reference aid per hectare was used to estimate public support to the extent that the reductions in turnover linked to the years of conversion and the current aid for conversion are quite close between EU 'zones'.

22. The CAP budget for 2023-2027, including national co-financing, allocates €3 billion per year for organic farming support and an extra €4 billion per year for other Agro-Environmental and Climate Measures (AECM), summing up to a total of €7 billion per year.

23. A VAT reduction could also be implemented but its price reduction potential is limited to -5,5% maximum (at least in France considering the VAT rate), i.e. less than 20% of the current average gap between conventional and organic food, currently around 30% (e.g. CLCV, 2020, enquête prix bio et conventionnel).

24. Plus, experience shows that VAT reduction is at risk to be captured by the agroindustry and distribution through increased margins (currently showing double margins on organic products), UFC, 2019, sur-marges sur les fruits et légumes.

25. Complementary sources of financing (e.g. a tax on ultra-processed foods) should be used to achieve significant price reductions for sustainable food products.

26. Combining both is bound to be more effective than a standalone 'carbon tax' at the borders, which only addresses GHG emissions and is more exposed to greenwashing claims. Moreover, implementing a carbon tax for agriculture is more challenging compared to heavy industry.

27. True Animal Protein Price Coalition.

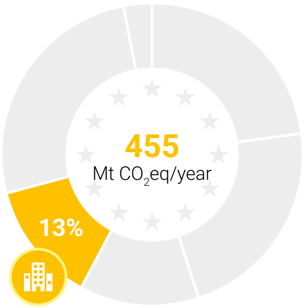
28. Compressed Natural Gas.

29. A 2050 fleet mix of 55% Biodiesel 100, 20% electric and 25% bioCNG is considered here. Hydrogen was not selected due to complicated distribution logistics, safety issues in uncontrolled environments, higher losses due to the need for a cryogenic reservoir, and much higher current starting prices.

Investments in the buildings sector

Efficient renovation of buildings, by trained professionals

Current emissions and reduction potential



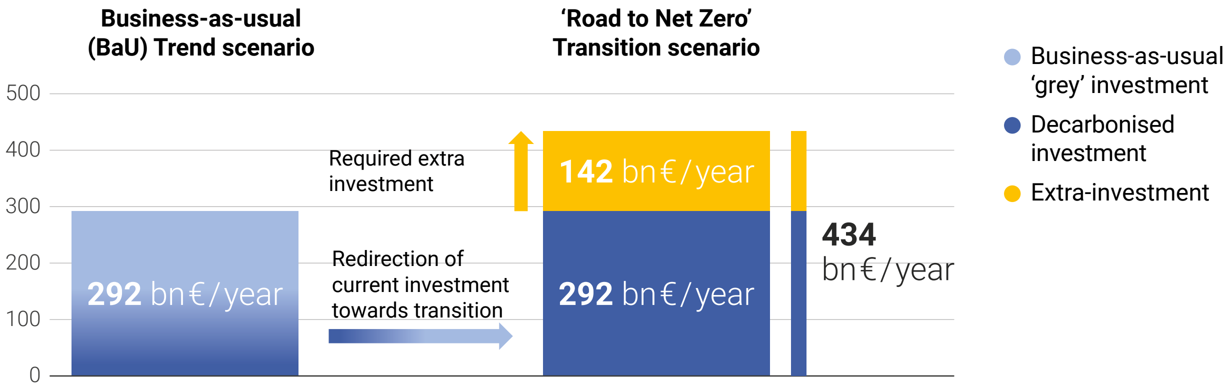
Action levers to mobilise:

1. Efficient renovation of housing
2. Efficient renovation of public Tertiary sector
3. Efficient renovation of private Tertiary sector

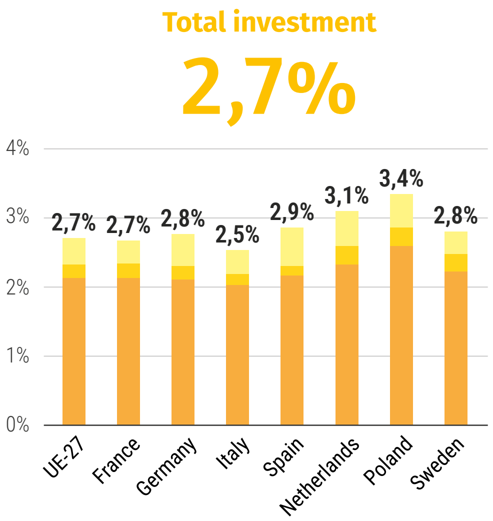
100%
2050 decarbonisation potential

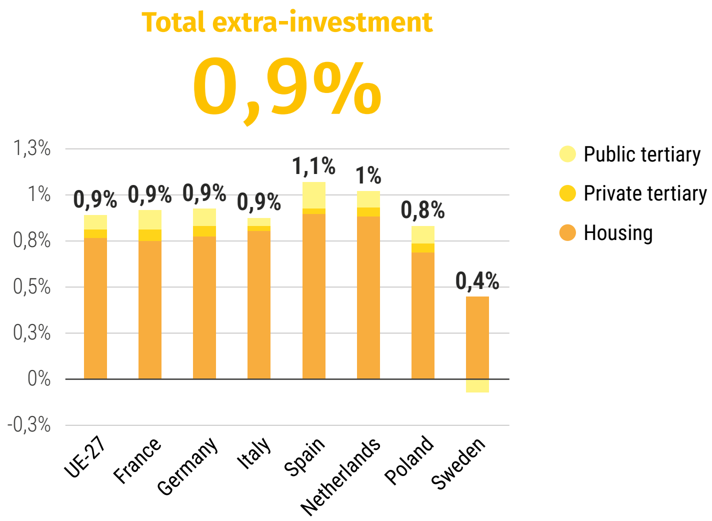
Global investment needs

UE-27 global investment and extra-investment



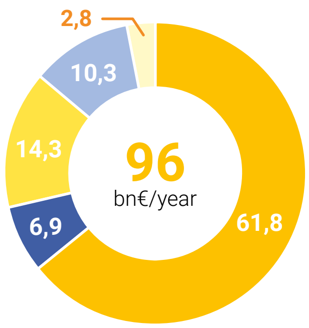
Global investment and extra-investment per lever, per country (in % of GDP):





Public investment needs

Total public investment in proposed public policies	Public share in total investment	Public extra-investment in % GDP
178 bn€/year	41%	0,6%



Total extra public investment in proposed public policies: 96 bn€/year

- Support to efficient renovation of housing
- Support to efficient renovation of public Tertiary sector
- Support to efficient renovation of private Tertiary sector
- Lower-interest loans to finance the remaining costs
- Technical support for individual housing renovation

Complementary measures:

+ Train construction workers in effective renovation
+ Introduce Gradual Energy Pricing

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT	
TOTAL	EXTRA	TOTAL	EXTRA
29%	39%	35%	38%

Key takeaways

- **Buildings' direct emissions are responsible for 13% of total emissions, rising to 35% when considering indirect emissions.**
- **Residential buildings are responsible for 2/3 of emissions (versus 1/3 for tertiary buildings) and require 78% of total renovation investment (versus 22% for tertiary)**
- **Upfront building insulation must be prioritised over decarbonising heating systems.**
- **Efficient renovations lag behind objectives by a 5 to 10 ratio.**
- **Annual investments in the efficient renovation of energy-intensive housing stock must quadruple, with public support needing to double.**
- **Public support must push for efficient renovations of low to medium-performing buildings; This represents from 57% (Germany) to 80% (Poland) of the housing stock.**
- **Public support ratios should be tailored to owners' means and status.**
- **To ensure an ambitious renovation pace, Member States might consider mandatory efficient renovations alongside subsidies, with a primary focus on significant owners of tertiary buildings.**

The buildings sector is a major consumer of final energy, which contributes to both direct GHG emissions (resulting from gas and fuel oil combustion) and indirect emissions (associated with electricity and heat production, as well as construction activities). The proposed measures for this sector aim to nearly **eliminate direct emissions and reduce heat consumption by 60%**, thus easing the strain on the electrical system and minimising biomass withdrawals for heat.

The central strategy revolves around robust support for the efficient renovation of the EU's energy-intensive building stock, excluding recently or deeply renovated structures.

A comprehensive investment of €434 billion per year (€11.7 trillion by 2050) is needed for energy work, representing a €142 billion per year extra cost compared to the business-as-usual scenario. In this total volume, €320 billion per year is allocated to the renovation of energy-intensive housing stock (€236 billion per year) and tertiary sectors (€83 billion per year).

An extra public cost of €96 billion per year is required. This covers €75 billion per year for housing and €21 billion per year for public and private tertiary sectors. Experiences from all studied countries highlight that without substantial support, only the least efficient work tends to be undertaken, such as periodic heating and window renewal every 20 to 30 years.

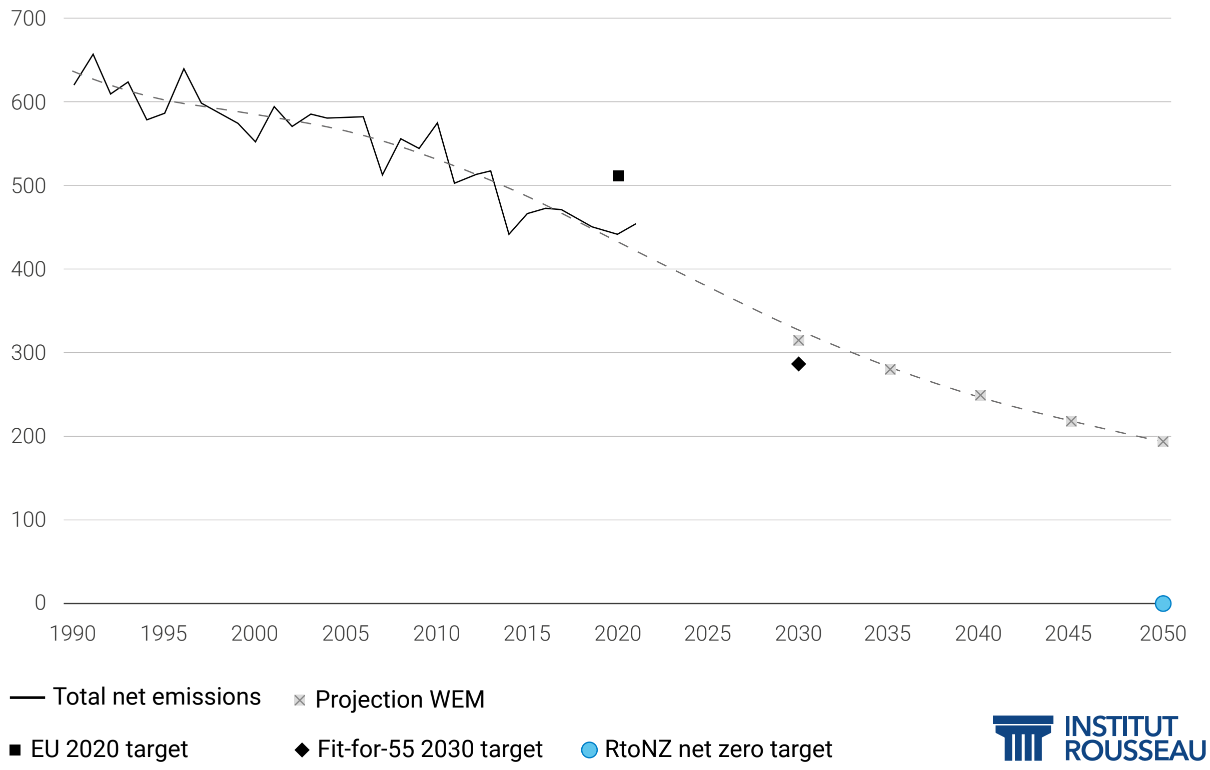
Beyond direct GHG emission reductions, these investments have been shown to reduce indirect emissions[1], increase wellbeing, lower energy bills[2], improve adaptation to climate have positive impact on health system, and foster local employment growth[3].

1 Emissions of the sector

Buildings' direct emissions, mainly due to gas and fuel oil combustion for heating and cooking purposes, were responsible for 13% of total emissions.

These direct emissions (455 $MtCO_2$-eq in 2021) have declined by 27% since 1990, an average reduction of approximately 5 $MtCO_2$-eq per year over the last decade. **To achieve the 2050 target, the annual reduction rate must double**; emissions have to be reduced by a factor of five for the Fit-for-55 2030 target to be reached. Projections based on existing policy measures indicate that meeting either of these targets is currently unlikely (2030) to extremely unlikely (2050), as illustrated in Figure 6.1.

Fig. 6.1 **Buildings past UE-27 domestic emissions and progress towards achieving 2030 and 2050 targets, in million tons of CO_2 equivalent ($MtCO_2e$).[4]**



WEM: With Existing Measures.

The Building sector however accounts for 40% of the EU's final energy consumption.

To grasp the full impact of building-related emissions, one must consider two thirds of the ‘Energy production’ emissions sector (to account for electricity and heat consumed by buildings) and around a quarter of the ‘Industry’ emissions (cement, steel, glass, and plastics production for construction). Consequently, **direct and indirect emissions in the buildings sector account for 36%[5] of GHGs** at the EU level.

2/3 of impacts come from residential buildings versus 1/3 for tertiary buildings

Residential buildings account for 71% of direct GHG emissions and 65% of energy consumption, while tertiary buildings represent 29% of emissions and 35% of energy consumption. Notably, both residential and tertiary sectors have seen stagnant final energy figures since 2012 and direct emissions since 2015, with **variations primarily tied to winter temperatures[6]**.

2 How to decarbonise the sector and how much investment does it require?

One strategy: efficient energy renovation

Efficient energy renovation is the primary strategy to significantly reduce both direct and indirect emissions in the building sector, thus lowering energy costs for households, businesses, and administrations. This involves comprehensive energy works to ensure the insulation of building envelopes (walls, roofs, floors, windows, and doors) and to upgrade heating and ventilation systems. These measures can surpass 'low consumption' standards and cut energy consumption by 40 to 80%, depending on initial insulation levels[7].

Upfront building insulation must be prioritised over decarbonising heating systems

The proposed approach prioritises building insulation, as a reliance on decarbonising heating systems has significant drawbacks:

- **A substantial increase in peak electricity demand during winter**[8]. This makes it challenging (if not impossible) to meet demand with low-carbon sources in the short term and considerably expensive in the long term (e.g. high electricity consumption by heat pumps in poorly insulated houses).

- **Limited impact on energy consumption**, leading to an increase in material extraction and importation for electricity production (cf. Energy production section) and/or increased reliance on agricultural and forestry biomass (cf. Agriculture and Carbon sinks sections).

Efficient renovations lag behind objectives by a 5 to 10 ratio

With only 0.2 to 0.5% of building stock undergoing efficient renovation annually, efficient renovation rates lag behind the national targets of 2 to 3%[9]. Major impediments include high costs for most owners, particularly in residential areas; public support favouring simple heating system changes and less expensive works (e.g., attic insulation); and quasi-inexistent technical assistance given the complexity of the required work[10].

Best Practices

In France, local initiatives supporting efficient renovations have achieved an annual rate exceeding 2% for eligible stock, compared to less than 0.3% for the overall private building stock[11].

In Germany, the 2021 new support for Efficient Houses (BEG WG) doubled the rate of global renovations[12], until the boost of public support for simple heating modifications during the 3rd trimester 2022, mirroring the situation in France.

Public support must push for efficient renovations of low to medium-performing buildings and should tailor public ratios to owners' means and status.

Public support must be tailored to owners' means and status:

- Housing: public support should represent 20% to 80% of capped costs, depending on owner income, with an average of 50%. This support should be supplemented by subsidised loans for remaining energy works.

- Public buildings: a 100% public massive investment.

- Private tertiary sector: public support of 20% to 50% for efficient renovations, averaging at 30%.

As stated in most studied countries' Long Term Renovation Strategies (LTRS), **priority should be given to stock** (>130 kwh/m^2/year in most cases) **built before recent thermal regulations** (varying greatly from country to country). **The building stock up for renovation should also include vacant housing**, in order to limit new construction projects, while increasing the total supply of housing[13] and curb land price hikes.

Considering various constraints weighing on comprehensive one-step renovations[14], **energy efficient renovations in 2 or 3 stages could also be supported, particularly in the ramp-up phase**. One-step renovations, as well as durable and resilient bio-sourced materials for insulation, could however benefit from higher support rates.

To ensure work quality and prevent fraud, these investments must be overseen by an independent technician. Training efforts are also crucial (cf. Cross-sector measures), especially to support workers transitioning from declining sectors (including the new construction sector[15]).

Finally, **implementing progressive energy pricing** would both enhance financial savings resulting from efficient renovations and encourage responsible consumption.

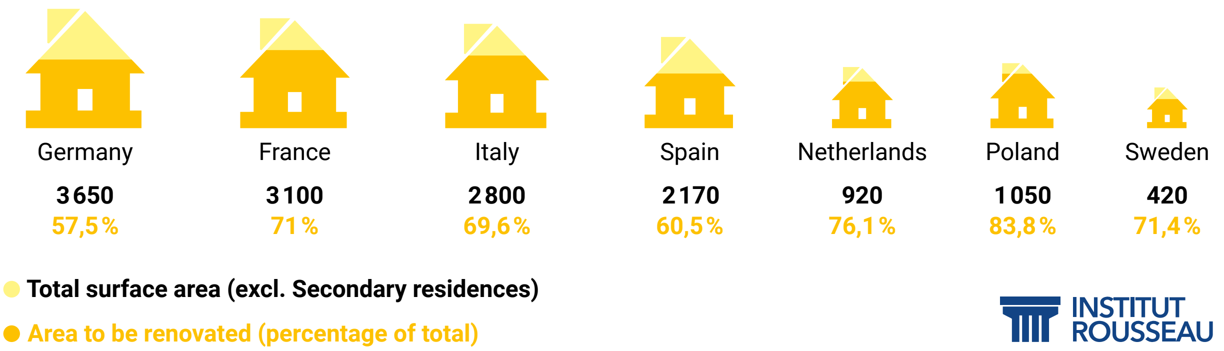
2.1 Efficient renovation of housing

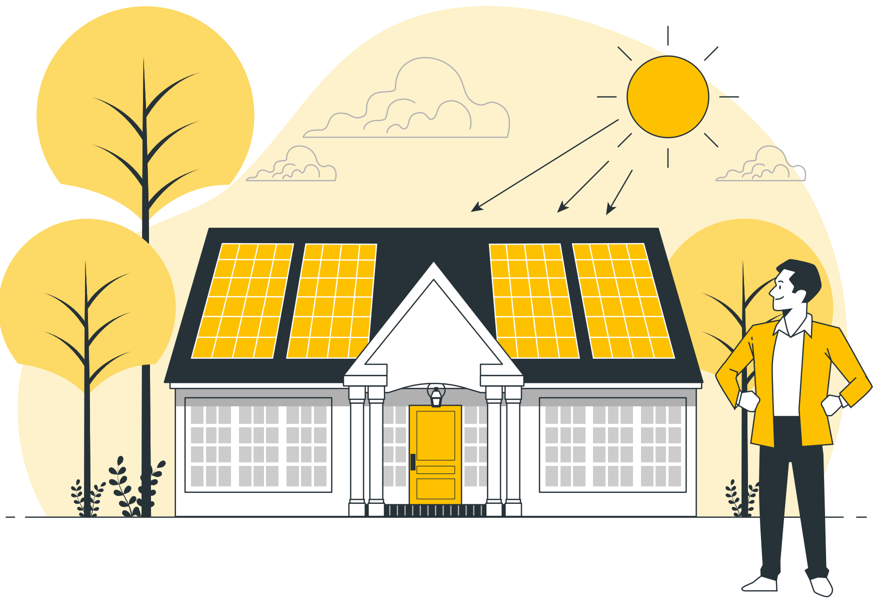
The share of the housing stock (primary residences and vacant units) that should be renovated efficiently varies from 57% (Germany) to 83% (Poland).

Thermal regulation is uneven across the EU-27: some countries (such as Germany and Sweden) have built efficient housing since the 1990s, whilst others (such as Poland and Spain) have only adopted high standards since the late 2000s.

Renovation targets align with each country's LTRS objectives (2 to 3% of the stock to be renovated annually). These were adjusted to account for both future demolitions (±2% of the stock between 2023 and 2050) and already 'deeply renovated[16]' housing stock (±0.2% per year, according to the EU comprehensive study or ±3% since 2010). In Spain, an alternative strategy to current government proposals was considered, advocating for the efficient renovation of the entire primary and vacant stock built before the 1980 regulation (NBE-CT-79). This would cover around 13.5 million homes, whereas the government proposal would concern the renovation of only the 7 million units most profitable in terms of energy savings.

Fig. 6.2 Efficient renovation targets for residential stocks (7 countries studied)[17]





Annual investments in the efficient renovation of energy-intensive housing stock must quadruple, with public support needing to double.

Efficient renovation costs are based on average expenses for energy-related works to achieve low consumption standards in housing. Reference costs are derived from extensive efficient renovation samples[18] or calculated from databases of average costs per work item[19], with Spain and Sweden estimates based on similar countries (Italy and Germany, respectively, considering recent inflation and VAT levels[20]). These 2016-2018 costs were adjusted for sector inflation until Q2 2022[21].

At an average cost of €328 billion per year (including €90 billion per year of BaU on the unrenovated stock), the efficient renovation of the energy-intensive housing stock will require public support of around €118 billion euros per year by 2050, which corresponds to an average public support of 50% of the cost of efficient renovations, roughly doubling the current support of €56 billion per year.

Measure 6.1

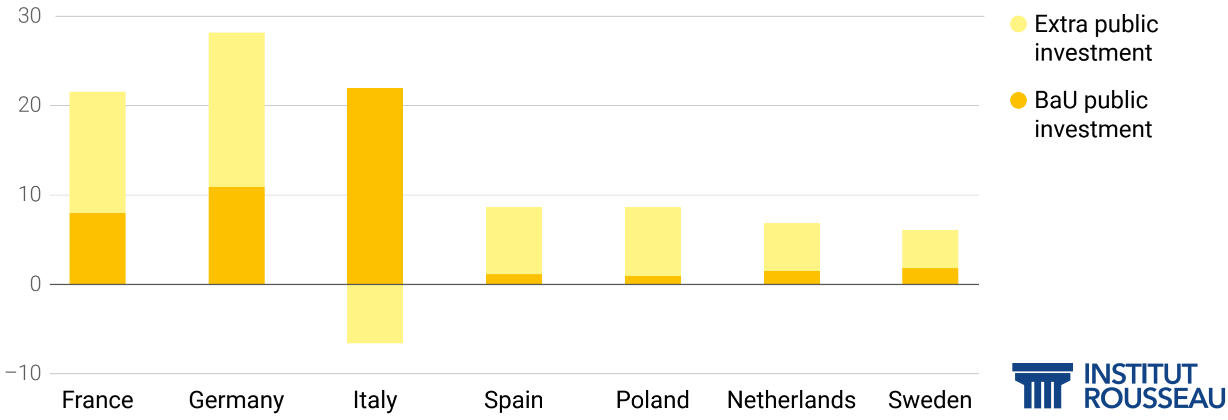
Support for efficient housing energy renovations (50% average public ratio)

Public cost
€118 billion per year
Public extra-cost
€62 billion per year

In addition to increasing support, redirecting business-as-usual investments is imperative, shifting from simple gestures to profound and efficient renovation.

While Germany and France already allocate substantial public support for residential renovation[22], the prevalence of individual houses in their targeted stocks requires a complementary increase of public support. This increase complements a mandatory **reorientation of current subsidies, which primarily target inefficient 'heating replacement'**. In the Netherlands and Spain, notable extra costs stem from low levels of public support. Specifically, Italy's 'negative' extra cost results from the 2020 launch of 'Superbonus 110%' leading to extensive and uncontrolled tax credit commitments. This underscores the need for independent pre- and post-control of renovations and a more balanced subsidy rate[23].

Fig. 6.3 **Annual public investment and extra-investment needed to renovate each country's housing stock (in €billion per year)**



Energy renovation costs are categorised under the 'Energy' sector when heating network development is involved, such as in the Netherlands and Poland (cf. Energy production section).

Additionally, it is recommended to finance the remaining costs borne by households through **subsidised loans, featuring a 2-point interest bonus on the nominal market rate** of a 20-year loan. The estimated cost for the seven countries in the study is €9 billion per year, with a total of €10.5 billion per year for the entire EU. Considering the marginal nature of public business-as-usual (BaU) expenditures (except in Germany), the extra cost is approximately €10 billion per year.

Measure 6.2

Provide owners with preferential-rate loans to cover the remaining costs

Public cost
€10.5 billion per year
Public extra-cost
€10 billion per year

To optimise renovation projects and mitigate fraud, these investments require consistent oversight from independent technicians.

Some public subsidies must also be directed towards project management assistance, focusing on individual and semi-individual private dwellings (an estimated 50 million for renovation). A proposed 100% subsidy, approximately €1500 per dwelling, addresses the pressing support requirements and current recourse limitations (to be compared, for instance, to the 'MAR' program in France, which provides an average 50% subsidy capped at €2000[24]). Conversely, tertiary property owners and social landlords already have access to in-house experts or technical support. The unique needs of collective private housing can be seamlessly integrated into broader subsidies for high-performance renovation.

Measure 6.3

Technical support for individual housing renovation

Public cost
€3 billion per year
Public extra-cost
€2.5 billion per year

2.2 Efficient renovation of tertiary buildings

Tertiary stocks, representing 15-30% of total surface areas, include about one-third as public stock. Efficient renovation is needed for 60-90% of this stock.

Tertiary stocks range from 15% (Italy) to 30% (Poland) of total surface areas. Public stock generally represents about a third of total tertiary stock, though data precision varies. The share of tertiary stocks requiring efficient renovation varies from 60% in Germany to over 80% in Poland, due to differing energy consumption States.

To ensure an ambitious renovation pace, Member States might consider mandatory efficient renovations alongside subsidies, with a primary focus on significant owners of tertiary buildings.

These owners, along with social and institutional housing landlords, possess greater financial means and engineering capabilities than most owner-occupiers. Conversely, small owners mainly need support, particularly due to the high costs and complexity of these investments. For all owners, obligations related to extensive work should be phased over time to align with sector capabilities and prioritise renovations of the most energy-intensive buildings[25].

Public support for the efficient renovation of tertiary buildings needs to double on average.

On an annual average investment of €92 billion (i.e. an extra investment of €19 billion per year), efficient renovation of the energy-intensive tertiary building stock requires a public investment of approximately €45 billion per year by 2050. Currently, public costs for support are estimated around €25 billion per year, indicating an extra expected public cost of around €20 billion per year between 2023 and 2050, primarily for the private tertiary sector (even if public park renovation is 100% publicly funded).

Measure 6.4

Support for efficient renovations in the public tertiary sector (100% average public ratio)

Public cost
€29 billion per year
Public extra-cost
€7 billion per year

Despite having twice the surface area to renovate, the public cost for private tertiary buildings is notably lower, mainly due to an average subsidy rate of 30% of energy investment costs.

The public extra-cost, however, is significant, given the current marginal public subsidies. While there is less available data on efficient subsidy rates compared to residential renovations, an average rate of 30% would be much higher than current low support (except in Germany[26]). This is notable, given the comparatively robust financial (and engineering) resources of tertiary space owners.

Measure 6.5

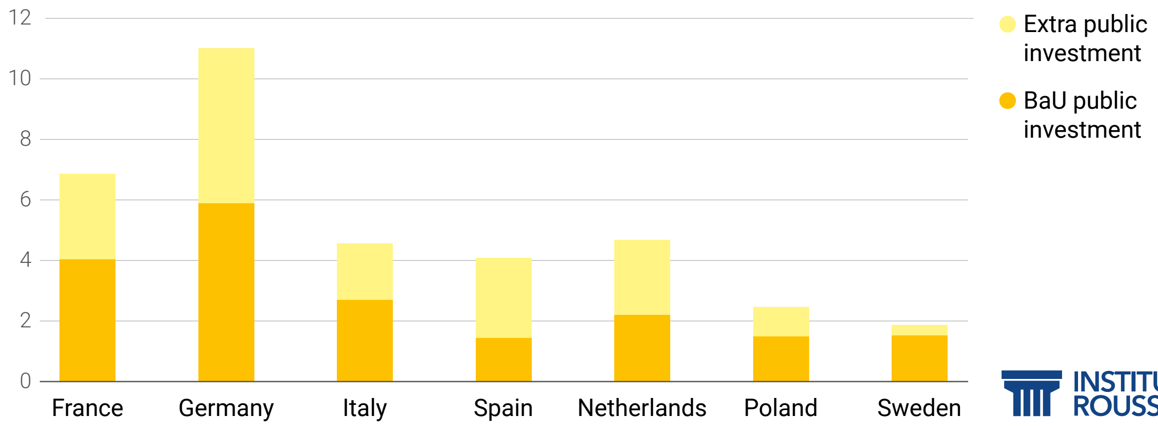
Support for efficient renovations in the private tertiary sector (30% average public ratio)

Public cost
€16 billion per year
Public extra-cost
€14 billion per year

Compared to the residential sector, tertiary renovation public policies are more homogeneous, as business-as-usual.

