newTRENDs

Report on Findings of the New Social Trends Pathway Analysis for all Sectors Including Selected Macro-economic Impacts.

Deliverable D3.3

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Executive Summary

The newTRENDs project develops the analytical basis for a low carbon economy taking into account New Societal Trends in energy demand:

- The project has identified the new societal trends and their clusters that are expected to be most relevant or disruptive for the future energy demand.
- The identification was done based on a wide scanning of existing studies and a series of expert workshops. In the end, 14 major trend clusters were identified.
- Four sectors were considered, including industry, transport, tertiary and residential sectors.
- All energy demand models available to the consortium have been improved and enhanced so as to integrate the new trends.
- Based on the updated models, we evaluated the impact of the trends on the energy demand in each sector.
- Then the output of the energy demand models has been fed to the GEM-E3 macroeconomic model so as to calculate the economic implications of the different trends.

Four scenarios have been quantified by the models:

1. Reference Scenario
2. Decarbonisation Scenario
3. New Societal Trends Scenario
4. Decarbonisation and New Societal Trends Scenario

The Reference Scenario aims to capture today’s level of policy implementation at the EU level and does not include any additional policies or measures that contribute to climate neutrality by 2050. In the Reference Scenario, the energy demand in each sector is calculated based on the most recent EU PRIMES Reference Scenario. The Decarbonisation Scenario on the other hand describes a pathway that achieves the long-term goal of at least 95% GHG reduction by 2050 compared to 1990. The scenario assumes a strong expansion of policy support and regulation to meet this target.

The Reference New Trends (Reference_NT) Scenario expands upon the Reference Scenario by incorporating the modelling of the new societal trend for each sector. Here, like in the Reference Scenario, no decarbonisation measures are introduced and carbon neutrality is not reached in 2050. Finally, in the Decarbonisation New Trends (Decarb_NT) Scenario, we combine how the energy demand develops with the decarbonisation measures in place and the unfolding of the new trends. Additionally, policies which influence the trends, in particular, are introduced in the sectoral models. The target of this scenario is carbon neutrality in 2050.

The main sectoral results, the models used, and key methodological aspects are summarised below.

In the **industry sector**, we use the FORECAST-Industry model to evaluate the impact of the transition to a circular economy. FORECAST Industry encompasses the entire industry sector, in line with its definition within energy balances, and considers non-energetic usage for feedstocks. We delve deeper into analysing the steel and the cement sectors as their modelling has undergone notable modifications in terms of circular economy potential representations. This enhanced perspective offers a more detailed understanding of the potential that the sector holds.

We find that:

- Total energy demand decreases significantly across scenarios. This is primarily driven by circular economy measures which drive a shift from primary to secondary production routes – these are often substantially more energy-efficient.
- A shift in energy carriers towards climate-neutral sources takes place across scenarios. The demand for electricity and hydrogen, and to a certain extent, biomass increases substantially across all scenarios. Electricity and hydrogen are two key energy carriers in the decarbonisation of process heat.
- Electricity consumption increases significantly across scenarios, predominantly driven by the use of electricity for low and medium-temperature applications such as industrial heat pumps and electrical boilers.
- Transitioning to electricity-based process heat technologies, particularly for low and medium-temperature applications, where technologies are mature and commercially available is critical.
- Hydrogen gains substantial importance in the long term, owing mainly to the transformation of the chemical sector; however, demand for hydrogen drops if substantially if circular economy measures are adopted.
- Final energy demand in the iron and steel sectors drops in all scenarios, and more so in the Decarb_NT Scenario (17%).
- Interestingly, in the cement sector, FED drops less in the Decarbonisation Scenarios (Decarb and Decarb_NT) than in the Reference Scenario, due to the electrification of cement heating processes.

In the **transport sector,** we use the PRIMES-TREMOVE model to assess the impact of moving to a sharing economy with the uptake of shared mobility.

We use a new module, PRIMES SHAREM Demand, developed exclusively in the context of this project, which enhances the modelling capabilities of PRIMES-TREMOVE transport supply model by taking car service, carpooling and car sharing explicitly into account.
Input data and main assumptions include household income spending by income group, activity and stock of cars, a classification of trips, occupancy rate and average speed, distance (km per trip) and value of time (€/hr per trip type) and

pricing, and historical shared mobility options (starting 2015) serving as starting point and calibration of the model.

We find that:

- Shared mobility reduces the activity of private cars, an effect that becomes more pronounced under a Decarbonisation Scenario context.
- Car-pooling features at the top of shared mobility options, especially in the shorter term. Car sharing increases its market uptake by a lot and becomes a key choice. Car service on the other hand remains the last shared mobility options, which is attributed to its higher ticket price.
- Shared mobility increases the average occupancy rates of vehicles, most notably in the Decarbonisation Scenarios, mainly due to carpooling, the option with the highest market share and occupancy factor.
- Under the Reference Scenario, the generalised cost of private cars is the lowest. The opposite holds for shared mobility, nevertheless the costs of car sharing and car service reduce with time. Moreover, the reduction of generalised costs is higher in the Decarbonisation Scenario.

In the **tertiary sector**, we assess the impact of digitalisation, work from home, and a sharing economy using the FORECAST-Tertiary model.

FORECAST-Tertiary is split into two different parts: heating demand is based on the building envelope and heating system parameters and its value depends on the energy reference floor area. The floor area itself is dependent on the number of employees working in that subsector and the specific floor area (floor area per employee). Second, the electricity demand of electric appliances depends on the installed power and its utilisation rate (effective full load hours). The technical equipment and its usage are differentiated by subsector and either depend on the floor area or directly on the number of employees.

The assessment of final energy demand and the GHG-emissions in the tertiary sector covers all process-specific sources of energy demand that occur inside the buildings of this sector. This includes lighting, space heating & cooling, sanitary hot water, ventilation & building services, process heat, ICT and other processes and applications.

We find that:

- Final energy demand in the tertiary sector drops in all scenarios, the reason being the growing efficiency in energy use. Meanwhile, the number of employees and the total floor area stay at a comparable level.
- Electricity demand increases with new trends, and specifically the higher activity of ICT. However, this increase is moderate compared to the Reference Scenario. In a decarbonisation policy context, small savings in electricity consumption are achieved ~6% (Decarb) and ~7% (Decarb_NT).
- Final energy demand for space heating and hot water drops in all scenarios and more so in the Decarb_NT Scenario. This is due to the combined effect of increased efficiency in heating systems and building insulation (decarbonisation context) and building automation systems and e-commerce (new trends).

- Teleworking reduces the overall demand for energy because it requires less demand for electricity and heating in the tertiary sector.
- The effect of e-commerce is small – however, in the retail subsector (shopping areas, spaces for storage and offices) total energy demand in 2050 declines by ~17% in both Reference (vs. Reference_NT) and Decarbonisation (vs. Decarbonisation_NT) Scenarios. The same applies for electricity and heat demand.
- Additional ICT demand pushes electricity demand up to about +12% in 2050, in both Reference and Decarbonisation Scenarios. Conversely, electricity demand from ICT devices in offices (desktop computers, monitor, copy machines and others) increases at a slower pace and is far lower, by a factor of more than 10.
- Electricity savings from building automation in the entire tertiary sector sums up to ~2% (Reference Scenario) and ~5% (Decarbonisation Scenario) in 2050.

In the **residential sector**, we evaluate the impact of prosumaging on the energy consumption of households with two groups of models (1) the INVERT&FLEX modelling suite, and (2) the PRIMES-BuiMo and PRIMES-Prosumager models. PRIMES-Prosumager takes a more holistic approach as it also includes investment decisions and analyses the behaviour of the prosumagers over multiple years. In doing so, however, the level of detail is lower to ensure model tractability: typical hours per day and typical days per year are considered. The FLEX model solely focuses on the optimised operation of household systems while the investment decision has already been made by the Invert/EE-Lab model. Thus, the comparison of these two modelling approaches gives insights into first how the explicit inclusion of prosumaging in the investment decision will affect results; and second how household behaviour shifts under different pricing conditions and countries.

We find that:

- In the Reference and Decarbonisation Scenarios, the final energy demand for space and water heating decreases due to the refurbishment of the building envelope and more efficient heating systems to about 75% (Reference Scenario) and 60% (Decarbonisation Scenario) in 2050 compared to 2020. Considering only delivered energy, i.e. subtracting the share of ambient and solar energy, the reduction is even more significant, resulting in a decrease to about 40% in the Decarbonisation Scenario by 2050 compared to 2020.
- The share of gases and liquids in final energy demand is lower than measured in terms of the heated floor area. This is partly because heating systems that are based on gases and liquids have the highest variable costs among all heating systems. It thus becomes more attractive to apply these systems in renovated homes or to renovate buildings with these heating systems.

Taking the sectoral results of the four scenarios as input, the macroeconomic implications of the new societal trends are evaluated with the dynamic general equilibrium model GEM-E3. The inputs are mapped to the GEM-E3 sectors and then transposed in a way that allows linking them with specific GEM-E3 variables and parameters.

The inputs include: *Changes* in the fuel mix across industrial sectors and material productivity improvements, mainly in steel and cement (Output of FORECAST-Industry), *Changes* in fuel mix in the tertiary sector (Output of FORECAST– Tertiary), *Shares* of carpooling and car sharing to estimate the effect of shared mobility on economic activity and employment (PRIMES- SHAREM Demand) and the *Fuel mix* in household energy consumption to assess the effect of prosumaging (PRIMES-Prosumager).

For the macroeconomic implications of new societal trends, we find that:

- Digitalisation has the strongest effect on GDP amongst all new trends examined, by boosting labour productivity and reducing floor area costs in the tertiary sector.
- The increased uptake of circularity in buildings in the period 2030-2050 has a positive effect on the economy, because the EU becomes less dependent on raw material, and upstream sectors lower their production costs and gain in competitiveness vis-a-vis their counterparts in the rest of the world. Moreover, these are the sectors, i.e. machinery and equipment, electronic equipment where new employment opportunities will be created.
- A growing adoption of shared mobility pushes GDP up. Not buying private cars results in an increase in disposable income of households, which is mostly directed towards services. In turn, service-sector jobs receive a boost.
- The impact of prosumagers on GDP is negative as (i) households shift demand from the power supply sector to the manufacturing of PV panels, which is a heavily imported technology, resulting in money flowing outside of the EU; (ii) It is more expensive for a household to install solar PVs. Still, in a decarbonisation context, electricity costs are higher, thus households that produce and consume their own electricity are better off.

List of Abbreviations

AAGR	Annual Average Growth Rate
AEPS	Advanced Energy Performance Standard
BACS	Building automation and control systems
CAGR	Compound Annual Growth Rate
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CCUS	Carbon capture, utilisation and storage
CGE	Computable general equilibrium
DC	Data Centre
DESI	Digit Economy and Society Index
DR	Diffusion Rate
EPBD	Energy Performance Buildings Directive
ESC	Electrical steam crackers
ESD	Energy Service Driver
ESO	Energy Saving Option
FED	Final energy demand
FLAP	Frankfurt, London, Amsterdam, Paris
FLH	Full load hours
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHGE	Greenhouse Gas Emissions
HVC	High-Value Chemicals
ICT	Information and Communication Technology
IEA	International Energy Agency
LCA	Life Cycle Analysis
MaaS	Mobility-as-a-Service
MEPS	Minimum Energy Performance Standard

Mt	Megatonne
MTO	Methanol-to-Olefins
NACE	Statistical Classification of Economic Activities in the European Community
O&M	Operation and maintenance
PUE	Power usage effectiveness
Q	Quantity Structure
RH	Relative Humidity
SC	Stream cracking
SCM	Supplementary cementitious materials
SED	Specific Energy Demand
SMR	Steam-methane reforming
TCO	Total cost of ownership
TED	Total energy demand
WFH	Work from home

Table of contents

List of figures

List of tables

1. INTRODUCTION

1.1 Background

The newTRENDs project develops the analytical basis for a low carbon economy considering New Societal Trends in energy demand. The aim of the project is to deepen the understanding – from a qualitative and quantitative perspective – of how these societal trends influence energy demand in European countries; and to improve the modelling of energy demand, energy efficiency and policy instruments in order to yield important insights regarding how these emerging trends can contribute to meeting climate neutrality.

Enhancing existing energy demand models to the extent that they can model the influence these new societal trends exert on energy demand, and hence to develop scenarios of their evolution into the future lies at the heart of the project. The new societal trends examined are the rise of prosumaging; the transition to a circular economy and a low-carbon industry; the digitalisation of the economy and of private lives; and the shift to a sharing economy.

Analysis produced earlier in the project shows that these new societal trends and their underlying factors have a contrasting impact on future energy demand: simultaneously decreasing, increasing, or shifting energy demand to other sectors. Furthermore, because such trends, i.e. urbanisation, remote work, etc., might also lead to demand shifts between sectors, we consider necessary to assess potential linkages from an inter-sectoral perspective, the aim being, overall, to grasp their role in the energy transition.

The current study is the culmination of work produced at different stages of the project. After identifying new, energy-relevant, societal trends and related narratives (WP2), recommending policies that can mitigate the energy demand of these trends (WP4) and ways in which demand-side models can best reflect these policies, establishing modelling gaps and defining pathways and scenarios for how these trends may affect the evolution of energy demand and emissions (WP3) and ultimately undertaking cross-sectoral modelling of the trends (WP5-WP7) covering the buildings, services, industry and transport sectors (independently), we now present the outcome of the quantitative modelling exercise and a comprehensive macro-economic assessment of the trends in the context of the low-carbon transition.

We link demand-side models with the improved macro-economic GEM-E3 model and move beyond the energy systems analysis towards exploring how macroeconomic structures may change as a result of decarbonisation and new trends – which sectors will be winning, losing, or emerging. GEM-E3 draws on technology information provided by WP4-6 and provides insights on the production of clean and energy-efficient technologies. The analysis also includes a detailed assessment of the manufacturing and trade of clean energy/energy-efficient technologies in differentiated policy settings and the potential for EU to develop competitive advantages.

In a nutshell, this study report demonstrates the interactions between the low-carbon transition and economic restructuring towards circular economy, digitalisation (teleworking, e-commerce, building automation), shared mobility and prosumaging and impacts on employment.

1.2 Objectives

The study at hand has a twofold objective: to synthesise the impacts of decarbonisation and new societal trends on energy demand (its structure and patterns) in the industry, transport, tertiary and residential sectors, and to deliver a comprehensive macro-economic assessment of decarbonisation and new trends by analysing their impact on economic growth, industrial competitiveness, employment trends by sector and skill.

New societal trends are expected to affect, in a mutually opposed manner, the current structure of the energy demand sectors; that is, to simultaneously decrease, increase, or shift energy demand between sectors.

The transition to a circular economy paradigm is set to have profound implications for the EU economy. A more efficient use of materials in industry including recycling as well as product and service redesign will bring energy demand down and create new material flows. Meanwhile, despite lowering CO_2 emissions, a low-carbon industry may at the same time require more energy to meet a growing demand for climate neutral fuels such as hydrogen.

Improving the modelling of circular economy has been a key objective of the project. Enhanced model capabilities now allow to explicitly consider material flows and stocks in different parts of the value chain including the potential for rebound effects and considering the links between products and countries, employment, and competitiveness (issues relating with material substitution, cost burden).

Likewise, the transition to a sharing paradigm in the transport sector may lead to structural changes in the economy. Car sharing, efficient logistics, improved product-service efficiency in the entire value chain, all together have the potential to lower fossil fuel consumption and GHG emissions and increase the efficiency of the transport system. Still, by spurring demand for new services (e.g., more driving of shared cars instead of the use of public transport) shared mobility may also increase demand for energy. Evidently the implications for economic activity, manufacturing, employment (highly skilled vs. low and medium-skilled jobs) are significant and the focus of the macroeconomic analysis in this study.

How do new working patterns in the tertiary sector (i.e. teleworking) affect energy consumption and the economy has also been studied, to shed light on the interplay between an ever expanding and energy-intensive ICT sector; the need for less floor space in the tertiary sector due to teleworking; and potentially higher demand for additional floor space (co-working spaces, private homes) as a result of working remotely.

Last, the rise of the prosumager, i.e. being a producer, consumer and manager of energy, may have a contrasting impact on energy demand. It may either result in reduced energy consumption through more flexible use of, for example excess generation of renewables. Or in less efficient use of energy, associated with small-scale generation, losses in electricity distribution systems and more.

Exploring the future impact of these new societal trends underlines the need to design scenarios that are not only techno-economic in nature but reflect lifestyle changes, the impact of a sharing economy and related cross-sectoral implications.

The scenarios examined in the course of the project are:

1. **Reference Scenario:** the energy demand in each sector is calculated based on the most recent EU PRIMES Reference Scenario. Carbon neutrality in 2050 will not be reached.
2. **Decarbonisation Scenario:** necessary decarbonisation policies and measures to reach carbon neutrality in 2050 are introduced.
3. **New Societal Trends Scenario:** the scenario projects how the energy demand will unfold with the new trends, when no decarbonisation measures are introduced. Carbon neutrality will not be reached in 2050.
4. **Decarbonisation and New Societal Trends Scenario:** the scenario combines the evolution of energy demand with decarbonisation measures in place and the unfolding of the new trends. Additionally, policies which influence the trends, in particular, might be introduced in the sectoral models. The target of this scenario is carbon neutrality in 2050.

GEM-E3 has received inputs from the following models: FORECAST-INDUSTRY; FORECAST-TERTIARY; PRIMES-SHAREDM; and PRIMES-PROSUMER. The inputs have been mapped to the GEM-E3 sectors and transposed in order to be linked with the specific GEM-E3 variables and parameters. Key features of the GEM-E3 model that have been further improved relate to the circular material / material productivity in industry, the calibration of structural shifts in the fuel mix used by firms, the shared mobility options, and the ability of households to become self-producers of electricity.

1.3 Structure of the report

The report is structured as follows: section 2 presents an overview of the methodology to model new trends, i.e. the model tools, links between models and scenario design. Section 3 presents the impacts of new societal trends on energy demand under the different scenarios, section 4 provides insights on the macroeconomic implications of these trends and section 5 is the conclusion.

2. METHODOLOGY

For a comprehensive analysis of the New Societal Trends and their influence on energy demand in different sectors of the economy – transport, industry, buildings – each modelling team performed: **(i)** an analysis of the trends and their clusters in the context of each sector; **(ii)** an identification of the mechanisms to model these trends and a summary of the gaps in the models; **(iii)** model enhancements; **(iv)** the definition of transition pathways and scenarios for energy-relevant new societal trends, model runs and impact assessment on sectoral energy demand and the macro economy. The report at hand documents the final step listed above.

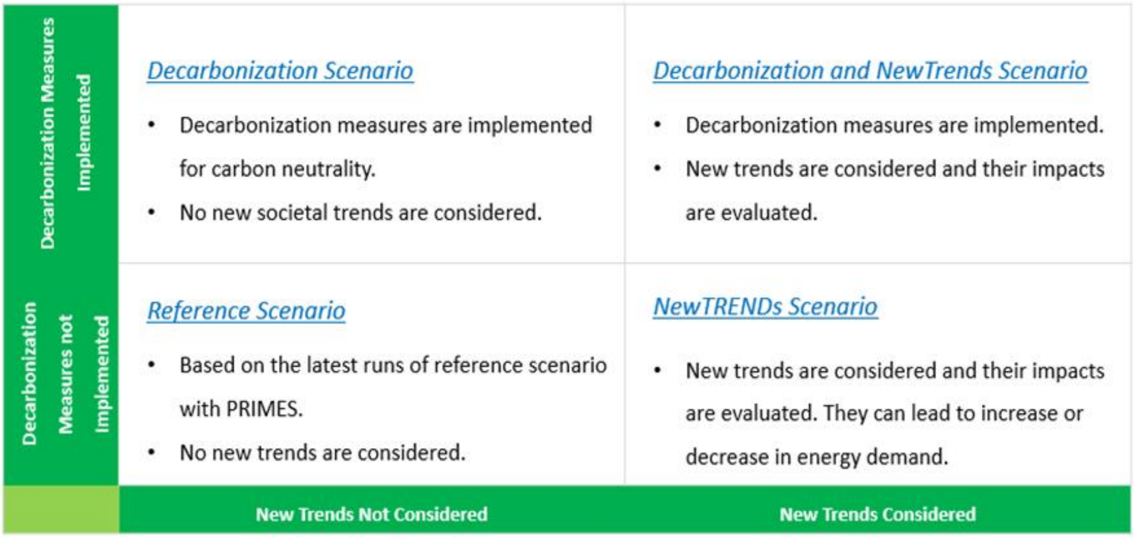
The models selected to document energy-relevant new societal trends are FORECAST-Industry for circular economy; PRIMES-TREMOVE for shared mobility; FORECAST-Tertiary for digitalisation, teleworking, buildings automation and e-commerce; FORECAST-Appliance, INVERT, and PRIMES-BuiMo for prosumaging. GEM-E3 deals with the macroeconomic implications of these new, energy-relevant societal trends. These are all well-established, bottom-up energy demand and macro-models, used extensively in the European context for projections up to 2050 and beyond (EU28 and individual Member States).

Based on these models, four pathways and scenarios have been developed: two standard scenarios, a Reference and a Decarbonisation Scenario. And two scenarios that consider the New Societal Trends. These are the Reference New Trends and the Decarbonisation New Trends.

The Reference Scenario aims to capture current policies implemented at EU level and does not include any additional policies or measures that contribute to achieving climate neutrality by 2050. Moreover, the Reference Scenario takes the energy demand of each sector from the most recent EU PRIMES Reference Scenario.

The Decarbonisation Scenario, on the other hand, describes a pathway that achieves the long-term goal of at least 95% GHG reduction by 2050 compared to 1990. To meet this target the scenario assumes a strong expansion of policy support and regulation. The New Trends scenario builds on the Reference Scenario by incorporating the modelling of the new societal trends for each sector. Finally, the Decarbonisation New Trends scenario combines the new societal trends with decarbonisation policies and measures.

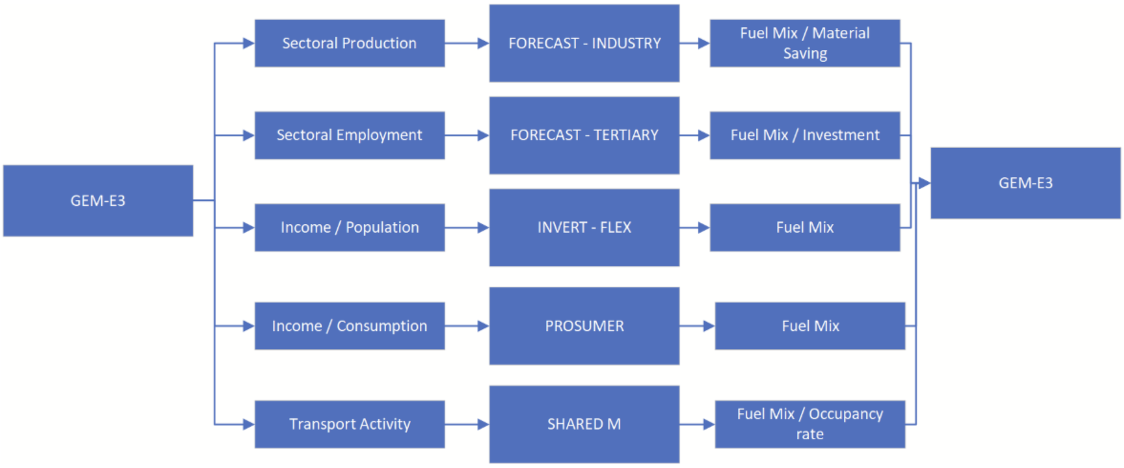
Figure 1 Overview of the four scenarios in newTRENDs



	New Trends Not Considered	New Trends Considered
Decarbonization Measures Implemented	*Decarbonization Scenario* - Decarbonization measures are implemented for carbon neutrality. - No new societal trends are considered.	*Decarbonization and NewTrends Scenario* - Decarbonization measures are implemented. - New trends are considered and their impacts are evaluated.
Decarbonization Measures not Implemented	*Reference Scenario* - Based on the latest runs of reference scenario with PRIMES. - No new trends are considered.	*NewTRENDs Scenario* - New trends are considered and their impacts are evaluated. They can lead to increase or decrease in energy demand.

The linking of the various models is not a straightforward process but one that requires the simultaneous manipulation of heterogeneous input within one consistent framework. The full suite modelling exercise involves the linking of the six models. The rationale is that the GEM-E3 model, encompassing in a top-down way all sectors of the energy and economic systems, provides the boundary conditions to the sectoral models.

Figure 2 Sequence of model linkage



Step1: Harmonisation of exogenous variables: harmonisation of all models to key common assumptions regarding socio-economic and energy price projections (GDP and sectoral economic activity, population, fuel prices)

Step2: Sectoral Concordance between the models: reconciliation and rearrangement of sectoral model outputs to match the GEM-E3 classification.

Step3: Sequence of Linking: The sequence of model linking is from GEM-E3 to the bottom-up models to GEM-E3. GEM-E3 provides an integrated simulation accounting simultaneously for all new trends.

3. IMPACTS OF NEW SOCIETAL TRENDS ON ENERGY DEMAND

3.1 Industry

This chapter outlines the main features of the applied model – FORECAST Industry – as well as the assumptions and results of the modelling performed in the industry sector. FORECAST Industry covers the entire industry sector in line with its definition within energy balances and considers non-energetic usage for feedstocks. The analysis delves deeper into the steel and the cement sectors since their modelling has undergone notable modifications in terms of CE potential representations. This offers a more detailed understanding of the CE potential in the two sectors.

3.1.1 FORECAST Industry: key features and improvements

The FORECAST model is a strategic decision support tool, primarily designed to develop detailed long-term scenarios for energy demand, greenhouse gas emissions, and decarbonisation strategies for the industry sector. Its main objective is to develop potential transition pathways and corresponding timelines based on technology diffusion and turnover in stock. By explicitly considering these factors, FORECAST can offer information regarding how various technologies are adopted and replaced over time.

FORECAST combines both bottom-up and top-down methodologies to derive transformation pathways for the various industry sectors. The bottom-up approach in the FORECAST model ensures a high level of technological detail. It delves deep into the industrial sector, its specific processes, and technologies, and assesses a wide range of mitigation options. Simultaneously, the top-down approach in FORECAST closes knowledge gaps and calibrates the model to align with energy balances and larger economic and policy dynamics.

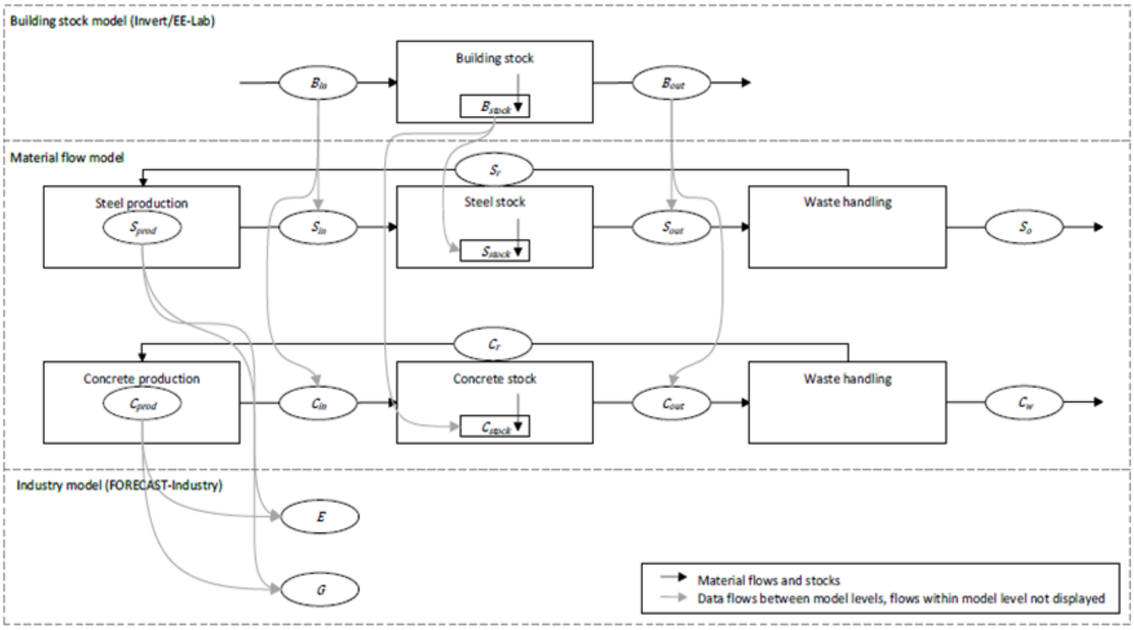
In newTRENDs the FORECAST Industry module is used to support strategic decision-making by simulating future energy demand and GHG emissions and assessing industry transformation pathways. The model projects the decarbonisation of the industry sector based on techno-economic assumptions. It considers a broad range of GHG mitigation options including material and energy efficiency, switching to carbon-neutral energy carriers and processes, switch to secondary production and recycling, carbon capture and use (Fleiter et al. 2018; Rehfeldt et al. 2020)).