In the public sector, European governments are mainly supporting low to medium renovations rather than high performing ones, more costly[27]. In the private sector, there is almost no public support, except in Germany. The extra-investments are mainly driven by respective surfaces and efficient renovation costs. Exception is Sweden where business-as-usual is already significant, added to a smaller tertiary building stock up to renovation due to older thermal regulations.

Fig. 6.4 **Annual public investment and extra-investment required to renovate each country's tertiary stock (in €billion per year)[28]**



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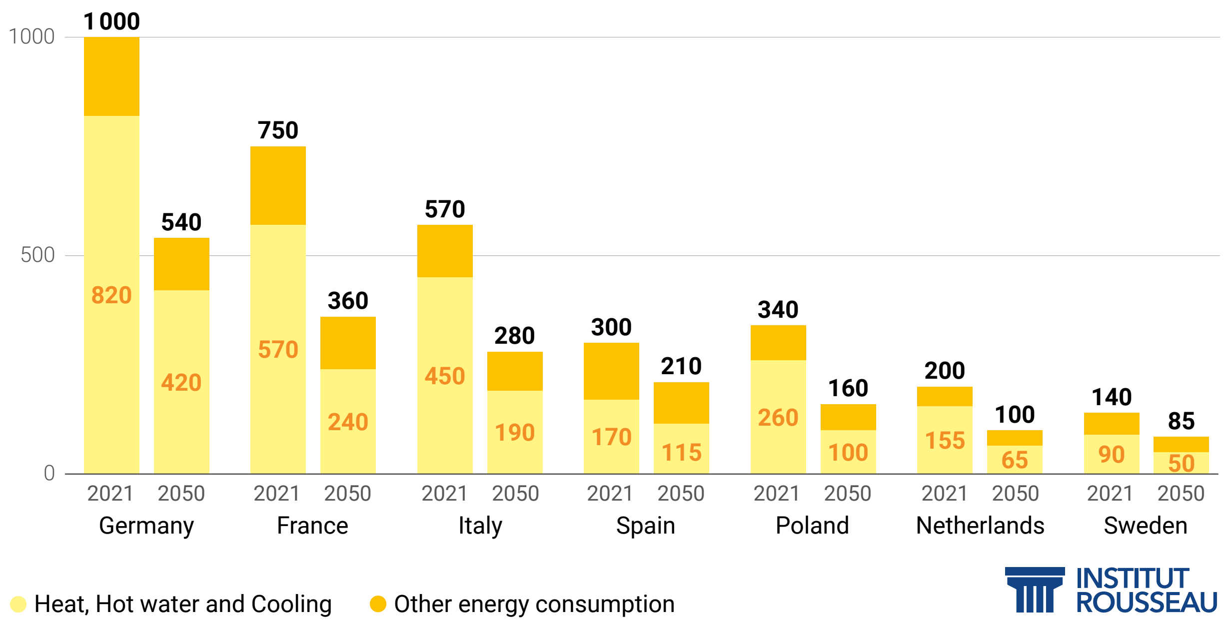
3 Direct and indirect energy impacts of this program

This comprehensive program for efficient energy renovations offers a 45% to 65% reduction in the final energy consumption of buildings by 2050.

The energy usage related to heating, hot water, and air conditioning (75-80% of consumption in most countries) can be reduced by 45-65%, depending on the country and the prevalence of initially energy-intensive structures. These gains are conservative, as they don't account for the (unsubsidised) enhancement of heating systems and windows in the 'already insulated stock'. Additionally, the projected increase of +10 to +20% in heated surfaces (a mix of new and existing vacant stock, see interactions with the Industry sector) will likely be counteracted by milder winter conditions, expected to exceed -15% (considering the observed reduction in winter severity from the 2000s to 2019-2022).

Fig. 6.5 **Final energy consumption reduction (TWh/year)**



Sources: EEA 2021, Eurostat 2021 (Final Energy consumption by sector and uses) and building/energy reports of DENA (Germany), SDES (France), Enea et LTRS (Italy), LTRS (Spain), GUS (Poland), CBS et LTRS (Netherlands) and Sweden

In addition to the energy gains from efficient renovations, the CLEVER scenario posits a minimum 30% reduction in specific electricity consumption (excluding Poland, where equipment rates are more limited). With a 50% average reduction in total final building consumption by 2050 compared to 2021, the energy mix can accommodate this decrease without imposing significant peak constraints on the electrical system. Considering the characteristics of each energy vector and the anticipated availability of wood resources (cf. Carbon sinks section) and fermentable biomass for biogas production (cf. Agriculture section), plausible mixes fall within the following ranges[29]:

- 40-60% heat pumps produce at least two-thirds of renewable ambient heat with less than one-third of electricity, facilitated by efficient insulation.

- 20-30% wood (individual and heating network) in line with estimates from the Carbon sinks sector (with a slight increase).

- 20-40% 'specific' electricity for lighting, appliances, and cooking.

- A minimal proportion of Biomethane, other uses being considered a priority (industry, transport).

Notes

1. From both the Energy (electricity and heat) production and Industry (construction) sectors. These gains are achieved through increased occupancy rate of vacant buildings, without the necessity to reduce housing supply.

2. From €1000 to 3000 per year for a 100m² equivalent, cf. Ademe, 2021, 'Perf In Mind' for individual houses actual post-renovation consumption and Dena, 2016, Auswertung von Verbrauchskennwerten energieeffizienter Wohngebäude for multi-family buildings actual gains 'before/after' efficient renovation.

3. Driven by labour-intensive tasks such as wall insulation.

4. Past data is sourced from the EEA Dataviewer. Targets for 2020 and 2030 reflect the EU's overall emission reduction goals of -20% and -55% from 1990 levels, distributed proportionally according to each sector's 2021 emission share. The 2050 target aligns with residual emissions in the RtoNZ transition scenario. WEM (With Existing Measures) projections, utilising EEA & Climact data, estimate future emissions considering measures already implemented by the EU and its Member States.

5. European Commission, 2020, 'Energy efficiency in buildings'.

6. JRC, 2020, Energy consumption trends in the UE and Eurostat, 2023, Final energy consumption by sector.

7. 'Efficient' energy renovations are those making it possible to achieve low consumption standards (between 50 and 100 kwh/m²/year for heat, hot water and cooling, depending on climatic zones) and/or 'deep renovation' within the meaning of the UE comprehensive study of building renovation (energy gains of at least 50-60%) close to low consumption standards (e.g. with partial insulation of the street facade due to technical/urbanistic constraints involving high surface losses).

8. Negawatt/Clever, 2023, Pompes à chaleur et rénovation performante.

9. cf. the objectives of the 7 countries studied in the Long Term Renovation Strategies.

10. See in particular 'Sichel report', 2022, Prognos 'Evaluations of BEG', 2021 and 'LTRS of Poland', 2020.

11. Fabrique de la Cité, 2024, 'Rénovation énergétique - stratégies pour un changement d'échelle' - to be published.

12. BMWK 'BEG reporting and evaluation', 2021-2023.

13. In order to facilitate remobilisation of vacant and occasional housing, tax advantages of tourist rentals and real estate retention must be reversed in favour of affordable housing in addition to this support program for overall renovations, cf. Institut Rousseau/Desquinabo, 2023, 'Quelle stratégie pour un logement durable et abordable' and APUR, 2020, 'Locations meublées à Paris et comparaisons avec 7 autres grandes villes'.

14. e.g. local availability of various competent craftsmen or recent partial works.

15. In all cases, it is crucial to assure owners, especially occupants, that any non-compliance won't lead to subsidy withdrawal, addressing an issue seen in some existing systems (e.g., Ma Prime Rénov' in France, where victims of fraud are often denied €10k to 20k in aid, leading to new social challenges).

16. Deep renovation is defined by the UE comprehensive study of building renovation as a renovation > 60% savings.

17. Main sources: Long Term Renovation Strategies (LTRS) of the 7 countries, DENA building report, 2018, Statistics Poland energy in households, 2020, CBS Climate and energy outlook, 2021 and CSB, Sweden dwelling stock, 2021.

18. Ademe, 2021, 'Perf In Mind' for France (+-520€/m² in houses and 300€/m² in collective housing) and Prognos, 2018, 'Evaluation EBS WG im Förderzeitraum' for Germany (+-680€/m² in houses and 500€/m² in collective housing for EH 100 renovations). Note that the VAT on energy works is 5.5% in France compared to 19% in Germany.

19. See in particular LTRS Poland 2022 (+- 350€/m² for individual houses including heating and 200€/m² for collective housing excluding work on heating networks), LTRS Italy (+- 450€and 320€/m² in average zone E) and BPIE for the Netherlands (+- 600€and 450€/m² which corresponds to the price difference of -10% with Germany).

20. European Commission, 2021, 'VAT rates applied in the Member States of the European Union'.

21. Maintenance-improvement inflation between 2018 and mid-2022 varied from 15% for Italy to almost 40% for Poland, to which was added the maintenance of BaU energy works on the non-efficiently renovated park (estimated thanks to the Comprehensive EU renovation study 2019, pp.30-34, updated prices 2022).

22. More than 60% of Bundesförderung für effiziente Gebäude (BEG) subsidies concerned new construction in 2021. These subsidies for new construction having a significantly lower efficiency than support for overall renovation, it is already planned to strongly reduce their proportion.

23. The Superbonus 110% supported the overall renovation of around 200,000 homes in 2021 for 16 billion euros in tax deductions and 700,000 homes for more than 50 billion euros in 2022. Considering the high level of fraud and inflation, the system was modified at the start of 2023 (ban on payments via third parties and deduction rather at 90%) and Recent data of Enea suggests stabilisation around €2-3 billion per month. As the year 2022 is very atypical, the pace of engagement in 2021 and a part of 2023 are used to estimate the 'current' public support especially since the deduction rate will reduce to 70% in 2024 and 65% in 2025.

24. Ministère de la Transition Énergétique, 28 November 2023, Mon Accompagnateur Rénov'. In Germany, the cost of supported services include all the project management services for all types of buildings.

25. It is worth noting that such obligations pertain to the commencement of the work rather than its outcomes. Even a social landlord cannot be subjected to hefty fines if they fall victim to subpar craftsmanship.

26. Aid for renovations of private tertiary buildings can cover 20 to 30% of work costs for many years.

27. European Commission, 2020, UE comprehensive study of building renovation.

28. Costs of efficient renovation per square metre exclude 'non-energy' work and are typically estimated based on reference costs for schools and offices due to a lack of references for shops and hospitals. Sources for the reference costs of tertiary buildings include Long Term Renovation Strategies (LTRS), providing data for France (€320 to €400/m² for schools and offices), Italy (~ €400/m² for schools and offices), and Poland (around €150/m² excluding heating). The 2019 assessment from NWG was used for Germany, estimating costs at around €550/m² based on a large sample, which was also employed to approximate average costs for the Netherlands and Sweden. As BaU data doesn't differentiate between public and private surface areas, we've made proportional estimates for the current costs of these two sub-sectors.

29. These ranges align with the forecasts provided by the CLEVER project partners, 2023, Residential Corridors study (p. 42).

Investments in energy production and infrastructure

A total decarbonisation of all energy vectors, facilitated by demand reduction

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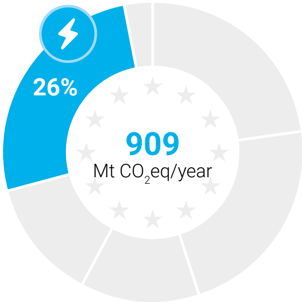
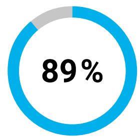
Current emissions and reduction potential



Decarbonisation levers to mobilise:

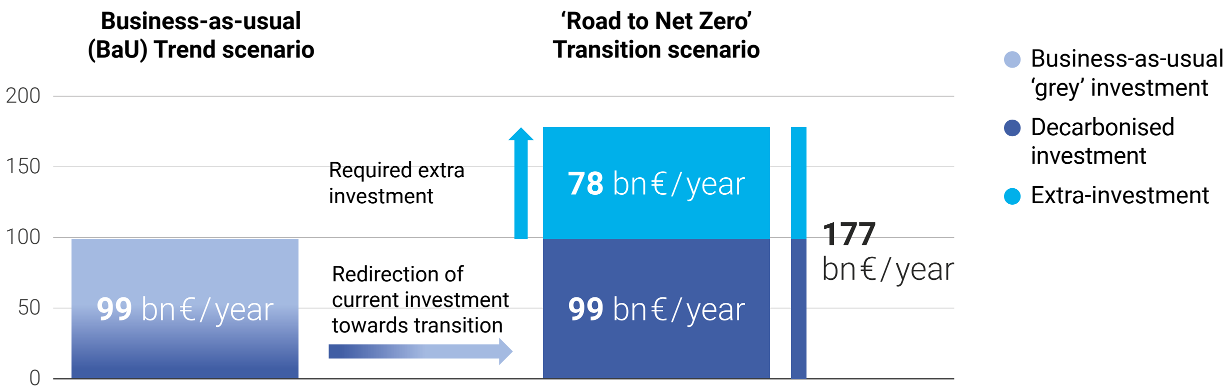
1. Decarbonise and adapt the power system
2. Switch from fossil gas to biogas and other ‘green’ gases
3. Phase coal and oil out, end conventional refining activities
4. Decarbonise heat production for district heating



2050 decarbonisation potential

Global investment needs

UE-27 global investment and extra-investment



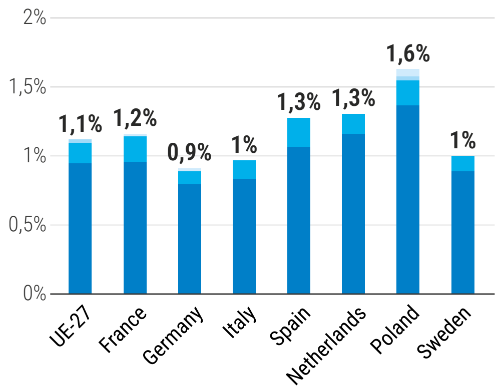
Global investment and extra-investment per lever, per country (in % of GDP):

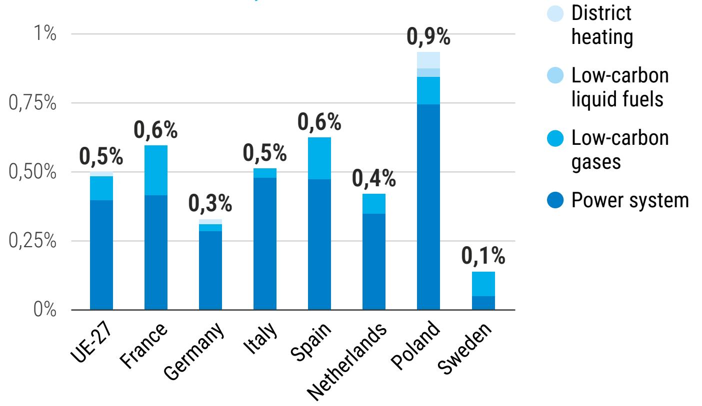
Total investment

1,1%

Total extra-investment

0,5%





Public investment needs

Total public investment in proposed public policies

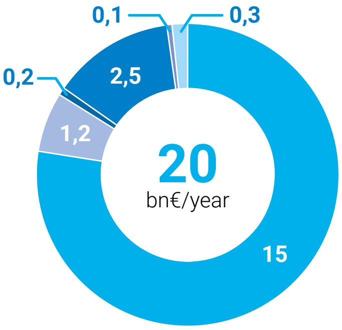
38 bn€/year

Public share in total investment

22%

Public extra-investment in % GDP

0,12%



Total extra public investment in proposed public policies: 20 bn€/year

- Support the development of renewable energy
- Support the development of nuclear power
- Support the development of flexibility solutions
- Support the development of 'green' gases*
- Support the development of SAF*
- Support the development of decarbonised heat networks

* downstream process costs not already included in previous categories (e.g. renewable capacity)

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT	
TOTAL	EXTRA	TOTAL	EXTRA
12%	22%	7,5%	7,7%

Key takeaways

- **Energy production is the most emissive sector (26%) and is pivotal for decarbonising the broader economy. Nearly complete decarbonisation (89%) is possible by 2050.**
- **If progress has been made to decarbonise EU energy production (73% low-carbon-based in 2021), EU final consumption is still 69% fossil-based as imports are still extremely fossil-intensive.**
- **A decarbonised energy system would ensure both energy sovereignty and considerable socio-economic and climate benefits. A sufficiency-based energy system promoting local production would further amplify these benefits.**
- **A strong reduction in final energy consumption is mandatory to expedite the decarbonisation of both EU energy consumption and production, while mitigating impacts and limiting geostrategic dependency on metallic resources.**
- **Overall, to decarbonise the energy production and infrastructure sector by 2050, annual investments must almost double (+80%) and definitely shift from fossil fuels. 78% of the extra investment needed will come from the private sector.**
- **Almost 90% of investments should be allocated to delete decarbonising, expanding and enhancing the power system, with 45% directed to production assets and 35% to network reinforcements.**
- **The renewable capacities must almost triple by 2050, putting especially significant pressure on the industrial deployment capacities of the wind energy sector.**
- **The exact cost of public support remains highly uncertain, as it is dependent on future market prices which are challenging to foresee.**

The energy production and infrastructure sector encompasses all the assets and infrastructure required for the production, transmission, and distribution of primary energy in the forms of electricity, fuels, and heat.

Energy production is the most emissive sector and is pivotal for decarbonising the broader economy.

This sector contributes to 26% of the EU's greenhouse gas (GHG) emissions in 2021, totaling 902 MtCO_2-eq. Beyond its direct emissions, the energy sector plays a central role in all policies directed at decarbonising the European economy, as the decarbonisation efforts in other sectors, such as transportation, buildings and industry, hinge on the availability of low-carbon energy.

Nearly complete decarbonisation of energy production is possible (89%), with incompressible leaks of biomethane in gas infrastructure and a few remaining refining emissions being responsible for small residual emissions. To achieve this, five conditions must be met:

1. **Energy demand must be reduced through sufficiency and efficiency measures taken in all downstream sectors**. Decarbonisation without reducing demand would pose challenges in securing resources[1] (cf. Appendix A.2) and managing both summer and winter peak demand. This is already a concern in Southern Europe and is set to be exacerbated by the growing impact of climate change and increased frequency of heatwaves.

2. **Electricity must be produced from decarbonised sources**, such as renewable energies and/or nuclear power. Since electricity is easier to decarbonise than other energy vectors, electricity production must increase significantly – at least 70% – and be used for all applications that can be electrified.

3. **Green gases, such as biomethane or hydrogen produced from decarbonised electricity, must replace fossil gas** to decarbonise applications challenging to electrify, such as certain industrial uses or a portion of transport.

4. **A phase-out of fossil fuels is necessary**, and certain activities, such as petroleum refining or coal usage, must simply cease. Biofuel and synthetic fuel could could help meet the incompressible demand for liquid fuels in sectors such as aviation.

5. **Heat production must also be based exclusively on renewable energy** sources.

To decarbonise the energy sector by 2050, annual investments must double and definitely shift from fossil fuels. 78% of the extra investment needed will come from the private sector.

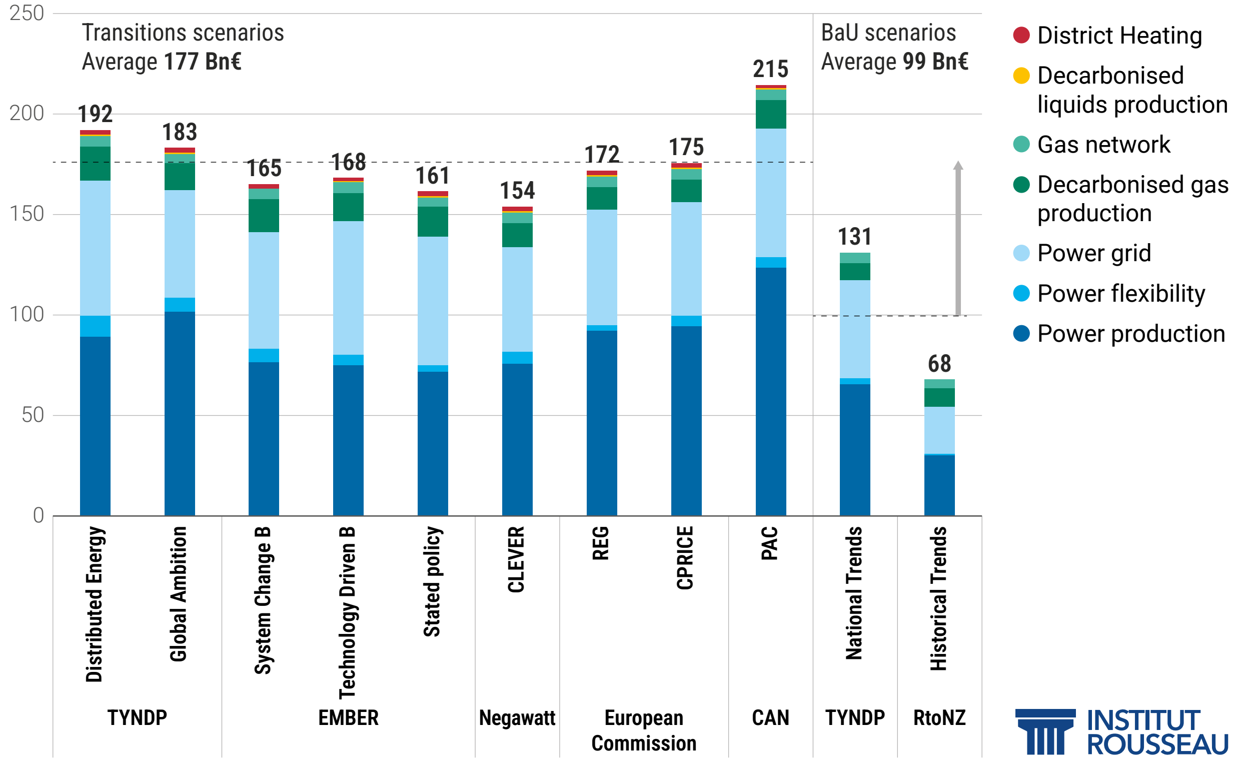
The overall investment effort necessary to achieve decarbonisation by 2050 is close to €5 trillion, i.e. €177 billion per year[2], as shown in Figure 7.1. This is twice the historical trend. Compared to an average business-as-usual trajectory, the extra investment required amounts to €78 billion per year, of which €12 billion are for the public sector (some 25% of the extra cost).

A decarbonised energy system, coupled with local production and lower consumption, ensures both energy sovereignty and considerable economic benefits.

1. Fossil fuels import amounted €654 billion in 2022 (i.e. 8,4 times the energy extra investment and almost twice the total extra investment required to achieve net zero across all sectors) and prices increase led to €195 billion of public pending in energy shields (cf. Box 7.1. The end of fossil fuels imports: increased sovereignty and major economic benefits).

2. Factoring in decarbonised fuel importation operational expenditures alongside the displayed CAPEX in Figure 7.1 would for example elevate the TYNDP GA total cost to an average of €450 billion per year, compared to €270 billion per year for the negaWatt CLEVER scenario.

Fig. 7.1 **Annual investment and extra-investment required in the energy production, transmission and distribution system, by 2050, per scenario and in average (in €billion per year)**



Based on Institut Rousseau's inhouse methodology. Only physical data (i.e. installed production capacity) was retreived from the scenarios. For the costs categories not available in the mentioned scenarios, an average of other scenarios was computed for comparative purposes.

Around 90% of investments must be directed towards decarbonising and developing the power system…

Investment in the power system represents ~88% of total investment and 90% of extra investment compared to the business-as-usual scenario. This annual investment of €155 billion would include:

- **Building low-carbon production capacities sufficient for at least a 70% increase in electricity production**, requiring an investment of €89 billion per year (+/- €20 billion depending on the scenario, except for CAN PAC) and an extra investment of approximately €43 billion per year compared to the business-as-usual scenario (+/- €17 billion per year);

- **Reinforcing the electrical transmission and distribution system** (€60 billion per year, including €24 billion more than in the business-as-usual scenario);

- **Building flexibility resources means** (€5,6 billion per year, mostly non-existent in the business-as-usual trend) to facilitate the integration of new capacities, particularly the variable share of the latter.

… 22% of which will need to be provided by public authorities (€34 billion per year), mainly to support renewable production.

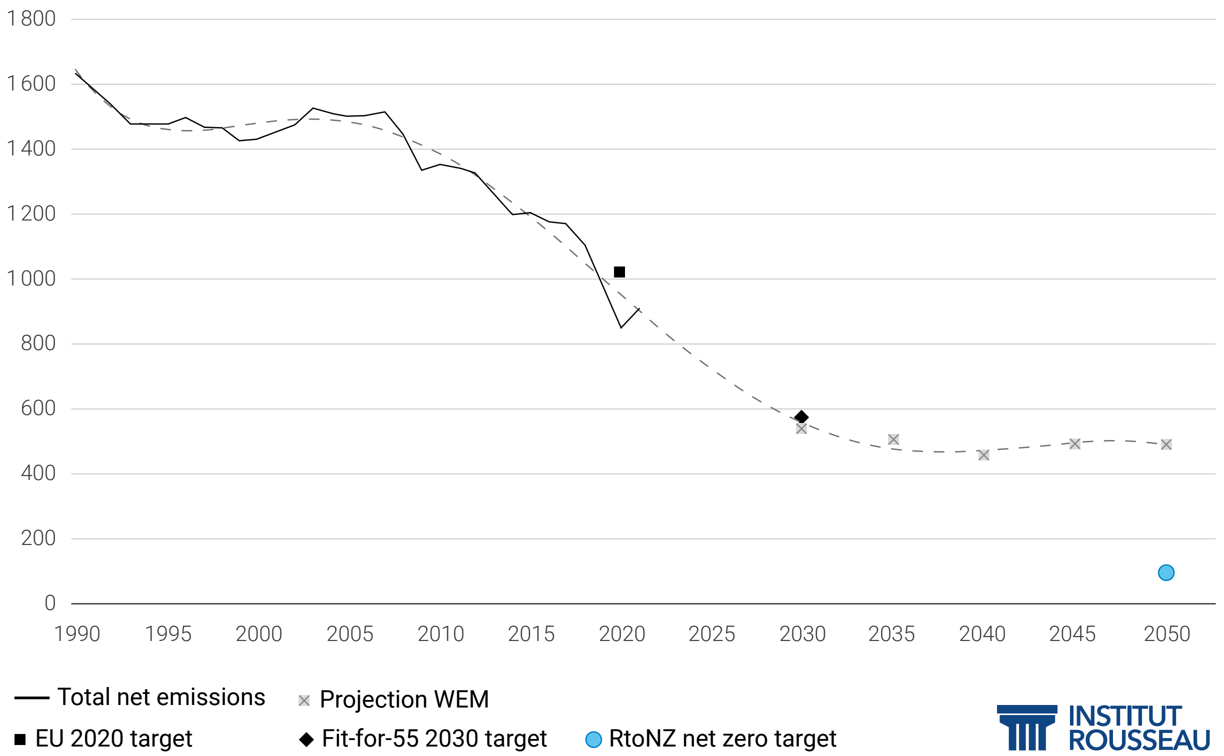
Providing additional compensation for currently non-profitable renewable energy sources constitutes 90% of the total required public support to decarbonise the energy production sector. The remaining 10% involve supporting potential investments in new nuclear power and offering subsidies for flexibility solutions, essential to maintaining network balance. **The exact cost of this public support remains highly uncertain, as it is dependent on future market prices which are challenging to foresee.**

1 Emissions of the sector

Energy production is the highest emitting sector in Europe (26%), despite an encouraging historical reduction trend.

The energy production sector emitted 902 $MtCO_2$-eq in 2021, i.e. 26% of the EU's GHG emissions. These emissions have declined by 44% since 1990, averaging a reduction of approximately 43 $MtCO_2$-eq per year over the last decade. Analysis shows that the current trend, if maintained, could be sufficient to meet the 'Fit-for-55' 2030 target aligned with the sector's current share. However, projections based on existing policy measures indicate that meeting the 2050 target is currently extremely unlikely, as illustrated in Figure 7.2.