Future production quantities are one of the main inputs for the model. These are determined partly with an inflow-driven material flow analysis (MFA) based on sectoral Gross Value Added (GVA) development and statistical production and demand data (Herbst 2017). The impact of a circular economy (CE) is taken into account through exogenous assumptions based on literature review or expert interviews (Fleiter et al. 2018). While this approach already provides a reasonable estimate of CE potentials for industry decarbonisation, it was further improved within newTRENDs.

The modelling of CE potentials was improved by explicitly considering material flows and stocks along the entire value chain. Until now, FORECAST focused strongly on the basic material industries. Therefore, it could only provide estimates of the material demand reductions in downstream processes and especially the use phase. Additionally, considering material stocks enables the determination of material outflows from the use phase and thus, the availability of secondary materials. By considering the flows and stocks, the impact of a CE can be determined consistently and endogenously.

For implementing the flows and stocks, a stock-driven MFA of steel and cement in buildings was implemented. As shown in the figure below, this approach serves as a soft linkage between building stock and the industrial sector. Within the newTRENDs project, the Invert/EE-Lab building model is used for this purpose. In addition, the model results were improved by an expanded database with respect to building material intensities (MI). Here, the aim was to distinguish between regions, age cohorts and building types.

Figure 3 Structure of the stock-driven MFA linking the building stock and the industry sector (Lotz et al. 2022)



The model and data base were applied to depict the eight following CE actions, which were selected to represent the 9R framework (Kirchherr et al. 2017):

- Using timber instead of (reinforced) concrete in residential buildings;
- Reducing floor space demand in residential buildings and offices;

- Reducing the over-specification of elements by volume;
- Protection of cultural heritage buildings;
- Renovation of existing buildings;
- Reuse of building elements;
- Reuse of building materials;
- Recycling of cement.

For further information on method and data, refer to the newTRENDs deliverable 6.1 - Focus study report on decarbonisation and circular economy in industry.

3.1.2 Input data and main assumptions

The primary input data for the FORECAST Industry encompasses a broad spectrum of parameters. These parameters include the central driving factors, such as production projections for major energy-intensive products, policy-related parameters, energy and CO_2 prices, structural information, as well as sector-specific techno-economic assumptions like the CE measure. The subsequent sections provide a summary of these key assumptions, with a particular emphasis on sectors characterised by the highest GHG emissions and energy demand, namely the iron and steel, cement and lime, and the chemical industry sectors. Nonetheless, it is important to highlight that FORECAST also evaluates other energy-intensive sectors and less energy-intensive sub-sectors in depth, thereby capturing the entire energy demands of the industry sector.

Within the scenarios considering the new trend circular economy for industry decarbonisation (i.e. Reference_NT and Decarb_ NT), a moderate diffusion of comprehensive CE actions is assumed, which address both construction methods and lifestyle changes. For this purpose, the following CE actions are modelled using the model and data described in section 2.1:

- Using timber instead of (reinforced) concrete in up to 50% of all single-family houses;
- Reducing floor space demand in residential buildings (-5.5%) and offices (-18%);
- Reducing the over-specification of elements by up to 6% for concrete and 20.5% for steel;
- Protection of cultural heritage buildings (reducing the demolition of buildings built before 1945 by up to 21.9%);
- Renovation of existing buildings (reducing the demolition of all buildings by up to 15%);
- Reuse up to 19% of building elements;
- Reuse up to 3% of construction steel directly;
- Recycling up to 10% of cement.

It becomes clear that these CE actions interact with each other. If the order of modelling was not methodologically predetermined, the 9R framework was used. For further information on the scenario parametrisation, refer to the newTRENDs deliverable 6.1 - Focus study report on decarbonisation and circular economy in industry.

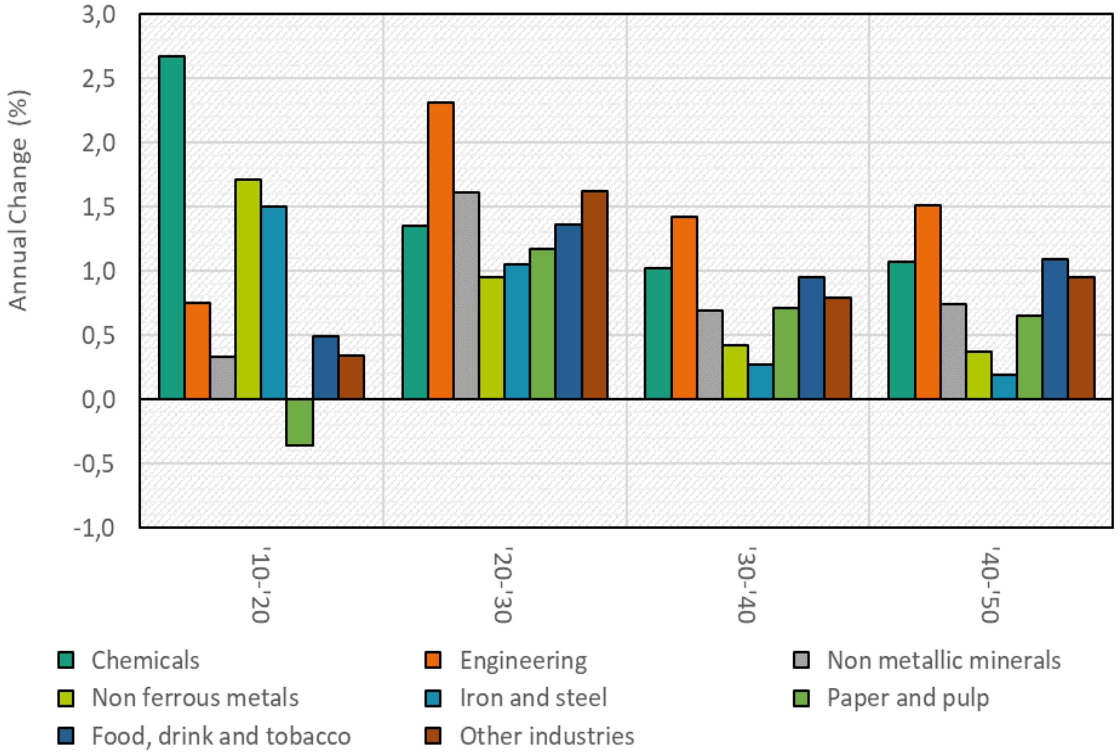
In addition, to the methodological improvements relevant for the scenarios considering the new trend (NT and NT_Decarb), further factors are relevant for the parametrisation of all scenarios. These are described in detail in the following sections.

3.1.2.1 Industrial economic development and production output

The projection of future physical production quantities and routes plays a pivotal role in shaping the energy demand and GHG emissions within the basic materials industry. FORECAST, the model being used for the industry sector, includes over 90 distinct processes, along with their resulting products and semi-finished goods, quantified in tons. The future physical production projections discussed below are exogenous inputs to the model based on historic production trends as well as our own assumptions on future developments. The switch to low-carbon process innovations like low-carbon cement or hydrogen-based steelmaking is also exogenous.

All scenarios use the same macroeconomic framework data, which is based on the European Reference Scenario (2020). An average annual growth rate in GVA of around 1.4% per annum (p.a.) is assumed for the industry until 2030, afterwards the growth rate declines to 0.8% p.a. The equipment goods industry (engineering) is projected to be growing at a steadily higher pace compared to the energy-intensive basic industries as shown in Figure 4.

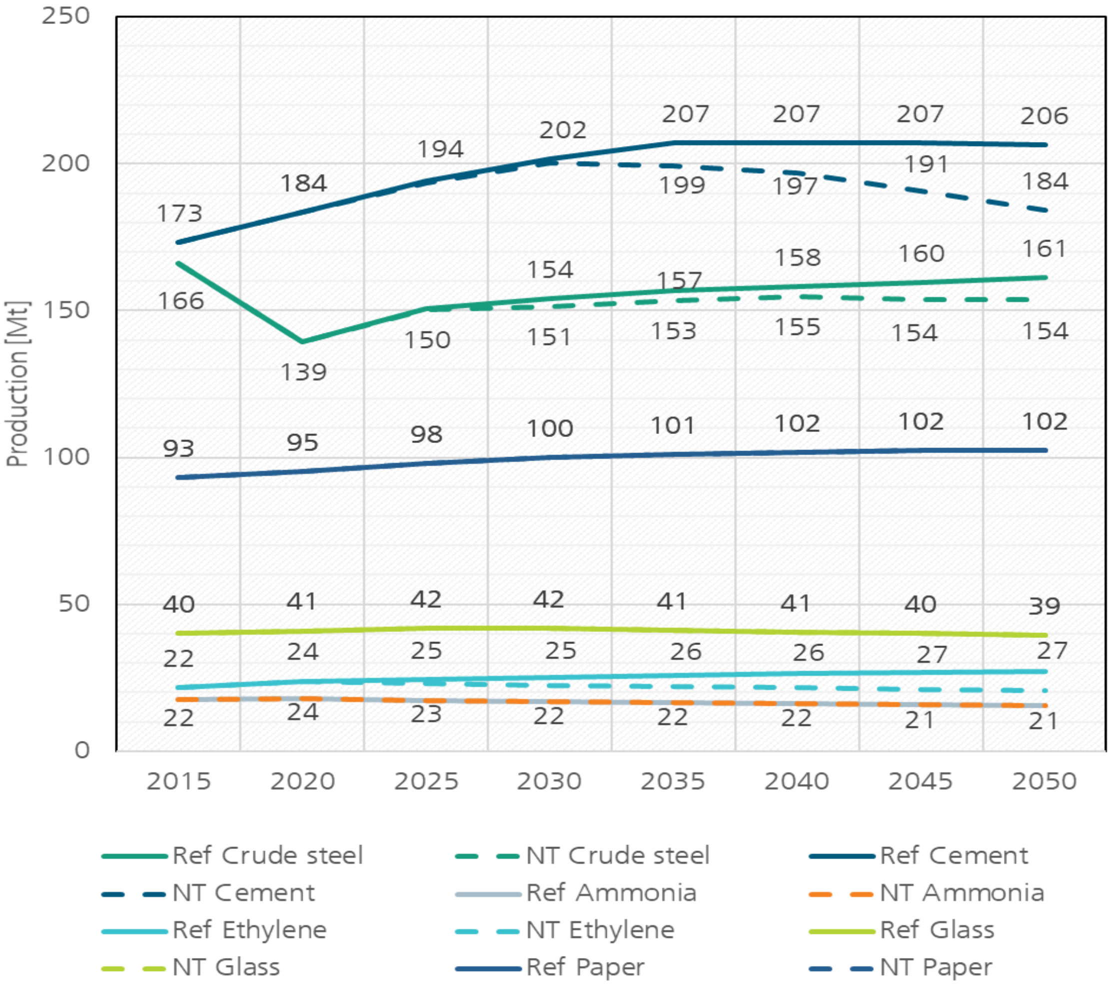
Figure 4 EU27+ UK average annual growth rate in industrial gross value added by sub-sector (2010-2050)



Assumptions on economic development, specifically in terms of GVA per sector, and material use and efficiency along the value chain and CE, lay the groundwork for the future production of major energy-intensive products in this work. In this context, similar assumptions about future physical production quantities are used for both the **Ref and Decarb Scenarios.** The same principle is also applied **to the NT and NT_Decarb Scenarios**, which both use equal assumptions about future production quantities.

In the **Ref Scenario,** we assume minimal decoupling between the GVA and the physical production outputs which means the GVA growth corresponds to the physical production output growth, indicating no additional improvements in material efficiency and material substitution across the value chain. In contrast in the **NT Scenarios,** a gradual decoupling of GVA and physical production outputs in basic industries is projected in the long term. Figure 5 shows the projection for the EU27+ UK production of selected GHG-intensive products in primary industries.

Figure 5 EU27+UK assumed production output of selected basic material products in Mt (2015-2050)



Note: Ref and Decarb Scenario use the same assumption for production output. This also applies to NT and NT_Decarb Scenarios

3.1.2.2 Iron and steel

The iron and steel industry forms a fundamental pillar of the EU27+UK economy. Accounting for 3% of the industry's GVA in 2015 and provides the backbone for industrial development, infrastructure, and construction. Furthermore, steel will also be an integral ingredient for the energy transition, supplying indispensable materials for various technologies that enable decarbonisation, such as wind turbines, electric vehicles, and advanced manufacturing processes. However, the iron and steel industry is also one of the most significant GHG emitters and was responsible for 18%[1] (157 Mt CO_2 equivalent) of the total industrial GHG

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[1] Including 1.A.2.a - Iron and Steel and 2.C.1 - Iron and Steel Production.

emissions in 2019 in the EU27+UK[2] (EEA greenhouse gases - data viewer) As such, the iron and steel industry is very carbon-intensive and its decarbonisation is essential if the EU is to meet its target of climate neutrality. Addressing this issue requires a comprehensive decarbonisation strategy considering the whole value chain, from supply chains and production processes to end-use applications.

The EU27+UK iron and steel sector is one of the largest in the world, with production surpassing 168 million tons of crude steel in 2018, and the primary production route using **blast furnaces-basic oxygen furnace (BF-BOF)** accounts for approximately 58% of steel production (world steel association 2019). This production route uses iron ore as raw material and relies heavily on coal, coke, and natural gas (NG) as reducing agents and energy carriers. The reduction of iron ore in the blast furnace to produce pig iron is responsible for most of the direct GHG emissions. The reduction reactions require high temperatures in the range of 1,100°C to 1,650°C. This production route is energy intensive requiring 22.4 GJ per ton of crude steel produced. On average, each ton of crude steel produced through the BF-BOF route is linked to 2.69 tCO2eq, of which 0.5 tCO2eq are process-related. On the other hand, the secondary production route using **electric arc furnaces (EAF)** to melt sorted steel scrap has a substantially lower specific energy consumption per ton of steel produced than the primary route (4.7 GJ/t). In addition, electricity is the main energy carrier here. This production route results in much lower emissions, on Average 0.26 tCO2eq.are emitted per ton of crude steel.

The secondary production routes, characterised by their lower energy consumption compared to primary routes, hold significant potential for decarbonizing industry, particularly when complemented by CE measures. Beyond reducing GHG emissions and climate protection measures, CE measures can also contribute to increasing industrial resilience by decreasing the dependencies on raw material imports. While secondary production routes hold significant potential to decarbonise the iron and steel industry, **they alone can't fully sustain EU steel production.** The availability of scrap of suitable quality will limit expansion towards 2050. Therefore, we also consider a shift in primary steel production from BF-BOF to **direct reduced iron (DRI).**

Sponge iron can be produced using **hydrogen in direct reduction shaft furnaces (H2-DRI).** The sponge iron produced from the H2-DRI will be melted and processed directly into crude steel using EAF. This option is currently considered by the major European steelmakers. The key advantage of this route is that the **technologies for the H2-DRI steel production are commercially available,** as existing natural gas-based direct reduction facilities can transition to operate on hydrogen. Assuming green hydrogen is used for the direct reduction in combination with renewable electricity for the EAF, this would result in GHG emissions-neutral steel. Table 1 provides an overview of the major assumptions for the iron and steel industry.

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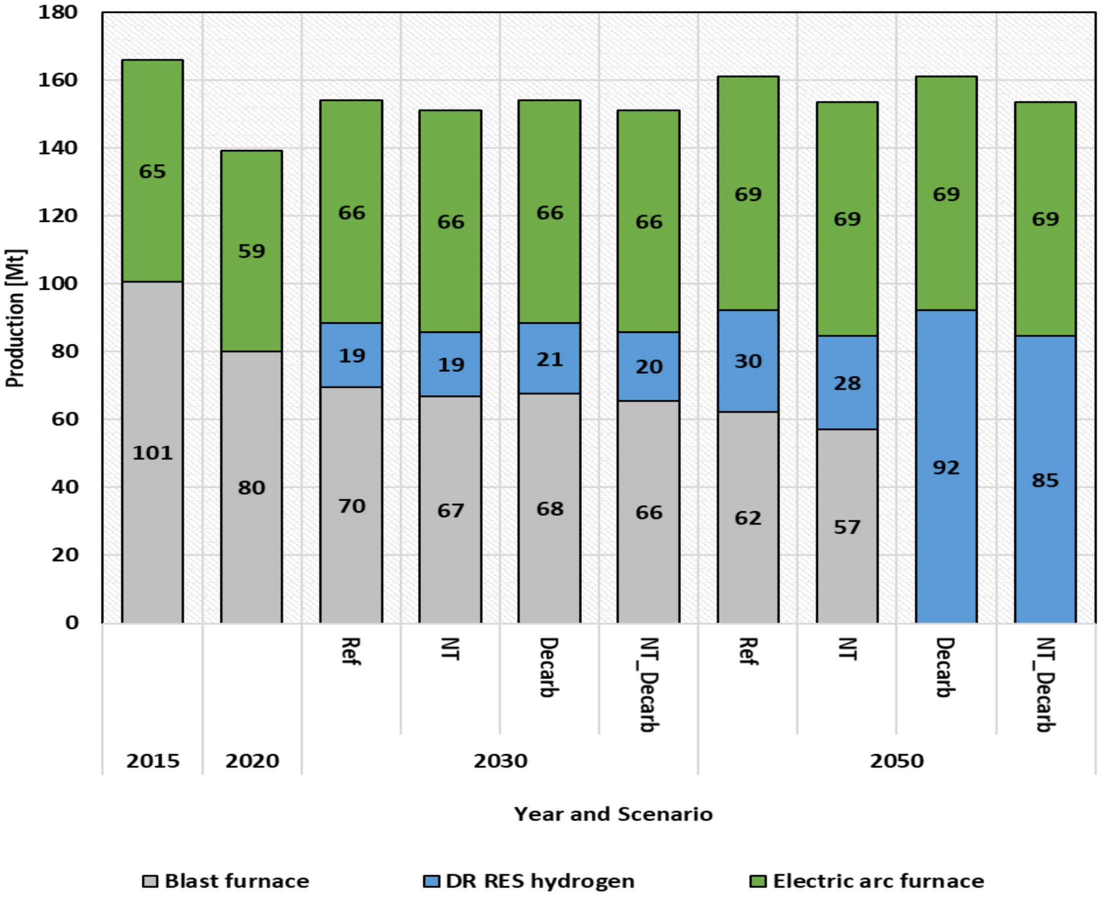
[2] Based on EUROSTAT definition, coal demand for direct reduction in blast furnaces is excluded.

Table 1 Overview of the major assumptions for iron and steel by scenario

	Ref	Decarb	NT	NT_Decarb
Circular economy	Total crude steel production decrease by ~4% in 2050 compared to 2018 (from 167 MT to 161 MT)	Total crude steel production decreases by ~9% in 2050 compared to 2018 (from 167 MT to 154 MT) based on CE actions described in the beginning of this chapter	Circular economy	Total crude steel production decrease by ~4% in 2050 compared to 2018 (from 167 MT to 161 MT)
Circular economy	Increase in EAF share from 39% (65 Mt) by 2015 to 45% (69 Mt) by 2050		Circular economy	Increase in EAF share from 39% (65 Mt) in 2015 to 43% (69 Mt) by 2050
Process switch	19 Mt H2-DRI by 2030 30 Mt H2-DRI by 2050	100% of the primary production shift toward H2-DR share by 2050 (92 Mt)	19 Mt H2-DRI by 2030 30 H2-DRI Mt by 2050	100% of the primary production shift toward H2-DR share by 2050 (86Mt)

Figure 6 shows the EU27+UK crude steel production by production route and scenario. Crude steel production data for the modelled countries has been updated based on data from the World Steel Association until 2020. However, due to the significant global disruption caused by the COVID-19 pandemic in 2020, we use 2018 as a more representative reference year for our projections and model calibration. The COVID-19 pandemic triggered 16.3% reductions in steel production. Following this considerable decline, in the **Ref and Decarb Scenarios,** we assume a robust rebound in steel demand between 2021- 2025. During the recovery period, we assume a Compound Annual Growth Rate (CAGR) of 1.54% per annum for the EU27+UK. However, this rebound is anticipated to plateau post-2035, leading to stagnant production levels from 2035 to 2050.

Figure 6 EU27+UK crude steel production by production route and scenario (2015-2050)



In the **Ref and Decarb Scenarios** the total crude steel production decreases by around 4% by 2050 compared to 2018 levels. When compared to the Ref Scenario, the total crude steel production is expected to decrease 5% further in the NT and NT_Decar) scenarios. In terms of total crude steel production, steel production decreases from 161 million tons in the Ref and Decarb Scenarios to about 154 million tons in the NT and NT_Decarb Scenarios by 2050. This decrease in the future demand for steel is caused by the moderate diffusion of comprehensive CE actions addressing construction methods and lifestyle changes such as reduced over-specification of building elements and renovation of buildings that avoids new construction.

It is assumed that the iron and steel industry will undergo a transformative shift, starting to abandon the use of coal as a reducing agent in favour of routes that reduce iron using H2-DRI with EAF. However, the pace of this transition varies across different scenarios.

By 2030, the production capacity in the **Ref and NT Scenarios** is projected to increase to approximately 19 Mt. An even more ambitious capacity increase is assumed in the **NT_Decarb and Decarb Scenario**s, with an increase to 20 Mt and 21 Mt respectively. These projections are in line with the capacity announced by major steel manufacturers and complement the strategies outlined in the RepowerEU and EU Hydrogen Strategy (Hydrogen) (REPowerEU). In the Ref and NT Scenarios, based on projected CO_2 and energy carrier prices, the H2-DRI process is expected to become economically viable between 2038 and 2042, depending on the specific country. Consequently, the capacity is projected to further increase to 30 Mt and 28 Mt by 2050, respectively. In the **NT_Decarb and Decarb Scenario** we assume that H2-DRI will fully replace blast furnace primary steel production by 2050 (see Figure 5)

Across all scenarios, the secondary steel production capacity in the EU27+UK is expected to rise from 65 Mt in 2015 to approximately 69 Mt by 2050, a net increase of about 4 Mt. This increase is limited by the availability of scrap. Consequently, a further increase in secondary production is not possible, even in the **NT** and **NT_Decarb Scenario**s. Nonetheless, the share of secondary steel production differs upon scenarios. In the **Ref and Decarb Scenario**s the share of secondary steel production is expected to increase from 39% in 2015 to approximately 43% by 2050, while in the **NT_Decarb Scenarios** the share increases to 45Mt. This relative increase is caused by the decline in overall steel demand.

3.1.2.3 Cement and lime

Cement and lime will play a significant role in decarbonizing the EU Economy offering core materials for renewable energy systems. Yet, the cement and lime industry are also a prominent source of GHG emissions, responsible for 12% (97 Mt CO_2 equivalent) of the total industrial GHG emissions in 2019 in the EU27+UK (EEA greenhouse gases - data viewer).

The production process of cement and lime is linked to considerable GHG emissions, primarily from two sources. The first source of GHG emissions originates from the burning of fossil or fossil-derived fuels such as plastic or tires. This combustion is necessary to generate the high heat required in the production processes - approximately 1200°C for cement and 900°C for lime. The second source of emissions, known as process-related emissions, are a direct result of the calcination process. Both cement and lime production rely on limestone (calcium carbonate, $CaCO_3$) as the primary raw material. During calcination, limestone is heated to high temperatures, causing it to decompose into lime (calcium oxide, CaO) and carbon dioxide (CO_2). This CO_2 is subsequently released into the atmosphere, contributing significantly to the industry's GHG emissions. The calcination process alone accounts for 0.53 tCO_2-eq. per ton of cement and between 0.73 to 0.78 tCO_2-eq. per ton of lime. Process-related emissions cannot be avoided if limestone is to be used as raw material. Nonetheless, the process-related emissions can be mitigated using technologies such as carbon capture, utilisation, and storage (CCUS).

Although significant efforts have been made in improving energy efficiency by improving the thermal efficiency of kilns, and using alternative fuels, these alone are insufficient to meet the ambitious reduction targets set out by international climate agreements. Therefore, innovative production routes are being explored to reduce process-related emissions. A pivotal strategy is to decrease the clinker-to-cement ratio, reducing the carbon intensity of the final product. The use of supplementary cementitious materials (SCMs) like Pulverized Fly Ash, natural pozzolans and Burnt shale. Current research and development efforts focus on creating favourable conditions for CCUS. However, the successful implementation of these CCUS will depend not only on technological advances but also on acceptance and regulatory support. Therefore, there is a need to reduce the demand for concrete, for example by optimising the concrete composition, minimising the binder phase and maximising the use of aggregates.

In addition to the strategies mentioned above, integrating further CE actions can contribute significantly to decarbonisation of the cement and lime industry. Comparable to the iron and steel sector, we consider a moderate diffusion of comprehensive CE actions, which influence both construction methods and lifestyle. Similar to steel, the renovation of buildings and the reduced over-specification have the highest impact on cement demand. However, timber construction and the reduced floor space demand in residential and office buildings make a significant contribution. Table 2 provides an overview of the major assumptions for the cement and lime industry.

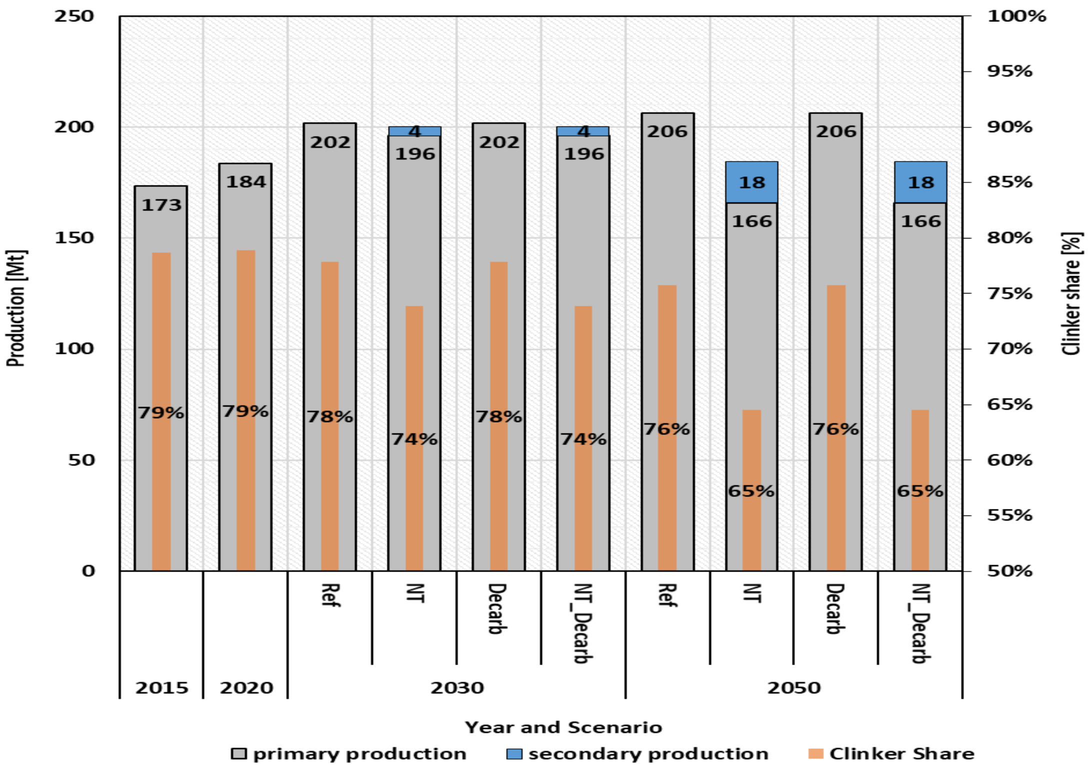
Table 2 Overview of the major assumptions for cement and lime by scenario

	Reference	Decarbonisation	NT	NT_Decarbonisation
Circular Economy	Increase by 15% in total cement production compared to 2018		Increase by 3% compared to 2018 based on CE actions (see p.26)	
Clinker Factor	No change clinker factor EU average 0.77		Decrease in the clinker share from 0.77 to 0.65 by 2050	
Process switch	No low-carbon types of cement enter the market and substitute	Low-carbon types of cement enter the market and substitute around 10 % by 2050 (18 MT)	Process switch	No low-carbon types of cement enter the market and substitute
CCS	CO_2 capture at limited sites	CO_2 capture at most plants by 2050	=Reference	=Decarbonisation

Cement production data for the modelled countries has been updated based on the figures available until 2019. As shown in Figure 7, in the **Ref** and **Decarb Scenarios**, the cement production increases significantly (by approximately 30 Mt), leading to a total output of 206 Mt by 2050. Approximately two thirds are expected to occur within the 2020 to 2030 period. This trend aligns with the macroeconomic framework data, which assumes a Compound Annual Growth Rate (CAGR) for Non-metallic minerals of 2.4% during this period. Consequently, clinker production also increases in these scenarios the clinker share does not change in these scenarios.

On the other hand, in the **NT** and **NT_Decarb,** we assume a more modest increase of 5 Mt in cement production compared to 2018 levels, reaching 185 Mt by 2050. The reduction compared to **Ref** and **Decarb** is caused by the described CE actions. Furthermore, these scenarios also anticipate a decline in the average clinker share by 12%, resulting in a 65% share by 2050. This decrease reflects a strategic focus on reducing the clinker content in cement, thereby lowering the associated process-related CO_2 emissions. While it would be possible to lower the clinker content further, the availability of the clinker substitutes described above as well as the technical applicability is limited. Finally, we assume in the **NT** and **NT_Decarb** CCS and CCU are used to capture the reaming process-related emission in the cement and lime production.

Figure 7 Cement production by production route and scenario (EU27+ UK)



3.1.2.4 Chemical industry

The chemical industry, an integral part of the EU industry in 2019 accounted for 15% of industry GVA. Despite its economic and strategic significance, the sector is characterised by heavy reliance on fossil fuels for both energy and feedstock demand. Between 2015 and 2019, the chemical industry's average annual final energy demand stood at a substantial 1678 TWh, with 83% of this demand being fossil fuels. The industry is diverse, producing an array of chemicals ranging from petrochemicals, pharmaceuticals, and polymers. However, despite the industry's broad spectrum of output, most of its energy demand and associated GHG emissions can be attributed to a limited number of production processes in particular, the production of High-Value Chemicals (HVC), ammonia, and, methanol. In 2019, the chemical industry contributed to 61 Mt CO_{2equ} (7% of industrial GHG emissions), with ammonia production and HVC emerging as the largest contributors (Statistics | Eurostat 2022). An additional source of emissions arises from the GHG embedded emissions in chemical products, such as plastics. When these products reach the end of their life and are disposed of, the embedded carbon is released, contributing further to GHG emissions. This presents an often overlooked, yet significant source of emissions within the chemical industry.

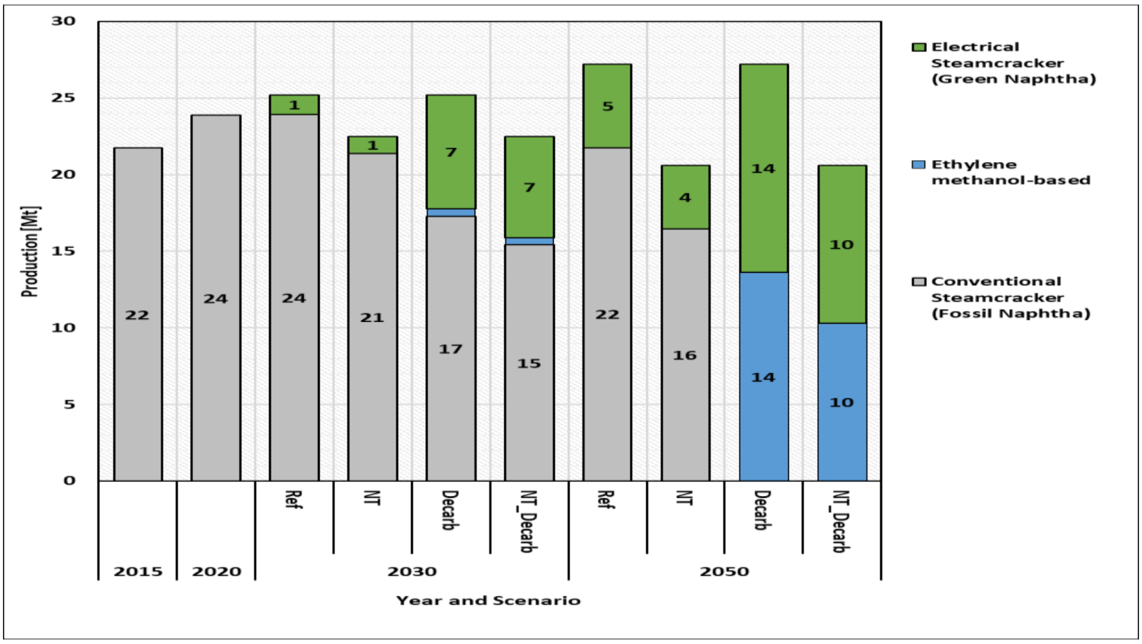
Chemicals such as ammonia, methanol, and HVC such as ethylene serve as feedstock (raw material) for various downstream industries. Ethylene (C_2H_4), for instance, is building block for many plastics and synthetic materials, whereas ammonia (NH_3) is used primarily in the production of nitric acid (HNO_3) for fertilisers. Currently, these chemicals production route predominantly relies on fossil fuels as both feedstocks and energy carriers. HVCs are produced by steam cracking (SC), which primarily uses naphtha derived from crude oil. Whereas ammonia is produced by the Haber-Bosch process, combining nitrogen from the air with hydrogen from natural gas steam-methane reforming (SMR), which is also used to produce Methanol.

Table 3 Overview of the major assumptions for chemical industry by scenario

	Reference	Decarbonisation	NT	NT_Decarbonisation
Material efficiency	13% decrease in Ammonia compared to 2015 15% increase in Ethylene production compared to 2018		13 % decrease in Ammonia from 18 MT to 15 MT by 2050 13% decrease in Ethylene compared to 2018	
Process switch Ammonia	43 % Feedstock H2 for ammonia	100 % Feedstock H2 for ammonia	=Reference	=Decarbonisation
Process switch High-Value Chemicals	MTO 20% ESC with Green Naphtha in countries where it is cost-effective.	50% MTO50% Electrical Steam Cracker	=Reference	=Decarbonisation

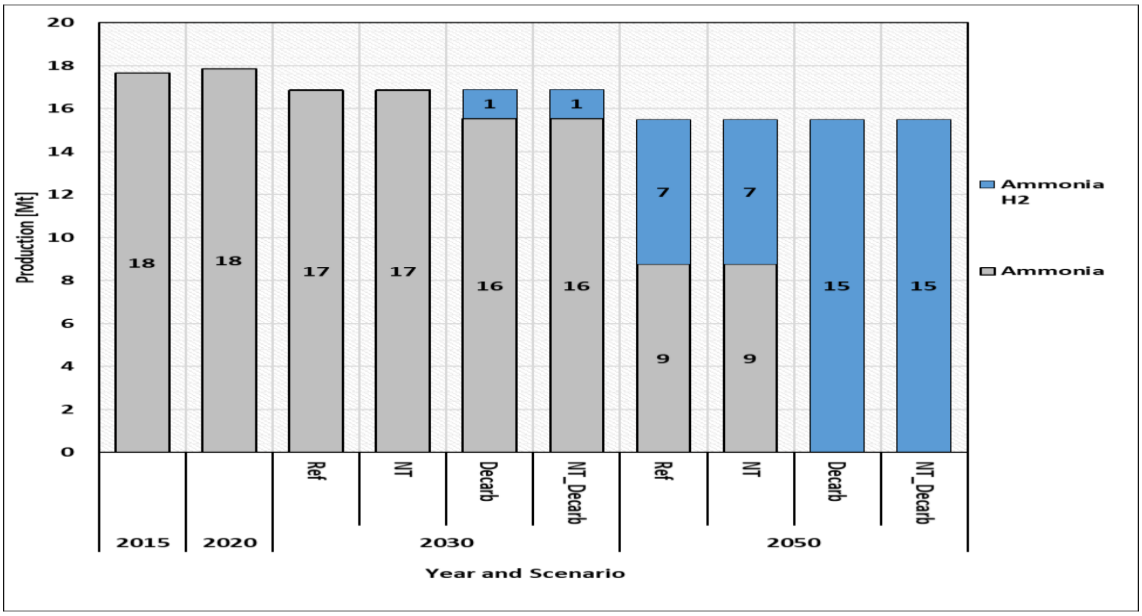
Figure 8 provides an overview of the major assumptions for the chemical industry. In the **Ref** and **Decarb Scenarios,** ethylene production within the EU27+UK is projected to increase by 15% by 2050 compared to 2018 levels, reaching approximately 27 million tons (Mt). On the contrary, in the **NT** and **NT_Decarb Scenarios** significant advancements in plastic recycling and CE measures are anticipated to result in a 13% decrease in ethylene production by 2050, dropping to around 20 Mt. Furthermore, for the **Ref** and **NT** Scenarios, we project that green naphtha and Electrical Steam Crackers (ESC) will reach 20% of ethylene production. In contrast, in the **Decarb** and **NT_Decarb Scenario**s, we assume 50% shift of ethylene production to the Methanol-to-Olefins (MTO) process. The MTO process uses methanol, derived from CO_2-neutral hydrogen and captured carbon dioxide, to produce HVC such as ethylene and propylene. The remaining 50% of HVC production will be based on green naphtha and electrical steam crackers (ESC).

Figure 8 Overview of the major assumptions for the chemical industry by scenario



As for ammonia, production is assumed to decrease by 13% in all scenarios. However, in the **Ref** and **NT Scenarios**, we assume that ~43% of the ammonia production will utilise CO_2-neutral hydrogen by 2050. In the **Decarb** and **NT_Decarb,** we assume that 100% shift toward CO_2-neutral hydrogen by 2050 (Figure 9).

Figure 9 EU27+UK Ammonia production by production route and scenario (2015-2050)

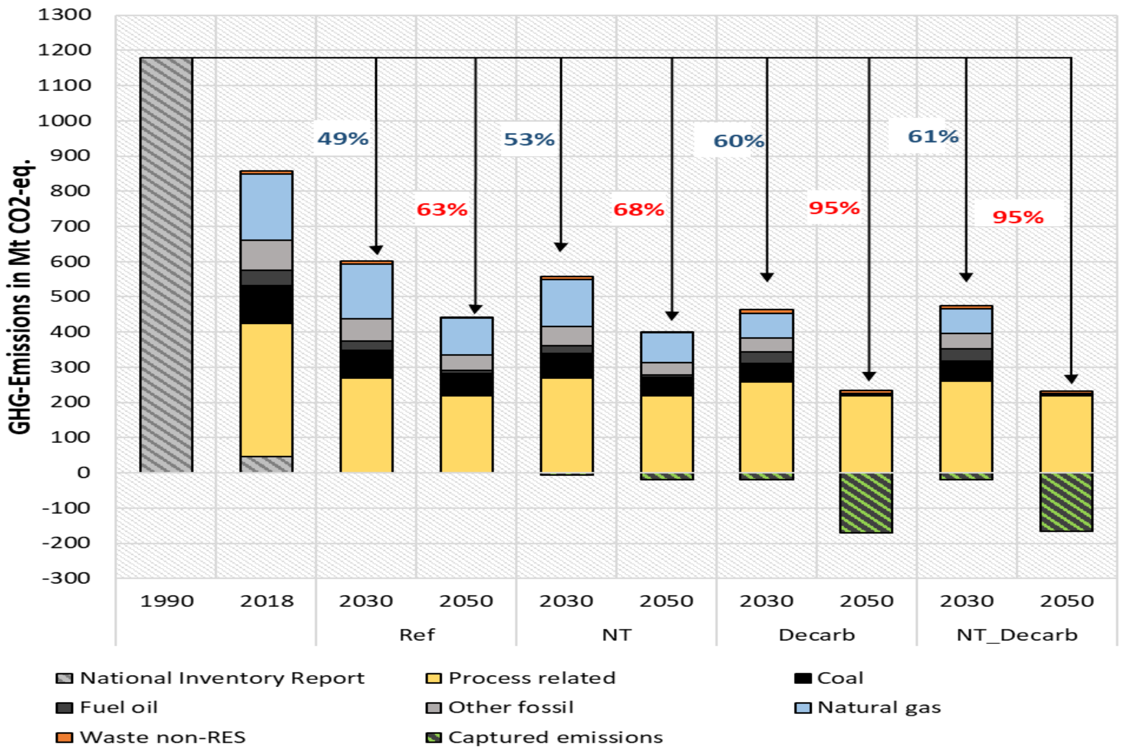


3.1.3 Results

Within this section, our primary focus is to assess how CE affects GHG emissions and overall energy demands. We will also dive into the specific impacts on key energy carriers of the future, such as hydrogen and electricity. Figure 10 shows the development of total GHG emissions by sources and scenario for the EU27 + UK. In the **Ref Scenario**, which considers current policies and trends, a further reduction of GHG emissions is anticipated, resulting in an estimated total of **600 Mt CO_2-equivalent** by 2030. This corresponds to a reduction of **49%** in industrial GHG emissions compared to 1990 levels.

By 2050, the **Ref Scenario** projects a reduction of approximately **63%** compared to 1990 levels. The **NT Scenario** includes additional modelling considering emerging **new societal trends**. Compared to the Ref Scenario, the NT Scenario results in a further decrease in industrial sector GHG emissions to **552 Mt CO_2-eq by 2030,** which represents a 53% decrease relative to 1990. **Ref and NT Scenarios by 2030** is about 43 Mt CO_2-eq, a discrepancy primarily attributable to the broader implementation of CE measures.

Figure 10 Overview of the development of the EU27+UK GHG emission by sources and scenario in the industry sector



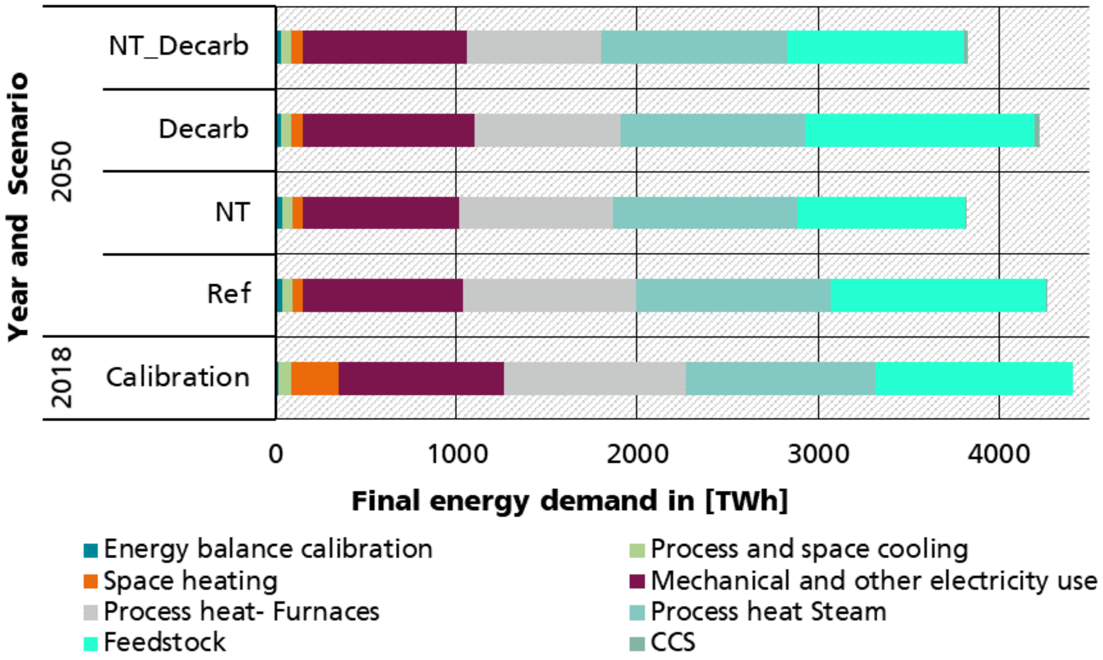
Source: 1990 national inventory report rest FORECAST

The **Decarb and NT_Decarb Scenarios** represent ambitious pathways, encompassing more progressive decarbonisation strategies compared to the Ref Scenario. In these scenarios, industrial sector GHG emissions are projected to decrease to ~445 Mt of CO_2-eq by 2030, representing a ~60% decrease with respect to 1990 levels. This highlights a substantial rise in ambition, especially given the limited timeframe to accelerate the transition. Moving towards 2050, the reduction in GHG emissions intensifies, resulting in a decrease of about 95% compared to 1990 levels. This reduction includes approximately **170 Mt CO_2-eq and 165 Mt CO_2-eq of captured emissions** from cement and lime plants in the Decarb and NT_Decarb Scenarios respectively. The two main drivers facilitating the additional GHG reduction by 2030 **Decarb and NT_Decarb accelerate the fossil fuel phase-out, particularly of gas and coal, and the transition towards climate-neutral manufacturing processes.** Increasing CO_2 prices and support for hydrogen-based steelmaking accelerate the reduction in coal use, replacing all coal-intensive BF-BOF by 2050 CO_2-eq. The remaining process-related GHG emissions mainly originated from the cement and lime industries are captured. A few more site-specific heterogeneous sources of process emissions that are too small to utilise CCS remain. Overall, the **Decarb Scenario and NT_Decarb** show a very fast and comprehensive decarbonisation of the industry sector.

3.1.3.1 Total energy demand and energy carrier mix

This section presents the results of the total industrial energy demand, which consists of final energy demand (FED) as defined by Eurostat plus the demand for energy carriers used as raw materials in the chemical industry and iron and steel (feedstocks). In the calibration year 2018 the EU27+UK industry TED was 4,408 TWh, with the chemical industry accounting for the highest energy demand (39% of TED), followed by the iron and steel industry (14%) and non-metallic mineral products (10%). Figure 11 shows the TED in 2018 and 2050 by scenario and end uses. Process heating was the largest end-use, making up to 47% of TED, followed by Feedstock for the chemical industry (25%) and mechanical energy (18%).

Figure 11 Projected total energy demand in the industry in the 2018 and 2050 scenario and by end-use (EU27+UK, 2018 and 2050)

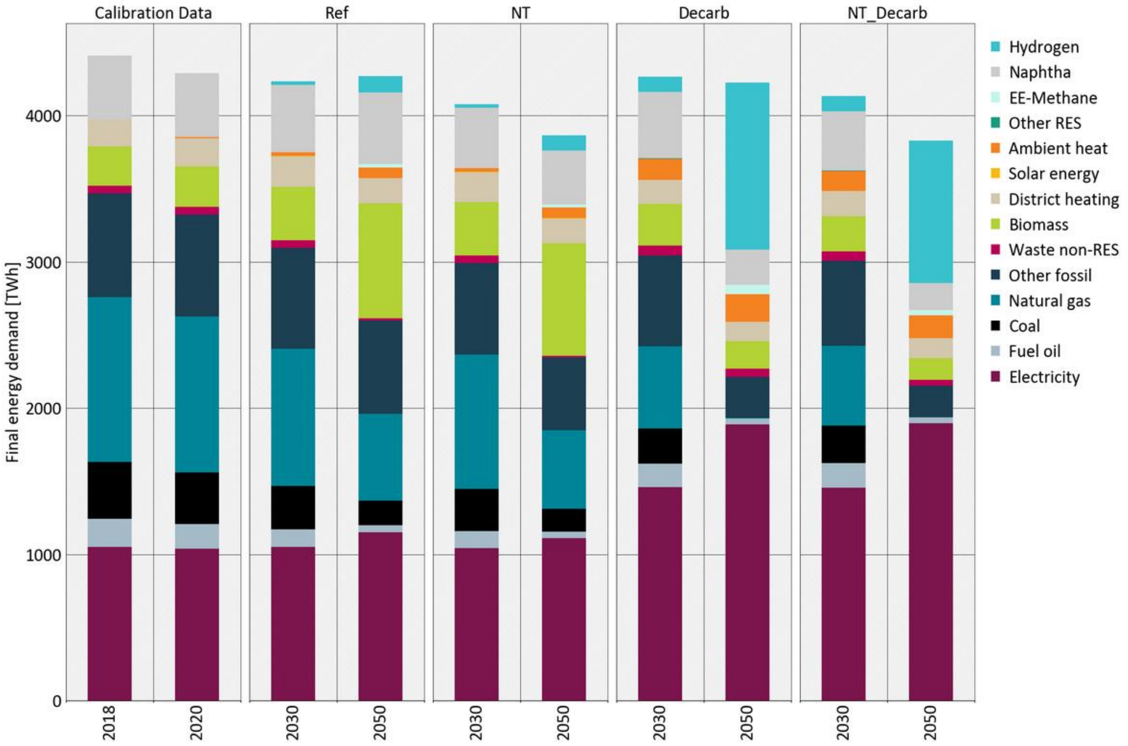


Note: 2018 is based on Eurostat, and the end-use balance is based on the method from FORECAST model (Rehfeldt et al. 2018)

The process heating energy demand breaks down relatively equally into high-temperature process heating in furnaces (>500°C) and low- and medium-temperature process heating for steam and hot water generation. In terms of future trajectories, the FED for high-temperature process heating in furnaces is projected to decrease. In comparison to the calibration year 2018, in the Ref Scenario, it decreases by 6%, and in the NT Scenario, it decreases by 16%. More significant reductions are observed in the Decarb Scenario (20%) and the NT_Decarb Scenario (27%). **This significant decrease in TED across all**

scenarios is primarily driven by the CE measures, leading to a shift from primary to secondary production routes, which are often substantially more energy-efficient. For instance, the FED for high-temperature processes in the iron and steel industry is expected to decrease across all scenarios: by 13% in the Ref, 19% in the NT, 16% in Decarb, and 22% in NT_Decarb by 2050. Even more significant reductions are projected in the high-temperature processes in the chemical sector, particularly, in the Decarb 40% and NT 46% in NT_Decarb. Figure 12 shows the development of TED by energy carriers. Across all scenarios, there is a continuous decrease in TED between 2018 and 2050. Compared to 2018 TED decrease by ~ 3% from 4408 TWh to 4267 TWh, in Ref by 2050. A more significant reduction of around 12% is observed in the NT Scenario, with the TED projected to reach about 3863 TWh.

Figure 12 Projected final energy demand plus feedstock demand in industry by scenario and energy carrier (EU27+UK)



Note: 2018 is based on Eurostat and the rest are based on FORECAST

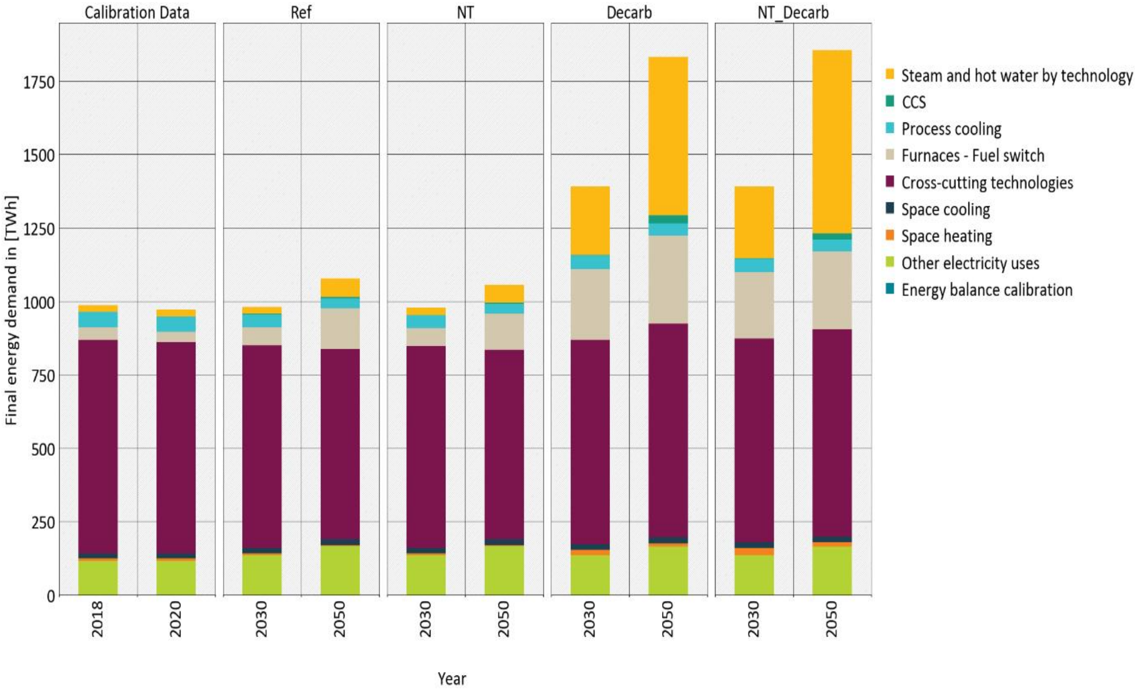
This substantial decrease can be mainly attributed to accelerated circular economy measures and enhanced across the industry, hinting at the substantial impact, these measures can have on overall energy demand. The Decarb Scenario anticipates a 4% decrease in the TED, a slightly greater reduction than the Reference Scenario. This greater decrease results primarily from efficiency improvements driven by the adoption of state-of-the-art technologies across the industry. In the most ambitious scenario, the NT_Decarb, TED decreases by 14%, reaching 3825 TWh by 2050. This scenario highlights the potential of combining circular economy measures, and state-of-art technology adoption, in reducing energy demand.

The energy mix across all scenarios reveals a shift in energy carriers towards climate-neutral sources. Specifically, the demand for electricity and hydrogen, and to a certain extent, biomass increases substantially across all scenarios. Electricity and hydrogen are two key energy carriers in the decarbonisation of process heat.

Figure 13 shows the development of direct electricity demand by scenario and end-use. In terms of electricity consumption, there is a clear upward trend across all scenarios, increasing from roughly 1005 TWh in 2018 to about 1150 TWh in the Ref Scenario, and slightly less, about 1110 TWh, in the NT Scenario by 2050. Despite this increase, no significant change in the end-use applications of electricity is observed. The increase is mainly attributed to the adoption of secondary production routes such as EAF and ESC.

In the Decarb and NT_Decarb Scenarios, electricity demand increases to approximately 1890 TWh, almost double that of the Ref Scenario. **This significant increase is driven mainly by the use of electricity for low and medium-temperature applications such as industrial heat pumps and electrical boilers**. Electricity demand for low and medium temperature grows from 22 TWh in 2018 to nearly 540 TWh and 623 TWh in the Decarb and NT_Decarb Scenarios respectively (Figure 13). The increased utilisation of electricity is supported by the fact that technologies **are ready and commercially available for this temperature level**.