Fig. 7.2 **Energy production past UE-27 domestic emissions and progress towards achieving 2030 and 2050 targets, in million tons of CO_2 equivalent ($MtCO_2e$).**[3]



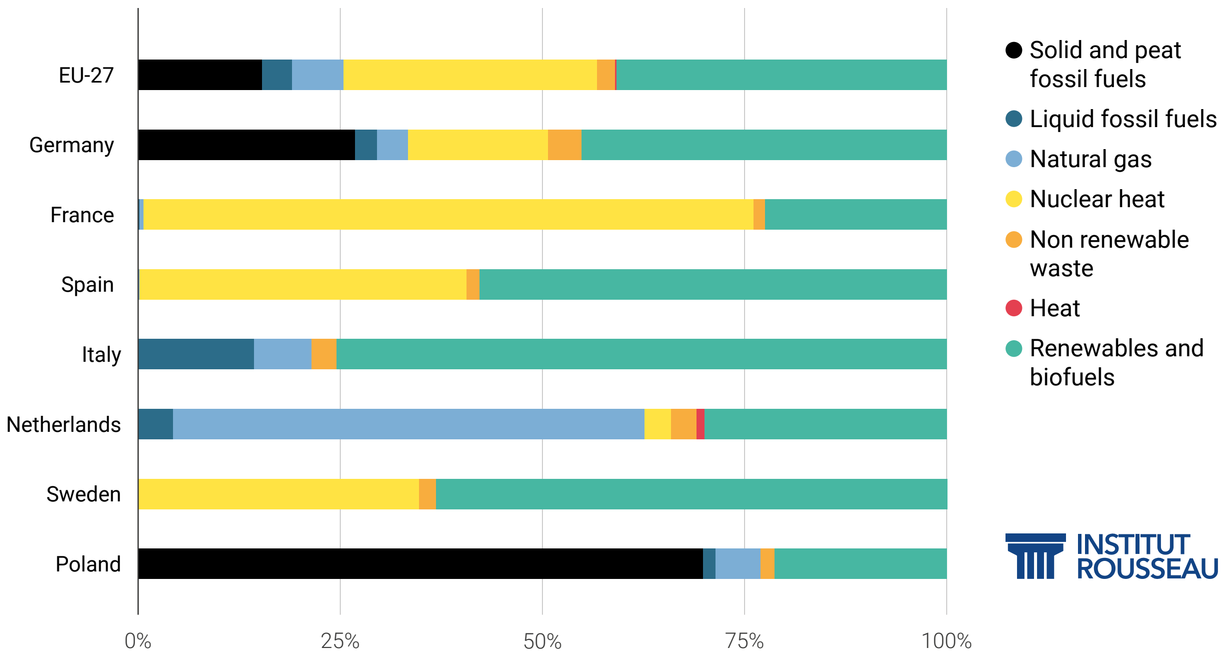
WEM: With Existing Measures.

This gradual decarbonisation of the energy production mix is the result of a sharp decrease in coal use for electricity production and the rise of renewables.

The share of renewable energies in the EU's energy production has surged significantly during the last decade, increasing from 24.2% to 40.8% between 2010 and 2021. Renewables are now the predominant source of energy produced on European soil. Additionally, the decarbonised energy production landscape has been supported by nuclear power, contributing to 32.2% of the energy produced in 2021. Despite this trend, the energy production mix was still highly carbon-intensive in 2021, with fossil fuels accounting for more than 25% of energy produced.

The average European production mix conceals significant variations among Member States. Notably, Portugal heavily relies on renewable energy, constituting 97.7% of its primary energy production. In contrast, Poland mainly produces solid fuels (coal) at 72%, the Netherlands leans on natural gas at 58%, and Denmark predominantly produces crude oil at 35%. France (76%) and Belgium (70%) primarily derive their national energy production from nuclear energy.

Fig. 7.3 **Primary energy production in 2021, per type (share %), for each of the 7 studied countries**[4]



Energy production represents only half of total consumption. 69% of EU final consumption is still fossil-based due to extremely fossil-intensive imports.

In 2021, the EU only generated 44% of its energy consumption domestically, with the remaining 56% being imported[5] mainly as fossil fuels[6]. **69% of EU's overall energy consumption was still based on fossil fuels[7], with renewable sources only weighting 21.8%.** While transitioning towards cleaner production facilities, an additional challenge thus lies in the reduction and decarbonisation of European energy imports. The Renewable Energy Directive[8] adopted in October 2023 aims to double the share of renewable energy in final energy consumption up to 42.5% by 2030, which requires a very significant rate of deployment, and especially a step-change in the wind sector.

To expedite the decarbonisation of EU both energy consumption and production, there must be a significant reduction in final energy consumption.

Despite a light 4.6% decline throughout the 2010 decade[9], **all carbon neutrality scenarios anticipate a substantial reduction in the EU's final energy consumption by 2050**. The Energy Efficiency Directive[10] amended in 2023 sets a target of reducing final energy consumption by at least 40% by 2030, compared with 2007 levels, presenting a major challenge given historical achievements.

2 Methodological specificity: about energy scenarios

Given the great complexity of the energy system, and in particular the electricity system, the study selected and compared nine existing scenarios achieving EU carbon neutrality by 2050. These scenarios, produced by recognised entities specialised in the energy sector[11], differ in their approaches (see below), reflecting different political choices and leading to diverse technological orientations and cost implications. Unlike the prescriptive approach taken for other sectors in this study, the energy sector analysis involved computing and comparing costs associated with various scenarios. This report **evaluated each scenario's assumptions, inputs, and outputs, determining minimum, maximum and average costs for the transition to a clean energy sector** (cf. Figure 7.4. For a more detailed version, please refer to the Methodological Appendix.)

Fig. 7.4 **Main underlying assumptions of the nine net zero scenarios studied**

Scenarios	TYNDP Distributed Energy	TYNDP Global Ambitions	EMBER System Change	EMBER Technology Driven	EMBER Stated Policy	négaWatt CLEVER	CAN PAC 2020 - EU28	EC REG (Regulation)	EC PRICE
Net zero target	2050	2050	Before 2040 ⚡	Before 2050 ⚡	Before 2050 ⚡	2045	2040	2050	2050
Decrease of Final Energy Demand (2021 - 2050)	– 21 %	– 14 %	*Not included*	*Not included*	*Not included*	– 44 %	– 51 %	– 36 %	– 31 %
Main driver(s)	**Efficiency** Sufficiency	**Efficiency** Sufficiency	**Sufficiency** Efficiency	**Efficiency** Sufficiency		**Sufficiency** Efficiency	**Sufficiency** Efficiency	**Efficiency** Sufficiency	**Efficiency**
2050 Electricity Production	Extreme increase (6300 TWh)	Significant increase (5600 TWh)	Significant increase (5640 TWh)	Significant increase (5620 TWh)	Extreme increase (6640 TWh)	Limited increase (4560 TWh)	Extreme increase (6320 TWh)	Significant increase (5090 TWh)	Significant increase (5360 TWh)
2050 Low-carbon gas Production	Sharp increase (3500 TWh)	Significant increase (2200 TWh)				Significant increase (1598 TWh)	Moderate increase (643 TWh)		
2050 Imports (TWh/yr)	Hydrogen 358 Decarbonized liquids 360	Hydrogen 756 Decarbonized liquids 844	Hydrogen 0 Others: out of scope	Hydrogen 0 Others: out of scope	Hydrogen 0 Others: out of scope	*No imports*	*Not included* Local production is favoured	*No analysis*	*No analysis*

These scenarios mainly differ in end-consumption reduction goals (sufficiency), the degree of centralisation versus decentralisation in production, the extent of end-use electrification versus reliance on gases, and the balance between imports and self-production.

To estimate a ballpark figure for the investment required in the energy system, an average of various scenarios is considered here. However, this doesn't imply that all these scenarios are equally realistic or desirable.

The criteria that should be prioritised and maximised for a realistic transition include the level of energy sufficiency (allowing for a decarbonisation more aligned with industrial deployment capacities and reducing the resource footprint of the energy system) **and the level of self-production** (enhancing energy and geopolitical independence and resilience). This is more evident in scenarios like NegaWatt's CLEVER and EMBER's System Change. The same principles guide the Road to Net Zero (RtoNZ) scenario developed in other sections of this report (refer, for instance, to the RtoNZ low-carbon gas consumption needs presented in Box 7.3., section 7.3.2.).

Two business-as-usual scenarios were also considered:

- **TYNDP 'National Trends' scenario**: TYNDP's estimation of the 'most likely' scenario, relying on the official National Energy and Climate Plans (NECPs) of EU Member States, and ongoing national initiatives (Hydrogen plans, etc.). This scenario was extended to 2050, filling a gap in coverage from 2040.

- **'Historical Trend' scenario**: an Institut Rousseau in-house regression analysis based on historical data, projecting future trends in installed generation capacity and final consumption.

3 How to decarbonise the sector and how much investment does it require?

As outlined in the introduction, five key decarbonisation strategies are essential for addressing emissions from EU energy production: significantly reduce energy demand through sufficiency and efficiency measures across all downstream sectors; decarbonise electricity production assets (combined with maximising the electrification of remaining end uses); replace fossil gas with low-carbon methane and hydrogen in cases where electrification is challenging; phase out the use of fossil fuels; decarbonise heat production assets.

Box 7.1

End of fossil imports: increased sovereignty and major economic benefits

As mentioned earlier, while this section addresses the decarbonisation of European energy production, which constitutes only 44% of domestic energy consumption, the remaining portion is predominantly sourced from imported fossil fuels. **The financial toll of this fossil fuel dependency is staggering**.

Current situation: the EU's expenses on imported fossil fuels reached €300 billion in 2021 and surged to €654 billion in 2022[12], comprising 21.7% of total extra-EU imports in 2022[13]. **The recent energy crisis triggered by the Ukraine invasion also resulted in significant public spending** (€195 billion in 2022[14], equivalent to 2.4% of total EU-27 government expenditure) to shield European citizens from price increases – a situation that could be alleviated in the future through the transition to a low-carbon energy system.

Box 7.1

Cumulated cost by 2050: around €3 trillion of import savings

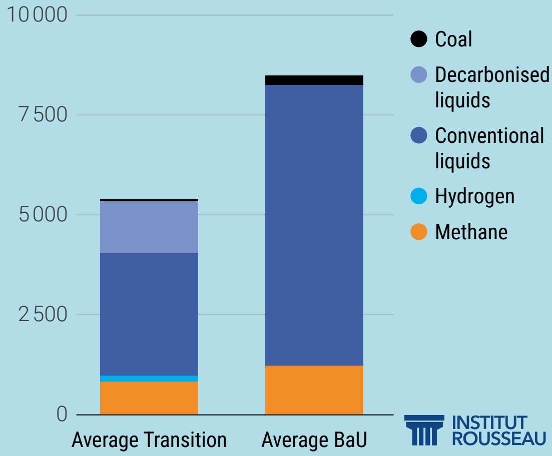
Comparing the average import costs across various transition scenarios and the two business-as-usual counterparts reveals that **a phased-out reliance on fossil fuels would yield substantial savings for the EU economy of approximately €3 trillion in operational expenditure (OPEX), amounting to an annual average saving of around €115 billion.**

This increasingly positive commercial balance is projected to grow progressively from + €50 billion per year in 2030 to + €220 billion per year in year 2050.

For further insights into the underlying assumptions, please refer to the methodological Appendix.

This reduction in fossil fuel dependency can be achieved through the sufficiency and efficiency measures outlined in other sections, in conjunction with the investments detailed in this chapter, essential for decarbonising EU domestic energy production. **The associated savings represent around 30% of the total extra investment required to achieve net zero across all sectors.**

Fig. 7.5 Average fuel imports (cumulative €billion over the 2022-2050 period)



These savings will lead to greater energy independence and, consequently, enhanced resilience in the European economy. However, to secure metal supply chains, it is vital to limit needs by encouraging a frugal and optimised use of resources. This ensures that one geopolitical dependency (fossil fuels) is not exchanged for another (mineral resources). For more details, cf. Appendix A.2. Compatibility of the transition scenario with critical material resources constraints and Appendix A.3. Geopolitical, environmental, and social risks associated with mining in the transition scenario.

The end of fossil fuel consumption will reduce public income, requiring compensation. Additional details on this issue will be addressed in the Institut Rousseau's report on 'Funding the Transition'.

3.1 Decarbonise and adapt the power generation, transmission and distribution system

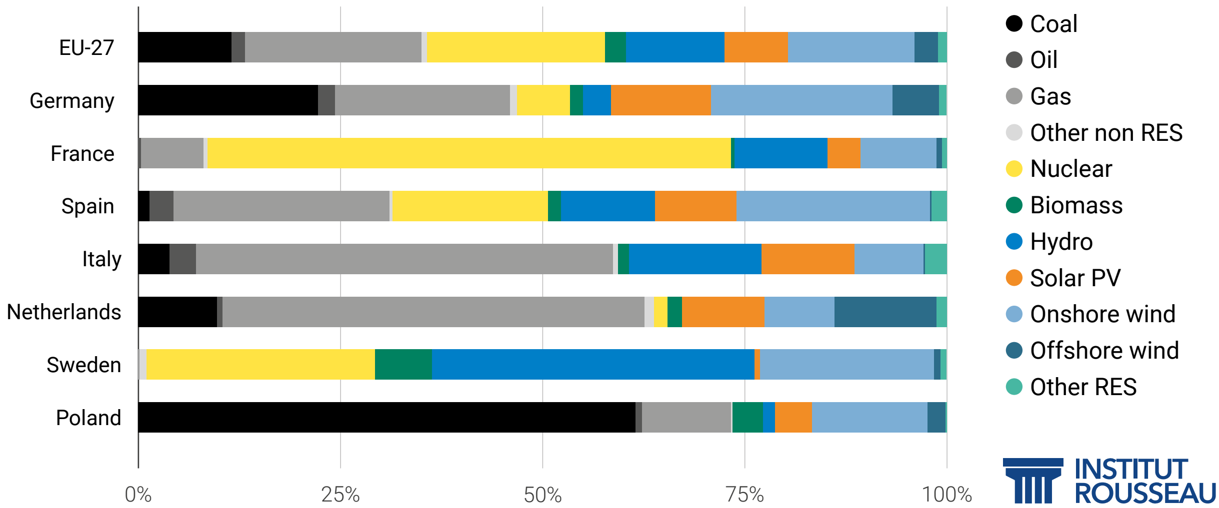
Electricity production must increase by at least 70% (85% on average, depending on the scenario) to meet the increased demand resulting from both the electrification of various downstream uses and the production of e-fuels (gases and liquids).

First, final direct electricity consumption in the EU will rise by 30%, from 2800 TWh to an average of 3600 TWh, due to the widespread electrification of various sectors, particularly buildings and transportation. This shift involves a substantial deployment of heat pumps for heating and the substitution of remaining conventional vehicles with low-carbon, predominantly electric, alternatives. **Second, a growing volume of electricity (+55% on average) will be needed for indirect needs** such as generating renewable gases and potentially liquids, such as low-carbon hydrogen, e-methane, and e-fuels (cf. Subsections 7.3.2. and 7.3.3.) **The transformation of the electricity sector by 2050 hinges on augmenting production and achieving decarbonisation.**

The current power generation capacities indicate each country's efforts to achieve decarbonisation.

The current electricity generation mixes vary significantly among EU Member States (Figure 7.6.), leading to diverse carbon intensities (in tCO_2-eq/MWh) and emissions. These are heavily influenced by historical political choices supporting renewables and/or nuclear power, as well as the presence of hydro resources. These distinct starting conditions will lead to divergent decarbonisation paths, encompassing the final energy mix, deployment speed, and associated costs. EU- and national-level cost assessment of the present report relies on comprehensive modelling studies that incorporate these national specificities.

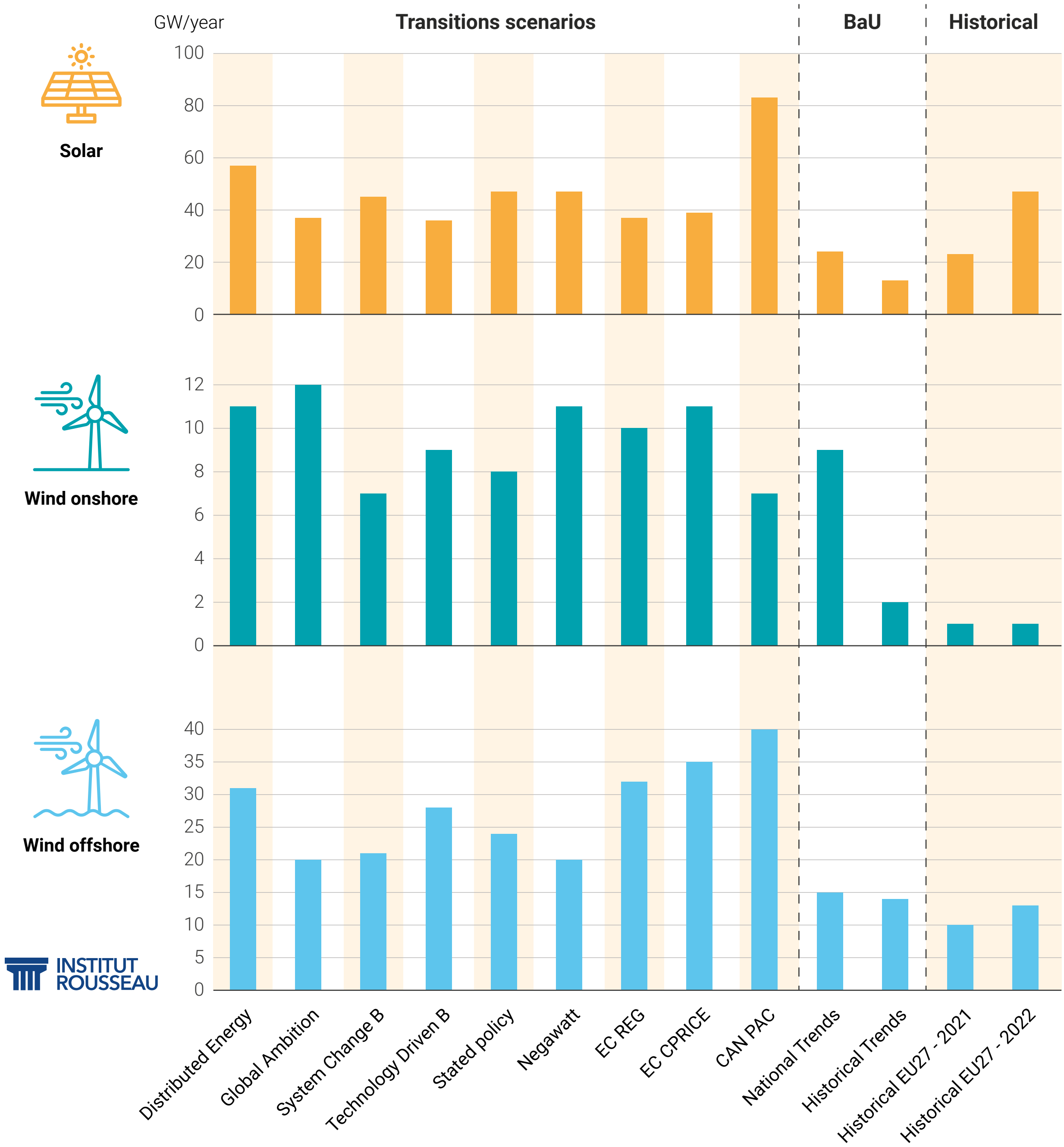
Fig. 7.6 Gross electricity production 2022, per technology (share %), per country[15]



The renewable capacities must almost triple by 2050, putting especially significant pressure on the industrial deployment capacities of the wind energy sector.

All the scenarios examined forecast a rise in annual electricity generation, each with distinct mix trajectories. By 2050, the average installed generation capacities are projected to reach approximately 2770 GWe, compared to today's 1000 GWe. **Solar and wind will dominate the EU electricity system in 2050.** Scenarios featuring more decentralised resources, specifically solar and onshore wind (e.g. TYNDP DE and CAN PAC), naturally result in higher total installed capacity due to their increased variability (meaning lower average production factors). As shown in Figure 7.7., the various scenarios imply high installation rates of renewable technologies. While this rate is close to the historical rate observed in 2021 for solar capacities (except for CAN PAC), it **would need to be increased significantly for wind capacities, both onshore and offshore**. Financing, supply chain but also operational bottlenecks will need to be overcome to reach such deployment rates in a transition scenario.

Fig. 7.7 **Annual EU-27 installation rates of solar and wind in various scenarios (average 2022-2050), contrasted with historical values 2021 and 2022 (in GW per year)**



The European electricity transmission and distribution networks, as well as flexibility capacities, need to adapt to handle rising power flows and generation variability.

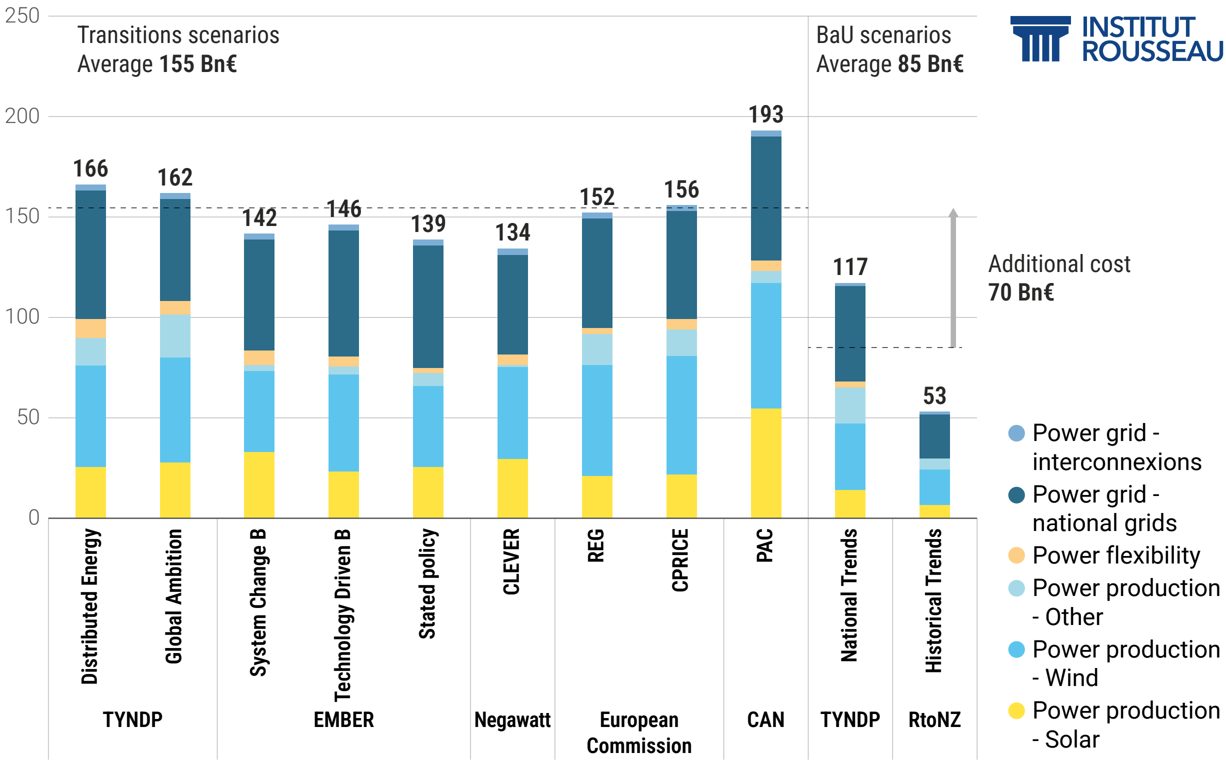
The European **electricity network plays a pivotal role in the energy system**, enabling the flow of electricity from production to demand. To enable decarbonisation, power networks need to evolve. First, to meet rising electricity demand and production, transmission capacity must be reinforced. Second, traditionally operating in a centralised manner, the network must also adapt to accommodate an increasing share of decentralised and intermittent generation resources. With most scenarios lacking data on transmission and distribution network adaptation needs by 2050, an in-house model was developed to assess required electricity network investments for each scenario, considering variable renewable resource penetration and total electricity demand (cf. Methodological Appendix for more details). Investments in interconnections between countries are also factored in.

Developing flexibility resources is imperative for managing a power system dominated by variable renewables. Flexibility encompasses the ability to adjust power production-demand equilibrium on various time scales, from seasons to seconds. This involves hydro reservoirs, other storage assets such as large-scale batteries, demand-side response, and flexible (renewable) gas plants.

Realising the entirety of the new European power sector in 2050 will require investments of some €4.4 trillion or €155 billion per year on average.

Summing all cost categories related to the power sector, the average investments needed from 2023 to 2050 amount to €4,362 billion, compared to €2,394 billion on average for business-as-usual (BaU) scenarios. This results in an **extra cost of €1,972 billion over the period, i.e. €70 billion per year on average**.

Fig. 7.8 **Annual investment and extra-investment required in the electricity production, transmission and distribution system, by 2050, per scenario and in average (in €billion per year)**[16]



The final differences observed between scenarios in terms of costs strongly depend on the hypothesis shaping electricity demand in 2050.

This includes electrification intensity, energy efficiency (high in EMBER), and energy sufficiency (significantly higher in CLEVER and EMBER System Change). The considered level of imports of hydrogen and other synthetic energies also has an impact on the demand. TYNDP considers significant imports in the 'Global Ambition' scenario and lower in the 'Distributed Energy' scenario, while EMBER and CLEVER consider no such imports.

The projected need for public support in new production and flexibility capacity is estimated at around €930 billion by 2050 (or €34 billion per year), far below current public expenditures. Considering an average public coverage of 38% for decarbonised production, 0% for networks, and 10% for flexibility from now until 2050[17], this incurs an additional cost of €417 billion over the period (or €17 billion per year on average) compared to the business-as-usual scenario. These estimates pertain solely to the CAPEX part of future investments. **Despite a substantial increase in renewable capacity installation, the percentage of public coverage is anticipated to decline significantly, leading to a marked reduction compared to past and present public expenditures associated with supporting operational assets** (cf. Box 7.2.)

Measure 7.1

Support to renewable electricity production and flexibility

Public cost
€34 billion per year
Public extra-cost
€16 billion per year

Box 7.2

Main principles and uncertainties around public support for renewable electricity production

Public support for renewable electricity production, governed by 2014 European community rules, adheres to the following principles:

- **Primary support for renewable energies is production-based**, supplemented marginally by research and development (R&D) support.
- States can utilise either feed-in tariffs (FiT) or, **increasingly, market-based remuneration mechanisms, known as 'Contracts for Difference'** (or CfD). In the former, every kWh injected into the public grid is bought by an obligated buyer at a predetermined rate, particularly effective in securing projects in nascent stages. In the latter, operators sell their production on the market, receiving a variable premium in addition until reaching a guaranteed amount. If the market price exceeds the guaranteed rate, the operator reimburses the difference to the state. **Both mechanisms aim to ensure the producer is remunerated to cover both capital and operational costs and ensuring normal project profitability.**

Box 7.2

The issue of projected public expenditure linked to these support mechanisms is both sensitive and intricate. Sensitive because renewable energy support mechanisms commit Member States to long-term contracts with significant financial implications[18]. Intricate because of the dependence of public expenditures on CfDs, heavily depending on the electricity market's long-term projections until 2050, which are difficult (not to say impossible) to foresee. Notably, public expenditures can turn into revenues when the market price exceeds the agreed-upon amount in state-producer contracts[19], as it is the case since the rise in prices that followed the Ukraine invasion. The future of public support for decarbonised power production and flexible capacities will also strongly depend on the outcome of the ongoing electricity market design reform[20].

Note: The public investments outlined in this section do not encompass the entirety of future public expenditures.

- To align with the study's focus on CAPEX, only the CAPEX portion of public spending is considered, representing approximately 75-80% of total costs for renewable[21] and 60-80% for nuclear[22] production assets.
- The presented public investments specifically address the public share of future investments. Ongoing and forthcoming public expenditures associated with supporting production assets initiated in the past 15-20 years[23] are excluded. For context, the total EU-27 public support to all types of renewable production amounted to €86 billion in 2021[24]. In terms of renewable electricity only, the estimated public expenditure for 2021 is ~ €70 billion[25], i.e. twice the average expenditure planned in the transition scenario.

3.2 Switch from fossil gas to biogas and other ‘green’ gases

Conventional methane use in the EU is projected to cease or become negligible by 2050. **In addition to reducing demand and replacing fossil gas for non-electrifiable applications, it is crucial to produce low-carbon gases, particularly Biomethane and Hydrogen.**

Biomethane, mainly derived from organic matter fermentation (anaerobic digestion)[26], boasts low lifecycle GHG emissions. However, its use is restricted by land availability and competition with other sectors for biomass resources. Biomethane production forecasts were evaluated through TYNDP, CLEVER and compared to historical production projections as business-as-usual.