Figure 13 Electricity demand by scenario and energy carrier (EU27+UK, 2018-2050)



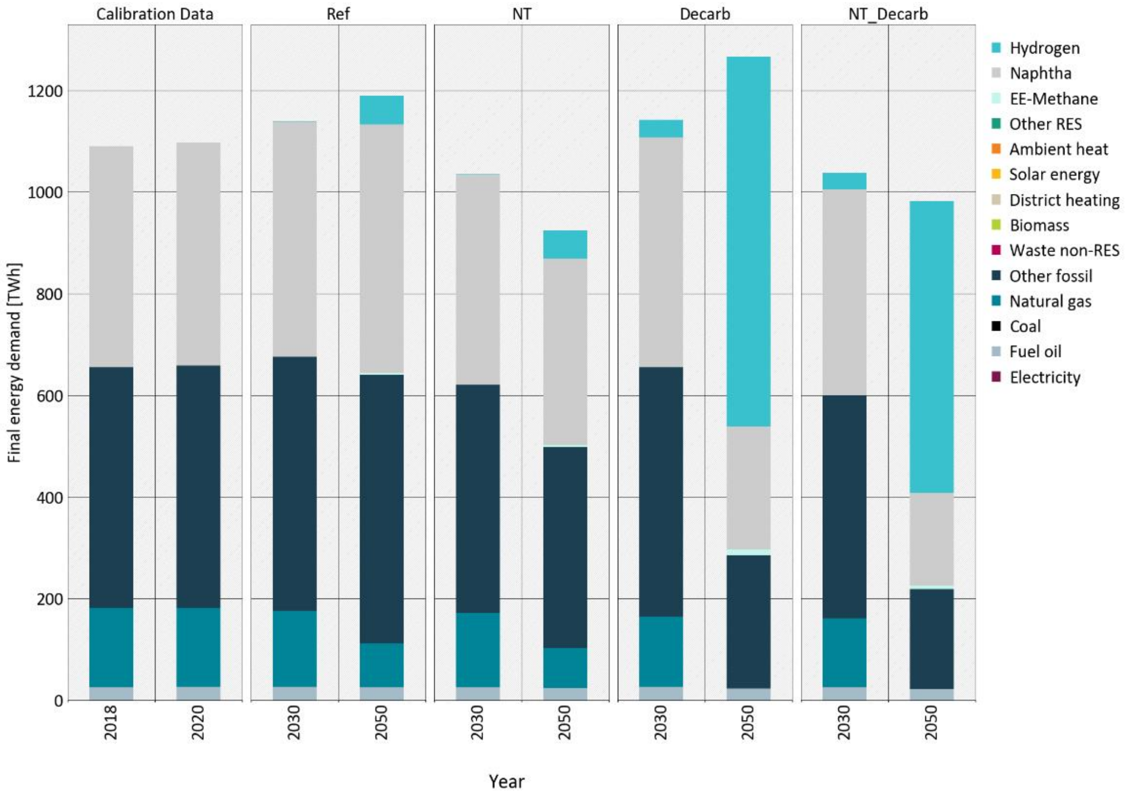
Note: 2018 is based on Eurostat and the rest are based on FORECAST

These findings emphasise the critical role of transitioning to electricity-based process heat technologies, particularly for low and medium-temperature applications, where technologies are mature and commercially available. However, the Ref Scenario indicates that in the absence of a proactive strategy, historical trends favouring fossil fuels may continue. **As such, there is a pressing need for clear policy direction providing a level playing field for carbon-neutral technologies.** This could be achieved through targeted incentives or regulatory measures that support the development, commercialisation, and rollout of innovative climate-neutral technologies.

High-temperature applications also in Decarb and NT_Decarb see a boost in electricity consumption. This trend is driven by the adoption of technologies such as EAF, induction and resistance heating applications, which result in an increase from 42 TWh to about 297 TWh in Decarb and 265 TWh in NT_Decarb Scenarios. It is worth mentioning that the deployment of CCSU technologies will result in an additional demand of about 30 TWh of electricity.

The role of hydrogen as an energy carrier for industrial transformation varies across different scenarios. **In the Ref and NT Scenarios, hydrogen plays a minor role from a system perspective, with limited demand concentrated in specific clusters within the iron and steel industry and niche products within the chemical industry.** The demand in these scenarios approximates around 110 TWh, therefore, the hydrogen economy's development in these scenarios remains limited.

Figure 14 Feedstock demand in the (petro-) chemical industry by scenario and energy carrier (EU27+UK, 2018-2050)



Note: 2018 is based on Eurostat and the rest are based on FORECAST

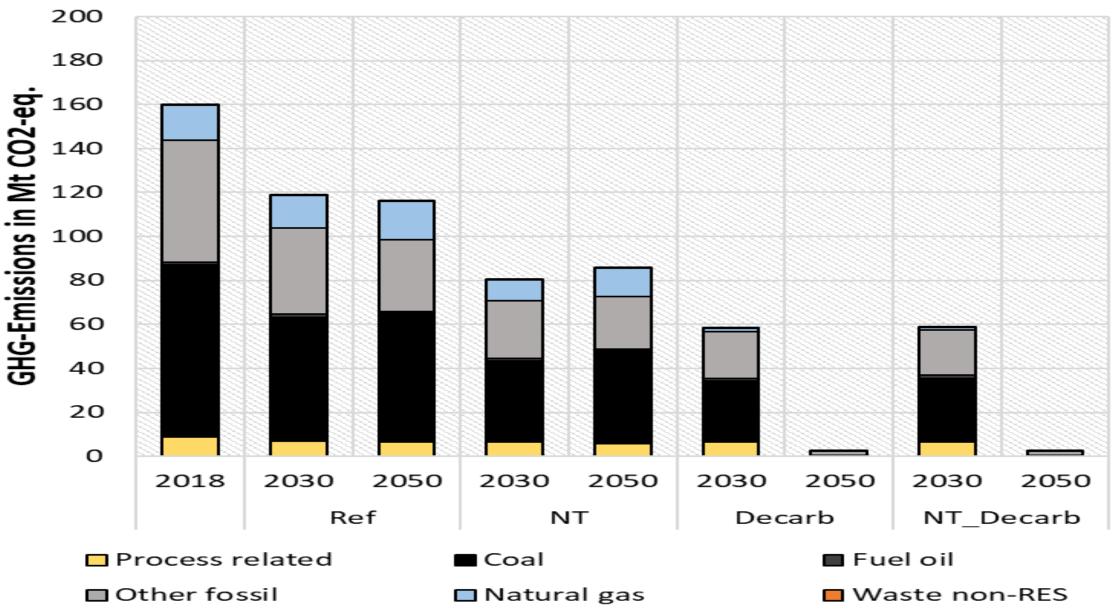
Contrarily, in the Decarbonisation (Decarb) and New Trends Decarbonisation (NT_Decarb) Scenarios, hydrogen gains substantial importance, especially in the long term. The transformation of the chemical sector primarily drives a substantial increase in hydrogen demand. Currently, the feedstocks for chemical production are based entirely on fossil fuels, mainly naphtha and natural gas, and accounted for around 1090 TWh in 2018 (Figure 14). The emissions from the conventional production of ammonia, methanol, and ethylene can be mitigated by shifting to alternative process routes and utilising green hydrogen as a clean energy carrier.

In the Decarb and NT_Decarb Scenarios, the chemical industry's hydrogen demand is projected to take off from 2025 with demonstration leading to 30 TWh of H2 by 2030. By 2050, in the Decarb Scenario, the hydrogen demand is projected to reach around 754 TWh. In the NT_Decarb Scenario, the hydrogen demand is significantly lower, reaching about 600 TWh by 2050. This difference of approximately 155 TWh underlines the potentially significant impact of CE measures in the chemical sector, suggesting that further emphasis on these strategies could yield substantial gains in reducing the hydrogen demand. In the iron and steel industry, hydrogen demand for H2-DRI is anticipated to reach approximately 232 TWh in the Decarb Scenario, and about 212 TWh in the NT_Decarb Scenario.

3.1.3.2 The Role of Circular Economy at subsector level

Figure 15 below shows the development of total GHG emissions for the iron and steel industry by sources and scenario for the EU27+UK. In the Ref Scenario, the GHG emission projects a modest reduction by around 27% by 2050, compared to 2018. This reduction is primarily driven by the switch towards H2-DRI - which result in around 48% reduction in the coal demand in 2050 - and an increase in the share of EAF. In the NT Scenario, GHG is projected to decrease by approximately 46%, this is mainly attributed to the introduced CE measures. Both Decarb and NT_Decarb achieve a 99% reduction in the GHG driven by the full diffusion of innovative GHG-neutral production routes.

Figure 15 Overview of the development of the iron and steel GHG emission for the EU27+UK by sources and scenario in the industry sector

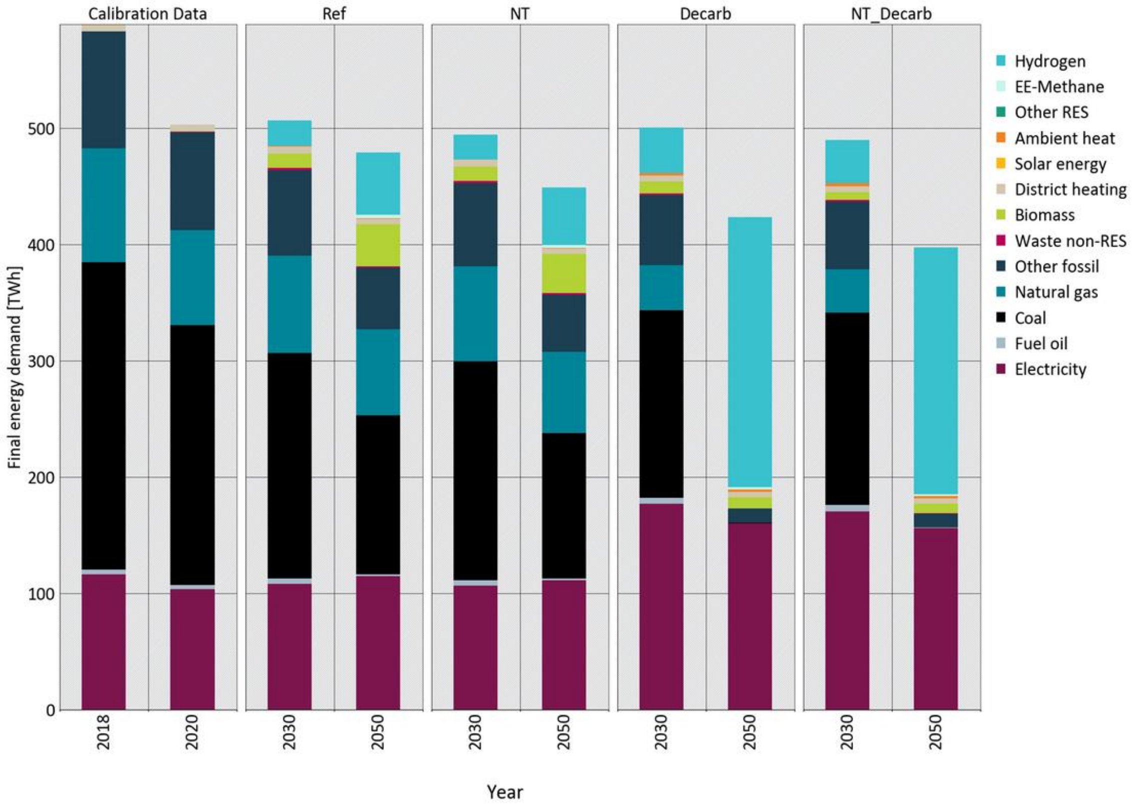


Source: FORECAST

Figure 16 shows the development of FED in the iron and steel industry scenario and by energy carrier. In terms of FED in the iron and steel industry, a decrease is projected across all scenarios. Compared to the Ref Scenario, the FED decreases by approximately 6%, while the NT-Decarb Scenario projects a decrease of around 12%. More substantial decreases in the FED are projected in NT_Decarb Scenarios, by about 17%.

Hydrogen plays a central role in decarbonising the EU's iron and steel industry. In GHG neutral scenarios, the **hydrogen demand for iron and steel varies from 210 to 230 TWh** in Decarb and NT_Decarb respectively. As for electricity demand, there is an increase in the Decarb and NT_Decarb Scenarios, reaching approximately 160 TWh, compared to 111 TWh in Ref.

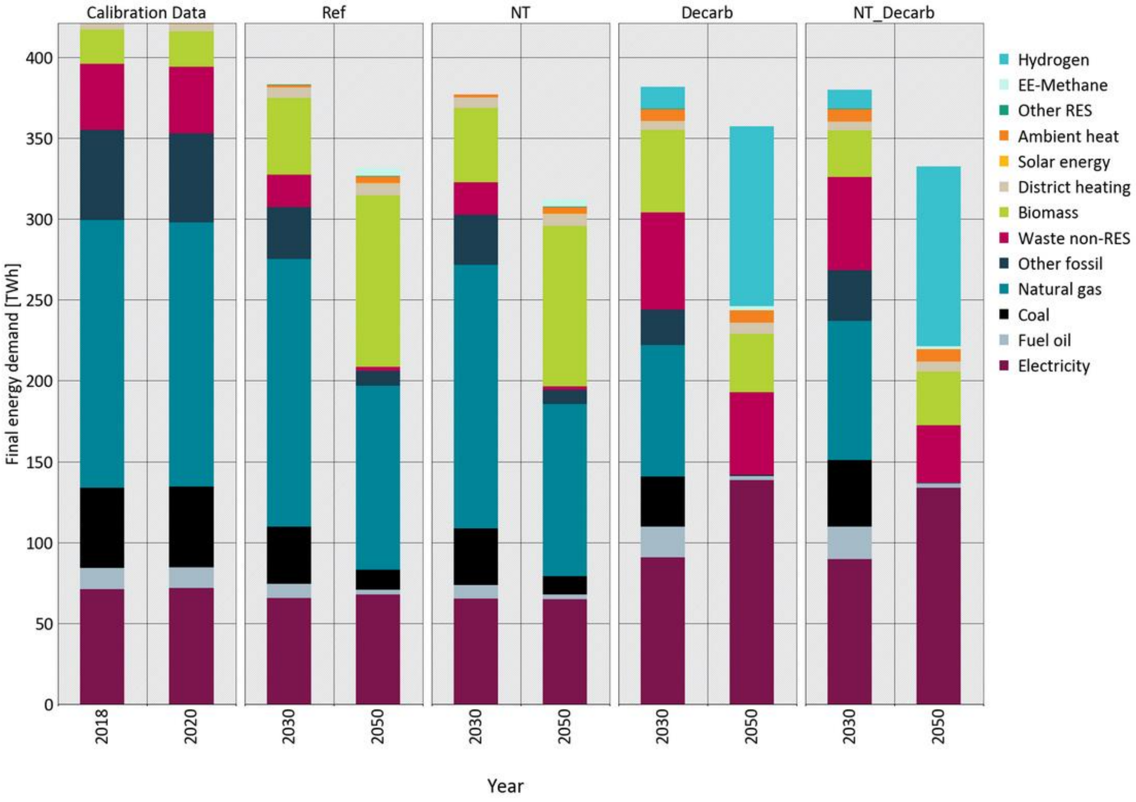
Figure 16 Projected final energy demand in iron and steel industry by scenario and energy carrier (EU27+UK)



Source: 2018 is based on Eurostat and the rest are based on FORECAST

For the non-metallic minerals sector, which includes cement production, the FED is projected to decrease across the various scenarios. In the Ref Scenario, the FED decreases by about 21%, while in the NT Scenario, the FED higher reduction is projected by approximately 26%. Interestingly, in the GHG neutral scenarios (Decarb and NT_Decarb) the FED reductions are less than in the Ref Scenario. This is due to the electrification of cement heating processes. This transition, while beneficial in terms of reducing GHG emissions, however, increases the FED of the production process.

Figure 17 Projected final energy demand in non-metallic mineral by scenario and energy carrier (EU27+UK)



Note: 2018 is based on Eurostat and the rest are based on FORECAST

3.2 TRANSPORT

This chapter outlines the main features of the model used, as well as the assumptions and results of the modelling performed in the transport sector.

3.2.1 PRIMES-SHAREMD: key features

The aim of the PRIMES-SHAREM Demand model is to identify and quantify the determinants (factors and reasons) that drive the selection of different mobility options. Hence, the focal points of the model's mechanism are the dynamics that affect the decision making of the users on shared mobility options.

The factor that affects commuters' choice the most has been found to be the total costs of the transport service. The total costs are divided into two main categories:

- Private costs (actual costs): that include purchase and operation and maintenance (O&M) of the vehicle, affecting the total cost of ownership (TCO)

- Hidden costs: i) social status / pride, ii) security / comfort arising from instant availability, iii) accessibility iii) privacy, iv) health concerns / safety and v) cost of time.

Even though contemporary shared mobility options like carpooling cost less than private mobility options, there is no significant transition towards shared mobility options (Bachmann et al., 2018). This indicates that hidden costs and not private costs affect user choices the most.

This has guided the focus of modelling towards:

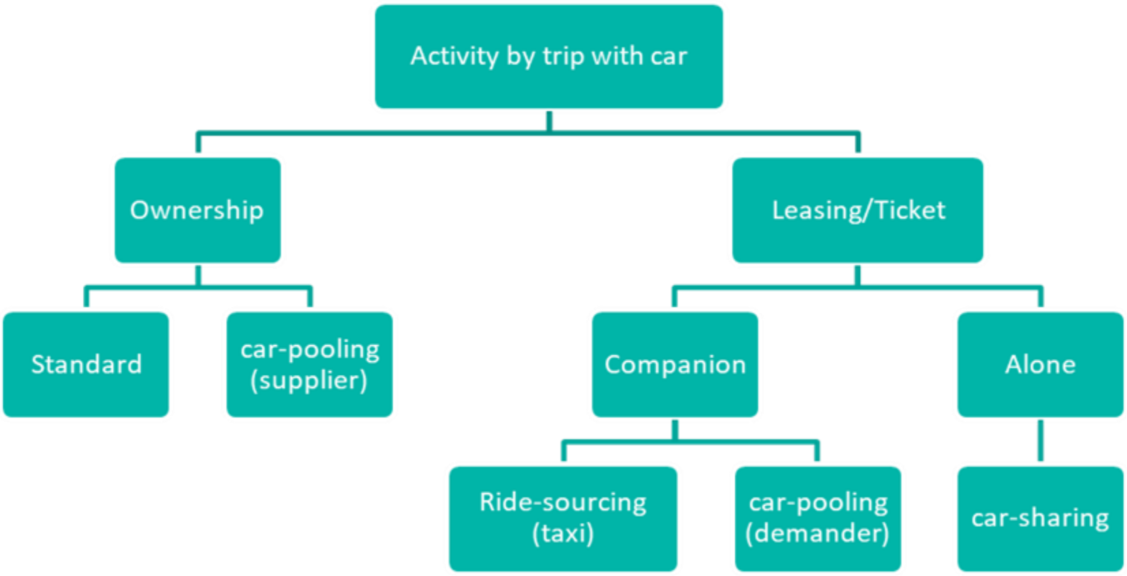
- Explicit representation of private and hidden costs
- Dynamic representation of how these costs change over time (endogenous, semi-endogenous, exogenous)

The model puts emphasis on the representation of households and users' behaviour as a utility function: utility maximisation for households and passenger transport and cost minimisation taking into account budget and other constraints.

In economics, discrete choice models or qualitative choice models describe, explain and predict choices between two or more discrete alternatives, such as choosing between modes of transport, choosing amongst different mobility options, through the use of logit functions.

These are also applied in the PRIMES-SHAREM Demand model, in which the allocation of the activity of an upper level between lower-level mobility options is defined using logit functions. The decisive variable inserted in the logit function in order to calculate the shares of the lower-level mobility options is the generalised cost of transport. The logit function compares the costs of the available choices of the lower-level mobility options (e.g. ride sourcing, carpooling, car sharing) and defines the share of every mobility option in the composition of the activity of the upper level. The above description of the mathematical structure of the PRIMES-SHAREM Demand model is summarised in Figure 18.

Figure 18 The nesting tree structure of the PRIMES-SHAREM Demand model



The choice over shared mobility options depends dynamically on the following factors:

- The income of the decision maker
- The characteristics of the trip (i.e. rural/urban/motorway/metropolitan, peak/off-peak, short/long, commuting/business/non-working)
- Environmental considerations (for the development of different scenarios with different decarbonisation policies)
- Total costs: actual and hidden costs

The logit functions are used to represent heterogeneity of preferences of individual consumers.

The PRIMES-SHAREM Demand model includes further heterogeneity by distinguishing households with different preferences in the choice of mobility option. Thus, for a better representation of household behaviour, the model includes ten different households distinguished by their income (from very low to very high income). Each household will maximise its utility and given its preferences, the various technological options/costs, prices and budget, it allocates its demand for transport services to the different options in order to meet its budget constraint.

The aggregate pkm per trip purpose (that is based on PRIMES-TREMOVE), it is allocated to different households either through fixed coefficients (representing base year demand) or through elasticity-driven choices. For a better representation, the model uses five distance classes for every trip purpose and household type. The classes are distinguished based on the distance of the trip (from shortest to longest trip). Every distance class has a different frequency.

Table 4 depicts the different classes and frequencies respectively, based on own assumptions.

Table 4 Histogram of distance classes

	A1	A2	A3	A4	A5
Distance difference of each distance class compared to typical trip distance	-70%	-25%	+16%	+60	+115%
Frequency	8.39%	37.26%	41.78%	10.84%	1.72%

Source: PRIMES-SHAREM Demand model (own assumptions)

Problem formulation

The PRIMES-SHAREM Demand model consists of two parts: supply and demand. The equilibrium comes when the two parts balance, that is, when the supply for passenger kilometres is equal to the demand for passenger kilometres for every trip.

In the demand side of the model, the decision maker (household) chooses between five different options for each trip. The choices can be categorised in three groups: self-service (private car operating their own vehicle either as a carpooling supplier), service from a company (car service or car sharing) and service from another car owner (carpooling).

The convergence of supply and demand is achieved through an iterative method between the two models: PRIMES-SHAREM and PRIMES-TREMOVE. The model of PRIMES-TREMOVE is appropriately expanded to include the part of the suppliers of private cars, car service, and car sharing companies.

The PRIMES-SHAREM Demand model calculates the demand for passenger kilometres for each of the five mobility options through a nested logit function and a constraint which ensures that the total demand of carpooling for every trip is equal to the total supply of carpooling.

The PRIMES-SHAREM Demand Model is written as a mixed complementarity problem. Therefore, the above constrain is split into two inequalities with two dual variables. The first from the side of the supplier (Supply>Demand dualS>0), and the second from the demander side (Supply<Demand dualD>0).

As a result, in the case that a household chooses carpooling as demander and the total demand for carpooling is more than the supply for carpooling, then the dual variable in this trip is dualD>0 in order to balance demand to supply. As a result, in the case that there are not enough suppliers for carpooling, the cost to use the carpooling service (i.e. carpooling ticket) increases so that Demand and Supply reach an equilibrium. That means that the demander has to pay more than the initial ticket price. The opposite happens when the Demand is lower than the Supply. In such case, when the household chooses carpooling as supplier and the total demand for carpooling is lower than the supply for carpooling, then in this trip the dual variable is dualS>0 in order to balance demand with supply. Therefore, in the case that there are not enough demanders for carpooling, the agreed ticket price drops and the household prefers not to choose carpooling as a supplier.

3.2.2 Input data and main assumptions

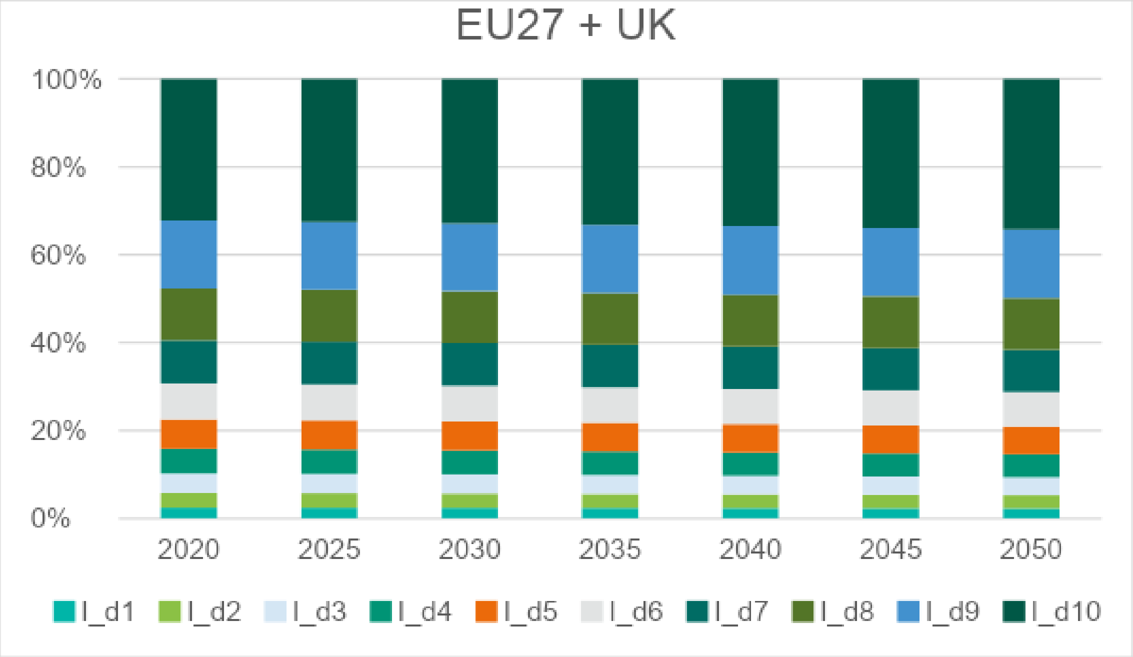
Intensive data collection was conducted so as to explore main characteristics of shared mobility and obtain insight into factors that affect the user choices. The collected data are secondary as they are derived from research, reports, and statistical sources, and are complemented also from the PRIMES-TREMOVE model databases. Information was searched at a country level; however, most data was found for Italy and Germany. These countries also formed the basis for the PRIMES-SHAREM Demand model development.

The PRIMES-SHAREM Demand model is calibrated to 2015 historical data. The stock of vehicles per transport mode (private cars, car service, car sharing), annual mileage, and occupancy rate are key parameters and are used in the phase of model calibration. The outcome of this calibration is adjustments in the annual mileage, split in total activity per transport mode by trips and purpose and adjustments in occupancy rates.

3.2.2.1 Household Income spending by income group

In terms of mobility options, income distribution can have a substantial impact on the opportunities available to households. Higher income households typically have greater access to various mobility options, such as private transportation, including cars, and other forms of transport. They may also have more flexibility in terms of housing choices, as well as the ability to live in areas with better amenities and infrastructure. Conversely, lower income households often face constraints that limit their mobility options. They may rely more heavily on public transportation or have limited access to transportation services, making it difficult for them to access employment opportunities, education, and healthcare. Limited financial resources can also restrict their ability to move to more economically vibrant areas, where job prospects may be more plentiful. The shared model features multiple households so as to better capture the adoption of different mobility options.

Figure 19 Income Distribution across income groups – deciles



3.2.2.2 Activity and stock of cars

Two main parameters that are used for the model development are the activity of passenger cars (Gpkm) and the stock of registered cars (thousand vehicles). These parameters were derived from the Eurostat's Statistic Pocketbook.

The fleet of different transport modes (cars) that used in the model is distinguished in three categories: private cars (for own use and carpooling), car service (taxis) and car sharing.

The stock of private cars, used also for carpooling, is assumed to be the difference between the total stock of passenger cars and the sum of shared mobility options, namely car service and car sharing. The total stock of passenger cars is provided by the Eurostat's Statistic Pocketbook for each year per country[3]. It is concluded that the average share of private cars in the total passenger cars is estimated to be 99.7% in 2015.

As far as the car sharing stock is concerned, in the absence of data from EUROSTAT, we rely on data from Statista (2022) and Fluctuo[4] (2022). Statista (2022) provides information for 8 EU countries at a country level (AT, DE, DK, ES, FR, IT, NL, SE,). Fluctuo (2022) provides data at the city level (several EU cities) but not at the country level. Therefore, the data was combined in order to

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[3] https://transport.ec.europa.eu/facts-funding/studies-data/eu-transport-figures-statistical-pocketbook/statistical-pocketbook-2022_en

[4] Fluctuo is a company which provides data regarding for shared mobility so as to accelerate the growth of shared mobility

populate the dataset of passenger cars used in car sharing for all EU countries, based on the following data-driven assumptions:

- For AT, DE, DK, ES, FR, IT, NL, SE, the share of shared mobility in total registered cars fluctuates between 0.02% and 0.04%, taking into account the data provided for the aforementioned countries according to Statista (2002).
- For the remaining EU countries, a share of 0.03% of shared mobility to total registered cars was assumed, which was derived based on Fluctuo (2022).

Data availability on the stock of taxis (car service) per country is also limited. The total number of taxis is derived from a case study of the European Commission (2016) that provides data provided for 5 countries (DE, ES, FR, SE and PL)[5]. In order to estimate the number of taxis (car service) in each country, the following assumptions have been made:

- GDP per capita (Trading Economics, 2021) was used as indicator to order the countries and to approximate the share of taxis in total car registrations.
- 6 classes of countries were defined based on the EC case study and then the share of taxis in the total number of registered cars for each country was estimated.
- The remaining countries were ordered based on their GDP per capita. EU countries were split into 6 categories, based on the point above, and the share of taxis for the countries was applied to each country. Then, this share was multiplied with each country's total car registrations to find the total number of taxis per EU country.

3.2.2.3 Trip classification

Another parameter used for the development of the model is trip classes. The model distinguishes 32 trip classes (Table 5). More precisely, passenger trips are divided into three main categories regarding the purpose of the trip: non-working, commuting and business trips.

Each trip category is further distinguished in 5 classes characterised by different frequency and distance, depicting behavioural changes during the year and a probability distribution for each class. The second level of the tree decomposes mobility by region and road types: urban areas (distinguished into metropolitan and other urban areas) and non-urban areas (distinguished into short distance and long-distance areas). Regarding the non-urban distinction, both short distance and long distance are also distinguished between motorway and other non-urban.

Last but not least, the next level of the tree decomposes the time of the day when the trip takes place and relates with congestion: peak and off-peak hours. The classification of traffic time was derived from the PRIMES-TREMOVE model

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[5] Though not in the EU27, also data for the UK were collected based on Gov.uk (2021).

in a less aggregated form as no differentiation regarding the size of the cars (small and big cars) was taken into account.

Table 5 Trip classification

Trip classification in PRIMES-SHAREM	
Trip 1	Non-working/non-urban/short distance /motorway/peak-time trip
Trip 2	Non-working/non-urban/short distance /other non-urban/peak-time trip
Trip 3	Non-working/non-urban/short distance /motorway/off-peak-time trip
Trip 4	Non-working/non-urban/short distance /other non-urban/off-peak-time trip
Trip 5	Non-working/non-urban/long distance /motorway/peak-time trip
Trip 6	Non-working/non-urban/long distance /other non- urban/peak time trip
Trip 7	Non-working/non-urban/long distance /motorway/off-peak time trip
Trip 8	Non-working/non-urban/long distance /other non-urban/off-peak time trip
Trip 9	Commuting/non-urban/long distance /motorway/peak-time trip
Trip 10	Commuting/non-urban/long distance /other non-urban/peak-time trip
Trip 11	Commuting/non-urban/long distance /motorway/off-peak-time trip
Trip 12	Commuting/non-urban/long distance /other non-urban/off-peak-time trip
Trip 13	Non-working/urban/Metropolitan /urban/peak-time trip
Trip 14	Non-working/urban/Metropolitan /urban/off-peak-time trip
Trip 15	Non-working/urban/other urban /urban/peak-time trip
Trip 16	Non-working/urban/other urban /urban/off-peak-time trip
Trip 17	Commuting/urban/Metropolitan /urban/peak-time trip
Trip 18	Commuting/urban/Metropolitan /urban/off-peak-time trip
Trip 19	Commuting/urban/other urban /urban/peak-time trip
Trip 20	Commuting/urban/other urban/urban/off-peak-time trip
Trip 21	Business/non-urban/short distance/motorway/peak-time trip
Trip 22	Business/non-urban/short distance/other non-urban/peak-time trip
Trip 23	Business/non-urban/short distance/motorway/off-peak-time trip
Trip 24	Business/non-urban/short distance/other non-urban/off-peak-time trip

Trip classification in PRIMES-SHAREM	
Trip 25	Business/non-urban/long distance/motorway/peak-time trip
Trip 26	Business/non-urban/long distance/other non-urban/peak-time trip
Trip 27	Business/non-urban/long distance /motorway/off-peak-time trip
Trip 28	Business/non-urban/long distance /other non-urban/off-peak-time trip
Trip 29	Business/urban/Metropolitan/urban/peak-time trip
Trip 30	Business/urban/Metropolitan/urban/off-peak-time trip
Trip 31	Business/urban/other urban/urban/peak-time trip
Trip 32	Business/urban/other urban/urban/off-peak-time trip

3.2.2.4 Occupancy rate and average speed

The occupancy rate of different options plays a crucial role in the decision-making process of the shared mobility user. The occupancy rate is defined as the average number of passengers in the vehicle when on duty. The average occupancy rate for private cars was derived from the PRIMES–TREMOVE model.

It was assumed that the occupancy rate for both car sharing vehicles and car service options (e.g. taxis) is the same with that of private cars. On the contrary, the occupancy rate of carpooling was estimated based on the occupancy rate provided by Bosch et al. (2017) for Switzerland (derived by a Swiss transportation micro census). More precisely, according to Bosch et al. (2017) the occupancy rate of carpooling options differs during peak and off-peak periods. The occupancy rate during off-peak hours is higher compared to peak hours. Furthermore, higher occupancy rates are also observed in non-working trips during off-peak hours. Such differentiation was applied to all trips by taking into account the average occupancy rate per trip. The occupancy rate for the remaining countries is calculated by employing the same methodology. Figure 5 shows the estimated the average occupancy rates per trip type for Italy and Germany.

Average speed (km/h) is also classified per trips over time. It is observed that through the years the average speed is increased. Average speed data were derived from the PRIMES-TREMOVE model and are not differentiated per shared mobility option (i.e. it is assumed that all shared mobility options have the same average speed).

3.2.2.5 Distance and trips

Another parameter taken into account is distance (km per trip). Information on distance per trip was provided by the PRIMES-TREMOVE model.

Moreover, in order to estimate the total distance and the time of the trip, five additional attributes were incorporated into each trip affecting the travel time and the cost of the trip. More precisely, the five attributes are the following:

- The actual travel time of trip
- Access time refers to the time spent getting to and leaving from a car
- Wait time is time while the commuter is waiting for the transport mode
- Search time is the time spent in searching for parking
- Delay time is the time spent for accessing the mobility service

The trips and time categories are also divided into the following categories:

- Private car (standard – travel alone/with family members)
- Carpooling (supplier side)
- Car service (taxis)
- Carpooling (demander side)
- Car sharing

The distance per trip for all categories (i.e. private cars – own use, car service, carpooling and car sharing) are the same. The distance ranges from 27 km (lower limit) for urban short-distance trips to 342 km (upper limit) for non-urban motorway trips.

With respect to additional costs, these relate with the additional distance that the shared mobility option covers due to detour in order to pick-up a passenger. For carpooling, the detour distance is 2,000 m. Other actions are translated into additional time relating with waiting time, delay, access time and search time.

3.2.2.6 Time

According to literature, a factor which plays crucial role in the users' decision making is time. Data on this aspect is based on another research.

An assumption has been made in order to estimate the amount of time for each trip. We use as reference the approach taken in PRIMES-TREMOVE for passenger cars where the volume of time is calculated based on the average speed and the sum of the km travelled and the extra time derived from other related actions (access time, search time, wait time, delay time). The same approach is applied on each shared mobility category.

Value of time

The data used in order to estimate the value of time were derived by Wardman et al. (2016). This paper provides data for car commuting, business trips with cars and takes into account parameters such as access time, wait time, search time and late arrival. The value of time for the parameters was calculated by considering multipliers for congestion, urban or inter urban trips etc. These time-related multipliers were implied by their meta-model. After applying the aforementioned factors and multipliers, the value of time (€/hr) per type of trip is provided and summarised the following table:

Table 6 Value of time (€/hr) per trip type

Trips	Purpose	Peak / Off-peak	Car	Access	Wait	Search	Delay
trip1	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip2	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip3	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip4	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip5	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip6	*Non-working*	PK	10.93	17.39	16.40	18.70	33.46
trip7	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip8	*Non-working*	OP	7.70	12.24	11.55	13.17	23.56
trip9	*Commuting*	PK	7.92	12.59	11.88	13.54	24.24
trip10	*Commuting*	PK	7.92	12.59	11.88	13.54	24.24
trip11	*Commuting*	OP	7.70	12.24	11.55	13.17	23.56
trip12	*Commuting*	OP	7.70	12.24	11.55	13.17	23.56
trip13	*Non-working*	PK	7.92	12.59	11.88	13.54	24.24
trip14	*Non-working*	OP	5.57	8.86	8.36	9.52	17.04
trip15	*Non-working*	PK	7.92	12.59	11.88	13.54	24.24
trip16	*Non-working*	OP	5.57	8.86	8.36	9.52	17.04
trip17	*Commuting*	PK	8.99	14.29	13.49	15.37	27.51
trip18	*Commuting*	OP	6.33	10.06	9.50	10.82	19.37
trip19	*Commuting*	PK	8.99	14.29	13.49	15.37	27.51
trip20	*Commuting*	OP	6.33	10.06	9.50	10.82	19.37
trip21	*Business*	PK	24.13	38.36	36.19	41.26	73.82
trip22	*Business*	PK	24.13	38.36	36.19	41.26	73.82
trip23	*Business*	OP	16.99	27.01	25.49	29.05	51.99
trip24	*Business*	OP	16.99	27.01	25.49	29.05	51.99

Trips	Purpose	Peak / Off-peak	Car	Access	Wait	Search	Delay
trip25	*Business*	PK	24.13	38.36	36.19	41.26	73.82
trip26	*Business*	PK	24.13	38.36	36.19	41.26	73.82
trip27	*Business*	OP	16.99	27.01	25.49	29.05	51.99
trip28	*Business*	OP	16.99	27.01	25.49	29.05	51.99
trip29	*Business*	PK	17.47	27.78	26.21	29.87	53.46
trip30	*Business*	OP	12.29	19.54	18.44	21.02	37.61
trip31	*Business*	PK	17.47	27.78	26.21	29.87	53.46
trip32	*Business*	OP	12.29	19.54	18.44	21.02	37.61

3.2.2.7 Pricing

Cost is one of the main parameters which determine the usage of shared mobility options. The purchase cost of a vehicle, the operating costs, fixed and variable costs are provided by the PRIMES-TREMOVE model.

However, the cost regarding the shared mobility options (car service, carpooling and car sharing) is calculated based also on ticket price. The ticket price per vkm is provided as the average cost per vehicle per passenger.

The data used for the estimation of the car service fare were provided by Numbeo (2022) and it is equal to daytime charge per km. Car-pooling cost for users per km was derived by Bosch et al. (2017) and was calculated based on taxis pricing. Regarding car sharing, the cost per km is provided also in Bosch et al. (2017) adjusted to carpooling pricing. Pricing (per km) remains constant for all trips.

Two pricing elements for the tickets are incorporated: the minimum ticket price and the ticket price per hour.

The minimum price of ticket per trip is used (also constant for all trip classes). Specifically:

- Car service (taxis): the minimum price is equal to the initial/starting charge (base tariff), which is estimated approximately to 2.5 € (Numbeo, 2022).
- Car-pooling and car sharing: the minimum price is also equal to base tariff reported by Bosch et al. (2017). However, the base tariff was adjusted based on car service pricing.

The ticket price per hour is also used in the model. In order to estimate the aforementioned variable, the following were taken into consideration:

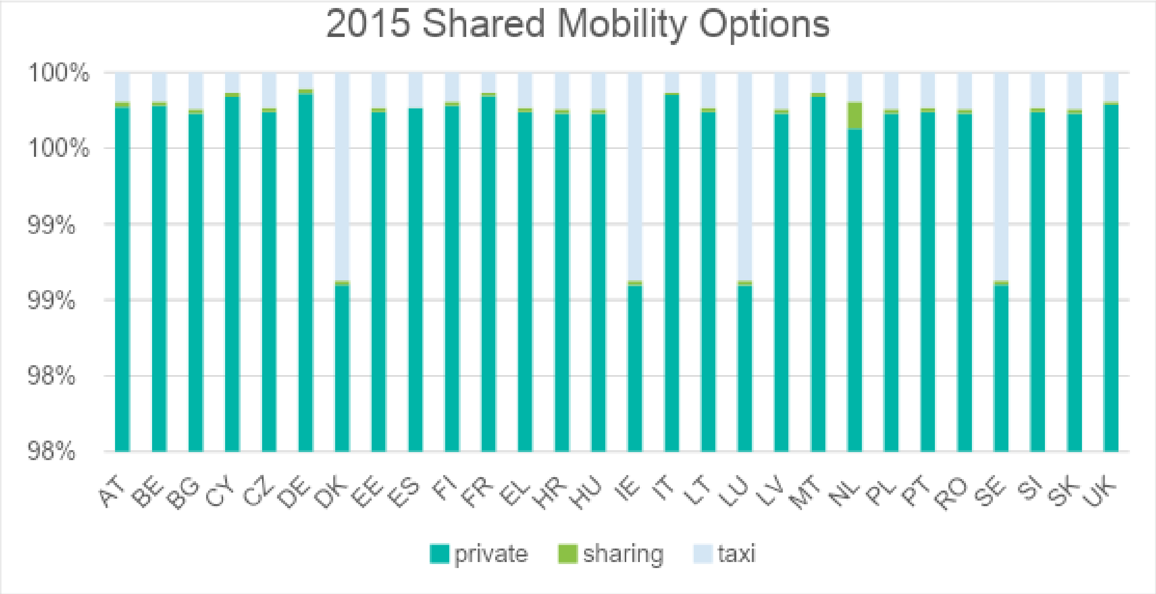
- Car service (taxis): the ticket price is calculated based on the hourly income of the car service driver income (€/h). The data used were provided by the ERI Institute (2022).
- Car-pooling and car sharing: it is assumed that the ticket price per hour for both carpooling and car sharing is equal and is referred to average transportation cost per hour. The data is based on Bosch et al. (2017).

3.2.2.8 Shared Mobility Options

The starting point and calibration of the model is on historical shared mobility options (starting 2015). In 2015, shared mobility options were gaining prominence across the globe, especially in urban areas, as a response to the challenges posed by congestion, pollution, and limited parking spaces. Some of the shared mobility options available during that time included:

- Ride-Sharing and Carpooling: Various platforms facilitated carpooling and ride-sharing services, enabling individuals to share rides with others heading in the same direction. This approach aimed to reduce the number of cars on the road and offered a more cost-effective transportation option for commuters.
- Car sharing Services: Car sharing companies provided access to vehicles on a short-term basis, allowing users to rent cars by the hour or for a specific duration. This option appealed to individuals who required occasional access to a car without the financial burden of ownership.
- Scooter-Sharing Services: Electric scooter-sharing programs began to emerge in various cities, offering a convenient and eco-friendly mode of transportation for short trips. Users could locate and unlock electric scooters through a mobile application, facilitating easy and flexible mobility.
- Ride-Hailing Services: Ride-hailing companies, such as Uber and Lyft, were gaining significant traction in the market. These services allowed users to book rides through mobile applications, connecting them with independent drivers using their personal vehicles.
- These shared mobility options were instrumental in addressing transportation challenges, providing more flexibility, and reducing the overall environmental impact of transportation systems. They also contributed to the evolving concept of Mobility-as-a-Service (MaaS), which aimed to integrate various forms of transportation into a single, accessible service, providing users with a seamless and integrated mobility experience.

Figure 20 Shared mobility options in PRIMES SHAREM-D



3.2.2.9 Overview of sources and data

Table 7 below presents the sources and the data which that were used in the development of the model.

Table 7 Data sources used in model development

Source	Year (data)	Data used	Data / Parameter
Eurostat (2022)	2016	Total registered Cars	“Passenger cars, by age”
Eurostat (2022)	2016	Population	“Population on 1 January by NUTS 2 region“
PRIMES-TREMOVE	2015	Mileage	“Ratio: activity & stock”
Fluctuo (2022)	2015	Car sharing (IT, DE, DK, FR)	“European Shared Mobility Index”
Statista (2022)	2015	Car sharing (DE, FR,NL, IT, AT, SE, ES)	“Car sharing vehicles in Europe by country 2014”
European Commission (2016)	2015	Nr. of taxis (DE, ES, FR, SE, PL)	“Study on passenger transport by taxi, hire car with driver and ridesharing in the EU”
Gov.uk (2022)	2015	Nr. of taxis (UK)	“Taxis, private hire vehicles and their drivers“
Trading Economic (2022)	2015	GDP per capita	“Taxis, private hire vehicles and their drivers”
Asamer et. al (2016)	2015	Taxis annual mileage (AT) km per day and operating days per year	"Optimizing charging station locations for urban taxi providers"

Source	Year (data)	Data used	Data / Parameter
ERI Institute (2022)	2015	Taxi driver income (IT)	"Taxi driver salary – Italy"
Numbeo (2022)	2015	Taxi tariffs (IT)	"Taxi fares in Italy"
Bösch, et., al. 2018	2015	Car sharing & carpooling (CZ): ticket price/ hour Occupancy rate cost per km the minimum price	"Cost-based analysis of autonomous mobility services"
Wardman et. al (2016)	2015	the value of time, access time, wait time, search time and late arrival	"Values of travel time in Europe: Review and meta-analysis"

3.2.3 Results

3.2.3.1 Activity of private cars

Figure 21 presents the change in activity of passenger cars between Decarb with and without shared mobility in EU27+UK. The reduction is about 2.2% in 2030 and 9.9% in 2050. When incorporating shared mobility options, the activity of private cars reduces As such, it can be concluded that shared mobility has an impact on the activity of private cars, reducing it and thus contributing to decarbonisation efforts. It should be mentioned that total activity (in passenger-kilometres) between the scenarios with and without shared mobility options is the same. However, due to the higher share of shared mobility options that have higher occupancy ratio, the total vehicle-kilometres travelled are lower leading to less emissions in the scenarios with shared mobility options.

Figure 21 Change in activity of passenger cars Decarbonisation vs. Decarbonisation NT Scenarios

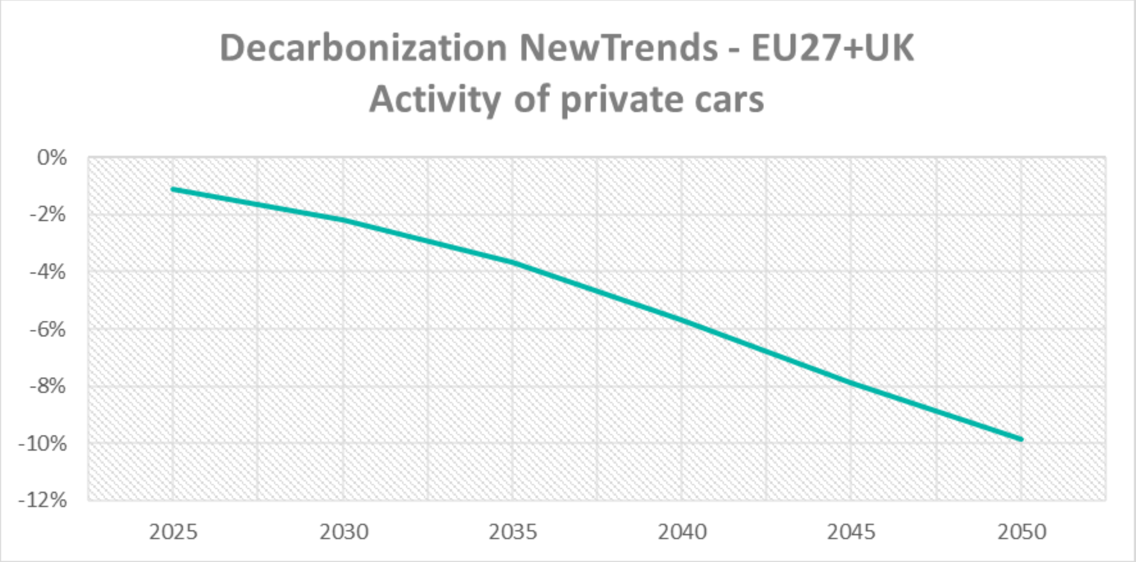


Figure 22 shows the contribution of different shared mobility options in the Base scenario. In 2030, across all shared mobility options carpooling is the predominant shared mobility option with about 0.8% of activity, followed by car-sharing (0.4%) and car service (0.3%). By 2050, shared mobility options increases to a total share of 2.6%.

Figure 22 Shared mobility options under the Reference NT Scenario

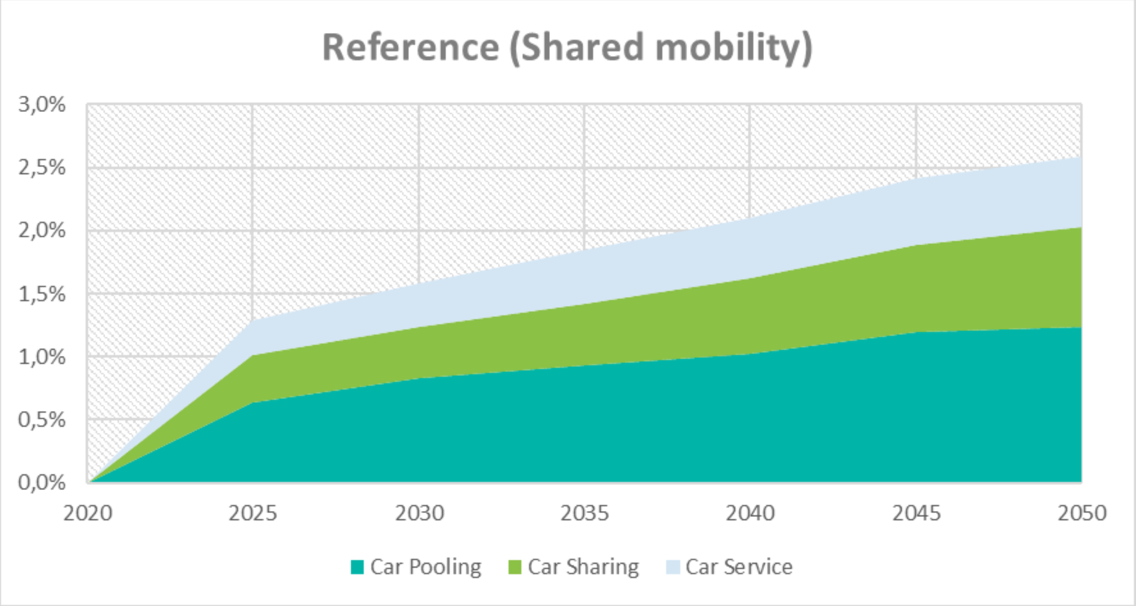
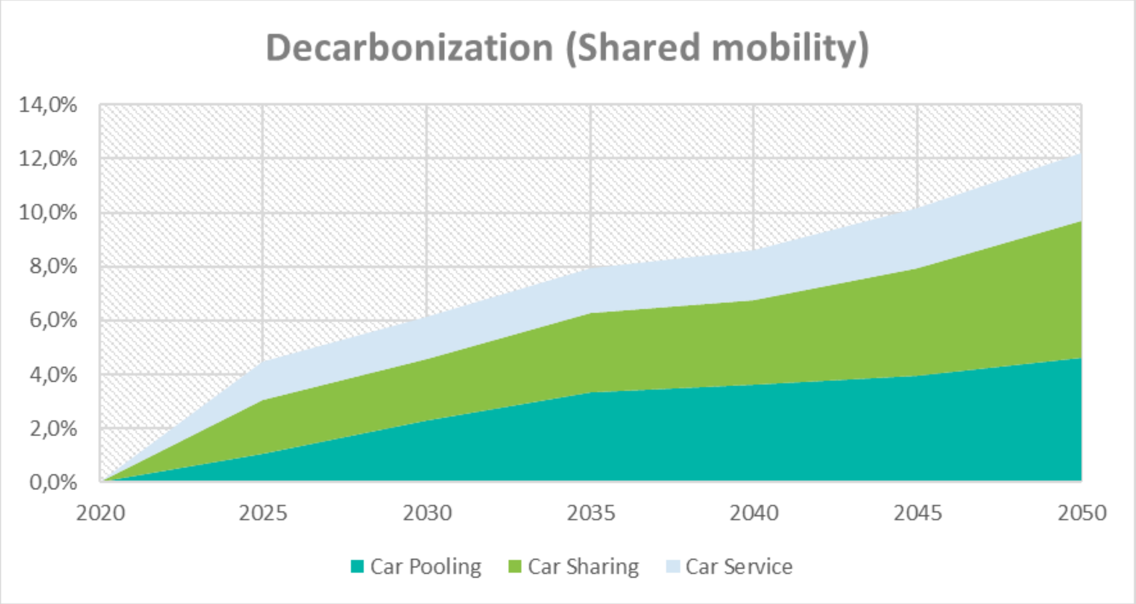


Figure 23 shows the contribution of different shared mobility options in the Decarb Scenario. As shared mobility options are taken up, their activity increases notably and in terms of relative contribution to passenger transport by car and in terms of absolute volume of activity compared to Base.

In 2030, across all shared mobility options carpooling and car sharing are both the predominant shared mobility options with more than 4.5% of activity followed by car service (1.5%). By 2050, shared mobility options increases to a total share of 12.2%.

From the above results it can be concluded that in the Decarb Scenario context the contribution of shared mobility increases, thereby reducing further the activity of private passenger cars. Car-pooling is the first choice for shared mobility, especially in the shorter-term. Car sharing increases its market share notably, and especially in the decarbonisation context, and becomes a key preference for shared mobility as well. Car service, on the other hand, remains the last choice of shared mobility service, owing to its higher ticket price.

Figure 23 Shared mobility options under the Decarbonisation_NT Scenario

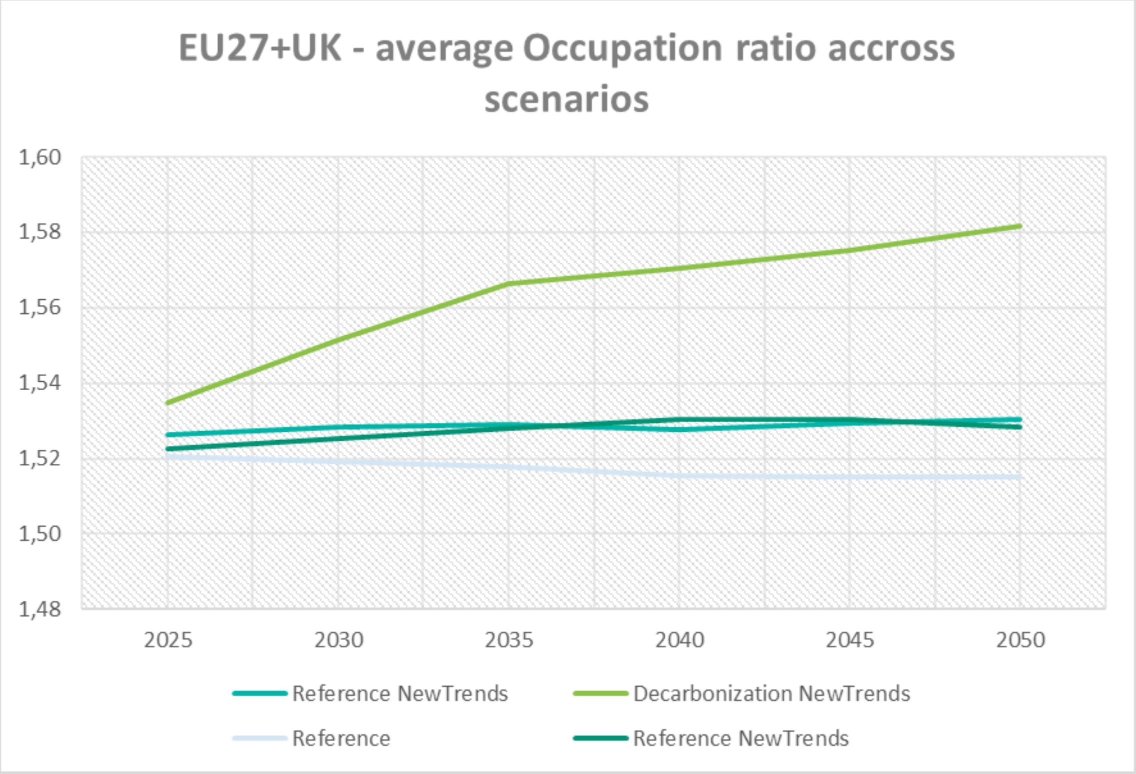


3.2.3.2 Occupancy rate

A direct impact of shared mobility is on occupancy rates. In Figure 24, it is shown that the occupancy rates increase in the Decarb Scenario compared to the Ref Scenario. Of particular importance is, however, that shared mobility options increase the average occupancy rates of vehicles most notably in the Decarb Scenario.