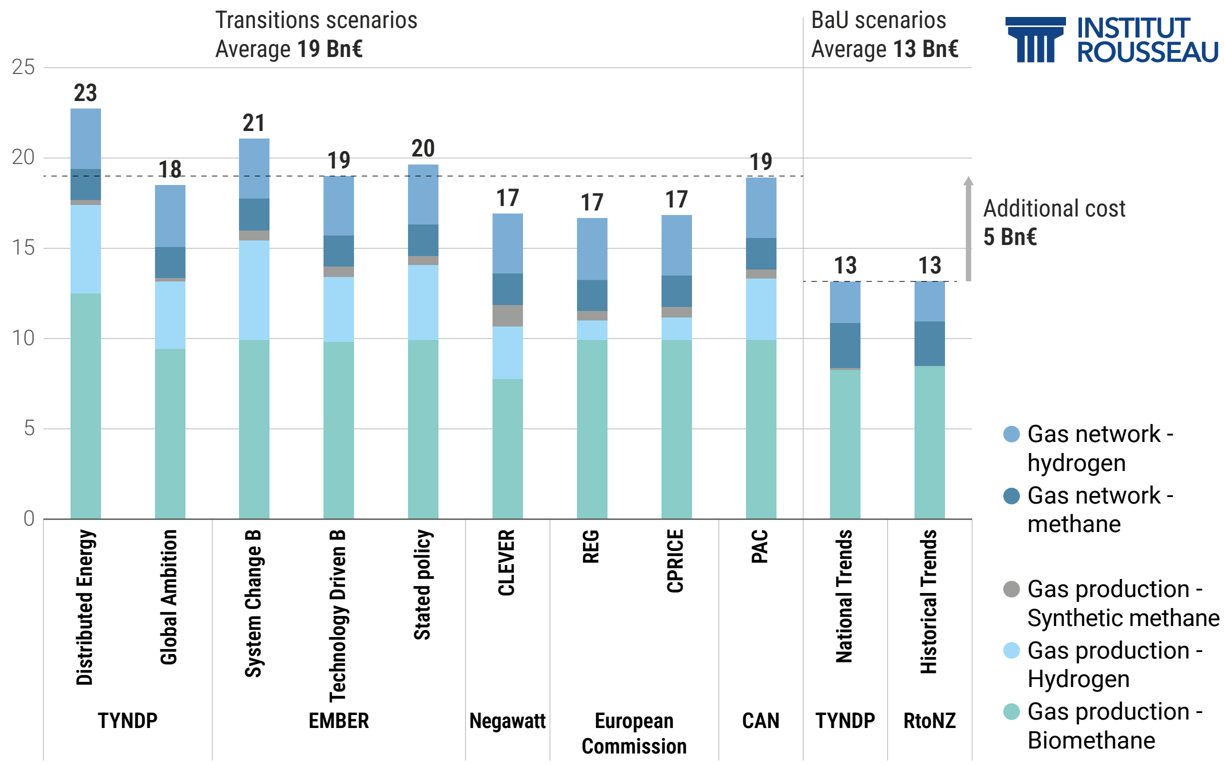
Hydrogen is anticipated to play a pivotal role in decarbonising the industry and, to a lower extent, transport sectors. It can also offer long-term flexibility and energy storage in an variable renewables-dominated power system. Current hydrogen production, produced through methane cracking, is highly carbonised. Low-carbon hydrogen can be produced by electrolysis (also called ‘power-to-gas’), using water and low-carbon electricity. All scenarios included hydrogen forecast, except CAN PAC.

Although currently showing lower maturity level, ‘power-to-gas’ can also lead to **synthetic methane** (‘e-methane’ or SNR for Synthetic Natural Gas) through the methanation process (combining hydrogen and CO_2 as a carbon source). Future synthetic methane production was assessed solely in the TYNDP scenario.

Developing a decarbonised gas production and transmission system by 2050 will require investments of some €530 billion or €19 billion per year on average.

Summing all cost categories, the average investments needed from 2022 to 2050 amount to €530 billion, compared to €377 billion on average for Business-as-Usual (BaU) scenarios. This results in an **extra cost of €147 billion over the period, i.e. €5 billion per year on average**.

Fig. 7.9 **Annual investment and extra-investment required in the gas production, transmission and distribution system, by 2050, per scenario and in average (in €billion per year)**[27]



Additionally, it's important to highlight that scenarios with increased low-carbon gas production will not only exhibit higher capital expenditures (see Figure 7.9) but also elevated operational expenditures. For imports, see Box 7.1.

Hydrogen and synthetic methane production also indirectly incurs around 25% of the investment costs in electricity production systems, i.e. €22 billion per year.

In this subsection, only the capital expenditures (CAPEX) for electrolysis and methanation systems are considered. Nevertheless, around 25% of the 2050 electricity production will be dedicated to hydrogen electrolytic production.

The estimated public cost by 2050, tied to both gas price evolution and green gases production cost reduction, is highly uncertain, akin to electric renewable energies.

Assuming an average public coverage of 23% for biomethane[28], 31% for hydrogen and e-methane[29] between now and 2050, the need for public investments would average around €114 billion by 2050, i.e. an **extra cost of €71 billion over the period (€2,5 billion per year on average)**.

Measure 7.2

Support to green gas production through guaranteed selling prices

Public cost
€4,1 billion per year
Public extra-cost
€2,5 billion per year

Box 7.3

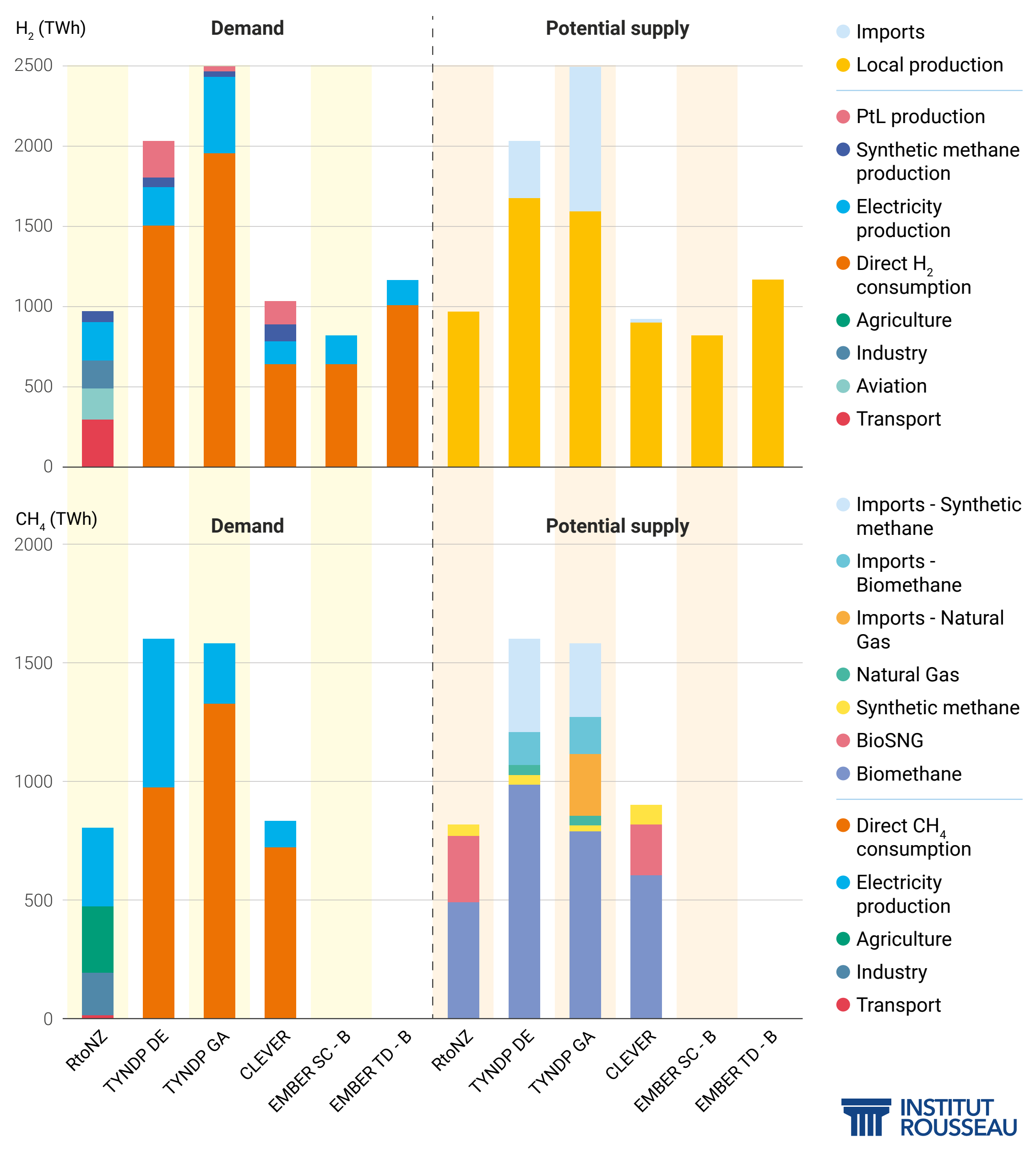
Ensuring 2050 green gases balance between production and demand

Regardless of the scenario, **green gas resources are bound to be scarcer** and costlier than historically used fossil gas, **due to limited biomass resources**. Therefore, prioritising gas applications is mandatory, starting with those most challenging to replace with electricity – especially in industrial use for heat production. Heavy transportation (tractors, trucks) should then be prioritised.

This study confirmed that the projected gas needs for different sectors by 2050 can be fulfilled by the outlined capacities for green gas production. Figure 7.10. summarises the 2050 requirements for downstream sectors in the 'Road to Net Zero' scenario and the anticipated gas production potential for each method (anaerobic digestion, pyrogasification, power-to-gas). These RtoNZ values are subsequently contrasted with demand and supply levels analysed in all primary energy scenarios covered in the energy chapter, indicating conservative realistic volumes.

Box 7.3

Fig. 7.10 **EU-27 hydrogen (top) and methane (bottom) demand and supply in 2050, for the RtoNZ general scenario and all main energy scenarios studied in the Energy section.**



These equilibrium points are subject to adjustment based on the current development speed of different green gas production methods, changes in their respective production costs, and competition with other energy vectors like electricity.

3.3 Phase out coal and oil, end conventional refining activities

The phasing out of oil, driven by decreases in both demand and supply, will accelerate the decline in conventional refining activities.

Beyond phasing out coal, which is mainly used for electricity production (cf. Subsection 7.3.1), reaching carbon neutrality also implies ending use of fossil oil. A complete phase out of liquid oil could prove more complex, even though European refineries have been shutting down for a long time already (13% of refining capacity in Europe closed over the last decade[30]) due to a lack of international competitiveness. All transition scenarios assume a strong decrease in both fossil oil supply, due to a progressive shortage of reserves[31, 32], as well as in fossil fuel demand, as mobility (representing 75% of refinery output[33]) electrifies rapidly. Adding to that, the move towards a more circular economy and recycling is also likely to decrease the demand for chemicals (plastics)[34]. Price distortions before peak demand and surging oil prices from restricted supply might even accelerate this trend away from fossil oil uses[35].

Like all conventional sectors affected by the net zero transition, **refineries slated for closure will require social support** through a dedicated Just Transition Fund (cf. Subsection 10.1.3.)

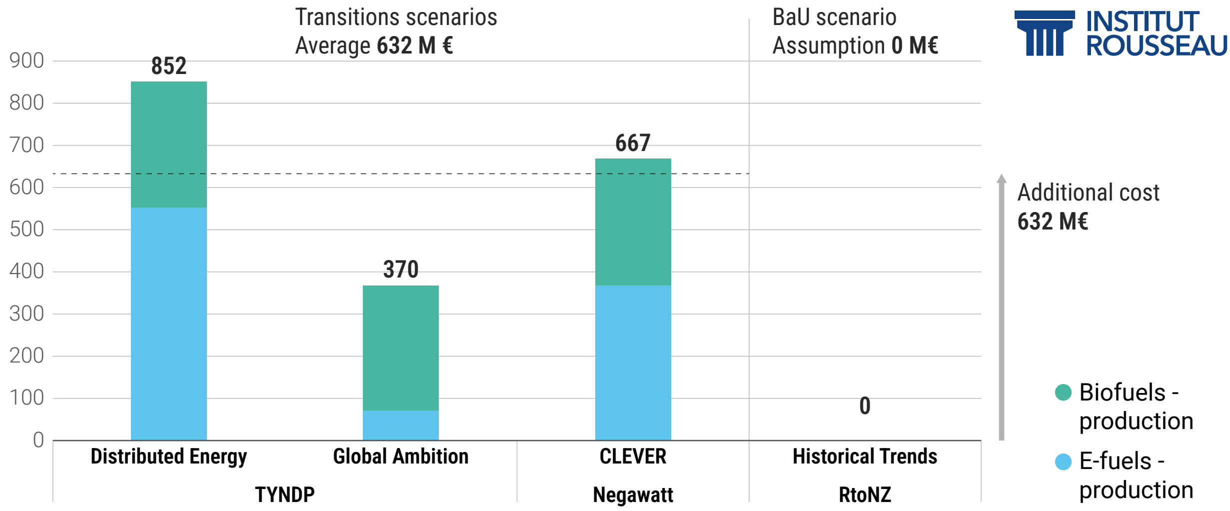
In transition scenarios, some refining activities will remain and be converted to the production of transition fuels.

But European refineries will not all have to close to adjust to the drop in fossil oil demand. **Some will be converted to transition needs and switch from fossil fuels to the required biofuels, hydrogen and e-fuels needed to meet the incompressible demand for liquid fuels.** Part of the petrochemical industry will switch to bio-based chemistry. Another (small) part of the activity may even remain and be equipped with carbon capture technologies to provide the e-fuel assets with CO_2 feedstock. In the end, the RtoNZ model estimates that **~90% of current refining emissions will be avoided by 2050**.

The level of investments needed for this switch is relatively low and depends on the part of alternative fuels to be imported versus locally produced. On average, it adds up to €18 billion in total by 2050, with an uncertain public part.

Average investments in biofuels and e-fuels-from 2022 to 2050 will amount to €18 billion, resulting in an **extra cost of €0.6 billion per year on average**. This covers only the CAPEX for fuel production, as the related renewable power and electrolysis assets are already accounted for in the previous sections. This assessment also very much depends on whether these decarbonised liquid fuels are locally produced (e.g. 100% in the CLEVER scenario) or partly imported (e.g. significant imports assumed in TYNDP[36]).

Fig. 7.11 **Annual investment and extra-investment required in liquid fuels production plants, by 2050, per scenario and in average (in €million per year)**[37]



These figures exclude the primary e-SAF investments required for the aviation sector, mainly categorised under the transport sector. Depending on the sufficiency level achieved, there could be an additional €3.1 billion per year (covering the entire chain from electricity production to e-fuels), equating to a maximum of €1.2 billion in additional public expenditures.

Synthetic liquid fuels production also indirectly incurs around 4% of the investment costs in electricity production systems, i.e. €3.6 billion per year.

In this subsection, the focus is on the capital expenditures (CAPEX) of assets converting hydrogen into synthetic liquid fuels. Nevertheless, around 4% of the electricity production will indirectly be needed to produce the hydrogen transformed into e-fuels.

The estimated public cost by 2050 is highly uncertain, as it depends on the evolution of market prices, akin to electricity from renewable sources. Assuming an average public coverage of 50% for e-fuels, and 0% for biofuels between now and 2050, **the need for public investments would average around €3.6 billion by 2050 (€0.1 billion per year on average)**.

3.4 Decarbonise heat production for district heating

Although the size of heat networks is set to increase, heat production is expected to decrease by 28% by 2050.

This paradoxical situation can be explained on the one hand by a fall in heat consumption in industry, and on the other by global stagnating consumption in better-insulated buildings, which means that networks need to be extended to connect new residential areas. Derived from negaWatt's CLEVER scenario[38], this decline in heat production masks significant variations among Member States[39] and is therefore not correlated with a halt in network investment. District heating systems, facilitated by centralising heat production and distribution, remain efficient tools to decarbonise heat consumption, especially in residential areas.

Summing production and network cost categories, the average investments needed from 2022 to 2050 amount to at least €57 billion. This results in a yearly minimum cost of €2 billion on average.

Investments will indeed be required to decarbonise heat production systems, through technologies such as biomass boilers, large-scale heat pumps and solar thermal power systems. Decentralised heat production assets are already covered in other sectors (e.g. buildings and industry). That said, without reliable data on the necessary expansion of heat networks by 2050, the average investment cost could turn out to be much higher than estimated.

Assuming an average public coverage of 12%[40] between now and 2050, the need for public investments would average around €7 billion by 2050, i.e. €0.26 billion per year on average.

Notes

1. And limiting the impacts of their mining and production.

2. The overall investment effort corresponds to the average cost of the energy transition scenarios studied and presented below.

3. Past data is sourced from the EEA Dataviewer. Targets for 2020 and 2030 reflect the EU's overall emission reduction goals of -20% and -55% from 1990 levels, distributed proportionally according to each sector's 2021 emission share. The 2050 target aligns with residual emissions in the RtoNZ transition scenario. WEM (With Existing Measures) projections, utilising EEA & Climact data, estimate future emissions considering measures already implemented by the EU and its Member States.

4. Eurostat, Simplified energy balance, consulted in November 2023.

5. Eurostat, 2023, 'Shedding light on energy in the EU - 2023 edition'.

6. In 2021, the main imported energy product was petroleum (64%), followed by natural gas (25%) and solid fossil fuels (6%).

7. Source: Eurostat. Compared with 82% of fossil primary energy consumption worldwide, according to the BP's *Statistical Review of World Energy 2022*.

8. European Commission, 2023, Renewable Energy Directive.

9. International Energy Agency, 2023, 'World Energy Outlook'.

10. European Commission, 2023, Energy Efficiency Directive.

11. For the European Union, nine scenarios were studied: three EMBER New Generation scenarios, European Commission's Stepping up Europe's 2030 climate ambitions REG and CPRICE scenarios, negaWatt's CLEVER, Climate Action Network (CAN) PAC, ENTSOS' TYNDP Global Ambition (GA) and Distributed Energy (DE) scenarios.

12. Eurostat, 2023, 'EU imports of energy products'.

13. €3004 billion, cf. Eurostat, 20 March 2023, 'Euroindicators'.

14. European Commission, 24 October 2023, 'State of the Energy Union'. In its 'National fiscal policy responses to the energy crisis' 2023 publication, the Bruegel institute announced €540 billion spent on energy shields since Septembre 2021.

15. Negawatt, 2023, CLEVER scenarios.

16. Only physical data, i.e. the annual installed production and storage capacity, was retrieved from the scenarios mentioned. The costs of flexibility and storage resources were assessed as the cost of new assets plus the costs of renewal. The power grid costs were added based on our own estimations. For scenarios lacking data on a certain category, the average observed in other scenarios was added (e.g. flexibility in negaWatt CLEVER).

17. Extrapolation based on the historical and current public support in 7 Member States, and the expected evolution of LCOE per technology.

18. The solar sector's surge and subsequent moratorium in the 2000s, for instance, underscores the need for careful anticipation and strict oversight.

19. For instance, the surge in electricity prices in 2021, reaching €190/MWh on February 7, 2022, resulted in market prices 2 to 3 times higher than the reference rate proposed by winners in the latest French tendering round for large-scale solar PV (€60/MWh).

20. Public backing for new investments in decarbonised generation should involve two-way Contracts for Difference. The resulting net public costs will be contingent on electricity price dynamics and administratively set auction cap prices. Simultaneously, strengthening corporate Power Purchase Agreements (PPAs) and forward markets can encourage private investments, potentially lessening the reliance on public support. Additionally, Member States must establish national flexibility targets, considering long-term support schemes like capacity payments to meet these objectives. For more details, see: European Council, dec 2023, 'Reform of electricity market design: Council and Parliament reach deal'.

21. Institut Rousseau, Greenpeace, 'Current costs of low-carbon energy production assets', nov 2021.

22. International Energy Agency, 'Levelized Cost of Electricity Generator' and French Ecology Ministry, 'Synthèse publique de l'étude des coûts de référence de la production électrique'.

23. Average Duration of Feed-in-Tariff (FiT) and Contracts for Difference (CfD) Support Agreements.

24. European Commission, Enerdata and Trinomics, 2023 report for the DG Energy, p.33, Study on energy subsidies and other government interventions in the European Union - Publications Office of the EU (europa.eu).

25. To calculate this amount, which was not available to us, we used our costing for total public spending in 7 Member States (representing the vast majority of public investment in RES-E production in the EU) to which we have applied an extrapolation ratio (we assume that our EU-7 total represents 79.36% of the EU-27 total). For more details about this calculation, please refer to the Methodological Appendix.

26. It can also be produced by gasification of woody biomass (a thermochemical process with a lower TRL than anaerobic digestion used to produce biogas).

27. Only physical data (i.e. the annual gas production) was retrieved from the scenarios mentioned. For scenarios lacking data on a specific gas, the average cost from other transition scenarios was used. The costs were assessed as the cost of new assets and renewal, based on unit costs detailed in the Methodological Appendix. The costs incurred by the development of the gas networks were assessed based on Institut Rousseau's in-house methodology.

28. Extrapolation based on the historical and current public support in 7 Member States, and the expected evolution of LCOG and gas prices cf. Methodological Appendix for more details.

29. For Hydrogen, extrapolation based on the difference between a reference price and LCOH projections in the 7 Member States. For e-methane, the coverage ratio is set at 50% cf. Methodological Appendix for more details.

30. Ricardo for Transport & Environment, 2022, 'What future role for conventional refineries in the decarbonisation transition?'.

31. Which will restrict the range of feedstocks available and increase pressure on refineries that are not flexible enough.

32. The Shift project, 2021, 'The future of oil supply in the European Union: state of reserves and production prospects for major suppliers'.

33. Road fuels represented 60% of 2021 refinery output; aviation and maritime fuels 15% (Eurostat).

34. negaWatt, 2022, CLEVER.

35. Pangea strategic intelligence, 'European Oil Refining – End of the Road?'.

36. 844 TWh in 2050 in Global Ambition, 360 TWh in Distributed Energy.

37. Only physical data, such as annual liquid fuels production, was obtained from the mentioned scenarios. The level of biofuel production relies on Negawatt's assumptions across all scenarios. For e-fuel production, only the investment costs of the synthesis plant are accounted for; the investments required for its inputs, hydrogen and electricity, are included in the Gas and Electricity Subsections. The Business-as-Usual (BaU) scenario assumes zero costs, as it conservatively maintains today's production capacities.

38. Note: Assumptions on the evolution of heat production systems were retrieved only from the Negawatt-CLEVER scenario.

39. The negaWatt CLEVER scenario can yield values that may significantly differ from the National Energy and Climate Plans.

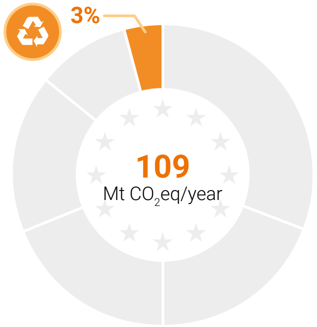
40. Extrapolation based on the historical and current public support in 7 Member States, and the expected evolution of Levelised Cost Of Gas production (LCOG) and gas prices.

Investments in the waste management sector

Reduce, Reuse, Recycle, Optimise

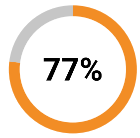
INSTITUT ROUSSEAU

Current emissions and reduction potential



Action levers to mobilise:

1. Separately collect and recover biowaste
2. Reduce plastic use, increase plastic recycling and substitution with other materials
3. Reduce wastewater treatment emissions through process adaptation
4. Produce biogas from waste and sludge



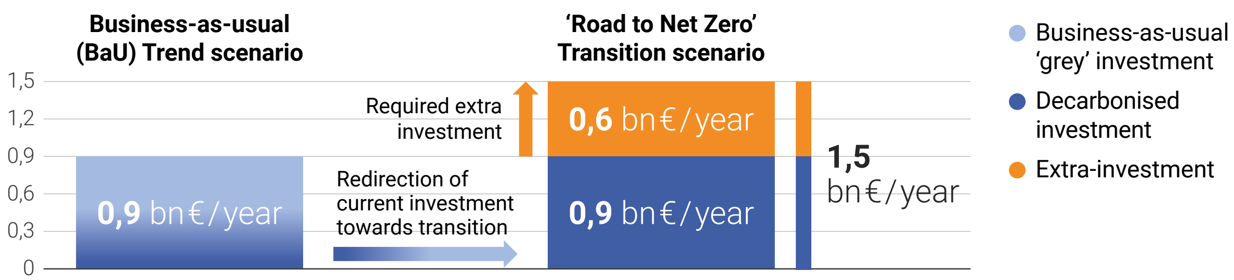
2050 decarbonisation potential

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT	
TOTAL	EXTRA	TOTAL	EXTRA
0,10%	0,18%	0,30%	0,25%

Global investment needs

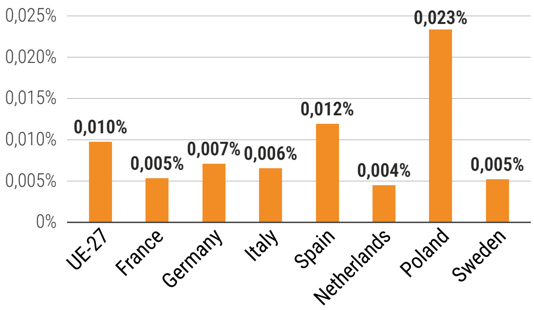
UE-27 global investment and extra-investment



Global investment and extra-investment per lever, per country (in % of GDP):

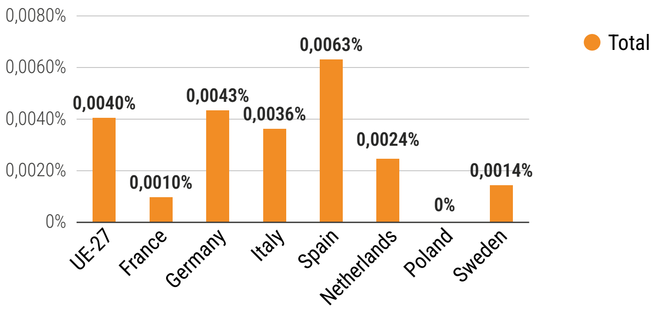
Total investment

0,01%



Total extra-investment

0,004%



Public investment needs

Total public investment in proposed public policies

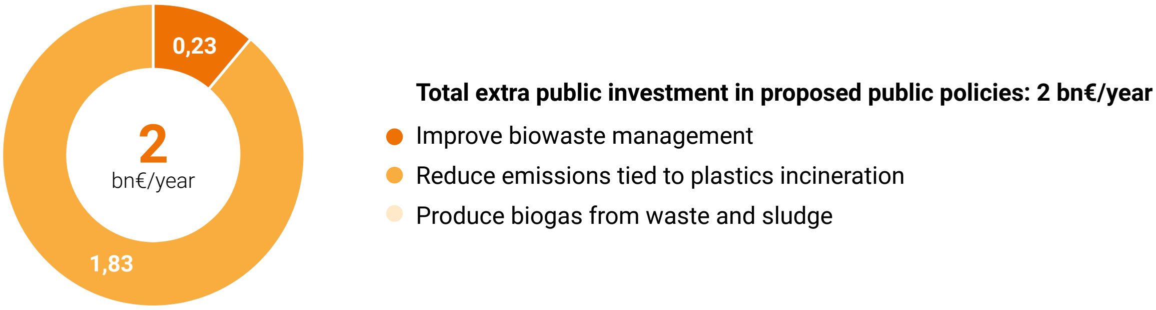
3,2 bn€/year

Public share in total investment

100%

Public extra-investment in % GDP

0,003%



Complementary measures:

+ Implementing the Landfill Directive for municipal biowaste management
+ Promote awareness for municipal biowaste sorting
+ Reduce plastic packaging
+ Harmonise the EU plastics tax system and further develop European standards for recycled plastics
+ Accelerate the inclusion of incinerators in the ETS (2028) and impose a ban on new incinerators
+ Make feed-in tariff with investment grants cumulative; Introduce biogas production certificates for WWTP; Further implement energy saving certificates for WWTP

Key takeaways

- **Waste management accounted for 4.2% of total EU27 emissions in 2021 (3.1% when excluding plastic incineration with energy recovery), representing 146 $MtCO_2$-eq.**
- **The main levers for reducing these emissions are the separate collection and recovery of bio-waste, the reduction of plastic use and increased recycling, the reduction of emissions from wastewater treatment and the production of biogas from waste and sludge.**
- **Combined, these measures represent an investment of €3.2 billion per year until 2050 (out of which €1.9 billion are included in the Industry section in this study). 65% of this amount represents extra investment compared to a BaU scenario and most of this extra-investment cost will have to be carried by public investment.**
- **Strong public measures are required to achieve emissions reduction, such as regulated tariffs for biogas, standards for recycled plastics or monitoring of the implementation of separate collection of bio-waste.**
- **Considered together, these measures will reduce the sector's emissions by 81% in 2050 (when including plastic incineration with energy recovery, against -77% without waste-to-energy). Beyond emission reduction, they also represent major opportunities in terms of energy autonomy, access to critical resources, soil management and public health.**
- **When it comes to waste management, and plastic waste in particular, it is critical to highlight the primacy of plastic demand reduction (global demand increased from 1 Mt in 1950 to 390.7 Mt in 2021) over plastic recycling. Plastic recycling shouldn't be discarded, but it is expensive, highly dependent on virgin material prices, and doesn't allow technically to break away from the linear economy. In this respect, it is important to note that the most advanced European countries in terms of recycling (e.g. Norway, Germany, Sweden) – with recycling rates above 40% – did not reduce their virgin fossil-based plastic demand by the same amount over the past years.**

The waste sector includes several activities:

- Storage (e.g. landfilling) of solid waste;
- Treatment and discharge of domestic and industrial wastewater;
- Waste incineration (with or without energy recovery);
- Other solid waste treatment methods (e.g. industrial composting and anaerobic digestion).

1 Emissions of the sector

Waste management accounted for 3.1 to 4.2% of total emissions in 2021.

The EU-27 waste sector emitted 109 $MtCO_2$-eq in 2021, rising to 146 $MtCO_2$-eq with incineration and energy recovery. It constitutes 3.1% or 4.2% of the EU-27's 3.5Gt total emissions in 2021, with incineration falling under the waste sector but allocated to the energy sector by the EEA due to its growing role in European energy production

Including waste-to-energy incinerators (WtE), the EU-27's 146 $MtCO_2$-eq emissions come from three main sources: landfills, wastewater treatment plants and incinerators.

- **Biowaste decomposition in landfills contributes to 52% of sector emissions**. Municipal biowaste in Europe, ranging from 78Mt[1] to 91Mt[2], includes food and garden waste. Only 32% to 39%[3] is separately collected, while the rest heads to incineration or landfill. This landfilling, causing methane (CH_4) emissions, reached 76 $MtCO_2$-eq in 2021.

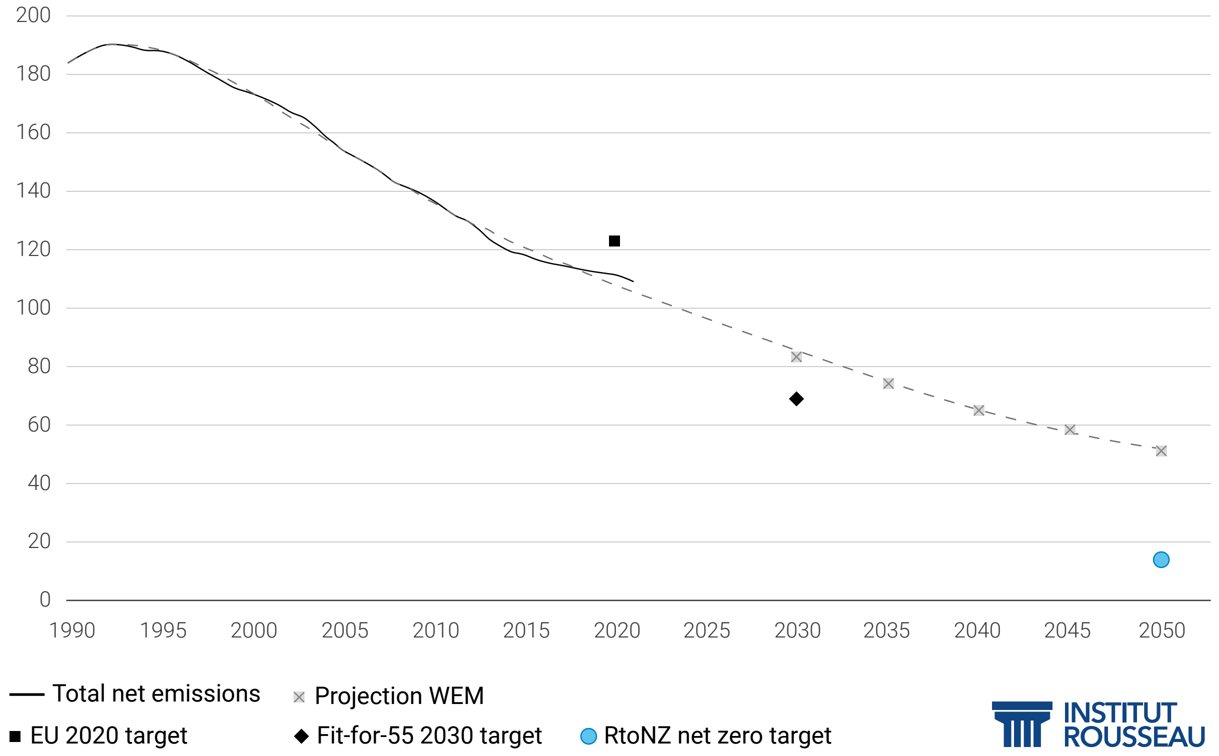
- **Waste incineration, primarily plastics, contributes 28% of sector emissions.** Almost all of the 40 $MtCO_2$-eq emissions arise from the 504 operational WtE incinerators in the EU-27[4].

- **Wastewater treatment plants (WWTP) contribute 16% of sector emissions**, with 23 $MtCO_2$-eq estimated for the EU-27 in 2021. Emissions include CH_4, N_2O, and CO_2 from various sources, with N_2O emissions and WWTP energy consumption being predominant. Notably, energy consumption largely stems from sludge aeration (50-60% of plant energy).

The sector's emissions have decreased by 41% since 1990 but are not aligning with climate objectives.

The waste sector's emissions have declined by 41% since 1990, an average reduction of 2.3 $MtCO_2$-eq/year over the last decade. To achieve the ‘Fit-for-55’ 2030 target aligned with the sector's current share, the rate of reduction would need to increase by a factor of 2.5. Projections based on existing policy measures indicate that meeting the 2050 target is currently extremely unlikely (2050), as illustrated in Figure 8.1.

Fig. 8.1 **Waste management past UE-27 domestic emissions and progress towards achieving 2030 and 2050 targets, in million tons of CO_2 equivalent ($MtCO_2e$).**[5]



WEM: With Existing Measures.

This trend hides contrasting dynamics between waste sub-sectors, especially when considering incineration with energy recovery. Emissions from incineration with energy recovery rose sharply over the period and, if included, would lead to a 'business-as-usual' scenario with rising emissions by 2050, making it impossible to achieve the European 'Fit for 55' targets.

In order to meet EU climate targets, it is therefore necessary to act on all waste sub-sectors, both by reducing the quantity of waste produced (plastics in particular) and channelling it into low-carbon waste treatment processes.

2 How to decarbonise the sector?

Several levers can be used to reduce EU-27 waste sector's emissions:

2.1 Methane emissions from biowaste decomposition in solid waste landfills

2.1.1 Separately collect and recover biowaste

- GHG emissions from landfills decreased by 45% (1990-2021), due to the **Landfill Waste Directive** (1999). Amended in 2008, it **now mandates all local authorities and biowaste-producing professionals to collect biowaste separately from January 1, 2024**.
- Composting enhances soil by returning organic matter to the soil and by improving water retention, mineral salt storage, and carbon sequestration. It reduces reliance on synthetic fertilisers, promoting long-term soil fertility.
- Biogas production through anaerobic digestion turns biowaste into renewable gas and organic matter. Currently, biowaste collection is evenly split between composting and methanisation on a European scale, which sets the right balance between soil fertility and energy mix decarbonisation. The lever is already known by public authorities, but deployment and capital investment are key.

2.2 Incineration of waste containing fossil carbon, mainly plastics

2.2.1 Reduce demand for plastic

The main lever to reduce incineration's emissions is to lower demand from the main plastic-consuming industries (e.g. packaging, consumer goods, automotive and construction: 75% of current EU-27 total plastic demand). The demand for packaging plastic should decrease under the deployment of deposit-schemes, new distribution models (based on re-use, 'as-a-service' models, bulk distribution) and the elimination of easily avoidable plastics.

2.2.2 Substitute plastics with other materials

In certain specific cases, plastics will be substituted with other materials, notably paper and cardboard, but also compostable packaging. These substitution solutions will have to be deployed on a case-by-case basis when no reduction lever can be considered, given the variable environmental gain of substitution depending on paper sources.

2.2.3 Increase plastic recycling

To address unavoidable plastic production and divert it from incineration, particularly in sectors like automotive or construction, intensifying mechanical and chemical recycling is crucial. To do so, Member States must:

- **Increase recycling capacities**, both mechanical and chemical.
- **Boost collection and sorting capabilities and enhance sorting efficiency**, especially through automated processes, which elevates recycled plastic quality.
- **Implement education programs** to promote proper plastic waste sorting and separate collection.
- **Integrate recycling-by-design principles**, incorporating design-based recyclability rules during production, which supports the standardisation and simplification of plastics. Shifting from complex to simpler plastics should facilitate recycling.

These levers could potentially reduce plastic incineration in Europe by 86% by 2050[6]. Globally, plastic recycling remains technically challenging. Mechanical recycling has a limited number of recycling cycles, and emerging chemical recycling cannot currently process all plastics (e.g. purification constraints) and is reportedly energy-intensive. Thus, it is imperative to prioritise uses, minimise demand, and consider recycling only as a last resort in end-of-life management.

2.3 Energy consumption and process emissions from wastewater treatment plants (WWTP)

2.3.1 Selective urine collection

Source separation of urine – mainly feasible for new buildings – has the potential to reduce downstream energy consumption and N_2O emissions associated with deammonification, while also providing a low carbon fertiliser, as urines are highly concentrated in nitrogen, phosphorus and potassium.

2.3.2 Deammonification

Deammonification reduces oxygen consumption during the treatment process, cutting aeration, energy needs, and N_2O emissions.

2.3.3 Adsorption/Bio-oxidation

The Adsorption/Bio-oxidation (A/B) process divides conventional activated sludge treatment into two stages. Initial adsorption leads to a -15% reduction in aeration and energy during subsequent bio-oxidation[7]. Generated sludge enhances biogas production by +17% during methanisation, reinforcing plant energy autonomy.

2.3.4 Plant monitoring, control and efficiency

Energy efficiency through controlled plant management can reduce energy consumption linked to the main consumer items (e.g. aeration and pumping, which account for around 70-80% of a plant's energy needs). Beyond control, efficiency can also be improved through equipment retrofit introducing high-efficiency motors, frequency inverters, etc.

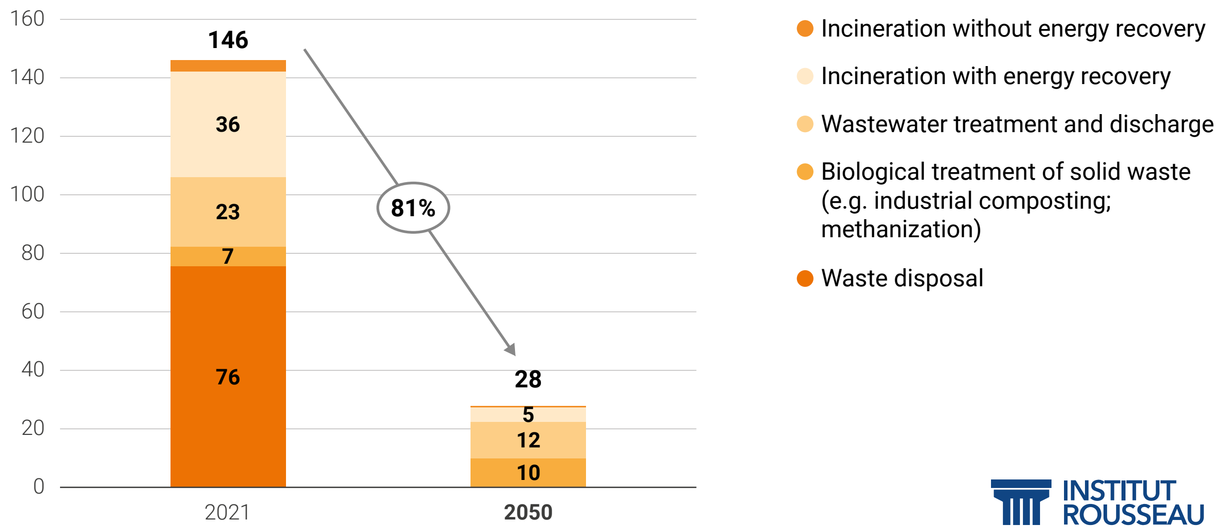
2.3.5 Biogas production and energy decarbonisation

On-site anaerobic digestion of sludge and injection of resulting biomethane into the gas network, coupled with decarbonisation of the energy consumed at the plant enable to reduce emissions and improve energy production. It is important to note that when it comes to biomass recovery (energy and return to the soil), other biological or thermochemical treatment processes may be considered on a case-by-case basis (e.g. enzymatic hydrolysis; gasification; etc.)

The combination of these levers will not only reduce the impact of wastewater treatment plants, but also make them energy self-sufficient or even energy positive. Due to data availability reasons, only the biogas production and energy decarbonisation levers have been included in the roadmap.

All combined, these action levers show a total GHG emissions reduction potential of 81% by 2050, as shown in Figure 8.2. The only waste sub-sector to see its emissions increase slightly (+52% in combined emissions over the period) is the biological treatment of solid waste (e.g. industrial composting and biogas production), impacted by the redirection of bio-waste flows from landfill to these sectors.

Fig. 8.2 **Decarbonisation levers' emissions reduction potential for UE-27 over the 2021-2050 period (in $MtCo_2eq$)**



3 How much investment does it require?

The investments needed to decarbonise the waste sector must nearly quadruple compared to the 'business-as-usual' investment trajectory, reaching €85.4 billion from 2023 to 2050.

Fig. 8.3 Annual investment and extra-investment needed to decarbonise the waste sector, per lever (€billion per year)

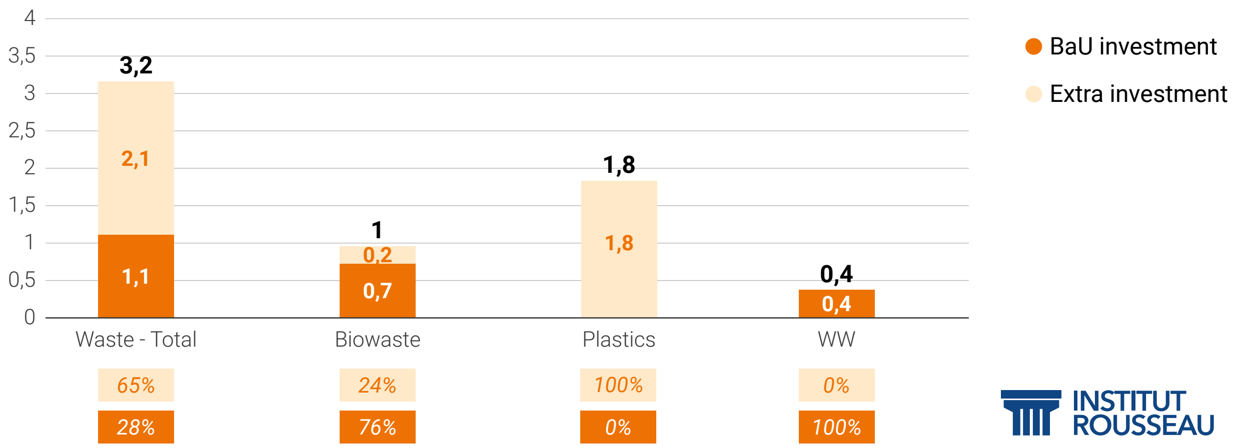
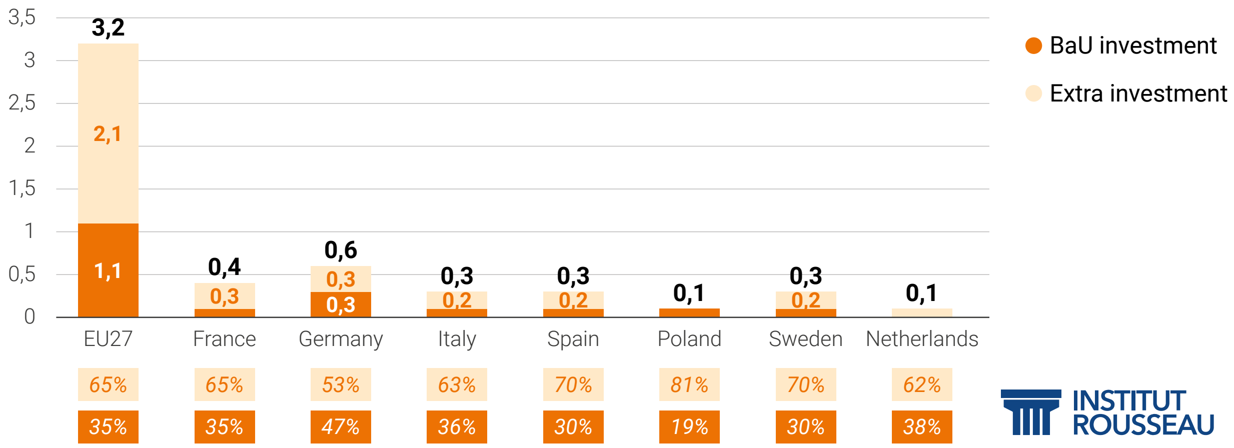


Fig. 8.4 Decarbonisation levers' required capex per year and per country (€billion per year)



Slight differences can be observed from one country to another regarding the weight of BaU investment against total required investment. This is mainly explained by countries' different current progress rate regarding the separate collection and sorting of biowaste. Indeed investments for plastics are exclusively extra-investment and investment for WWTP are exclusively BaU, no matter the country. Some countries (namely Netherlands, Germany, Italy, Sweden, France) show a positive trend towards increased composting and anaerobic digestion (AD) in the waste end-of-life treatment mix, while this composting/AD rate progressed slower in other countries (namely Poland and Spain).

4 What role for the public sector?

Public authorities have a major role to play in the transition of the waste sector, as most of the financial investment required alongside public policy measures will have to be deployed by public authorities.

All this extra capital represents a total of €55.6 billion to be deployed by public authorities over the period 2023-2050. Of this €55.6 billion, €49.3 billion - i.e. extra investment dedicated to the plastics sector) is accounted for in the industry sector in this study.

Beyond financial investments, the success of decarbonising the EU-27 waste sector depends on the implementation of several public policies.

4.1 Biowaste

- **Implementing the Landfill Directive:** the Landfill Directive mandates separate biowaste collection in Europe by 2024. To ensure effective application and stability, enhancing control and sanction capabilities for non-compliant producers and involving regional authorities in regulation implementation are crucial measures.

- **Promoting Awareness:** biowaste recovery success relies on high-quality, uncontaminated waste. National communication campaigns targeting professionals and individuals can promote biowaste sorting and prevent contamination, especially from plastics.

- **Optimising Collection Schemes:** while various collection schemes exist, drop-off points demonstrate superior effectiveness in both collection rates and waste quality. Paris's case study comparing door-to-door and drop-off points collection highlights the latter's quantitative (capture rate) and qualitative advantages[8].

- **Reducing Plastic Packaging:** the reduction and substitution of plastic packaging are crucial to minimise sorting errors. The European Commission's proposed ban on lightweight conventional plastic bags aligns with this objective, ensuring uncontaminated bio-waste streams.

At a time when many European countries have recently been criticised by the European Commission for not meeting their 2035 waste recycling targets (Landfill Directive), all the investments and measures described here will help to significantly accelerate the appropriate management of biowaste, which accounts for a major share of municipal waste (around 30%).

Measure 8.1

Improve biowaste management by ensuring separate biowaste collection, enhancing control measures, optimising drop-off point collection schemes, and reducing plastic packaging to accelerate bio-waste treatment

Public extra-cost
€0.23 billion per year

4.2 Plastics

- **European Standards for Recycled Plastics:** Imposing European standards, aligned with the eco-design draft regulation, is vital for promoting recycling and expanding the use of recycled plastics. This initiative, particularly for food packaging, secures economic outlets for the growing recycling sector.

- **Incinerator Regulation and Ban:** Accelerating the inclusion of incinerators in the ETS (2028) and imposing a ban on new incinerators, along with halting public funding, to slow down the 'waste-to-energy' sector and avoid 'locking in' certain investments and their associated emissions.

- **Harmonising Plastics Tax System:** Protecting the European market from high-emission plastics through Carbon Border Adjustment Mechanism and harmonising intra-European plastic taxes.

- **Sector-Specific Regulations** in the Construction Industry (enforce mandatory selective demolition and on-site sorting), Automotive Sector (e.g. increase incineration or landfill costs for vehicle shredder residues), Distribution Innovation (introduce incentive programs for new distribution methods and deposits).

These multifaceted regulations encourage the separate collection of used plastics across diverse sectors, contributing to a more sustainable and circular approach.

Measure 8.2

Enact comprehensive policies, including the imposition of European standards for recycled plastics, the regulation and ban of incinerators with accelerated inclusion in the ETS (2028), and harmonisation of the plastics tax system.

Public extra-cost
€1.83 billion per year

4.3 Wastewater treatment plants

- **Increasing and stabilising the biogas feed-in tariff** to guarantee project developers a sustainable investment framework.

- **Indexing feed-in tariffs to the price of energy** to adapt subsidies to the changing economic environment of operators.

- **Cumulating feed-in tariff with investment grants**.

- **Introducing biogas production certificates** to provide additional income for projects.

- **Further implementation of energy saving certificates** for the retrofitting of certain equipment in treatment plants (e.g. high-efficiency engines; variable frequency drives; etc.), as initiated in France, for example.

- **Support research around water treatment** to - among other topics - understand into further details WWTP emissions (e.g. N_2O) and pursue research around unconventional bioprocesses reducing oxygen consumption while maximising recoverable biomass.

- **Regulatory possibility of mixing sludge and biowaste** on digesters to create synergies, circular economy and facilitate project development.

The funding required for wastewater measures totals €383 million annually, which can be sourced through the redirection of existing business-as-usual investments.

Notes

1. EEA, 2020, 'Bio-waste in Europe - Turning challenges into opportunities'.
2. ZWE, 2020, 'Biowaste in the EU: Current capture levels and future potential'.
3. *Ibid.*
4. CEWEP, Map of Waste-to-Energy plants.
5. Past data is sourced from the EEA Dataviewer. Targets for 2020 and 2030 reflect the EU's overall emission reduction goals of -20% and -55% from 1990 levels, distributed proportionally according to each sector's 2021 emission share. The 2050 target aligns with residual emissions in the RtoNZ transition scenario. WEM (With Existing Measures) projections, utilising EEA & Climact data, estimate future emissions considering measures already implemented by the EU and its Member States.
6. SystemIQ, 2022, 'ReShaping Plastics'.
7. Marlène Choo-Kun, 'Integration of sludge anaerobic digestion into an alternative wastewater treatment process based on the A/B process', 2017.
8. Expert calls - Les Alchimistes.

Investments in the carbon sinks (LULUCF) sector

Sustainably storing residual emissions in biomass and soils

Current emissions and reduction potential

Decarbonisation levers to mobilise:

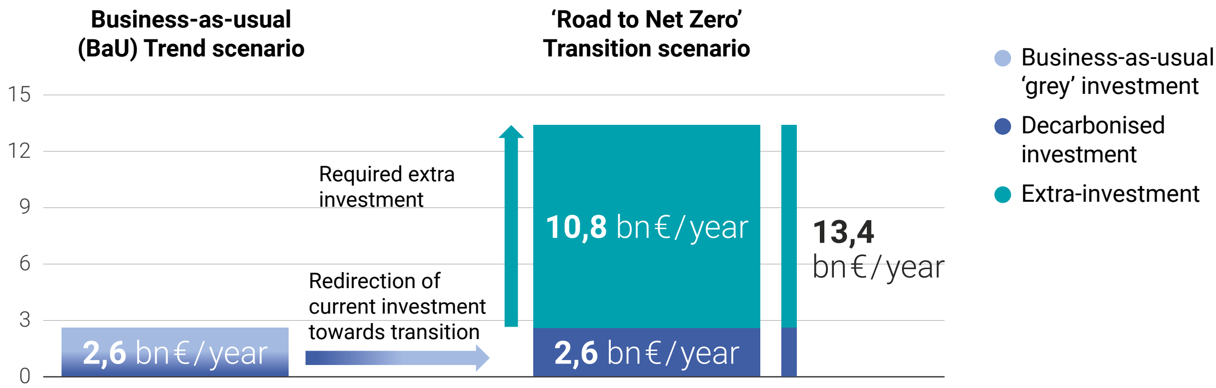
1. Improve forest management
2. Revitalise degraded ecosystems
3. Support wood industry adaptation
4. Increase forest area
5. Turn grasslands back to net sinks
6. Plant hedgerows and field trees
7. Protect wetlands and peatlands
8. Reach net zero artificialization

×2,5

2050 expansion potential

Global investment needs

UE-27 global investment and extra-investment



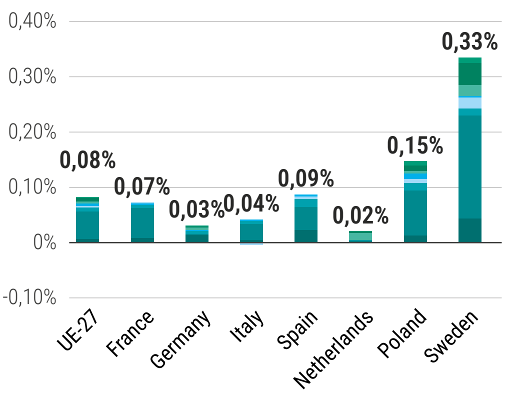
Global investment and extra-investment per lever, per country (in % of GDP):

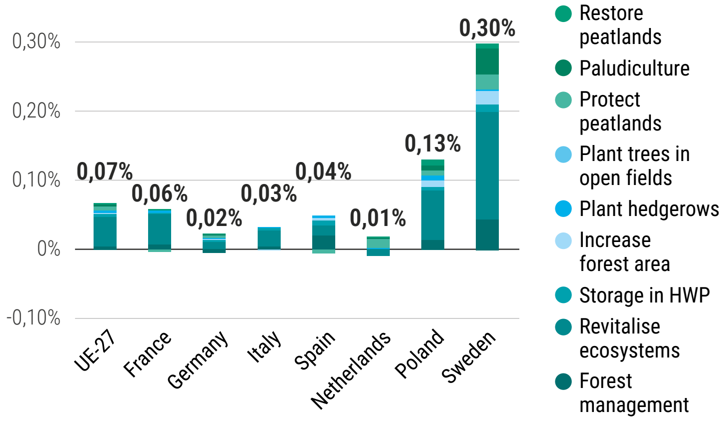
Total investment

0,08%

Total extra-investment

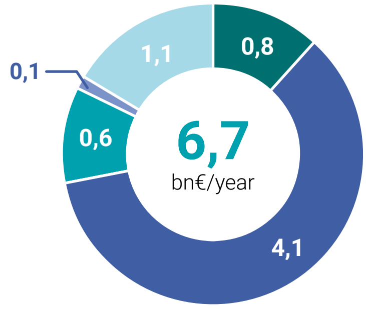
0,07%





Public investment needs

Total public investment in proposed public policies	Public share in total investment	Public extra-investment in % GDP
13,4 bn€/year	64%	0,04%



Total extra public investment in proposed public policies: 6,7 bn€/year

- Improve forest management
- Revitalise degraded ecosystems
- Support wood industry adaptation
- Increase forest area
- Turn grasslands back to net sinks
- Plant hedgerows and field trees
- Protect wetlands and peatlands

Complementary measures:

+ Enhance Forest management labels
+ Preserve 10% of each country's forests from exploitation and deforestation
+ Establish a legal framework to ensure the protection of wetlands and peatlands
+ Implement an artificialization tax for companies funneled toward protected area expansioı

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT	
TOTAL	EXTRA	TOTAL	EXTRA
0,9%	3%	1,7%	2,6%

Key takeaways

- **Carbon sinks are critical from both climate change mitigation (absorbing other sector's residual missions) and adaptation standpoints.**
- **The current net sink capacity in the EU not only falls short of covering the residual emissions projected for 2050 but is expected to decline.**
- **Carbon sinks vary greatly from one country to another and must be considered within a European context. Current net-emitting ecosystems must be converted into net sinks.**
- **Climate change challenges impose a fundamental shift in forest management, based on local customisation and strategic long-term planning. Clear cuts must be strongly regulated.**
- **Wetland ecosystems, though ecologically crucial, currently emit greenhouse gases due to human-induced degradation. They must be protected at all costs.**

Carbon sinks are critical from both climate change mitigation and adaptation standpoints.