In particular, in the Decarb Scenario the increase in average occupancy owing to shared mobility reach 4.4% in 2050 compared to the reference without shared mobility. It should be noted that in the Base context shared mobility options reverse the trend of occupancy rates that tend to reduce over time, when shared mobility services are not available. The average occupancy rate increases mainly due to the contribution of carpooling, which is attributable to its higher market share and its higher occupancy factor compared to the other shared mobility services.

Figure 24 Average occupation ration across scenarios (EU27+UK)



3.2.3.3 Generalised cost

In Figure 25 (Reference with shared mobility scenario) and in Figure 26 (Decarbonisation with shared mobility scenario), the generalised cost of all transport options in PRIMES-SHAREM is presented (i.e. for private cars and for shared mobility options). It should be noted that the generalised cost includes actual costs and hidden costs. Moreover, in the figures below, average generalised costs are presented.

In both Reference and Decarbonisation with shared mobility, the generalised cost decreases between 2025 and 2030. In the Base scenario, private cars have the lowest generalised cost compared to the shared mobility options. The generalised cost of private cars remains relatively stable with time. On the other hand, shared mobility options have a higher generalised cost, however, the costs of car sharing and of car service reduces with time. The reduction of generalised costs is higher in the Decarbonisation Scenario. The steeper reduction of generalised costs in Decarbonisation sets the average generalised cost of lower than the generalised cost of private cars, explaining the higher uptake of this option in the Decarbonisation compared to the Reference Scenario.

Figure 25 Generalised price of activity in the Reference_NT Scenario (EU27+UK)

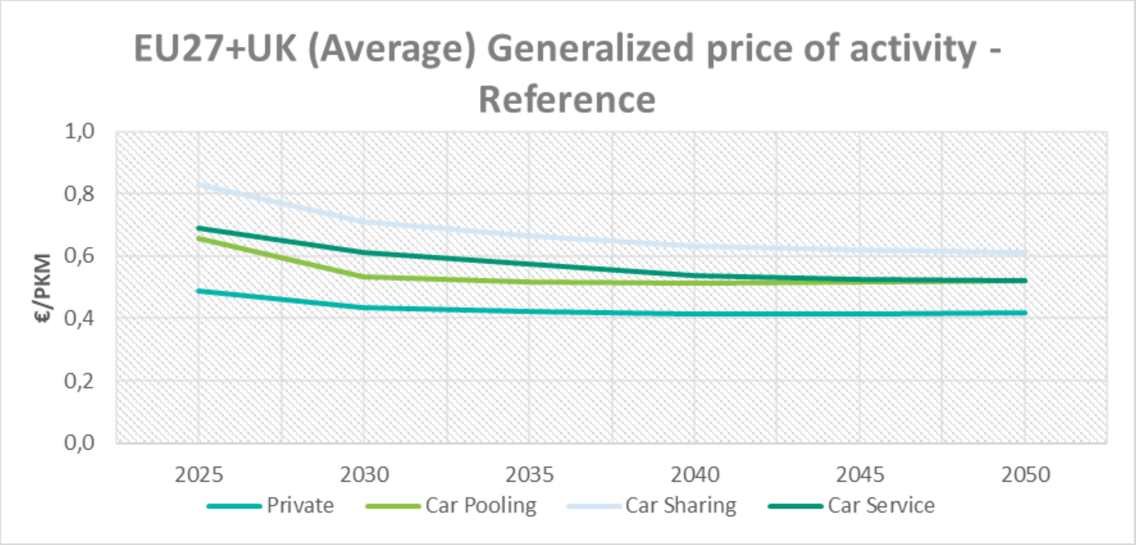
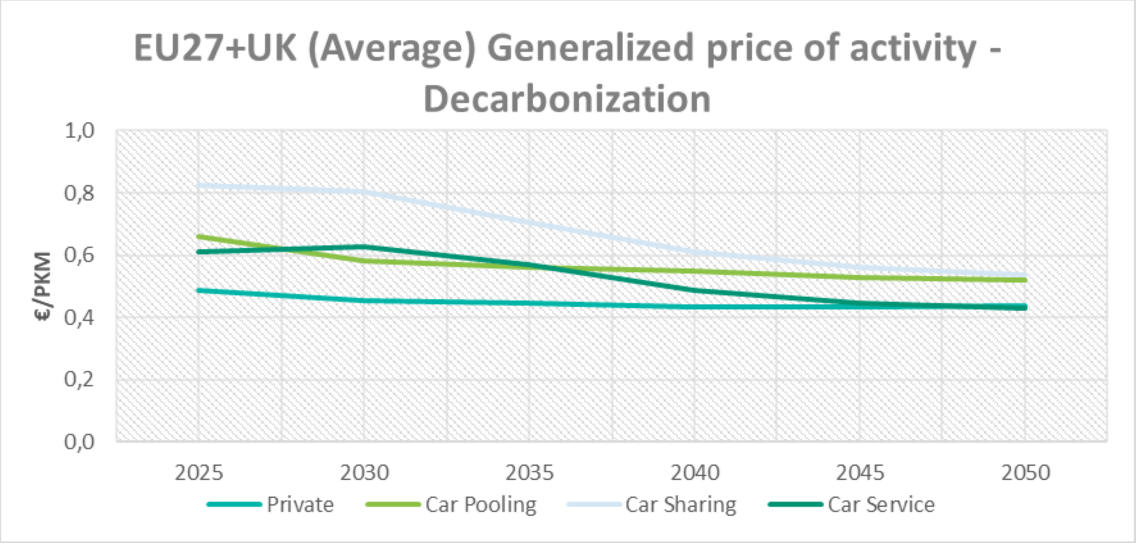


Figure 26 Generalised price of activity in the Decarbonisation_NT Scenario (EU27+UK)



Non-monetised aspects that further explain user choice, and in particular perceived costs such as commercial barriers, infrastructure, privacy and security issues linked with shared mobility options.

3.3 TERTIARY

3.3.1 FORECAST Tertiary: key features and improvements

The energy demand in the tertiary sector is simulated using the FORECAST Simulation Framework. FORECAST stands for FORecasting Energy Consumption Analysis and Simulation Tool. FORECAST aims to develop annual long-term scenarios for future energy demand of individual countries and world regions until 2050. It is based on a bottom-up modelling approach considering the dynamics of technologies and socio-economic drivers. The model allows to address research questions related to energy demand including scenarios for the future demand of individual energy carriers like electricity or natural gas, calculating energy saving potentials and the impact on greenhouse gas (GHG) emissions.

The FORECAST platform comprises four individual modules for the sectors *Industry*, *Residential*, *Tertiary* and *Others*.

The tertiary module that is used in newTRENDs is split into two different parts. Firstly, the heating demand is based on the parameters of the building envelope and the heating system. Its value depends on the energy reference floor area. The floor area itself is dependent on the number of employees working in that subsector and the specific floor area (floor area per employee). Secondly, the electricity demand of electric appliances depends on the installed power and its utilisation rate (effective full load hours). The technical equipment and its usage are differentiated by subsector and either depend on the floor area or directly on the number of employees.

FORECAST model differentiates between the following subsectors:

- Wholesale and retail trade
- Hotels, cafes, restaurants
- Traffic and data transmission
- Finance
- Health
- Education
- Public offices
- Other services

Whereas the first subsector *Wholesale and retail trade* is split into wholesale and retail, which act as individual subsectors in the framework of this project.

Distinguishing between individual technologies via a bottom-up approach, FORECAST makes it possible to model the diffusion of technologies as a result of individual investment decisions taken over time. For all types of investment decisions, the model follows a simulation approach rather than optimisation to better capture the real-life behaviour of decision-makers. Whenever possible, the investment decision is modelled as a discrete choice process, where decision-makers choose among alternative technologies to satisfy a certain energy service. It is implemented as a logit-approach considering the total cost of ownership (TCO) of an investment plus other intangible costs. This approach ensures that even if one technology choice is more cost-effective than the others, it will not gain a 100 % market share. This effect reflects heterogeneity in the market, niche markets and non-rational behaviour of decision-makers, which is a central capability to model policies. Still, the resulting technology development (and energy demand) is price-sensitive. The replacement of equipment/buildings/technologies is based on a vintage stock approach allowing to realistically model the replacement of the capital stock considering its age distribution.

In FORECAST Tertiary, the main drivers are the number of employees by subsector and the floor area per employee by subsectors. For the decision model, the following parameters are considered (among others):

- Prices of energy
- CO2 price
- Investment costs of heating systems or other building components
- Willingness-to-pay for investments
- Lifetime Installed power and annual full load hours

3.3.2 Input data and main assumptions

This chapter outlines the assumptions of the modelling performed on the tertiary sector. The tertiary sector (also called services sector), as it is modelled in FORECAST, originally consists of these subsectors:

- Wholesale
- Retail trade
- Hotels, cafes, restaurants
- Traffic and data transmission
- Finance
- Health
- Education
- Public offices
- Other services

The objective of the analysis is the final energy demand and the GHG-emissions in this sector, consisting of all process-specific energy demands that are considered inside the buildings of this sector. This includes lighting, space heating & cooling, sanitary hot water, ventilation & building services, process heat, ICT and other processes and applications.

Four new trends are identified to have an important impact on the energy demand in the tertiary sector:

- Teleworking
- E-Commerce
- Building Automation
- Digitalisation (data centres)

As presented in the Methodology section, the study at hand is structured around four scenarios. These scenarios are defined by different levels of decarbonisation and realised new trends. The difference in the cross-sectoral assumptions between the models has to do with different energy price trajectories; different CO_2 prices; and slight deviations in the willingness to invest in new heating systems (only building sectors).

3.3.2.1 Teleworking

Teleworking is the major trend that forms the future working pattern and the energy demand in offices. However, working remotely practically applies only in office jobs, which is also the assumption in newTRENDs.

The impact of teleworking on the energy demand is twofold. One aspect is related to the floor area energy demand for heating, cooling, lighting and other applications. The other aspect is the increase in ICT demand when there is a higher usage of web meetings and cloud services.

By shifting the work location from offices to private homes, the needed floor area in the tertiary sector shrinks in the long run. At the same time, the floor area in the residential sector increases. The portion of space occupied by offices is only a subset of the total floor area in the different subsectors, as there are other areas like for shopping, storage, packing or manufacturing that stay untouched by teleworking trends.

The percentage of the floor area occupied by offices for the different subsectors is shown in Table 8. This forms the upper limit that theoretically could be reduced in the tertiary sector if all office employees would work from home.

Table 8 Share of office space in comparison to total floor area per subsector

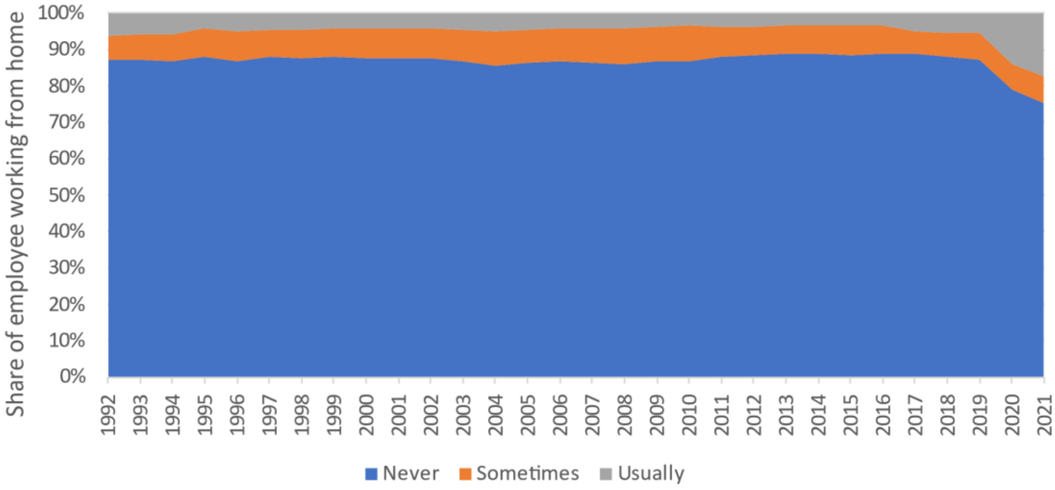
Subsector	Share of office space
Wholesale and retail trade	5%
Hotels, cafes, restaurants	5%
Traffic and data transmission (including ICT companies)	85%
Finance	85%
Health	5%
Education	20%
Public offices	90%
Other services	70%

Source: Own assumptions

Eurostat provides a data set on the share of employees working from home, differentiated by country and frequency.

Figure 27 shows the data set of Germany. The situation before Covid-19 was quite stable, dominated by a share of employees larger than 85% who never worked from home. Covid-19 changed the picture in the years 2020 and 2021: the number of employees that usually work from home tripled in 2021 compared to 2019.

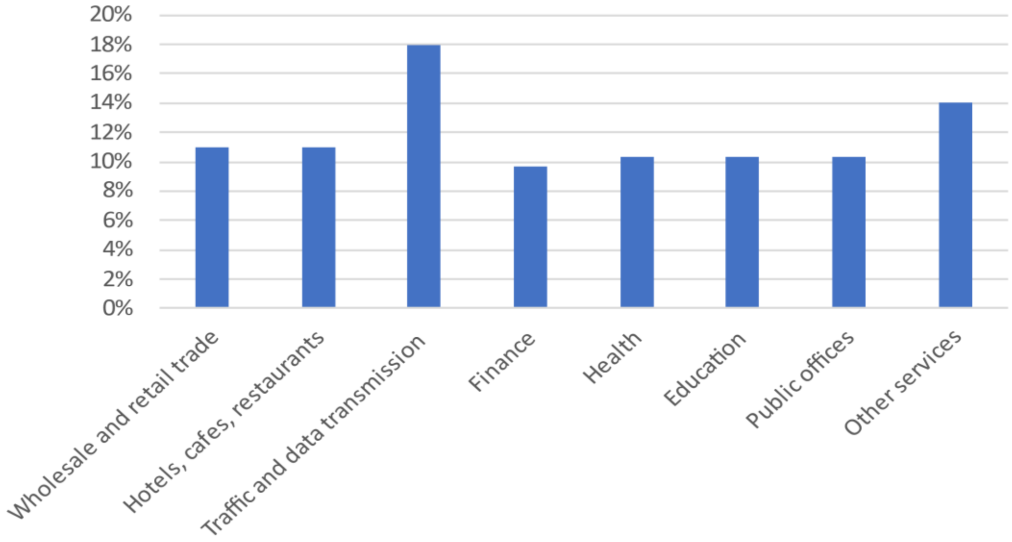
Figure 27 Share of Employees Working from Home in Germany



Source: own figure based on Eurostat (2023), table LFSA_EHOMP

To model the impact of teleworking on the different subsectors separately, differentiated input data is needed. Figure 28 shows the share of employees usually working from home in 2018 by subsector using the example of Germany. Employees of the ICT field working in the traffic and data transmission sub-sectors show the highest value.

Figure 28 Share of employees usually working from home in Germany (2018)



Source: own figure based on Eurostat (2023), table ISOC_IW_HEM

Data about the work from home patterns per subsector is available for all European countries and is used to split the above generated country-specific trajectory into its subsectors.

The basis of analysing the impact of teleworking on the energy consumption in the tertiary sector is the trajectory of the work-from-home share per subsector over the whole simulation horizon, until 2050. It is generated based on the presented statistical data and scenario assumptions.

We have defined a multiplicative factor to describe the relative development assumptions of the teleworking share (relative to 2021) for the Ref and Ref_NT Scenario (see Table 9). While both scenarios consider a decrease in work-from-home activities after the Covid-19 lockdown peaks, we expect that the share of teleworking will remain higher than pre-Covid-19 levels, due to increased familiarity among employees and businesses with this form of work. After 2024, we differentiate the two trajectories.

Table 9 Scenario Assumptions for Teleworking

Scenario	Factor 2030*	Factor 2050*	Description
Teleworking Reference	1.0	1.5	**Share of teleworking** The share of work from home rises linearly until 2030, reaching again the level of the Covid-19, in year 2021. Then in the following 20 years up to 2050, the share increases to a level of 1.5 compared to 2021. **Co-working spaces** 20% of the employees working remotely are using co-working spaces. **ICT demand** Teleworkers cause 15% higher ICT demand through web meetings and cloud services.
Teleworking NewTrends	1.2	2.5	**Share of teleworking** The share in 2030 is 1.2 times larger compared to 2021 and in 2050 it is 2.5 larger, compared to 2021. **Co-working spaces** 20% of the employees working remotely are using co-working spaces. **ICT demand** Teleworkers cause 15% higher ICT demand through web meetings and cloud services.

* As compared to 2021

The floor area that is reduced in office spaces is not directly proportional to the number of employees working from home, due to still needed meeting rooms including those for online meetings and other commonly used spaces. This relationship between floor area and teleworking activity is presented in newTRENDs' deliverable D7.2 "New Trends in Energy Demand Modelling".

Figure 29 shows the total floor area of the Reference Scenario in EU27 for subsectors which are impacted by teleworking. The decreasing trend in the presented subsectors is caused by less employees in these subsectors and a shrinking value of specific floor area per employee.

Figure 29 Total floor area in tertiary sector (EU27) in the Baseline Scenario (moderate teleworking activity)

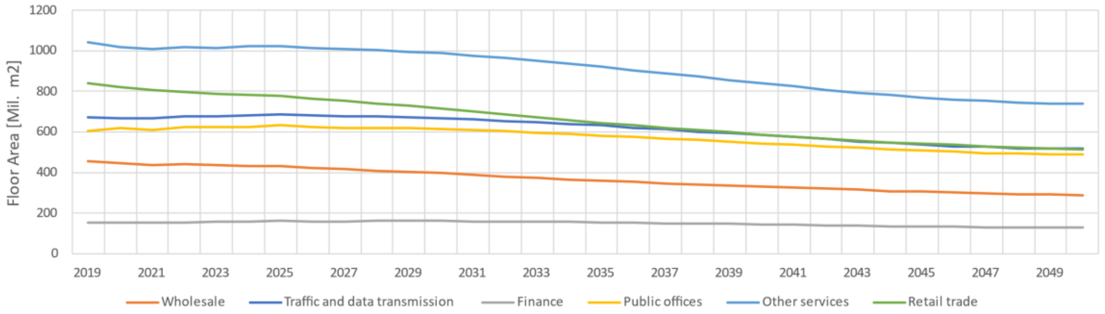
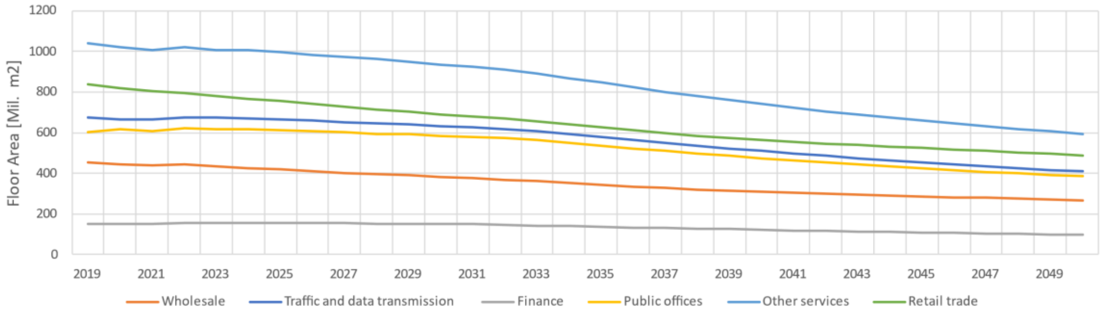


Figure 30 shows the same data for the newTrend-Scenario, that assumes a higher share of teleworking activity. The floor area in the newTrend-Scenario is decreasing in comparison to the Baseline Scenario. The decline of the total floor area varies for each subsector, as the share of employee in office jobs, the availability and willingness of working remotely and the subsector specific floor area per employee are different between the subsectors.

Figure 30 Total floor area in tertiary sector (EU27) in the newTRENDs Scenario (advanced teleworking activity)



3.3.2.2 E-Commerce

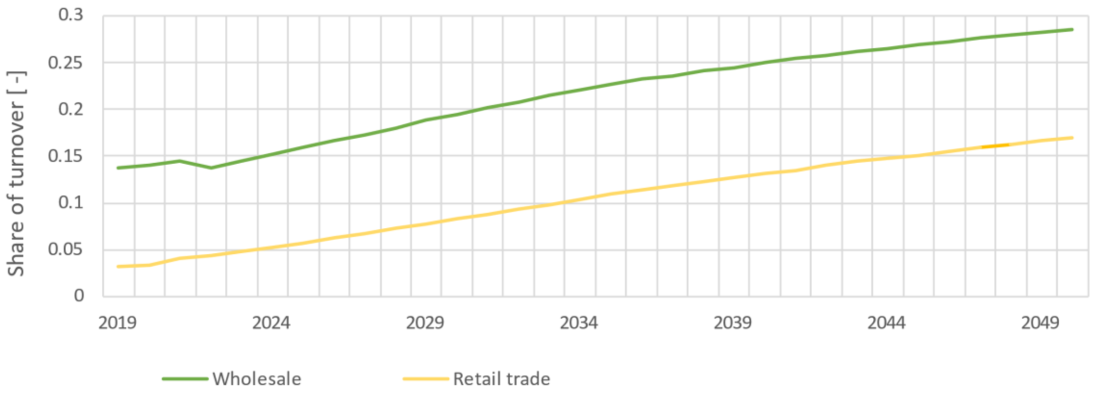
E-Commerce or online shopping has gained high shares in the trading balances, and it is assumed that this trend is holding on / newTRENDs D6.2.

The main impact of e-commerce on the energy consumption is the change of the floor area in the trading subsectors and its linked energy consumption. Inside the trading subsector, the following types of floor areas are differentiated:

- Shopping and exhibition area: decreasing with the ongoing e-commerce trend.
- Back-office area: decreasing decentral on-site but increasing central and increasing workload in ICT sub-sector (handled in trend "Data Centre").
- Storage area: increasing with the ongoing e-commerce trend.

The share of turnovers that are allocated to the e-commerce is steadily rising in the Baseline Scenarios. In the wholesale subsector (business-to-business trade), it will increase from 14% in 2019 to 29% in 2050. In the retail trade (business-to-client trade), it will rise from 4% to 17% (Figure 31).

Figure 31 Share of EC in the total trading turnover (EU27) in the Baseline Scenario (moderate EC activity)



In the newTRENDs Scenarios, these increase rates are higher. In the wholesale subsector they reach 47% in 2050, in retail trade 37%.

Figure 32 Share of EC in the total trading turnover (EU27) in the newTRENDs Scenario (advanced EC activity)

The share of e-commerce turnover is linked to the number of employees and this number is linked to the floor area of offices, sales surfaces, storage areas and others. This means there is a relationship between e-commerce activity and the energy demand of the total floor area in the subsector. Additionally, it is assumed that employees who sell goods via e-commerce generate more turnover per employee than their colleagues in conventional shops. This seems logical as the latter are also responsible for other tasks such as consulting clients, billing, packing and managing the storage. The increasing share of e-commerce means that either less employees would be needed to generate the same turnover or more turnover is generated with the identical head count. The simulation of the tertiary sector focuses on the energy demand and does not analyse the employment trends. A potential shift from subsectors with shrinking work force demand (like trading) to subsectors with a rising demand like ICT related branches are considered in the macro-economic and cross-sectoral assumptions.

The FORECAST simulation framework was adapted to model the e-commerce trend. In the original model the wholesale and retail subsectors were not differentiated, according to the availability of statistical data. For this report, these subsectors could be modelled separately. The description of the model adaptation is described in D6.2[6].

3.3.2.3 Digitalisation and Data Centres

The workload demand of ICT is not an easily tangible term. Moreover, rising demand for energy decouples from rising demand for ICT as technology improvements in the fields of hardware and software could compensate the rising demand partially. For the future, it is not clear how long the technical development can keep pace with the rising demand.

In FORECAST, the ICT demand is modelled as an energy service that is defined by the number and power of the installed servers in data centres. The electric

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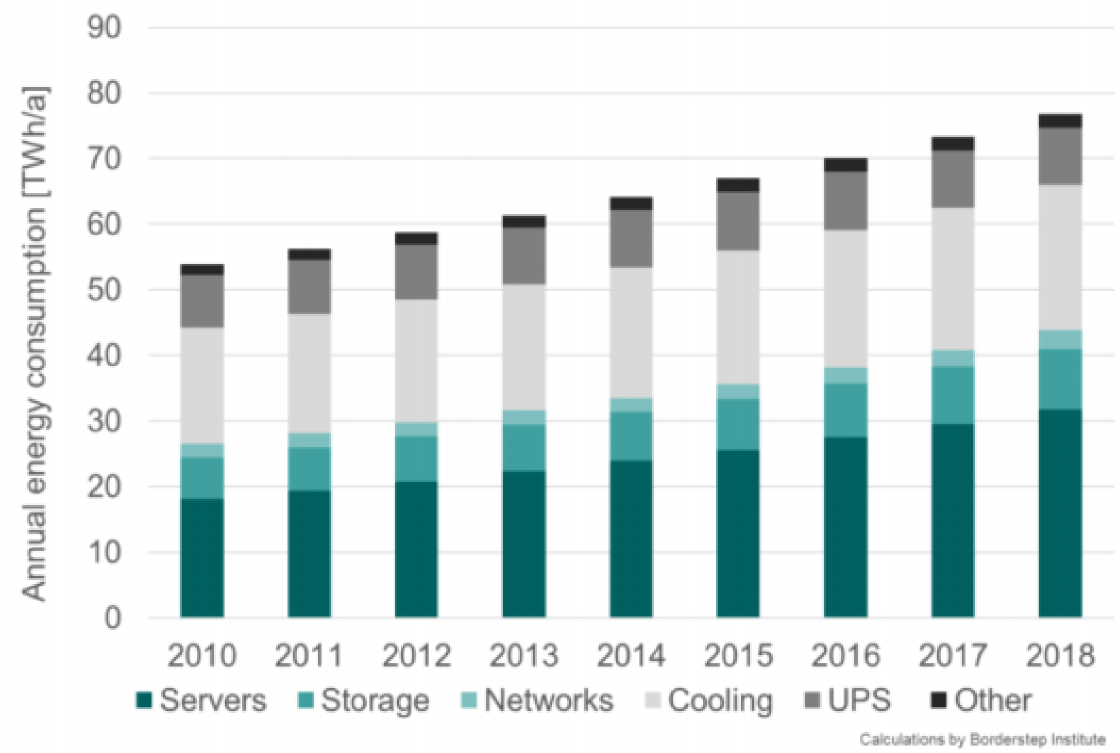
[6] D6.2 newTRENDs Focus study report Digitalisation in the Tertiary Sector

demand of data centre infrastructure such as cooling, and UPS is considered explicitly. A sensitivity analysis of four different ICT demand scenarios is conducted (newTRENDs D7.2) to analyse the impact on the total energy demand in the tertiary sector.

Montevecchi 2020 assumes an increase in electrical consumption from data centres in EU28 of 42 % between 2010 and 2018, whereas servers, storage and networks rise by 65% and the infrastructure (cooling, UPS and others) by only 20% (Figure 24).

Figure 33 Evolution of the energy demand of data centres in the EU28 from 2010 to 2018 / Montevecchi 2020



The Reference Scenario in newTRENDs assumes that the number of servers per employee increases from 0.05 in 2019 to 0.36 in 2050 in average across all subsectors of the tertiary sector (Figure 34). The according electric demand of the computing energy of servers without storage and networks (Figure 26) increases more slowly due to efficiency gains.