The LULUCF ('Land Use, Land Use Change and Forestry'[1]) sector, encompasses emissions from Forest Land, Cropland, Grassland, Wetland, Settlements, and Harvested Wood Products (HWP). The stakes for the sector are twofold, with an aim to both mitigate and adapt to climate change:

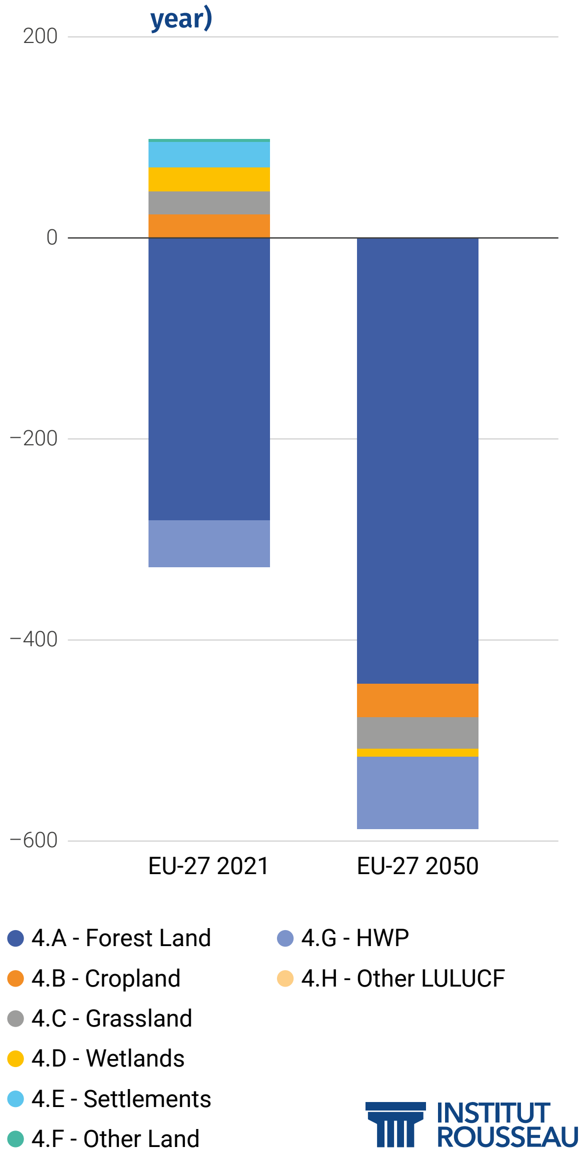
1. ***Mitigation***: achieve a level of negative emissions equivalent to the EU's positive residual emissions in 2050, in order to reach 'net zero';

2. ***Adaptation***: build a forestry and soil management model to store residual emissions sustainably for the long term and maximise resilience to climate change. A successful adaptation to climate change is also a prerequisite to unlock the mitigation potential of forests.

In the EU, insufficient funding for public forests and wetlands hinders effective management of fragmented and degraded ecosystems. Despite the 2030 Biodiversity Strategy and the '3 billion Trees' plan from the European Green Deal, current policies and practices are unsuited to deal with long-term challenges. While public entities lay the groundwork for national management, the private sector must adopt new practices, transforming the economic landscape. Public institutions must serve as catalysts for change, providing a vision and supporting necessary private investment.

Ecosystems and healthy soils are vital for carbon sequestration, biodiversity support, and ecological functions. A strong sustainability approach, especially in biodiversity conservation, recognises intrinsic ecosystem value, which is crucial for preserving natural areas, regulating water flow, mitigating floods, storing carbon, stabilising soil, and maintaining clean air. Often underestimated, reversing soil degradation plays a key part in ensuring global food security, protecting biodiversity, and addressing climate challenges[2].

Fig. 9.1 **EU-27 emissions of the LULUCF sector in 2021 and 2050 as per the RtoNZ scenario (in million tons per year)**

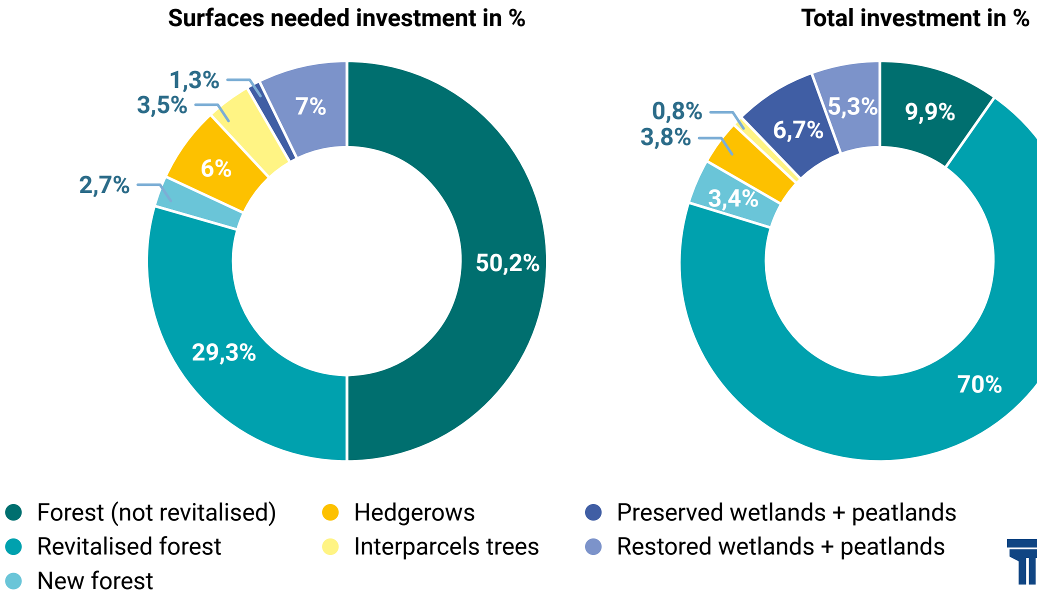


European Environment Agency (EEA) 2021 & Study results

Focusing on carbon neutrality, this sector's role is to absorb all residual emissions by 2050.

Taken together, the proposed measures will ensure that 587 $MtCO_2$-eq are captured per year by 2050. This is a conservative estimate, with a slight margin of around 13% between the neutrality target and the projected storage capacity to 2050[3].

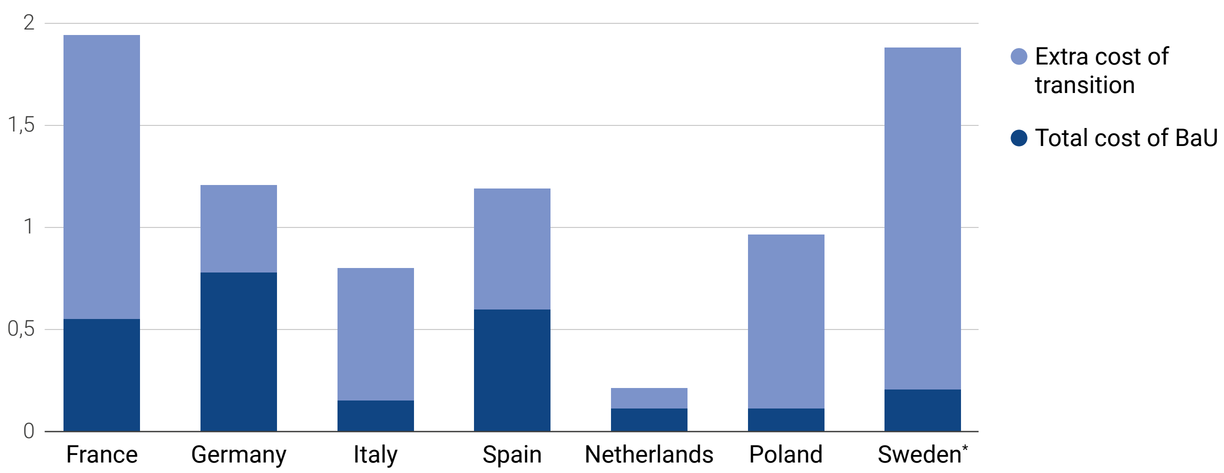
Fig. 9.2 Share of surface of different carbon sink types in 2050 (left) and investment needed in each of them (right)



A requirement of €13 billion annually, predominantly sourced from public funding.

Adopting a strong sustainability nature-based approach, the total **LULUCF associated costs represent €362 billion until 2050 or €13.4 billion per year on average (0.9% of cross-sector total). The extra public cost is €180 billion until 2050 or €6.7 billion per year (2.7% of the cross-sector total).** A share of these investment efforts must be carried out urgently to minimise emissions produced before 2050 and enable the newly-adapted forests to grow despite multiplying disruptions.

Fig. 9.3 Annual investment and extra-investment in the LULUCF sector (in €billion per year)



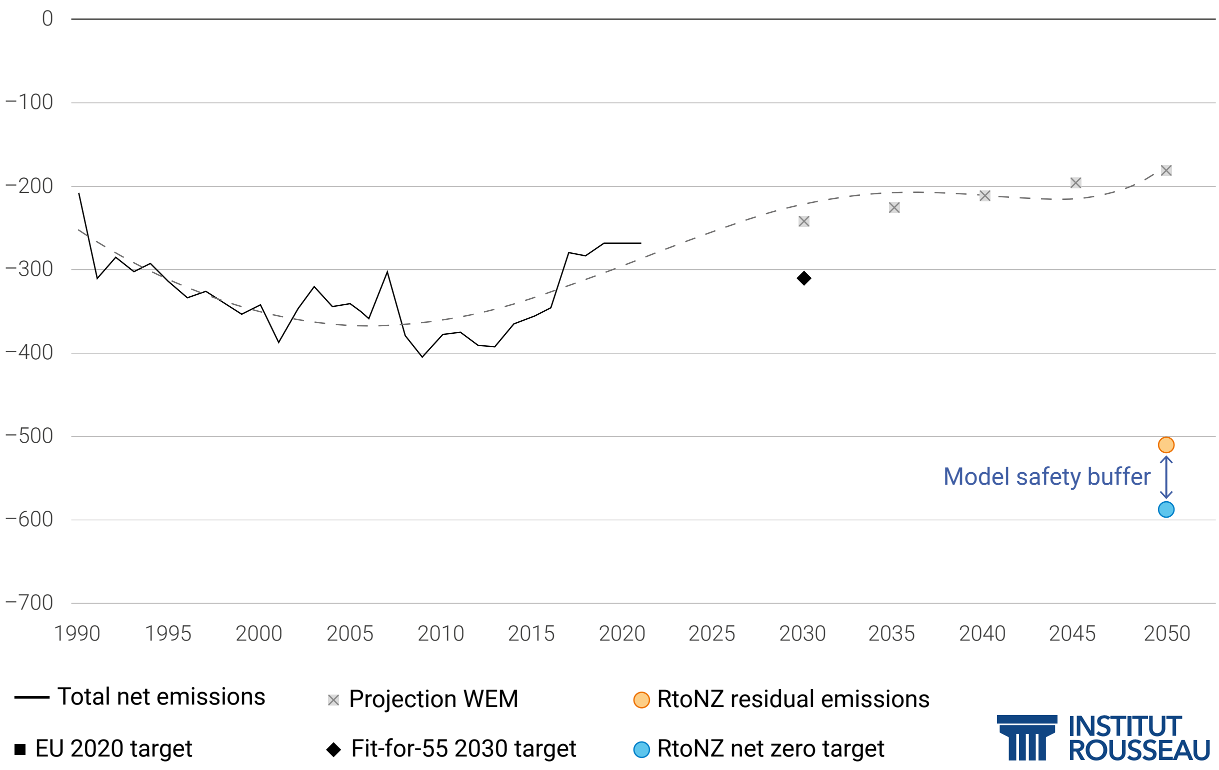
*Sweden's BaU costs do not include most recent investments. Extra cost are therefore overestimated here.

1 Emissions of the sector

The current net sink capacity in the EU not only falls short of covering the residual emissions projected for 2050 but is expected to decline.

The EU's current net sink capacity[4], at 230 $MtCO_2$-eq in 2021, represents less than half of the projected 2050 residual emissions of 519 $MtCO_2$-eq from other sectors, as shown on Figure 9.4. With existing measures, this capacity is expected to decline steadily due to climate change[5], posing a considerable risk and requiring immediate action.

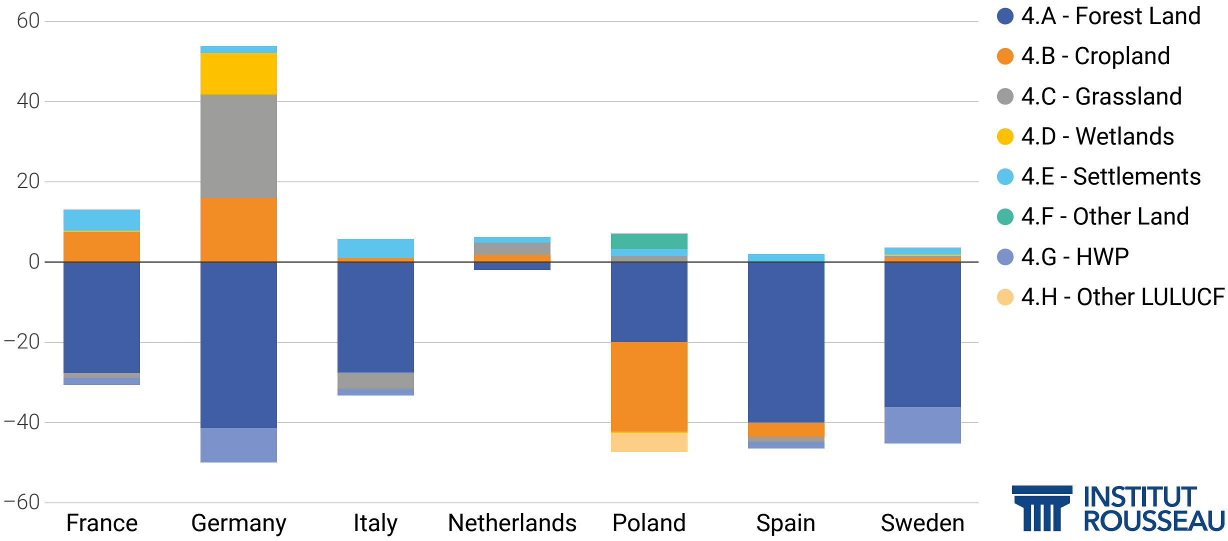
Fig. 9.4 **LULUCF past UE-27 negative emissions and progress towards achieving 2030 and 2050 targets, in million tons of CO_2 equivalent ($MtCO_2e$).[6]**



WEM: With Existing Measures.

Carbon sinks vary greatly from one country to another and must be considered within a European context. Current net-emitting ecosystems must be converted into net sinks.

Fig. 9.5 **Current LULUCF emissions (2021), per country and category (in $MtCO_2$-eq)**



European Environment Agency (EEA) 2021

The 7 core countries exemplify how settlements, wetlands, grasslands, and croplands currently contribute as net emitters (mostly due to methane and nitrogen emissions), especially in Germany. To reverse these trends, forest management is needed to increase the overall sink capacity. However, achieving this requires transforming net emitter categories into negatives.

2 How to increase carbon capture potential and how much investment does it require?

To achieve carbon neutrality by 2050, the proposed EU-27 strategy focuses on four pillars.

1. **Forests**: prioritising sustainable forest management, revitalising ecosystems, expanding forest areas, and boosting the wood industry for resilient and efficient carbon capture.

2. **Agroecology**: transforming grasslands into carbon sinks, implementing agroforestry, and planting hedgerows to enhance carbon sequestration.

3. **Wetlands and Peatlands**: targeting zero net loss of wetlands, preserving pristine peatlands, and restoring degraded peatlands.

4. **Land Artificialisation**: aiming for zero net artificialisation to preserve natural landscapes and biodiversity.

While the strategy emphasises strong sustainability, it does not delve into non-carbon benefits listed in the introduction. Notably, the wood substitution effect integrated within the construction and energy sectors plays a crucial role in decarbonisation, warranting attention across sectors. Additionally, substantial R&D efforts are recommended to deepen understanding of carbon flows, innovations in the logging industry, and species adaptation potential.

Fig. 9.6 **Contribution of each lever to strengthening net negative emissions until 2050 (in $MtCO_2$-eq)**

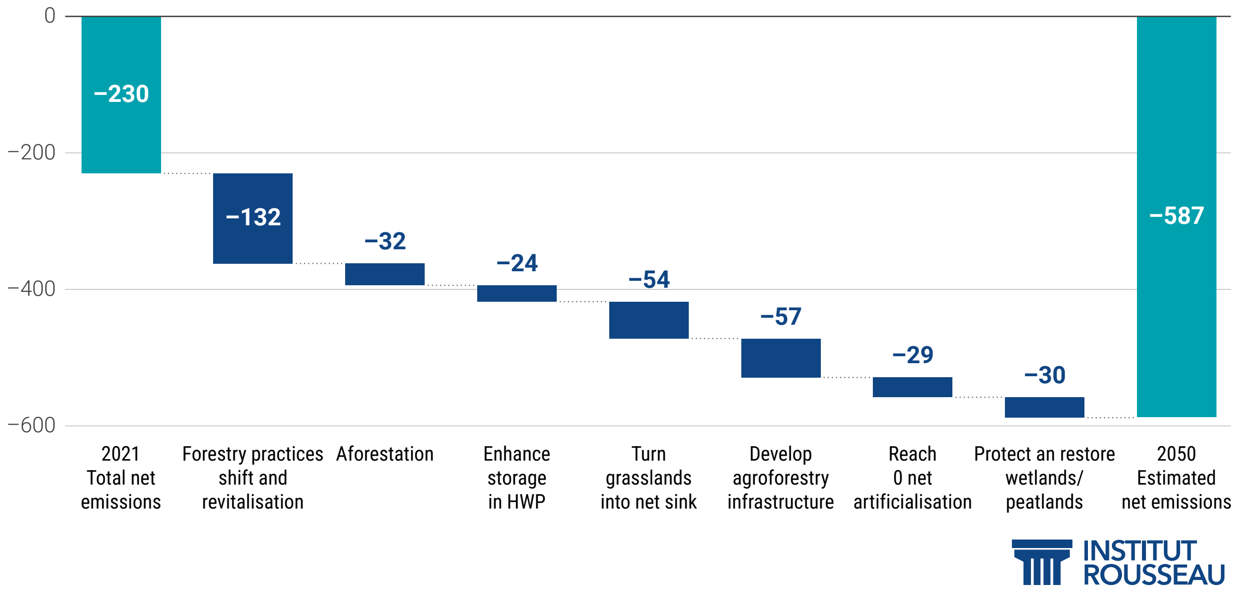


Figure 9.6 illustrates how the carbon sink capacity gap between 2021 and 2050 is bridged to reach net neutrality. Although all levers have a significant role to play, most of the additional sink capacity will be generated from enhanced forest management as well as turning grassland and wetlands from emitters to sinks. The following section breaks down this 4-pillar strategy into a series of public policies that need to be implemented to restore the full sequestration capacity of European ecosystems, and estimates their costs on public finances. The implementation of these public policies will have to consider the specific characteristics of each ecosystem and the socio-political contexts in which they are scaled up.

2.1 Enhance carbon sequestration in forests

Forest ecosystems, central to LULUCF emissions, require meticulous management, achieving a balance between on-site carbon storage and wood exportation for GHG gains through fossil fuel substitution.

Sustainable forestry involves managing ecosystems with a focus on continuous cover[7], climate-resilient species[8], enhanced diversity[9], and optimised practices for carbon sequestration.

Detailed descriptions and designed measures are provided to estimate GHG gains and quantify the required financial effort. These include improving forest management, revitalising degraded ecosystems, optimising the wood industry, and increasing forest area.

2.1.1 Improve forest management

Climate change challenges impose a fundamental shift in forest management, based on local customisation and strategic long-term planning.

In recent decades, European forests have shown positive trends in size, growth, health, and protected areas[10]. However, increasingly frequent droughts, fires, diseases, and invasions call for a fundamental shift in forest management[11, 12]. In 2020, 22-30% of forests adopted Continuous Cover Forestry (CCF) approaches[13], highlighting the gap that needed addressing. Successful CCF implementation requires tailored field practices for each parcel. Long-term, planned forest management is vital to harmonise wood demand and ensure tree species diversity and ecosystem maturity. A one-size-fits-all intervention model cannot capture the reality of local ecosystems and sub-national settings.

The subsequent sections outline on-the-ground measures and investment strategies that must be balanced at subnational scales. They involve training forestry workers, reinforcing tree nurseries, and adjusting harvest logistics.

2.1.1.1 Forestry workers

Targeted training programs must be implemented to increase the number of skilled forestry workers.

It is expected that the workforce will shift from carbon-intensive sectors to sustainable occupations ('green jobs') in the near future. However, several European nations suffer from a shortage of forestry workers per hectare. Thus, it is crucial to implement targeted training programs to increase the number of skilled forestry workers[14], aiming for a more optimal ratio of forest workers per hectare[15].

Quality climate training is essential to tackle Europe's forest challenges. A higher number of skilled forest workers can accelerate forest transitions, curb deforestation, boost biodiversity, enhance soil quality, and improve carbon capture[16, 17]. This not only benefits the environment but also generates jobs, especially in rural areas[18], supporting a just transition away from fossil fuels. Ensuring excellent training is vital for the prosperity of forest ecosystems and for the safety and protection of forest workers in this transformative process.

Measure 9.1

Finance the training of forestry workers

Public cost
€0.71 billion per year
Public extra-cost
€0.50 billion per year

2.1.1.2 Nurseries

As illustrated by the current seedling supply shortage, tree nurseries can be potential bottlenecks for sustainable forestry development.

The nursery strategy must focus on adapting to species-specific demand, scaling up to meet increased demand, and fostering public-private collaboration for a sustained supply.

Measure 9.2

Support the expansion of public and private tree nurseries[19]

Public cost
€0.016 billion per year
Public extra-cost
€0.012 billion per year

2.1.1.3 Access and thinning

As clear-cutting decreases in favour of 'selective' felling, adjustments in harvest logistics are essential.

Improved accessibility is critical, addressing insufficiently granular forest road grids, particularly in countries like Poland, and to a lesser extent, France, Italy, and Spain. Additionally, upgrading the forestry machine fleet to lighter and more agile models is also necessary[20].

Thanks to the new management practices and the recommended investments, forests are expected to increase their annual carbon sequestration potential. The selective logging approach requires additional manpower and resources but increases carbon storage – despite maintaining harvests levels. As displayed on Figure 9.7, two country segments emerge: industrial forestry nations like France and Sweden will drastically enhance their capture potential while other nations with lower productivity will remain at stable levels.

Measure 9.3

Enhance and adapt forest track networks to new operation models for improved forest access

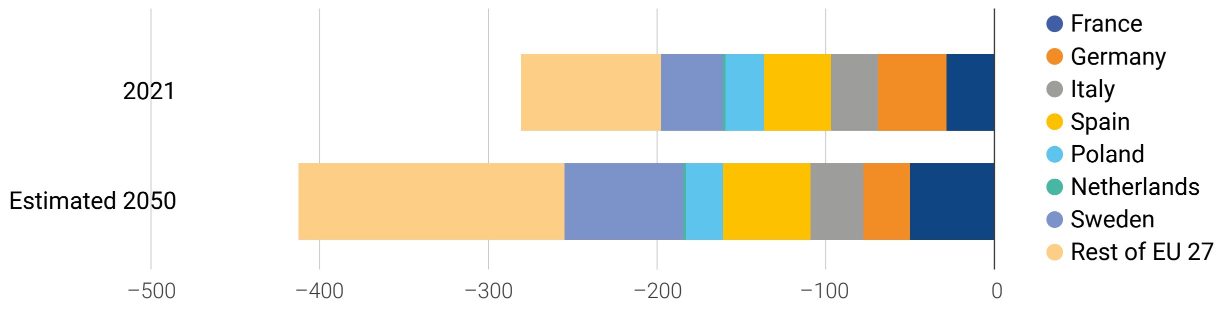
Public cost
€0.35 billion per year
Public extra-cost
€0.25 billion per year

Measure 9.4

Subsidise the renewal of machine fleets for selective logging, offering up to 50% support. This subsidy is targeted at countries with a low ratio of wood output to forestry workers

Public cost
€0.020 billion per year
Public extra-cost
€0.014 billion per year

Fig. 9.7 **Forestland emissions in 2021 and in 2050 as per the RtoNZ scenario (in $MtCO_2$-eq)**



European Environment Agency (EEA) 2021 & Study results

In order to develop this potential, the first step is to restore European forests to their best condition. Hence, restoring degraded ecosystems is the key prerequisite.

2.1.2 Revitalise degraded ecosystems

Degraded forest ecosystems must be restored. Clear-cutting must be strongly regulated.

Revitalising ecosystems is crucial due to declining storage potential, driven in part by higher rates of tree mortality. Forest restoration holds significant carbon capture potential[21], emphasising the need for regulated clear-cutting and deforestation prevention to improve existing ecosystems. This revitalisation will enhance resilience to climate change, improve health, and ensure long-term carbon capture impact[22]. Recommended subsidies to regenerate ecosystems focus on tree growing, as opposed to tree planting: sapling protection, soil management, prioritising native species when possible, etc.

Measure 9.5

Subsidise public forest revitalisation and implement a tax-subsidies mechanism to encourage private ecosystem restoration

Public cost
€4.87 billion per year
Public extra-cost
€4.12 billion per year

2.1.3 Support wood industry adaptation

The wood industry must adapt to a changing climate while addressing rising demand.

Challenges facing the wood industry include the need to manage climate-related risks to forest stocks, implement resilient practices, boost production capacity, and optimise on-site waste recycling. Policy proposals focus on three key areas: fostering R&D (cf. Cross-Sector Investments, Measure 10.2.), investing in the logging industry, and adapting the industry to climate-resilient practices.

R&D plays a pivotal role in developing and implementing innovative technologies and practices for a more sustainable logging industry. Investment in R&D can explore and promote new methods for efficient timber production, creating long-lasting wood products[23], reducing waste, using biomass locally, improving forest management, and optimising supply chains.

Increasing private investments in logging is crucial to responsibly meet the growing demand for wood products, support a circular economy, and use waste efficiently.

Strategic private investments should be adapted to the local context and should focus on managing rising tree mortality, enhancing local log storage and processing capacity, using waste efficiently[24], and reducing the consumption of energy wood and the reliance on exports[25].

Subsidising the logging industry is also crucial to promote sustainable practices, incorporating modern monitoring processes for enhanced transparency and quality sawmills. This measure aims to integrate technologies like remote sensing to improve forestry practices and align with climate and biodiversity policies.

Measure 9.6

Foster private investment through state guaranteed loans to face increasing demand[26] and subsidise the adaptation of the logging industry to sustainable practices

Public cost
€1.29 billion per year
Public extra-cost
€0.56 billion per year

2.1.4 Increase the forest area

Despite a recent slowing down, forestland continues to expand in most EU countries, with potential for further growth in some regions.

Young forests, in particular, exhibit higher annual carbon sequestration capacity[27], justifying an expansion target of 3.3%[28] across 27 countries. The emphasis must be on expanding existing plots to enhance canopy continuity rather than initiating new afforestation projects.

Existing financial support schemes are not suited for long term practices implementation. Much like in Ireland[29], Germany or Switzerland, payments over 10-15 years are recommended to compensate for practices based on objectives rather than on operations.

Measure 9.7

Include sustainably managed forest expansion initiatives and CCF practices within existing environmental labels (like PEFC, FSC, EU EcoLabel, Nordic Ecolabel, Sustainable Forestry Initiative, Blue Angel...)

Private cost
€0.39 billion per year

2.2 Leverage the agro-ecology potential

2.2.1 Turn grasslands back to net sinks

Recent studies reveal that grasslands, akin to cultivated areas, are transitioning into CO_2-emitting zones due to intensive management practices[30]. However, adopting alternative management approaches, especially those aligned with agroecology, can reverse this trend, turning grasslands into carbon sinks once again (cf. Agriculture section). According to the TYFA Model, the estimated carbon sequestration potential for grasslands is 0.5 tCO_2-eq/ha/year[31].

2.2.2 Plant hedgerows and field trees

Within the agroecology system described in the Agriculture section, cultivating hedgerows (12% of total UAA) and planting trees in agricultural parcels (8% of total UAA) enhances carbon sequestration potential and offers additional benefits: increased biodiversity, reduced soil erosion, enhanced land productivity, and less need for fertiliser.

A public subsidy covering 25% of the planting costs is proposed to support agroecology infrastructure development (i.e.planting trees and hedgerows).

Measure 9.8

Support the plantation of Hedgerows & Trees in Open Fields

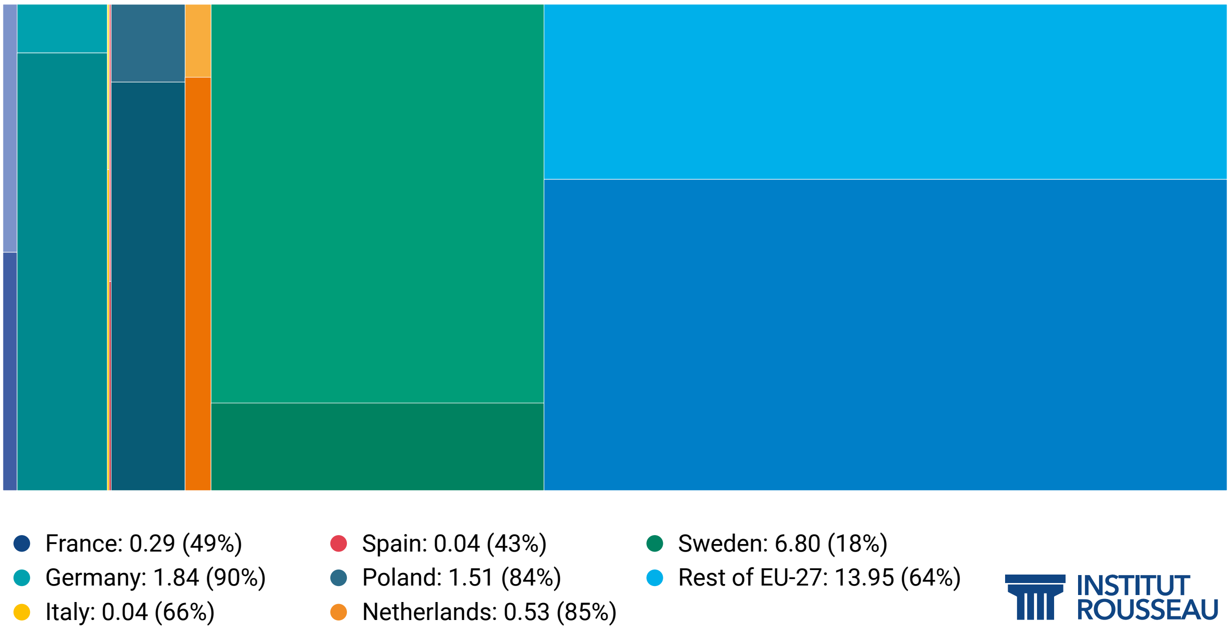
Public cost
€0.13 billion per year
Public extra-cost
€0.13 billion per year

2.3 Protect and restore wetlands and peatlands

Wetland ecosystems, though ecologically crucial, currently emit greenhouse gases due to human-induced degradation.

Wetland ecosystems, especially peatlands, provide benefits such as biodiversity preservation, water regulation, flood/drought prevention, and carbon storage. They store twice as much carbon as all the world's standing forests[32] but face severe degradation, emitting an average of 26 tCO_2-eq/ha per year[33, 34]. Currently, 50% of EU peatlands are drained, primarily for agriculture and peat extraction[35]. Greenhouse gases emissions from drained peatlands amounts to 220 million tCO_2-eq per year[36].

Fig. 9.8 **Wetland areas (in Mha, 2022) and % of degraded wetlands to be restored, per country[36]**



Greifswald Moor Center, 2023

National wetland offices would develop multi-year strategies, execution plans, stakeholder oversight, and funding allocation. Aligning with the EU Biodiversity Strategy, which targets the protection of 30% of EU land and sea by 2030 with one third under strict protection[38], a 10% increase of this target in absolute terms for peatlands is suggested. Each state should acquire the corresponding peatlands area and convert it into reserves, such as National Parks or Natura 2000 areas, to strictly protect unused peatlands. Rewetting operations might also be necessary if less than 10% of undrained peatlands are available for acquisition.

Measure 9.9

Acquire 10% of peatlands for strict protection (National parks, Natura 2000, etc.)

Public cost
€0.76 billion per year
Public extra-cost
€0.76 billion per year

Given agriculture's role in peatland deterioration, promoting peat-friendly practices, such as paludiculture, is crucial.

Paludiculture, wet agriculture alternatives, protects the carbon stored in the peat. To encourage paludiculture development, up to 34%[39] of the investment needed for a typical project will be subsidised. This measure would provide farmers with compensation and carbon credits[40], contributing to sustainable practices.

Measure 9.10

Subsidise paludiculture projects at a level of €2,500 per hectare

Public cost
€0.23 billion per year
Public extra-cost
€0.23 billion per year

Peatland restoration involves rewetting projects[41], vegetation management (planting and maintaining peatland species), soil conservation (building peat dams to retain water and prevent erosion), and water management (managing the water table level closely to the peatland surface to enable peat growth while avoiding methane emissions).

Peatland restoration projects will gain economic value in carbon credit markets, as these develop and increase in price. The main benefit of these projects is avoided emissions with avoidance rates amounting to between 10 to 18 tCO_2-eq/ha per year[42]. The accumulation of organic material over time also leads to a net sequestration of CO_2 at a Long Term Carbon Accumulation Rate 0.66 tCO_2-eq/ha per year[43]. **To incentivise private stakeholders, a State subsidy of up to one third of the average cost per hectare for peatland restoration projects[44] is recommended, without limitations on the total area.**

Measure 9.11

Subsidise peatland restoration projects at a level of €400 per hectare + 10% of carbon credits (if applicable)

Public cost
€0.20 billion per year
Public extra-cost
€0.11 billion per year

In addition to addressing GHG emissions, public authorities must take decisive action to safeguard ecosystems from various ecological disturbances and threats.

As discussed, wetlands (including peatlands) are highly vulnerable and present a potent warming potential. Despite the modest surface coverage of wetlands and peatlands, significant investments are required to avoid emissions. Authorities must also combat general ecosystem disruptions and threats, encompassing activities like removing invasive species, cleaning and depolluting rivers and swamps, recreating retention space for water capture through reactivating natural river floodplains and planting reedbeds, thus rising the overall landscape water level. These measures haven't been quantified in terms of investment, as their focus extends beyond carbon storage.

2.4 Reach Net Zero Artificialisation

Soil plays a crucial role in environmental health and carbon storage[45]. However, over 70 000 Ha (about the Berlin Metropolitan area – 90 000 Ha) of natural soil is lost annually in the EU due to artificialisation[46], posing a threat to arable land and natural areas. Achieving no net artificialisation faces challenges tied to conflicting interests in environmental preservation, car-centric spatial planning, and economic considerations. Comprehensive policies are needed, covering housing, transport, and agriculture.

Quantifying the carbon removal potential of a reduction in artificialisation is challenging, limiting studies to qualitative assessments. The **required investments are estimated in the range of dozens of billions**[47, 48]. The true cost of compensation should prevent most projects and prioritise renovation over new construction projects.

Key measures include increasing the occupation rate of existing buildings, supporting renovation of vacant dwellings (to limit construction without negative impacts on housing prices), **prioritising land recycling** (especially in brownfield areas), **implementing compensation mechanisms, and, when necessary, densifying urban areas and remixing activities** (residential, commercial, professional) **at the neighbourhood level**. Transport projects, including new parking spaces and roads, require rigorous evaluation. Crucially, EU directives overseeing artificialisation should shift from non-binding to binding regulations with specific milestones and penalties for enforcement.

Notes

1. EEA, 2020, Climate and energy in the EU.

2. FAO, 2022, Healthy soils for healthy people and planet.

3. This margin can be considered as a buffer cushion to anticipate deleterious events or late adoption of recommended measures. Taking a conservative approach is of first importance here: given the threat on ecosystems, permanence of sequestration is at risk.

4. EEA, 18 April 2023, EEA greenhouse gases, European Environment Agency (data viewer tool).

5. BaU emissions' projections for 2050, even from the AR5 conservative RCP2.6 IPCC scenario, could decrease to -100 $MtCO_2$-eq per year. Pilli, R., Alkama, R., Cescatti, A., Kurz, W. A., & Grassi, G., 2022, The European forest Carbon budget under future climate conditions and current management practices.

6. Past data is sourced from the EEA Dataviewer. The EU 2030 target was published in the Official Journal of the EU in 2023. The 2050 target aligns with residual emissions in the RtoNZ transition scenario. WEM (With Existing Measures) projections, based on Pilli & al., 2022, 'The European forest carbon budget under future climate conditions and current management practices' estimate future emissions considering measures already implemented by the EU and its Member States.

7. Ecosystem services and health as well as carbon capture capacity reach highest levels with continuous canopy cover. Clear-cut practices are phased out except for rare cases. IPCC AR6 WGII - Page 769.

8. Global warming drives climate shift faster than species can adapt or migrate. About 94% of the European forested area is expected to experience species range shifts. Anticipating local climate evolutions to best assist future ecosystems is a major challenge to tackle. Han, Q., Keeffe, G., & Cullen, S. (2021). Climate connectivity of European forests for species range shifts. Forests, 12(7), 940.

9. Altering the tree species composition of European forests can enhance their resilience and reduce the overall vulnerability. IPCC AR6 WGII Page 1861. Billing, M., Thonicke, K., Sakschewski, B., von Bloh, W., & Walz, A. (2022). Future tree survival in European forests depends on understorey tree diversity. Scientific Reports, 12(1), 20750.

10. Bussotti, F., & Pollastrini, M. (2017). Traditional and novel indicators of climate change impacts on European forest trees. Forests, 8(4), 137.

11. Forzieri, G., Dakos, V., McDowell, N. G., Ramdane, A., & Cescatti, A. (2022). Emerging signals of declining forest resilience under climate change. Nature, 608(7923), 534–539.

12. IPCC AR6 WGII FR - Page 600 & IPCC SR CCL SPM - Page 17.

13. Mason, W. L., Diaci, J., Carvalho, J., & Valkonen, S. (2022). Continuous cover forestry in Europe: usage and the knowledge gaps and challenges to wider adoption. Forestry (London, England), 95(1), 1–12.

14. From about 500 000 workers in 2020 to about 900 000 workers in 2030.

15. This ratio (5.85 workers/1000 Ha) is determined as the average of European countries with a temperate forest (biotope with the most workers per hectare in Europe).

16. Cf Rudel, T. K., Meyfroidt, P., Chazdon, R., Bongers, F., Sloan, S., Grau, H. R., … Schneider, L. (2020). Whither the forest transition? Climate change, policy responses, and redistributed forests in the twenty-first century. Ambio, 49(1), 74–84.

17. Meyfroidt, P., & Lambin, E. F. (2011). Global forest transition: Prospects for an end to deforestation. Annual Review of Environment and Resources, 36(1), 343–371.

18. Cf Leveraging forests for a just transition | by Carbon180.

19. 0.15 €/ha/year across EU-27: Average from UK, US and France existing schemes.

20. Heavy machinery, while operating, releases long-sequestered CO_2-eq from the soil due to soil ploughing. Upgrading to more agile machines enhances selectivity in tree felling, addressing the inadequacy of the current fleet. Increased budgets for machinery in several countries aim to boost worker efficiency.

21. Mo, L., Zohner, C. M., Reich, P. B., Liang, J., de Miguel, S., Nabuurs, G.-J., ... Crowther, T. W. (2023). Integrated global assessment of the natural forest carbon potential. Nature.

22. Numerous indicators can be used to assess the vitality of trees and forests, one of them is crown defoliation. Indeed, studies showed that crown defoliation is directly related to a bad health state for the forest. Crown defoliation is classified in 5 categories, from 0 to 4 (0 is no defoliation and 4 is dead). It was decided to consider the forests classified in the stages 2 to 4 (moderate defoliation to dead) as degraded forests. In addition, forests damaged by fire, insects, and diseases are considered degraded forests too. Given the high vulnerability and degree of uncertainty linked to climate disruption, a wide range of degradation levels was considered as degraded.

23. Hurmekoski, E., Seppälä, J., Kilpeläinen, A., & Kunttu, J. (2022). Contribution of wood-based products to Climate Change mitigation. In Forest Bioeconomy and Climate Change (pp. 129–149).

24. Timber residues and by-products from sustainable logging operations can be utilised for various purposes, including bioenergy production, biofuels, and bio-based materials contributing to renewable energy generation. Nonetheless, it is important to encourage the use of solid wood for materials and small parts and waste for energy instead of fuel oil. This involves public support for the sawmill and panel industries and limiting public funding to relevant uses of wood energy.

25. Such as precision felling, improved extraction methods, and optimised transport systems. Outdated machinery and practices can be inefficient and environmentally damaging.

26. Enabling to double current investment (2022) in machinery for forest logging (eurostat data). The cost of the measure chosen is conservative: 10% of total loans (Cost of warranty + recovery of defects).

27. Final 'emissions factor' for new forests computed for each country (combines deciduous and coniferous as well as forest types + a buffer coefficient of 0.66): between 5.00 and 7.40 tCO_2-eq/ha/year. (vs existing forest assumptions: between 2,30 and 3,25 tCO_2-eq/ha/year).

28. Objective of 3% for all countries except Poland and Netherlands with 10% (potent afforestation potential).

29. Forestry Standards Manual (Woodland Improvement Scheme: Continuous Cover Forestry). Department of Agriculture, Food and the Marine, p. 28.

30. Beillouin, D., Corbeels, M., Demenois, J. *et al*. A global meta-analysis of soil organic carbon in the Anthropocene. Nat Commun 14, 3700 (2023).

31. Agroecology and carbon neutrality in Europe by 2050: what are the issues? Findings from the TYFA modelling exercise.

32. UNEP, 2022, Global Peatlands Assessment – The State of the World's Peatlands: Evidence for action toward the conservation, restoration, and sustainable management of peatlands. Main Report. Global Peatlands Initiative. United Nations Environment Programme, Nairobi.

33. Tanneberger, F., *et al*. (2021) Towards net zero CO_2 in 2050: An emission reduction pathway for organic soils in Germany, Mires and Peat ,Vol 27, Article 05, 17 pp.

34. Testimonials, examples of actions to be implemented for decision-makers. 2021 - Rhône Méditerranée Corse Water Agency - France.

35. Greifswald Mire Centre, Global Peatland Database 2022.

36. Greifswald Mire Centre, National University of Ireland, Galway, Wetlands International (2021), Peatlands in the EU – Common Agriculture Policy (CAP) after 2020.

37. Global Peatland Database, Greifswald Mire Center (2023).

38. European Commission, 28 January 2022, Biodiversity: Commission guidance on new protected areas to help put Europe's nature on path to recovery by 2030.

39. de Jong, M., van Hal, O., Pijlman, J., van Eekeren, N., & Junginger, M. (2021). Paludiculture as paludifuture on Dutch peatlands: An environmental and economic analysis of Typha cultivation and insulation production. The Science of the Total Environment, 792(148161), 148161.

40. The EU will create a scheme that allocates 10% of the carbon credits (if applicable) to the farmers converting to paludiculture.

41. Blocking channels and ditches to make the water table rise and restore the ecological function of peatlands.

42. Greifswald Mire Centre, Peatlands in the EU – Common Agriculture Policy (CAP) after 2020; Förster, J. (2010), Peatlands restoration in Germany – a potential win-win-win solution for climate protection, biodiversity conservation and land use.

43. Conservative value: Long Term Rate instead of Recent Rate and lower end of the ranges from Beaulne, J., Garneau, M., Magnan, G., & Boucher, É. (2021). Peat deposits store more carbon than trees in forested peatlands of the boreal biome. Scientific Reports, 11(1), 2657.

44. Rebekka R.E. Artz, Michela Faccioli, Michaela Roberts, and Russell Anderson (2018). Peatland restoration – a comparative analysis of the costs and merits of different restoration methods. ClimateXChange.

45. Terrer, C., *et al*. (2021). A trade-off between plant and soil carbon storage under elevated CO_2. Nature, 591(7851), 599–603.

46. Artificialisation is defined as the lasting alteration of a soil's ecological functions, including biological, hydric, climatic, and agronomic aspects, through occupation or use, encompassing sealing, mineralisation, or compaction.

47. Assemblée Nationale, 27 January 2021, Rapport d'information n°3811 - 15e législature - Assemblée nationale.

48. France Stratégie, 2019, Objectif « zéro artificialisation nette » : quels leviers pour protéger les sols ?.

Cross-sector investments

Train, Educate, Innovate

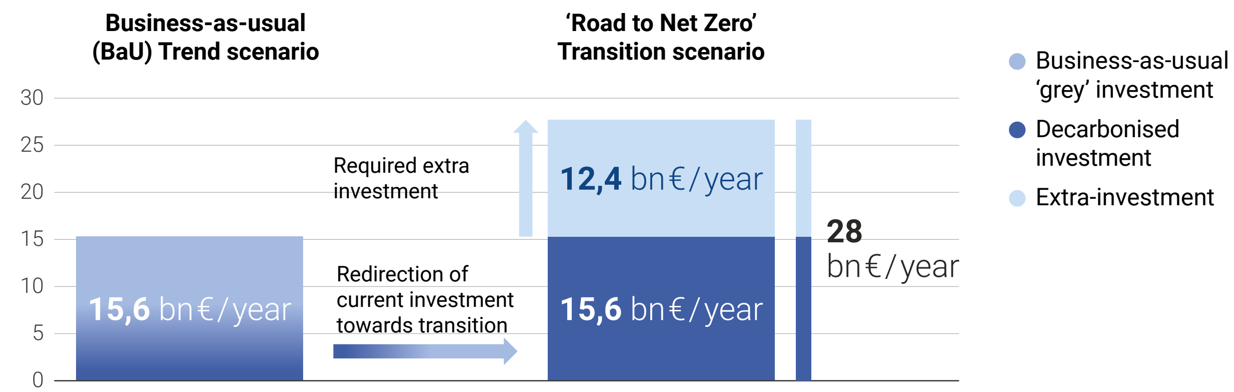
Complementary cross-sector measures

Decarbonisation levers to mobilise:

1. Enhance Research & Development in transition solutions
2. Foster public awareness of environmental issues
3. Boost the Fair Transition Fund to support professional transition

Global investment needs

UE-27 global investment and extra-investment



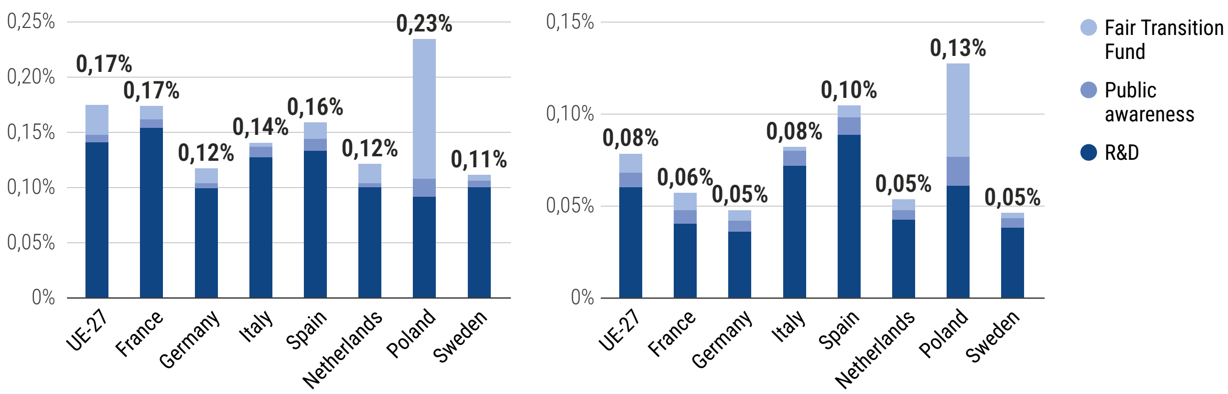
Global investment and extra-investment per lever, per country (in % of GDP):

Total investment

0,17%

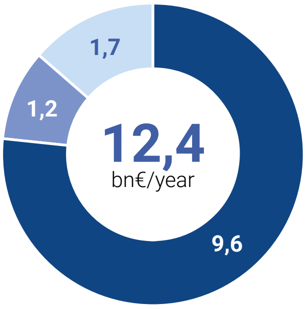
Total extra-investment

0,08%



Public investment needs

Total public investment in proposed public policies	Public share in total investment	Public extra-investment in % GDP
28 bn€/year	100%	0,1%



Total extra public investment in proposed public policies: 12,4 bn€/year

- Enhance Research & Development in transition solutions
- Foster public awareness of environmental issues
- Boost the Fair Transition Fund to support professional transition

Complementary measures:

+ Expand government workforce to monitor the transition
+ Adapt the content of initial and ongoing training to deeply integrate ecological issues
+ Train independent workers in transition sectors (e.g., agriculture, renovation)
+ Regulate and prioritise digital uses, promote low-emission digital technology

Sector's weight in necessary investments (in % of all sectors)

TOTAL INVESTMENT (Public + Private)		PUBLIC INVESTMENT	
TOTAL	EXTRA	TOTAL	EXTRA
1,8%	3,5%	5,4%	4,9%

Key takeaways

- **The decarbonisation of all previous sectors requires an increase and reorientation of current R&D spending to meet EU commitments. Public support should focus on transition-related topics.**
- **Transition policies will result in a net job increase of hundreds of thousands of positions in the EU-27. Significant support is required to assist workers in developing the necessary skills.**
- **Public intervention is crucial to ensure the effectiveness and equity of the labour market's shift toward a carbon-neutral economy. In particular, the Fair Transition Fund budget must increase to retrain workers affected by the transition.**
- **European citizens do not feel sufficiently informed about the low-carbon transition, which public policies should tackle with media campaigns and widespread workshops for the population.**

Some key cross-cutting measures are necessary to enhance the impact of various sector-specific levers, including:

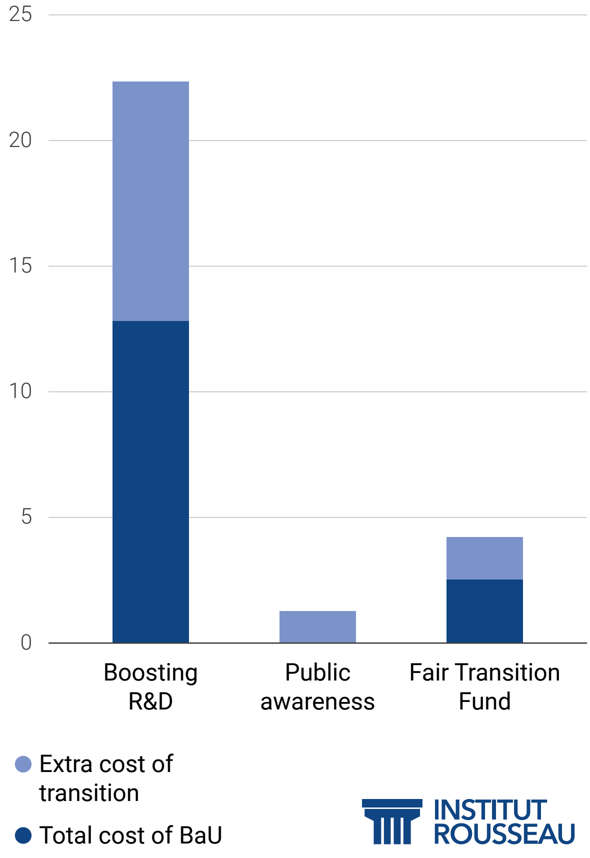
- **Enhancing Research and Development (R&D)** across energy and ecological transition domains to boost efficiency, sustainability, and cost-effectiveness of supported alternatives.

- **Conducting practical awareness campaigns targeting all citizens** to inform them about available solutions to environmental issues.

- **Providing training for professionals in new practices and technologies** and retraining employees in sectors facing significant decline before retirement.

- **Complementing and training the workforce dedicated to overseeing proper fund use**, mitigating fraud, and combatting widespread greenwashing strategies.

Fig. 10.1 Annual public investment and extra-investment required per cross-sector measure (in €billion per year)



The **main interactions with other sectors** are:

- R&D Boost: critical for addressing energy storage challenges (cf. Energy and Transport sections), promoting widespread adoption of agroecology systems (cf. Agriculture section) and promoting innovation in the wood industry (cf. Carbon sinks section). Sharing research outcomes with professionals and their advisors is crucial.

- Supporting reconversion training will concern the Buildings and Agriculture sectors in particular, as deep renovations and agroecological systems require much more labour and a highly-skilled workforce. These two sectors will also represent a significant part of the additional public personnel needed to manage and control practices and investments.

- Citizen awareness/training actions will also concern all sectors, with a focus on the investments that concern them more directly (e.g. efficient housing renovation, adoption of light electric vehicles, etc.).

1 Enhance Research & Development in transition solutions

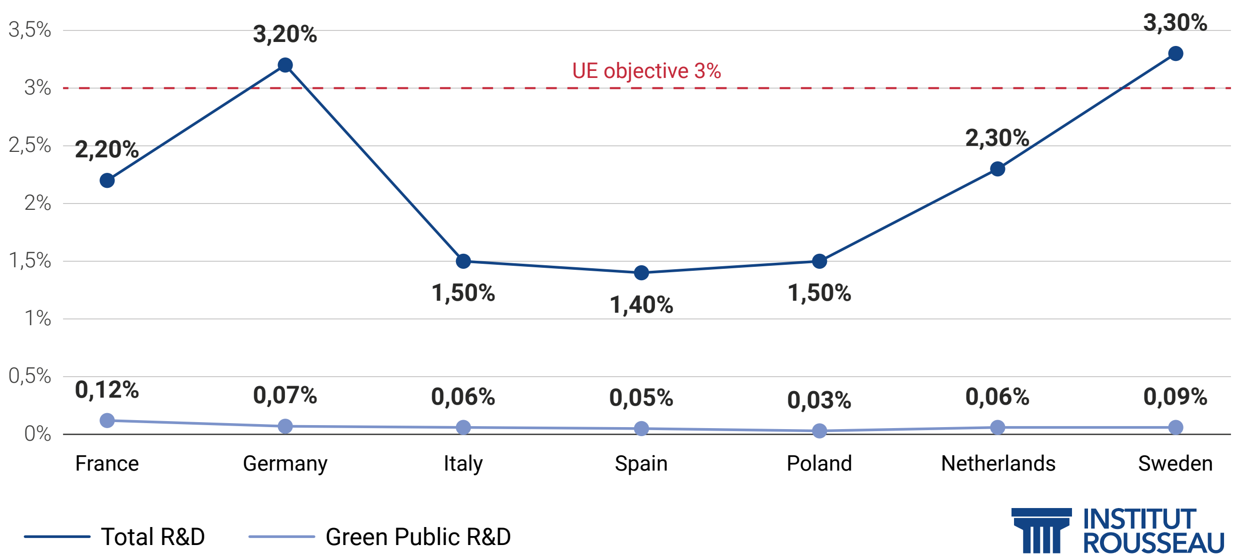
Transition-related public R&D efforts must at least align to EU commitments.

To achieve 2050 carbon neutrality, enhancing fundamental and applied knowledge is crucial for more efficient, sustainable, and cost-effective ecological alternatives in various sectors. R&D should intensify, specifically in low-carbon energies, cross-sector energy efficiency, electricity storage, agroecological systems, and carbon sinks.

Quantifying the direct link between R&D spending and knowledge improvement is challenging both on a global and national scale, making a fully objective 'research' transition scenario unlikely. R&D efforts should at least align with key EU commitments, which include:

- IEA Innovation Mission: doubling public spending on 'clean energy' research[1], since spending stagnated between 2015 and 2019-2021 relative to GDP.
- EU Organic Action Plan[2]: pledging 30% of EU agricultural R&D funds to organic agricultural practices, aiming to support the 25% organic objective and address the purported 'lack of alternatives' to intensive agriculture's reliance on fossil fertilisers and chemicals.
- General EU R&D Objective: reaching 3% of GDP dedicated to R&D[3], compared to the current cap of around 2.3% of GDP in public and private R&D spending by 2021. A goal that remains unfulfilled in numerous countries, as illustrated in Figure 10.2.

Fig. 10.2 **Total national R&D budgets compared to the EU objective, and % of public R&D dedicated to energy efficiency and agriculture (both in % of 2021 GDP)[4]**



Doubling current spending on clean energy R&D solutions.

Business-as-Usual (BaU) from the UE States for low-carbon energy, energy efficiency (in different sectors) **and electricity storage is around €6 billion in 2019-2021**, or 0.04% of 2021 EU GDP[5]. As R&D spending has increased significantly in 2021 or 2022 due to recovery plans (particularly in France and Spain), a 2019-2021 average was used to limit the biases linked to multi-year commitments. **These public expenditures vary greatly**: they range from 0.02% of GDP (Poland and Spain) to 0.07% (France and Finland), including 0.03 to 0.04% for many EU countries (including Italy, the Netherlands and Germany).