Figure 34 Energy Service Driver_ICT Data Centres: servers per employee in tertiary sector in the Ref Scenario

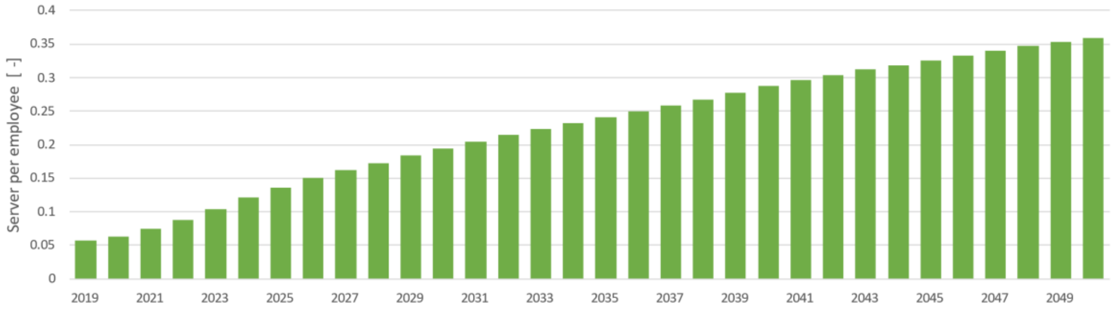
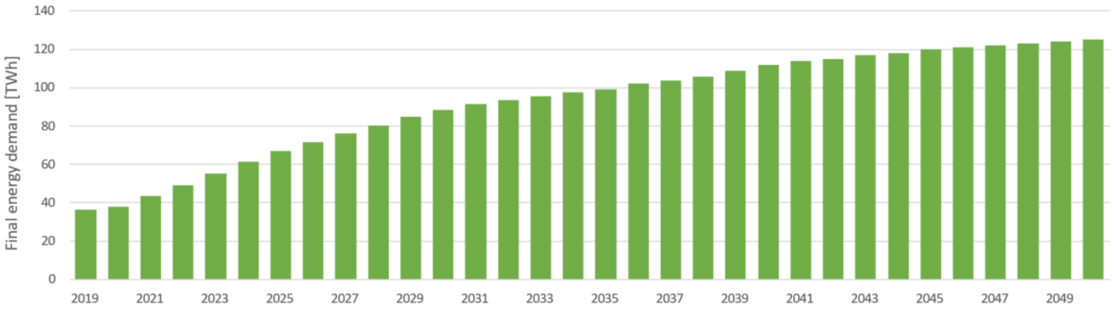


Figure 35 Electric demand of the computing energy in data centres in EU27 in the Ref Scenario



The energy demand of the data centre infrastructure including cooling and UPS is presented in Figure 36. The development of the future demand until 2050 assumes a steady increase that is partially decoupled from the demand of servers thanks to efficiency gains. The potential efficiency gains are assumed to be higher in the IT infrastructure than in the computing field.

Figure 36 Demand for data centre infrastructure (cooling in server rooms, UPS, etc.) in EU27 in the Ref Scenario

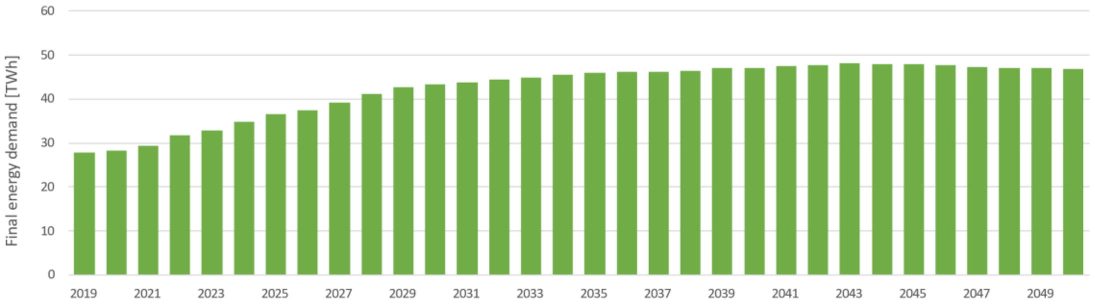


Table 10 summarises the key parameters of the modelled data centres in this project. For comparison, the equivalent numbers of Montevecchi (2020) are added. Whereas this project refers to EU27 and simulates from 2019 onwards, Montevecchi refers to EU28 (including UK) and performs an ex-post-analysis finishing in 2018. In general, the energy demand of the servers and infrastructure lies in the same range and the yearly increase rates of the Baseline Scenario are comparable.

The PUE (Power Usage Effectiveness) of the data centres is the quotient of the overall energy consumption including infrastructure for cooling, UPS and others, divided by the demand for the core IT equipment (servers, storage and network).

For EU28, Montevecchi gives a value of 1.76 for 2018, whereas in FORECAST for EU27, the value for 2019 is slightly more efficient (1.71). It is assumed that the development in the Baseline Scenario will reach and underpass the level of 1.4 in 2050. In the newTRENDs Scenario, the diffusion of more efficient equipment will be faster and a value of 1.33 is reached in 2050.

Table 10 Comparison of the energy demand and the yearly increase of the two NewTrends Scenarios and Montevecchi (2020)

	Servers		**Infrastructure**				
	Energy Demand [TWh]	**Average Yearly Increase 1)**	**Energy Demand [TWh]**	**Average Yearly Increase 1)**	**PUE in 2018**	**PUE in 2019**	**PUE in 2050**
Baseline Scenario (EU27, 2019)	36	7.9%	28	2.2%		1.77	1.38
NewTrends Scenario (EU27, 2019)	36	13.8%	28	4.0%		1.77	1.38
Montevecchi (EU28, 2018)	44	4.9%	33	2.2%	1,76		

The average yearly increase of the source from Montevecchi is calculated by dividing the given development by the given period of 8 years (base year 2018). It indicates the past development. In the case of the FORECAST scenarios, the average yearly increase is calculated based on the simulated future time period, covering the years from 2019 to 2050.

The comparison of the average yearly increase of the server' energy consumption shows that we assume a higher future increase than what was reported in the past due to over-proportional rising ICT demand. For the infrastructure, we assume a decoupling from the server energy consumption due to efficiency improvements.

The higher demand caused by teleworking and working in co-working spaces is added to these energy services.

3.3.2.4 Building Automation

Building automation has many facets. The applications extend from simple motion sensors to fully automated ventilation systems which are interconnected with other technical (smart) building systems. While the FORECAST simulation framework already includes a variety of energy saving options (ESO), the advanced and standardised smart building concepts, particularly the so-called BACS (Building automation and control systems) were added in this project. The details of the implementation can be found in D6.2[7].

The energy saving effects of BACS are considered through the reduction of full load hours of energy applications (such as e.g., ventilation) as well as varying diffusion scenarios. The foundation lies with ESOs that promote a minimum and advanced energy performance standard (MEPS and AEPS). The full energy efficiency potential of BACS is then represented by a novel ESO, based on the building automation norm EN 15232, namely its *BACS-factors*. These factors provide an estimation of the expected energy savings from BACS. In this report, we only focus on the effect of BACS on electricity applications (i.e. heat demand will not be affected). The new ESO is deployed at a slower pace than the MEPS and AEPS of the same energy services. To model the effects of BACS due to new trends, we implement two different diffusion developments of the A-level BACS: the moderate BACS scenario as part of the Baseline Scenario, and the high BACS scenario as part of the newTRENDs Scenario. The high scenario promotes a stronger adoption of very efficient BACS measures such as interconnected room automation with automatic demand detection and sustainable energy optimisation (additional policy-relevant scenarios are also modelled and discussed in D6.5). For both moderate and high diffusions, we assume that the new ESO prevails at a fraction of the AEPS diffusion rates. These assumptions result in the final diffusion curves depicted in Figure 37 and Figure 38. For the example of ventilation, shows that the diffusion of advanced BACS is rising steadily from below 1% in 2012 to 8% in 2050 in the Baseline Scenario.

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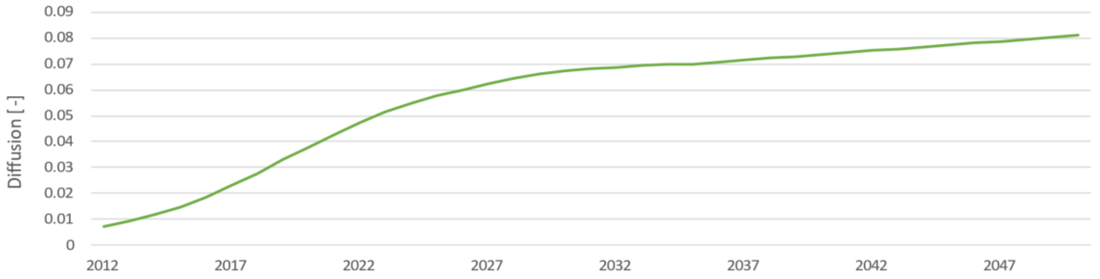
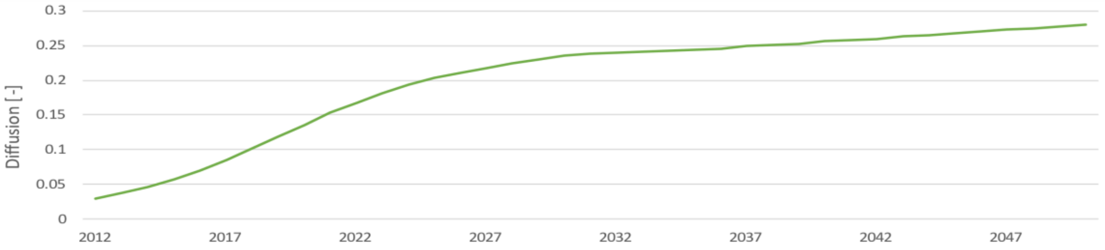
[7] D6.2 newTRENDs Focus study report: Digitalisation in the Tertiary Sector

Figure 37 Diffusion curve for ventilation (Advanced BACS) in the Ref Scenario (moderate diffusion)



In the Reference_NT (Figure 38), the diffusion reaches a higher value of 28% in 2050. In this example, the energy consumption for ventilation is 109 TWh for EU27 in the Baseline Scenario and 108 TWh in the more efficient newTRENDs Scenarios.

Figure 38 Diffusion curve for ventilation (Advanced BACS) in the newTRENDs Scenario (higher diffusion)



3.3.3 Results

Figure 39 shows the final energy demand in the tertiary sector. This includes all applications like space heating and domestic hot water, and all types of electric appliances like lighting or ventilation. Furthermore, the ambient heat that is used by a heat pump to produce usable heat, is also part of the balance. By this approach, the chart shows that the energy transferred into the building depends on the demand and on the efficiency of the appliances. For example, a light bulb with higher efficiency reduces the electric demand in the building as well as a better insulated window or a heating system with higher efficiency.

All four scenarios show a decrease in energy demand, while the number of employees and the total floor area stays at a comparable level. The reason for the decrease is the growing efficiency in energy use.

Comparing the different scenarios shows that the Decarbonisation Scenarios require less energy than the Reference Scenarios. The difference in demand increases over the course of the simulated years and reaches ~ 6% in 2050. The newTRENDs Scenarios also contribute to an energy reduction, however to a smaller extent.

Figure 39 Final energy demand in tertiary sector (EU27) for all applications

Figure 40 focuses on the electric consumption excluding the demand of space and domestic hot water (that is included in the next chart). The first observation is that the newTRENDs Scenarios have higher demand that results from the higher ICT activity. However, the difference is moderate, at its peak in 2050 is below +2.5% (Reference Scenarios) respectively +3.4% (Decarb Scenarios).

In general, the electric consumption stays at a level of ~600 TWh in the Reference Scenario. The Decarb Scenarios can reduce consumption at its most in 2050 by ~6% (Reference Scenario) respectively ~7% (newTRENDs Scenario).

Figure 40 Electric consumption in the tertiary sector (EU27) for all applications

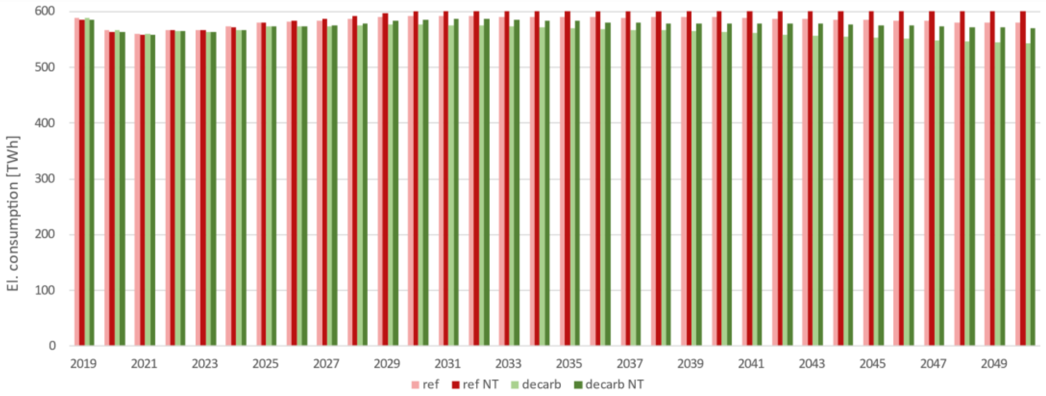


Figure 41 shows the final energy demand for space heating and hot water, including ambient heat that is used by heat pumps to be transferred into usable heat. In all scenarios, a significant reduction due to increased efficiency of the heating systems or to the building envelope performance can be observed.

Compared to 2019, the reduction is up to 46% (Reference Scenarios) respectively 49% (Decarb Scenarios) in 2050.

The Decarb Scenarios demand decreases by a higher extend compared to the Reference Scenarios, due to increased efficiency ambitions. The newTRENDs Scenarios decrease the demand by activities in the field of building automation and due to the reduced floor area in the retail subsector, caused by rising e-commerce.

Figure 41 Final energy demand in tertiary sector (EU27) for space heating and domestic hot water applications

Figure 42 summarises the greenhouse gas emissions of the four scenarios. As expected, the Decarb Scenario emissions are lower than those of the Reference Scenario. The Decarb Scenario reaches ~3 Mt CO_2-eq in 2040 whereas the Reference Scenario in 2050 still has 11 to 12 Mt CO_2-eq of emissions. The difference between the Baseline and the newTRENDs Scenarios are rather small. The gain in efficiency is partly compensated by the higher demand of electricity for the ICT usage.

Figure 42 Total GHG emissions in the tertiary sector (EU27)

3.3.3.1 Teleworking

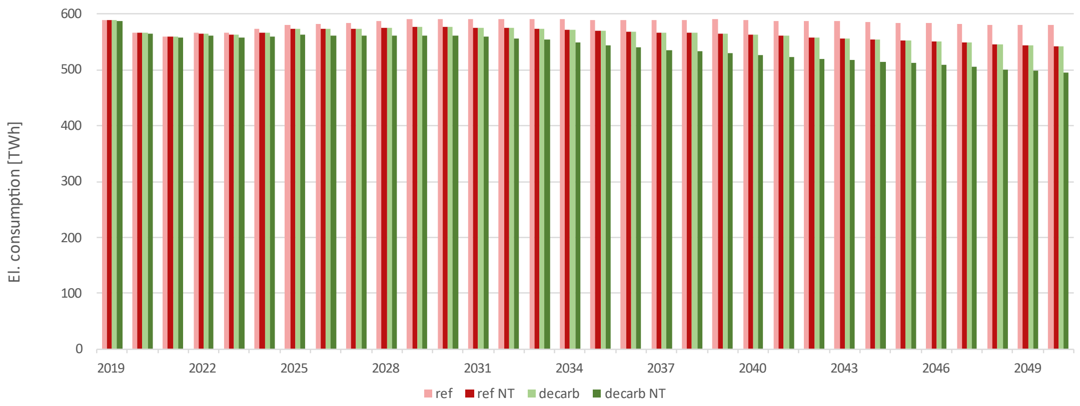
This chapter focuses on the effects of teleworking (TW). The newTRENDs Scenarios reduce the overall demand of energy compared to the Baseline Scenarios (Figure 43). The reduction in 2050 is ~6% (Reference Scenarios) respectively ~8% (Decarb Scenarios).

Figure 43 Final energy demand in the tertiary sector (EU27) for all applications (only TW effects)

This overall reduction of energy demand in the newTRENDs Scenarios is caused both by less electric demand (Figure 44) and less heating demand (Figure 45). As this section only describes the tertiary sector, the demand in this sector declines if more employees work in their private homes.

The electric demand (Figure 44) stays at the same level of approximately 600 TWh in the Reference Scenario. In the newTRENDs Scenario, it is ~7% lower in 2050 (~9% lower in Decarb Scenario).

Figure 44 Electric consumption in the tertiary sector (EU27) for all applications (only TW effects)



The heating demand for working space and domestic hot water in general goes down due to improved building insulation and heating system efficiency (Figure 45). The effect of TW (newTRENDs Scenario) reduces the demand to a higher extent, as the needed floor area of working spaces is reduced. As not all employments are suitable for teleworking and not all employees use this option, the savings are less than ~5% (Reference Scenario).

Figure 45 Final energy demand in the tertiary sector (EU27) for space heating and domestic hot water applications (only TW effects)

3.3.3.2 E-Commerce

This chapter focuses on the effects of E-Commerce (EC). When looking at the whole tertiary sector, the effects of EC are moderate, as many subsectors are not impacted by the increasing e-commerce activity (see Figure 46 Figure 47 Figure 48).

Figure 46 Final energy demand in tertiary sector (EU27) for all applications (only EC effects)

Figure 47 Electric consumption in tertiary sector (EU27) for all applications (only EC effects)

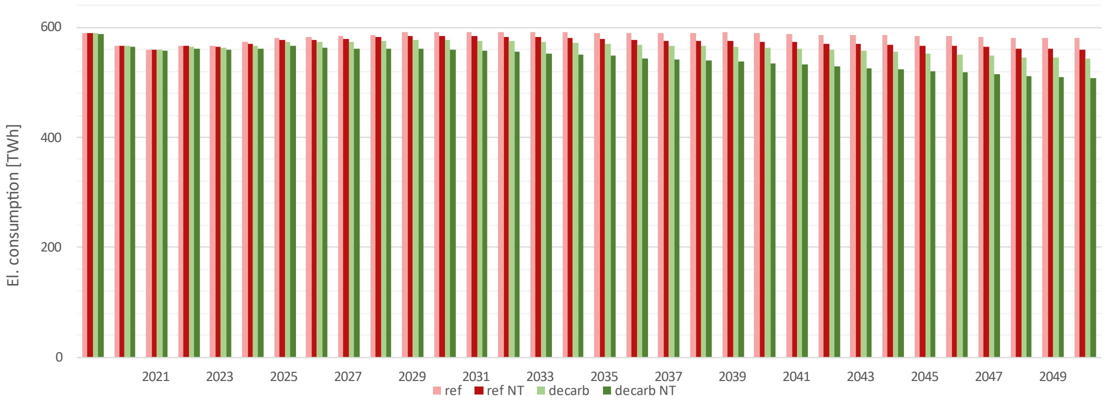


Figure 48 Final energy demand in tertiary sector (EU27) for space heating and domestic hot water applications (only EC effects)

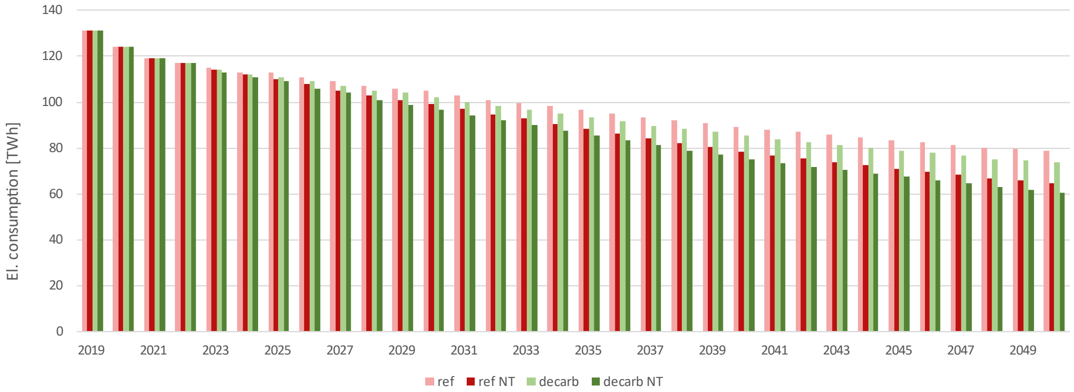
When focusing on the retail subsector, the difference between baseline and increased e-commerce activity are getting more obvious.

In general, the rising e-commerce activity leads to less shopping area and therefore to less heated floor area. Besides heating, other applications like cooling, lighting, ICT and others are relevant regarding the energy demand in retail buildings. The retail subsector not only includes the shopping areas but also the spaces for storage and offices. With the assumed increase of EC, the total energy demand in 2050 declines by ~17% (in both reference and Decarb Scenario) in the case of increased EC (newTRENDs) compared to the reference (Figure 49).

Figure 49 Final energy demand in the retail subsector (EU27) for space heating and domestic hot water applications (only EC effects)

Figure 50 shows the electrical demand in the retail subsector. The higher share of e-commerce is responsible for ~18% reduction in 2050. The reason is the reduction of sales area, and its energy demands of lighting, ventilation and ICT in the shops.

Figure 50 Final energy demand in the retail subsector (EU27) for space heating and domestic hot water applications (only EC effects)



The heat demand in the retail subsector (Figure 51) goes down by ~17% (for both reference and Decarb Scenarios) in 2050 due to less shopping areas as shown in the section of the scenario assumptions, 3.3.1.2.

Figure 51 Final energy demand in the retail subsector (EU27) for space heating and domestic hot water applications (only EC effects)

3.3.3.3 Digitalisation and Data Centres

This chapter focuses on the effects of Digitalisation and Date Centers (DC). The additional ICT demand is only electric, as there is no additional heating demand assumed in data centres or in office spaces due to higher ICT demand.

newTRENDs Scenarios lead to higher data traffic and computing power. The overall effect in the tertiary sector regarding the electricity demand sums up to ca. +12% in 2050 in both reference and Decarbonisation Scenario (see Figure 52).

Figure 52 Electric consumption in tertiary sector (EU27) for all applications (only DC effects)

While the electric consumption of the core IT equipment rises steadily in the newTRENDs Scenarios (Figure 53), the demand of the data centre infrastructure (equipment for cooling, UPS and others) reaches saturation.

Figure 53 Electric consumption in tertiary sector (EU27) for data centre core applications (only DC effects)

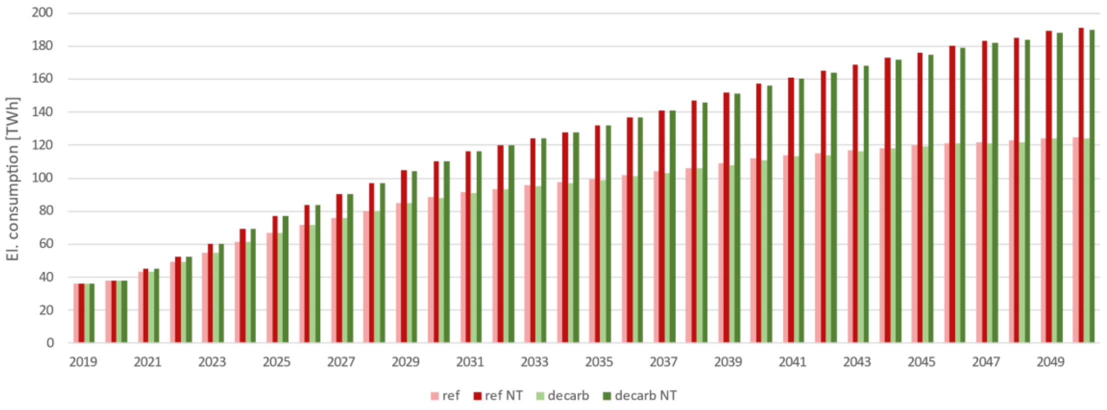
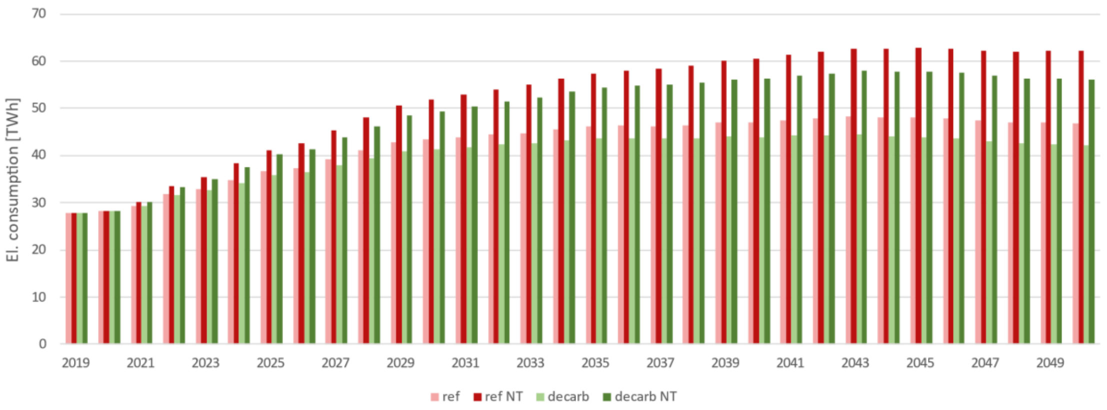


Figure 54 Electric consumption in tertiary sector (EU27) for data centre infrastructure (only DC effects)



This behaviour reflects the increasing efficiency, the according PUE values are shown in Table 7. Whereas all scenarios start with a value of 1.77, they reach different efficiencies levels in 2050. In 2050 the highest power usage is in the reference Baseline Scenario (1.38) and the best value in the decarbonisation newTRENDs Scenario, where both decarbonisation ambitious and technological improvements help to increase the efficiency (PUE 1.30).

Table 11 PUE (Power Usage Effectiveness) of data centres in EU27 in the different scenarios

Scenario	PUE in 2019	PUE in 2050
Reference Baseline	1.77	1.38
Reference NewTrend	1.77	1.33

Scenario	PUE in 2019	PUE in 2050
Decarb Baseline	1.77	1.34
Decarb NewTrend	1.77	1.30

Compared to the data centres, the energy demand of ICT devices in offices (desktop computers, monitor, copy machines and others) increases slower and is far lower, by a factor more than 10 (Figure 55**Error! Reference source not found.**).

Figure 55 Electricity consumption in tertiary sector (EU27) for ICT office devices (only DC effects)

The total demand of data centres compared to the total electricity demand in EU27 is displayed in Table 8. In all scenarios the share starts at 11% in 2019. In the Baseline Scenarios it rises to 30% (Reference Scenario) respectively 31% (Decarbonisation Scenario) in 2050. The newTRENDs Scenarios with their much higher ICT demand reach values of 38% (Reference Scenario) respectively 40% (Decarbonisation Scenario).

Table 12 Share of electric demand of data centres compared to the total electricity demand in the tertiary sector in EU27

Scenario	Share in 2019	Share in 2050
Reference Baseline	11%	30%
Reference NewTrend	11%	38%
Decarb Baseline	11%	31%
Decarb NewTrend	11%	40%

3.3.3.4 Building Automation

This chapter focuses on the effects of Building Automation (BA). In general, the assumed activities (see 3.3.1) lead to a reduced energy demand in the tertiary sector. As the BA measures are advanced, the additional reduction compared to other energy saving options that are already considered in the model, is limited. The BA measures that are subject of analysis are:

- Lighting
- Room air conditioning
- Ventilation
- Circulation pumps and other heating auxiliaries
- Cooling in server rooms

They all reduce the electric energy demand by reducing the yearly hours of utilisation. The heating demand of the buildings is not changed by these measures, the change of energy demand takes place only on the electric side, for non-heating applications (Figure 56). The electricity savings induced by advances in building automation in the entire tertiary sector sums up to ~2% (Reference Scenario) resp. ~5% (Decarb Scenario) in 2050.