In addition to these national public expenditures, around **€2 billion per year of EU funding has been allocated in 2019-2021**, including the EU 'Horizon' amounts for energy and mobility[6], which should increase from around €1 to €2 billion per year by 2027. This is supplemented by €1 billion per year for Nuclear, through Euratom and ITER programs. These public expenditures include subsidies of private and public/private research programs, except tax support for private R&D (see below).

To boost R&D on clean energy solutions and align with key EU commitments, R&D spending should double compared to current spending. This investment corresponds to approximately 0.1% of GDP, equating to €16 billion annually (in € 2021) for public expenditures. As the public business-as-usual expenditure stands at approximately €8 billion per year (in 2019-2021), the average extra public cost between 2024 and 2050 should reach €8 billion annually.

Measure 10.1

Boost R&D on clean energy and efficiency

Public cost
€16 billion per year
Public extra-cost
€8 billion per year

Reorient and increase current spending toward agroecology and agroforestry R&D.

Current annual public expenditure on agricultural R&D stands at approximately €5 billion[7], encompassing marginal investments in forests and agro-ecological system R&D[8]. As also stated in the Agriculture section of this report, it is imperative to gradually redirect public support for agricultural R&D towards agro-ecological systems and carbon sinks. This includes deepening our understanding of carbon flows and species adaptation potential and developing new logging techniques. To achieve this, an additional €1.5 billion per year (in € 2022) is proposed, contributing to the overall targeted increase of R&D expenditure to 3% of GDP and thus to a +30% rise from the EU average of 2.3% in 2021.

Considering that the current public expenditures for agriculture and forest R&D amount to €5 billion per year, the anticipated extra public cost between 2022 and 2050 is set to reach €1.5 billion annually. The reorientation of business-as-usual R&D towards agroecological systems is also expected to increase public R&D on agroecology and carbon sinks by more than €6 billion per year.

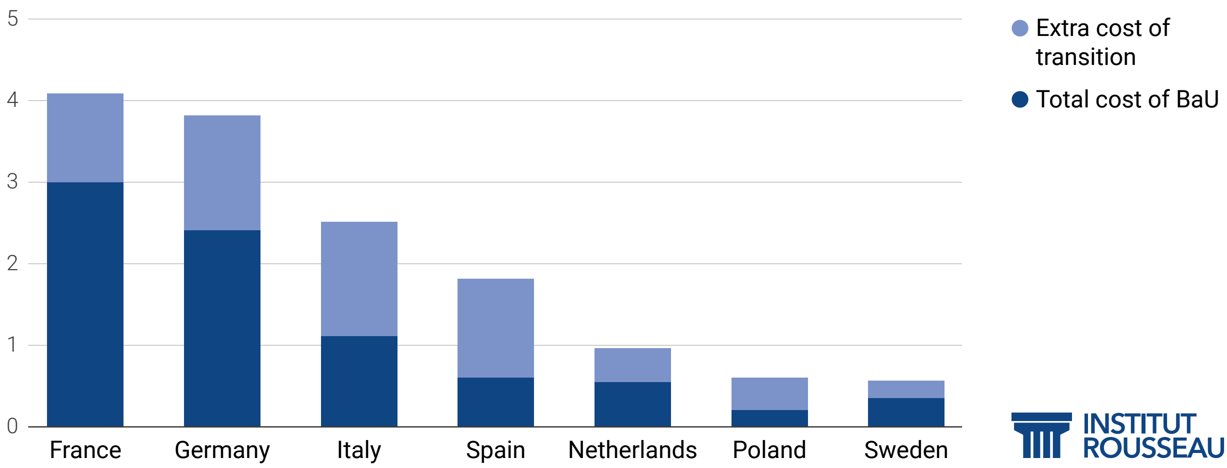
Measure 10.2

Boost R&D on agro-ecology systems and carbon sinks

Public cost
€6.5 billion per year
Public extra-cost
€1.5 billion per year

France's relatively low additional cost is due to the current significant public support of energy R&D, predominantly in the nuclear sector. This stands in contrast to Spain and Italy, where the business-as-usual support of energy and agriculture is more limited. Germany and the Netherlands align more closely with the EU average in terms of energy and agriculture R&D. The cost estimates for each country do not incorporate their share of EU public support (predominantly through programs like Horizon):

Fig. 10.3 **Annual public investment and extra-investment required in transition-related R&D, per country (in €billion per year)**



Public support for private R&D should be contingent upon alignment with transition-related topics.

The IEA omits consideration of public tax incentives for private R&D, which is mainly relevant for France[9] (0.3% of GDP, yet without specifying the portion allocated to clean energy and efficiency), while the EU average for these incentives is below 0.1%[10]. Public support for private R&D should be conditional on a commitment by companies to devote it to clean energy and energy efficiency programmes. Currently, findings from the Clean Energy Transitions Program studies underline that private energy R&D spending heavily favours fossil fuels at 80%[11], while, according to the IEA, the portion of public energy R&D spending allocated to fossils is below 5%.

Box 10.1

Reducing the GHG emissions of the digital sector

The digital sector's GHG emissions, growing at 6% annually, already constitute 3.5% of global emissions, a figure set to double by 2025, which directly opposes ecological transition and carbon neutrality goals. Data centres and IT infrastructure, notably developing AI models like Chat-GPT, have a significant carbon footprint, mostly due to the intensive consumption of energy from non-renewable sources. Manufacturing, responsible for approximately 80% of a smartphone's carbon footprint, involves stages with notable environmental impacts, including raw material extraction, production, and disposal[11].

Measures such as data centre optimisation or enhanced terminal recycling can curb new device production. Public awareness is crucial, especially regarding the frequent market turnover. Among few studies on IT's climate impact mitigation, the Shift Project proposes general strategies: building new digital governance, innovative economic models and digital management tools[12]. Present public funding for the sector is minimal, as there are no specific budgets for green IT in both European Commission initiatives and EU countries.

2 Foster public awareness of environmental challenges and solutions

European citizens do not feel sufficiently informed.

Public awareness campaigns are essential to better understand the ecological transition but are currently perceived as inadequate by the majority of citizens, despite some noticeable efforts (e.g. University of Liege's campaign on the IPCC Report[14]). A 2020 IFOP study in France (15-35 age group) found that only 55% of respondents felt sufficiently informed, with just 10% who considered that they were very well informed[15]. Drawing from successful smoking awareness campaigns, public authorities could endorse general public campaigns. The 'Tobacco Control Scale 2021 in Europe,' which recommended allocating €2 per person per year, can be used to help calculate the cost of similar environmental campaigns[16]. Also, one-day workshops led by non-profit organisations could provide basic climate information and address behavioural changes directly, to further counteract climate-sceptic notions.

The total cost of this measure amounts €33.1 billion until 2050 or €1.2 billion per year, considered as public extra-cost.

Measure 10.3

Media campaigns and citizen engagement workshops

Public cost
€1.2 billion per year
Public extra-cost
€1.2 billion per year

3 Boost the Fair Transition Fund to support professional transitions

Retrain workers in carbon-intensive sectors to match the staffing needs of newly-created jobs.

The climate change transition will cause profound changes in the workforce, with an increase in jobs in some sectors, such as building renovation and agriculture, and a loss of jobs in others, such as the oil and gas sector. Some recent studies suggested that 187 million jobs would be lost by 2050, but that 202 million new jobs would be created[17]. In France, the Shift Project estimates that 800,000 jobs will be created, while 1.1 million will be lost[18]. The people who will lose their jobs will have to be trained to find a new orientation in a different sector.

Addressing the primary challenge of financing professional reorientation requires public intervention. Based on McKinsey assumptions extrapolated to the EU population, an estimated 11 millions jobs will be lost, yet compensated by job creation resulting in a net gain of 900,000 new jobs. Considering the retirement rate and average retraining costs of €16k[19] per individual and averaging results from extrapolating the Shift Project and McKinsey, the projected total training-related costs should reach €112.3 billion by 2050, or a €4.2 billion yearly investment. The Just Transition Fund, already operational in the EU, commits €17.5 billion for the period 2021-2027[20], with Poland (20%), Germany (13%), and Romania (11%) emerging as the primary beneficiaries. Consequently, the total additional costs amount is equivalent to €1.7 billion annually.

Measure 10.4

Increase the Fair Transition Fund budget by 70% to retrain workers impacted by the transition

Public cost
€4.2 billion per year
Public extra-cost
€1.7 billion per year

Workers in transitioning sectors, particularly agriculture and construction, require retraining to acquire new skills. Quantifying these costs is challenging due to limited data on current training expenditures across sectors and countries[21].

New civil servant positions should be opened to implement and oversee transition policies

To ensure effective implementation of newly introduced measures and counteract greenwashing strategies, additional positions should be created in Member States' administrations. However, quantifying this measure proves challenging due to limited access to data on staffing levels and needs, which vary significantly between countries. France has already initiated an increase in staff for the Ministry of Ecological Transition, announcing the recruitment of 700 new civil servants in its 2024 budget, in addition to the existing 40,800. In contrast, some countries, like Sweden, rely on a minimal number of civil servants to define major strategies, outsourcing implementation to private companies, with a total of 2,500 public employees in the Ministry of the Environment and environmental agencies.

In conclusion, public intervention is essential to guarantee the efficiency and fairness of the labour market's shift towards a carbon-neutral economy. The challenges in quantifying training costs and staffing needs across different sectors and countries underscore the complexity of this transition. Yet, proactive measures, like focused retraining programs and increased staffing in relevant governmental bodies, are crucial for steering this shift successfully and building a sustainable workforce for the future.

Notes

1. UE Commission, 2016 European Union joins Mission Innovation.

2. UE Commission, 2021 Organic Action Plan.

3. Horizon UE, 2021, UE Pact for research and innovation.

4. International Energy Agency, 2023, Energy Technology R&D Budgets Data Explorer; Eurostat, 2023, Government support to agricultural research and development; INSEE, 2022, European Research Expenditures.

5. International Energy Agency, 2023, Energy Technology RD&D Budgets Data Explorer.

6. MESRI/Horizon, 2021, Présentation du cluster 5.

7. Eurostat, 2023, Government support to agricultural research and development and Horizon Europe Program, 2023, 'Agriculture, forestry and rural areas'. Eurostat data has been corrected for France, whose national publication indicates €900 million extra per year. OECD/Eurostat and French ministry have been interviewed, they indicate slight differences in the scopes of these data but do not explain theses significant differences between these two data, cf. French Minister for Research and Education.

8. Their respective shares within total agricultural R&D is not disclosed, but IFOAM estimated that agro ecological system R&D is less than 2% with regard to 2014-2020 EU funds.

9. Furthermore, this tax aid has a limited knock-on effect according to evaluations of the research tax credit in France France Stratégie, 2021, Évaluation du Crédit d'impôt recherche - Rapport CNEPI and the more general OECD study OCDE, 2023, Incitations fiscales à la R-D et à l'innovation.

10. OECD, 2023, Tax incentive for R&D and Innovation.

11. IAE, 2020, Energy technology R&D budget, p.12-13. In addition, an unspecified portion of private R&D spending in energy-related sectors does not clearly concern energy, particularly in the automotive sector (e.g. product developments). The location of these global companies R&D investments also remains uncertain, which also explains the difficulty of estimating the total cost of energy R&D in the EU.

12. FDM Group, 2023, The environmental impacts of digitalisation.

13. The Shift Project, 2021, Environmental impacts of Digital Technologies: 5-year trends and 5G governance.

14. La Voix du Nord, 2023, 'Ce soir c'est rapport du GIEC': la surprenante campagne publicitaire lancée à Liège.

15. ACTED, 2020, Projet 1Planet4all : les jeunes et le changement climatique.

16. Smoke Free Partnership, 2021, The Tobacco Control Scale in Europe.

17. McKinsey, 2022, Building the net-zero workforce.

18. The Shift Project, 2021, Plan de transformation de l'économie française : axe emploi (note that this study includes job losses in construction which are mainly linked to demographic change and not to the ecological transition).

19. Based on French average reconversion costs in the building insulation sector (wood or facades + roofs) and agroecology farming training, see for instance Professional Training Association and this vocational diploma in farm management (1000-1200 hours of training excluding practical courses).

20. Toute l'Europe, 2023, Le Fond pour une Transition juste.

21. For instance, the benchmark cost for upgrading skills in energy renovation for construction employees and craftsmen in France is approximately €5k, totaling less than €20 million annually over 27 years for a maximum of 90,000 individuals. The extent to which these costs replace existing expenditures on energy efficiency or other unrelated training remains unclear.

Conclusion

The total extra investment required to reach net zero by 2050 is estimated at an average of €360 billion per year, which represents around 2,3% of the current EU-27 GDP. The magnitude of these investments may appear substantial, yet they stand as an absolute necessity to fulfil the climate targets set by both the European Union and the Paris Agreement. Around 70% of this extra-investment falls within the remit of the public sector, which represents €250 billion per year. This is equivalent to doubling average annual public investment, which is not only necessary, but would also be manageable under adequate budgetary rules. These costs also carry the potential to yield substantial economic and social benefits, augmenting the undeniable environmental gains for climate, biodiversity, and the overall health of our ecosystems.

It is paramount to appreciate time as an increasingly scarce resource. Urgent and decisive actions are imperative if we are to stand a chance at realising our set objectives and preserving habitable conditions on Earth. Delays in these crucial steps only serve to jeopardise the future of our planet, a risk we cannot afford to take. The challenges may be significant, but the consequences of inaction are far greater.

In navigating this complex landscape, it is essential to emphasise that the path forward requires to navigate complex landscapes long considered as obscure. The direction is now clear and financial commitments well understood. What

remains is the crucial need for courage and political will. The obstacle is not a deficit in knowledge or capability, but a lack of collective determination and tangible commitments. This report is a call for European decision-makers to implement the necessary policies.

In this pivotal moment, we find ourselves standing at the crossroads of possibility and peril. The opportunity to secure a sustainable and resilient future for generations to come lies within our grasp, and now is the time to seize it. Today's collective actions will determine the legacy we leave for the future: let us choose the path of responsibility, courage, and commitment to safeguarding the future of our shared home.

Appendix A - Biodiversity and resource-related limits of the RtoNZ project

1 Integration of biodiversity and broader nature-related considerations

The world has entered the Anthropocene, marked by human activities threatening Earth-system tipping points like the Amazon rainforest's savanisation and biodiversity's sixth mass extinction[1]. **Biodiversity collapse poses a direct threat to humanity**, jeopardising ecosystemic services and leading to a world of unpredictable fluctuations. Neglecting this issue could result in challenges not only for human prosperity but also for sheer survival, ranging from pandemics to agricultural yield reduction. Social justice concerns arise from international outsourcing, transferring biodiversity deterioration burdens to resource-exporting nations.

While this report focuses on GHG reduction, efforts to minimise economic pressures on biodiversity are integrated. First, carbon neutrality directly alleviates biodiversity pressures linked to climate change. Moreover, in the net zero scenario, Agriculture and LULUCF sectors, which are at the centre of many pressure on biodiversity, undergo transformation through widespread adoption of agroecological practices, reduced use of nitrogen fertilisers and pesticides, forest ecosystem revitalisation, cultivation of hedgerows and trees in agricultural areas, and wetlands and peatlands restoration – all contributing to ecosystem pressure relief.

Developing nature-based solutions in the LULUCF sector also offers co-benefits, including enhancing climate change adaptation (e.g. reducing flood impacts) and increasing carbon sequestration without harming biodiversity. Conversely, preserved biodiversity contributes to crop protection and soil fertility, thereby reducing the reliance on chemicals. This underscores the interconnectedness of biodiversity and climate preservation, and the need to preserve both.

Beyond the crucial role of biodiversity in providing ecosystemic services, its collapse raises ethical questions about our relationship with the living world and its intrinsic value.

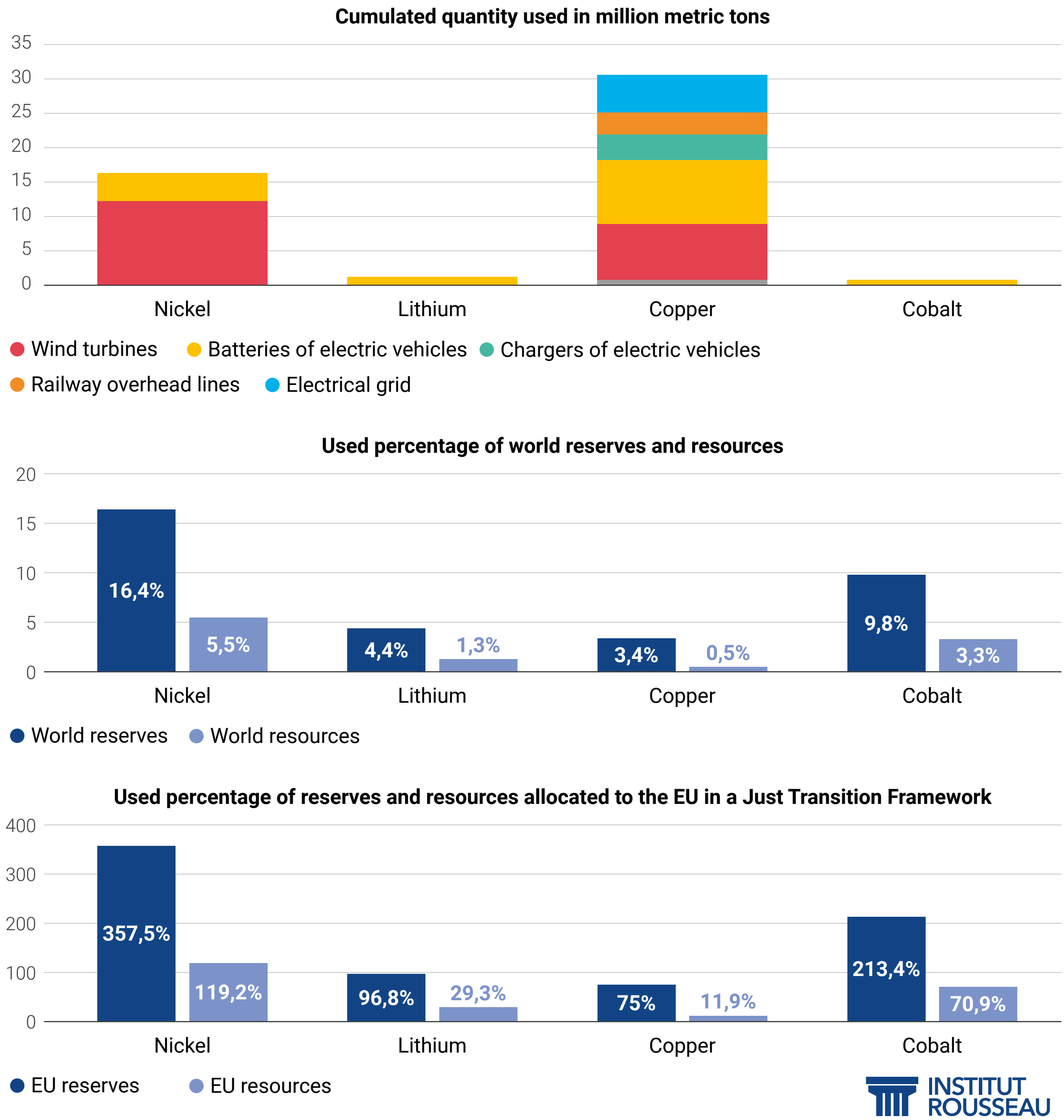
In terms of regulation, the European Parliament passed a diluted 'Nature Restoration Law'[2] in July 2023, despite protests from the conservative European People's Party and farmers. The law aims to expedite nature restoration, aligning with the 2022 UN Kunming-Montreal Protocol[3]. Biodiversity protection also recently faced setbacks with the extension of the glyphosate herbicide[4].

2 Compatibility of this scenario with critical material resources constraints

Concerns about the shift from a fossil-intensive to a mining-intensive economy in the decarbonisation process have been raised due to the metal demands of green technologies. Recent research indicates that a renewables-based economy would require less overall mining than the current fossil-based one[5]. However, there remains a risk of potential bottlenecks in the availability of critical materials. To assess this risk, the critical raw material[6] requirements of the Road to Net Zero transition scenario were compared with available reserves and resources[7]. Reserves are economically viable deposits with current technologies, while resources encompass all known deposits, whether economically extractable or not.

Using material intensities from the LOCOMOTION[8] research project, potential constraints were identified for four metals, as illustrated in Figure A.1.

Fig. A.1 **A potential resource bottleneck is identified for the transition scenario of this report regarding four key metals: nickel, lithium, copper and cobalt.**



Quantities in the upper part of Figure A.1. represent the total requirements for key technologies' production in the Road to Net Zero transition scenario between 2023 and 2050 – not the EU economy's overall needs. **However, nickel, lithium, copper, and cobalt requirements still constitute a notable share of global reserves and resources**, as displayed in the middle segment of Figure A.1. With the perspective of transition fairness, a similar share can be computed, not taking the global reserves and resources but instead the fraction of them which would be allocated to the EU. This fraction can for example be computed by multiplying the global reserves and resources by the average ratio of the EU population to the global population throughout the transition period. The lower segment of Figure A.1. displays the percentage of these reserves and resources allocated to the EU, which are used in the Road to Net Zero scenario. Notably, these figures surpass 100% for reserves of nickel and cobalt. To overcome this mismatch, the International Council on Clean Transportation put forward the following policies for accelerating reuse and recycling practices[9]:

- Incentivising domestic capacity for battery reuse and recycling.

- Setting standards for battery durability, safety, and information accessibility that optimise reuse and recycling processes.

- Supporting research and development in lithium-ion battery recycling technologies to expand the range of materials that can be recovered.

- Introducing mandatory recovery rates and recycled content targets to ensure efficient recycling of all key battery materials.

Adding to these policies the discovery of new resources (the resource estimates of lithium and nickel more than doubled during the last decade[10]), the projections about technology improvements (i.e. increased material efficiency) and material substitution, several international organisations claim that the supply-demand gap will be closed[11].

Figure A.2. scores the recyclability and substitutability of several prominent critical minerals and the geopolitical and socio-environmental risks associated with their mining.

Fig. A.2 **Criticality score for several materials (from 1-none to 5-major)[12]**

	Lithium	Cobalt	Platinoid	Rare earths	Copper	Graphite	Silicon	Aluminium	Nickel	Steel
Extraction and processing monopoly	4	5	5	5	3	5	5	2	3	2
Substituability	4	3	5	3	4	1	3	3	4	4
Recyclability	3	3	1	4	1	5	4	1	2	1
Socio-environmental impacts	5	5	3	5	5	3	2	4	3	3

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The discussion above concerns only stocks of extractable minerals. **When looking at flows of extractable minerals *per year*, the previously cited organisations acknowledge that important bottlenecks could arise by 2030**[13]. In that regard, it is recommended to:

- Diversify material sources to improve supply resilience to trade wars and external shocks
- Develop intra-European projects for resource extraction
- Reduce timescales to obtain permits and achieve regulatory compliance for mining in Europe[14]
- Implement strong regulation for supply chain traceability of mining outside of the EU[15], to alleviate the negative impacts of the accelerated opening of new mines.

This major challenge of critical materials availability, especially regarding the 2030 horizon, emphasises the crucial role of energy sufficiency policies across all sectors to enable a successful transition. Further research and policy proposals need to be considered beyond what is proposed in this report to tame such tensions, with the ambition to achieve (and not just assert) global environmental justice.

3 Geopolitical, environmental, and social risks associated with mining in the transition scenario

As countries around the world shift towards a low-carbon economy and renewable energy systems, there is a growing demand for critical materials crucial for technological advancements (IEA, 2021[16]; IRENA, 2019[17]). The heightened significance of these minerals has prompted governments worldwide, including the US, Japan, China, and the EU[18], to secure their supply of these resources, as evidenced by recent reports on 'critical minerals'. Nonetheless, critical materials have serious geopolitical, environmental, and social risks associated with their extraction.

3.1 Geopolitical risks

The extraction of certain critical materials is heavily concentrated in specific geographic locations, raising concerns about the vulnerability of global supply chains (IRP, 2020[19]; Teer & Bertolini, 2023[20]). Notably, the RAND Corporation identifies 14 critical materials, with production concentrated in countries characterised by weak governance. In addition, China is the leading producing nation for 30 of the 50 critical minerals, including a dominant position in rare earth elements, supplying about 70% of their global production in 2022[21]. The concentration also applies to the processing stage, with South Africa and Indonesia controlling significant portions of Platinum and Nickel processing, respectively (IEA, 2021; IRENA, 2023[22]).

3.2 Environmental risks

Mining activities have severe environmental repercussions, leading to erosion, sinkholes, loss of biodiversity, and contamination of soil, groundwater, and surface water (Murakami et al., 2020[23]; Sonter et al., 2018[24], 2020[25]). Such biodiversity loss namely consists in the destruction of various ecosystems, causing habitat loss for endangered species. Moreover, mining and mineral processing operations release greenhouse gases, which contribute to climate change. The associated high water footprints and alterations to land use further disrupt local ecological systems.

3.3 Social risks

The socio-environmental impacts of mining have triggered waves of resistance and conflicts globally. Local communities, indigenous groups, and environmental activists frequently engage in legal actions, labour strikes, roadblocks, and demonstrations to advocate for environmental justice and equitable working conditions (Lunde Seefeldt, 2022[26]). Examples include protests in China against water pollution from lead mining, resistance against copper mining in Tibet, and ongoing protests by indigenous communities in Latin America against lithium mining (Environmental Justice Atlas, 2015[27], 2017[28], 2018[29], 2019[30], 2021[31]). A striking example is the recent closure of the biggest mine of Panama after multiple protests[32].

Moreover, due to the existence of artisanal mines and opaque mining structures, mineral extraction can sometimes be linked to military conflicts, human rights abuses, and the funding of armed groups (Jamasmie, 2017[33]; Church & Crawford, 2018[34]). The United Nations Environment Program[35] estimates that about half of the internal conflicts since the 1950s have been related in some way to natural resource exploitation, often leading to supply disruptions[36].

Such geopolitical, environmental, and social risks need to be always born in mind when designing transition scenarios. They can only push for integrating as much sufficiency as possible in policy making, as already advocated for in the previous section.

Notes

1. IPBES, 2019, Global Assessment Report on Biodiversity and Ecosystem Services.
2. European Commission, 2023, 'Nature Restauration Law'.
3. Euractiv, 12 July 2023, 'Parliament backs EU nature restoration law, despite right-wing opposition'.
4. Euractiv, 15 November 2022, 'Commission to temporarily re-approve glyphosate without member states' go-ahead'.
5. Sustainability by numbers, 2023, The low-carbon energy transition will need less mining than fossil fuels, even when adjusted for waste rock.
6. The definition of critical raw materials adopted here is the one from the EU Raw Materials Information System (RMIS).
7. Estimates for reserves and resources are taken from: Energy Transitions Commission (ETC), 2023, Material and Resource Requirements for the Energy Transition.
8. LOCOMOTION, Main project reports.
9. International Council on Clean Transportation (ICCT), 2023, Scaling up Reuse and Recycling of Electric Vehicle Batteries: Assessing Challenges and Policy Approaches.
10. ETC, *Ibid*.
11. Sustainability by numbers, 2023, We have enough minerals for the energy transition, but medium-term supply is a challenge [Part 1].

12. Source: Ledoux E., Chardon A. (2022). Circular low carbon economy – an integrated approach - Final report. INEC, CAPGEMINI INVENT.

13. Sustainability by numbers, 2023, We have enough minerals for the energy transition, but medium-term supply is a challenge [Part 2].

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26. Lunde Seefeldt, J. (2022). Water as property: Contention between indigenous communities and the lithium industry for water rights in Chile. Latin American Policy, 13(2), 328–353.

27. Environmental Justice Atlas. (2015). Pujada-Hallmark nickel mine on ancestral lands, Oriental Davao, Philippines.

28. Environmental Justice Atlas. (2017). Lithium mining in the Salar de Atacama, Chile.

29. Environmental Justice Atlas. (2018). Residents and monks of Lhamo Mountain affected by Ganhetan Industrial District Park pollution, Qinghai, China.

30. Environmental Justice Atlas. (2019). Bauxite Mines on the Sangaredi Plateau & Kamsar port installations, involving the multinationals Alcoa, Rio Tinto and Dadco, Guinea.

31. Environmental Justice Atlas. (2021). Lithium mining in Salar del Hombre Muerto, Argentina.

32. Mongabay (2023, November 28). Panama copper mine to close after Supreme Court rules concession unconstitutional.

33. Jamasmie, C. (2017, April 6). 'Conflict minerals' entering tech supply chains from countries beyond Africa. Technical Report. Mining.com.

34. Church, C., & Crawford, A. (2018). Green Conflict Minerals: The fuels of conflict in the transition to a low-carbon economy [IISD Report]. International Institute for Sustainable Development.

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