Figure 56 Electric consumption in tertiary sector (EU27) for all applications (only BA effects)

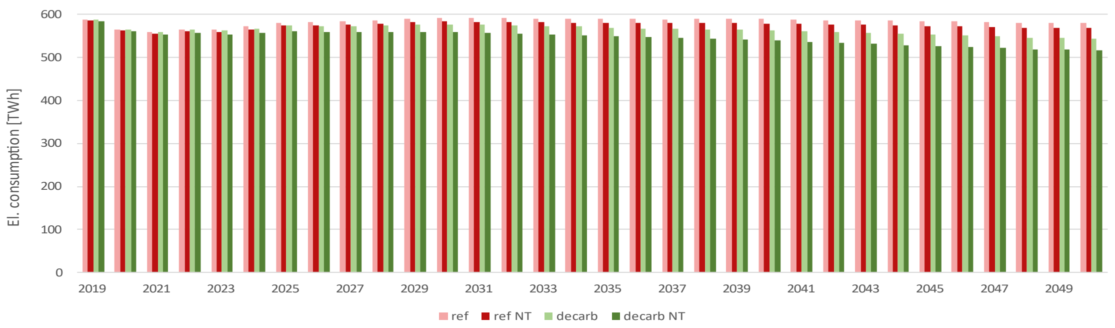


Table 13 lists the savings in three different BA fields for both the reference and the Decarbonisation Scenario. The amount of saved energy from very efficient A-level BACS is biggest for room air conditioning and of minor extend for lighting and ventilation and building services. The total saved energy of the advanced BACS depends on the overall energy consumption of the according appliances and the already assumed contribution of the upstream ESOs, namely MEPS and AEPS ESOs (see also D6.2 and D6.3).

Table 13 Savings of the A-level-BACS in comparison of the baseline and NewTrend-scenarios in the reference and the decarbonisation cases

Scenario	Reference		Difference		Decarbonisation		Difference	
	Baseline Abs. Consumption [TWh]	New Trends Abs. Consumption [TWh]	[TWh]	[%]	Baseline Abs. Consumption [TWh]	New Trends Abs. Consumption [TWh]	[TWh]	[%]
All Electric Applications without Space Heating and Hot Water	595	579	-16	-3	554	541	-13	-2
Ventilation and Building Services	109	108	-1	-1	99.9	99	-1	-1
Room Air Con-ditioning	104	90	-14	-13	92.5	81	-12	-12
Lighting	97	96	-1	-1	87.3	86.4	-1	-1

3.4 RESIDENTIAL

We start with an outline of the scenario design and some data related aspects (chapter 3.4.1) before we present and discuss scenario results for the two model-families, first for Invert/EE-Lab and Invert/Flex (chapters 3.4.2.1 and 3.4.2.2, respectively) and second for the PRIMES-Prosumager model (chapter 3.4.2.3).

3.4.1 Invert/EE-Lab | Invert Flex | PRIMES-Prosumager: key features and improvements

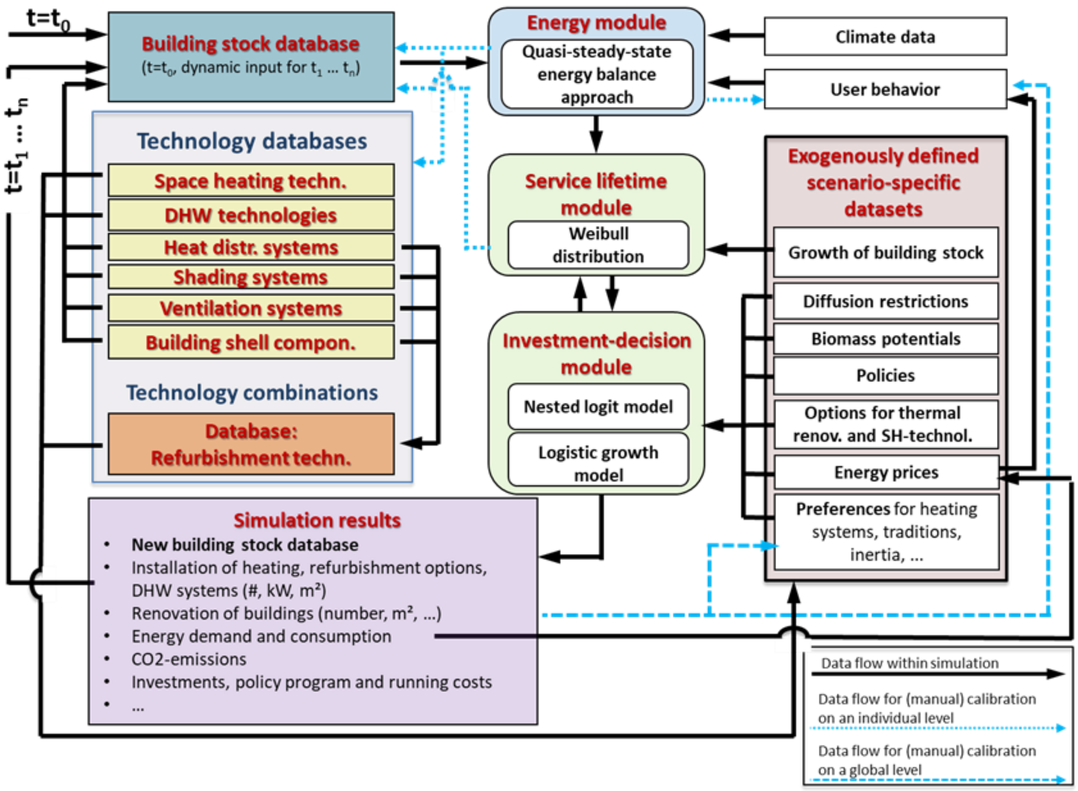
3.4.1.1 Invert/Flex

Invert/EE-Lab is a techno-socio-economic bottom-up building stock model that simulates energy-related investment decisions in buildings, specifically focusing on space heating, hot water generation, and space cooling end-uses. It segregates the building stock by several types of building categories (e.g., single – versus multi-family homes in the residential sector and different and different commercial sectors), construction period and refurbishment status in the initial simulation year as well as heating systems and regional aspects (e.g urban vs rural) by using building archetypes.

The model calculates the useful energy demand (or energy needs) of the buildings and, thus, the building stock on a monthly basis. This is done using building-physics based quasi-steady state approach. Besides calculating the energy demand and consumption of an existing building stock, the model anticipates the possible evolution of the building stock and its energy performances under predefined framework-conditions. This means that many input parameters, such as energy prices, investment costs for different refurbishment activities, building component lifetime distributions, climate change, availability of energy carriers and heating systems as well as different normative and financial policy measures and others, are defined exogenously.

The model then decides endogenously in which year which share of building components have reached their end of lifetime and the share of successor technologies that replace those components. These Investment decisions are taken once per simulation period, which can be on a yearly basis. The investment decision for single buildings to improve energy efficiency measures or to switch heating systems is simulated through a combination of a discrete choice approach and technology diffusion theory with additional constraints for each heating system and building type. The model horizon of Invert/EE-Lab is usually 2050 (depending on the scenario).

Figure 57 Flow chart of the Invert/EE-Lab building stock simulation model



In the Invert/EE-Lab model, the time-resolution for the energy consumption is monthly, while investment decisions are considered annually. In more flexible energy market, the existing model struggles to give relevant answers to research questions that explicitly address the impact of these flexibilities. E.g., the model doesn't foresee concrete load profiles and is unable to endogenously consider load shifting and its impact on the load profiles and costs.

To overcome this fundamental barrier, the FLEX model was developed to enable investigation of research questions which need a higher level of temporal resolution. For example, the impact of variable energy price tariffs or the impact of prosumagers (households that consume, produce and manage their electricity) can be obtained with this higher time granularity. A detailed description of the FLEX extension to the Invert/EE-Lab model is provided in [REF].

3.4.1.2 PRIMES-Prosumager

The PRIMES-Prosumager model represents in the form of a mathematical programming problem the decision-making process of individual households within a multi-year projection horizon. It includes options regarding building envelope renovation interventions that result in improved efficiency of the building shell. It also covers the various energy uses of the household both in terms of investments in equipment and appliances but also in terms of operation to cover needs on an hourly basis. Finally, the model offers the possibility for the household consumer to invest in onsite generation through installing a rooftop photovoltaic (PV) system and a battery energy storage system (BESS). Through this combination of systems and through active management of the various energy resources the household covers its energy needs and at the same time interacts with the electricity distribution network.

The multi-year projection horizon is divided into five-year intervals, which allows to consider the investment dimension throughout the technical and economic lifetime of the equipment and appliances. The operational dimension is simultaneously considered by equivalently representing each year in the projection horizon through seven typical days, each one comprising eight characteristic hours. Thus, the investment and operational options are simultaneously considered and affect one another allowing a holistic approach.

The PRIMES-Prosumager model has been developed as an optional add-on of PRIMES Buildings Model (PRIMES-BuiMo) (Fotiou et al. 2019) and uses the useful demand projection as provided by PRIMES-BuiMo. Its detailed description is included in (Asimakopoulou et al. 2022).

The PRIMES-Prosumager model, being representative of a single household, considers in the optimisation procedure given characteristics as to:

1. the type of building (single or multi-storey),
2. the location (urban, rural, semi-urban),
3. the income class (low, medium, high income), and
4. the existing stock of equipment for covering the heating needs.

To demonstrate the behaviour in different scenario frameworks, the model is solved for a number of residential consumers of varying characteristics selected in such a way that the existing stock of equipment for covering the heating needs complies with the type and location of the building – not all technologies are available, e.g. district heating is available for urban households, and on the other hand with the observed fuels as documented in the relevant statistics [REF].

3.4.1.3 Input data and main assumptions

We implemented the overall scenario framework, being applied in this report.

Table 14 Scenario design for the residential sector

Decarbonisation Measures Implemented	*Decarbonisation Scenario* Decarbonisation measures are implemented with a strong focus on direct electrification via heat pumps High energy efficiency measures, in particular related to the renovation of the building envelope are implemented. No focus on and no explicit incentives for prosumaging.	*Decarbonisation and New Societal Trends Scenario* Decarbonisation measures are implemented with a strong focus on direct electrification via heat pumps High energy efficiency measures, in particular related to the renovation of the building envelope are implemented. Focus on and explicit incentives for prosumaging.
Decarbonisation Measures Not Fully Implemented	*Reference Scenario* No stringent efficiency policies are implemented No stringent phase out policies of gases and liquids are implemented No focus on and no explicit incentives for prosumaging.	*New Societal Trends Scenario* No stringent efficiency policies are implemented No stringent phase out policies of gases and liquids are implemented Focus on and no explicit incentives for prosumaging.
	New Societal Trends Not Considered	**New Societal Trends Considered**

Invert/EE-Lab and Invert/Flex

The *Reference Scenario* and the *Decarbonisation Scenario* are calculated once with Invert/EE-Lab as the scenarios where new societal trends are not considered. The building stock data from these Invert scenarios is then further processed with the FLEX model to calculate the impact of new societal trends. A chosen societal trend in the residential building sector is prosumaging, thus the model runs are focusing on the impact of prosumagers on the electricity demand on country level. In doing so we compare an extreme scenario where all buildings with electrified heating systems are responding to hourly electricity tariffs in the future as prosumagers. In doing so we show the potential of the European building stock to shift electricity demand in the future through electrified heating systems. A detailed description of the FLEX model is provided in D5.2 (Mascherbauer et al. 2022). Assumptions for future developments of storage applications as well as electricity prices are provided in newTRENDs deliverable D5.4[8] in chapter 2.4.

Another new societal trend, namely the trend towards remote working and home-office on energy demand patterns in the residential, non-residential and mobility sector was analysed in DX.X, and thus is not being presented here explicitly.

PRIMES-Prosumager

The scenarios defined for the needs of the newTRENDs project being differentiated by the inclusion or not of the prosumager trend and by the type of projection, serve as guide for setting the framework within which the prosumager model is applied.

Excluding the prosumager trend from the scenarios implies that the PRIMES-BuiMo is applied in its entirety. Including the prosumager trend in the scenarios implies that the useful demand projection supplied by the PRIMES-BuiMo is used as input to the developed prosumager model. Subsequently, the latter is applied to produce the projected final energy demand of the modelled households both in terms of total volume and in terms of fuel mix: renovation interventions of varying depth may result in energy savings for heating and cooling ranging between 5%-90%; equipment choice may result in fuel switch in heat uses; rooftop PV in combination or not with BESS may result in lower electricity grid consumption during certain hours of the year or even electricity exports to the distribution grid in case of surplus renewable generation.

The projection obtained is further affected by the type of policy framework considered in each scenario: The Reference Scenario is in line with the EU Reference Scenario (European Commission 2021) i.e. it includes policies until 2030 and assumes no additional measures for the subsequent years. The Decarbonisation Scenario, on the other hand, considers an energy policy framework that sets more ambitious targets in terms of greenhouse gas emissions, energy efficiency and share of renewable energy in the energy mix. The two distinct frameworks affect the inherently decided capacity for onsite PV and BESS, investments in appliances and equipment for the various end uses as well as renovation intervention measures.

3.4.2 Results

In the following, we present first the Invert results describing the development of the building stock under Decarbonisation Scenario and the Reference Scenario. Based on this building stock information, the FLEX model is applied and delivers information on how the new societal trend of prosumaging could impact energy consumption in these two scenarios. These results are described in Chapter 3.4.2.2.

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[8] https://newtrends2020.eu/publications/

3.4.2.1 Decarbonisation and Reference Scenario (Invert/EE-Lab)

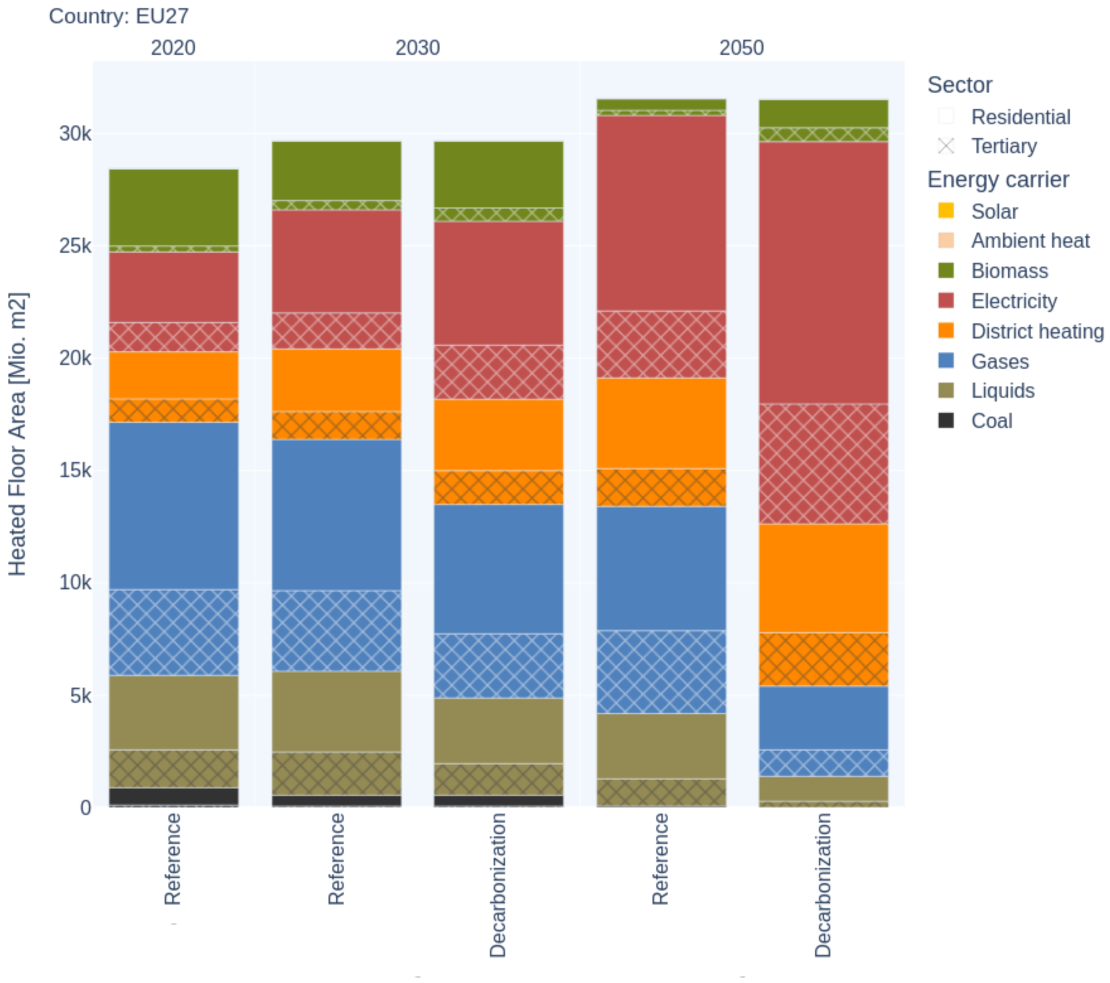
Figure 48 shows the absolute development of heated floor area by energy carrier, which is used to supply space heating. The figure only includes main energy carriers and no secondary energy carriers to avoid double counting, which is why solar and ambient heat do not explicitly show up. In both scenarios, the share of electricity (mainly heat pumps, only to a minor extent resistance electrical heating) and of district heating increase. However, in the Reference Scenario more than a third of the floor area is heated by liquids and gaseous fuels, which stay in the supply mix despite of high fuel prices because of early decisions for these heating systems, resulting from a lack of stringent regulatory measures and resulting in lock-in effects. On the other hand, the Decarbonisation Scenario reduces the share of gases and liquids on the heated floor area to below 20% by 2050, because of an even stronger increase of heat pumps and partly district heating (and to minor extent biomass). This is mainly a result of stringent regulatory policies for phasing out gas and oil-based heating systems at an early stage.

A closer look on the final energy demand in these scenarios (Figure 58) reveals two main effects:

First, in both scenarios the final energy demand for space and water heating decreases due to refurbishment of the building envelope and more efficient heating systems to about 75% (Reference Scenario) and 60% (Decarbonisation Scenario) in 2050 compared to the year 2020. Considering only delivered energy, i.e. subtracting the share of ambient and solar energy, the reduction is even more significant, resulting in a decrease to about 40% in the Decarbonisation Scenario by 2050 compared to 2020.

Second, the share of gases and liquids on the final energy demand is lower than measured in terms of the heated floor area. This is partly because gas- and liquid-based heating systems have the highest variable costs among all heating systems. This makes it most attractive to apply these systems in renovated homes or to renovate buildings with these heating systems.

Figure 58 Heated floor area by energy carrier for space heating in EU-27, reference and Decarbonisation Scenarios, Invert/EE-Lab



3.4.2.2 Prosumager impact on residential energy demand (Invert/Flex)

Based on the results of Invert the FLEX results are calculated. Within this project the FLEX model was developed to simulate prosumagers and their impact on electricity demand on country level in a low temporal resolution (hourly). In this chapter some aggregated results are shown for the EU27 member states.

The hourly electricity price is the driving factor of the optimisation with which the prosumager behaviour is simulated. A high standard deviation coupled with a high frequency of price changes results in a high incentive to shift electrical load. To capture the both the magnitude of change in price as well as the frequency we describe the electricity price with the mean absolute change (MAC) factor:

$$MAC = \frac{}{1-n}\sum^{-1} \quad | \quad {}_{i+1} \quad {}_{i}|$$

Prosumagers in countries with a high electricity MAC factor have a high incentive to shift electrical loads.

Figure 59 Mean Absolute Change (MAC) of the electricity prices in 2020 for the EU27 in cent/kWh

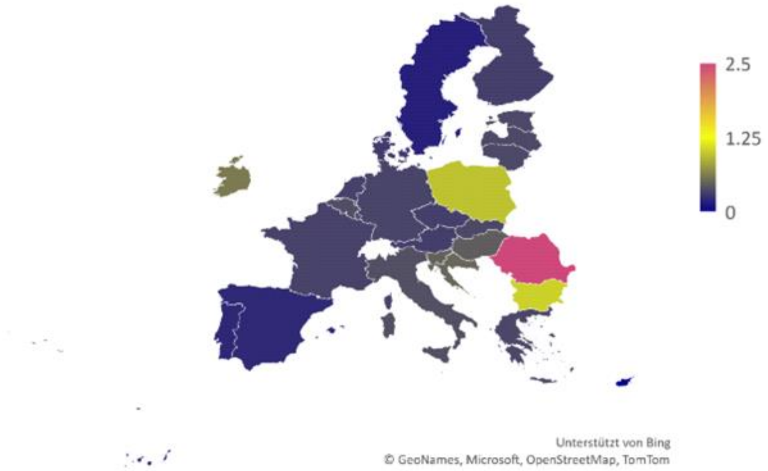
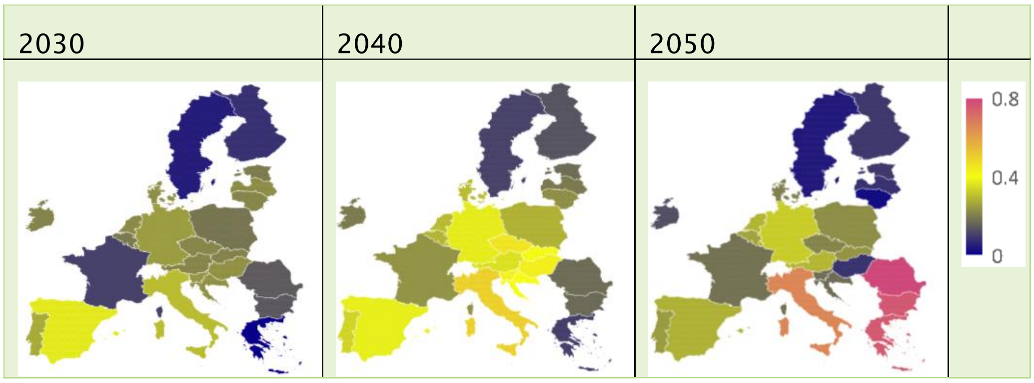


Figure 60 Mean Absolute Change (MAC) of the electricity prices in 2030, 2040 and 2050 for the EU27 in cent/kWh



Comparing Figure 59 and Figure 60 we can see that the MAC is potentially much higher in some countries in 2020. This is due to the higher frequency of price changes that occurred which are not occurring in the simulations for 2030, 2040 and 2050[9]. Price volatility is the main incentive for households to shift load. Because the MAC is significantly different between 2020 and the other years, the following results are going to presented for 2030, 2040 and 2050 only. Different

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[9] http://aures2project.eu/

results for load shifting in countries with similar MAC can be explained by differing building stock and the weather.

In deliverable D5.4 indicators were described to describe the impact of prosumagers on country level. These indicators were described as percentage values to facilitate the comparison between the PRIMES-Prosumager model and the Invert/FLEX combination. In this section we use the same indicators but absolute values on country level.

3.4.2.2.1 Total amount of shifted electricity

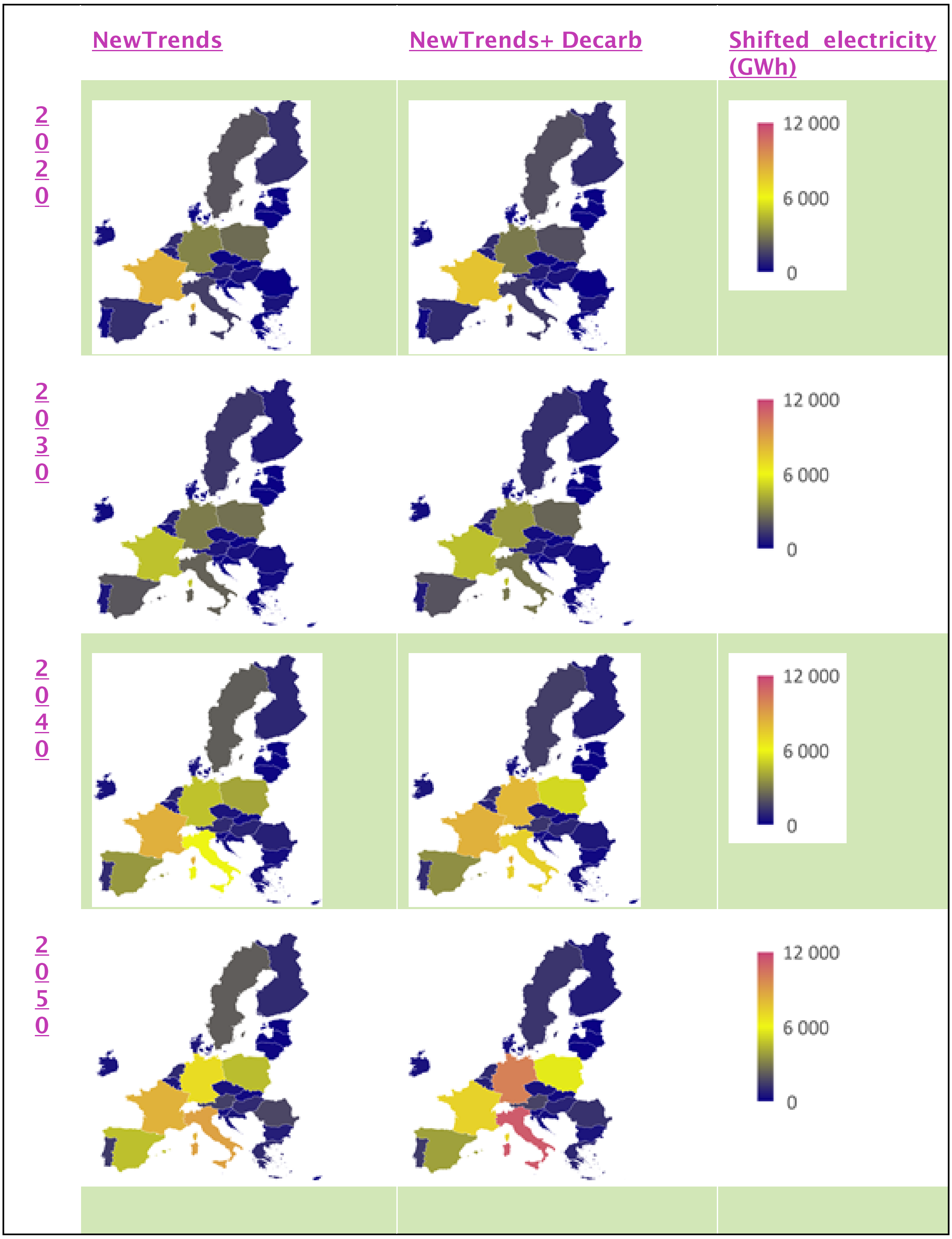
The total amount of shifted electricity refers to the electricity shifted away from peak demand hours in all buildings within the country that have electrified heat uses. The benchmark load $P_{benchmark}$ is the load of the exact same building without prosumaging behaviour and P_{SEMS} represents the prosumager electricity grid load.

$$P_{shifted} = \sum \int \quad P_{benchmark,t} - P_{SEMS,t} \; dt \qquad if \; P_{benchmark,t} > P_{SEMS,t}$$

Figure 61 shows how the amount of possible shifted electricity increases in European countries in the future due to the electrification of heating systems and increase in storage applications. Main driver for the total amount of shifted electricity are the building stock specifics and the total amount of buildings with electrified heating systems as well as the volatility of the electricity price in each respective country. The Nordic states do not shift an increasing amount of electricity through the building sector. Reason for that are small price differences due to all time high generation of renewables and the lightweight wood buildings which have a low thermal capacity.

The amount of shifted electricity is especially high in 2050 in Italy, France, Germany and the Czech Republic. These countries show a high energy demand due to their size of the building stock as well as the possibility to shift load in summer and in winter (cooling and heating needs). Especially in southern countries, an increase in load during peak PV generation hours can be observed, reducing the need for cooling later in the day. The high amount of possible shifted electricity in France in 2020 is attributed to the volatility in the electricity price and to the fact that it has the highest number of buildings with electrified heating systems. In countries with an even higher electricity price volatility (eg. Romania, Czech Republic) electrified heating systems are very rare. Therefore, the absolute amount of shifted electricity is much less.

Figure 61 Shifted electricity in the EU27 in 2020, 2030 and 2050 through prosumaging



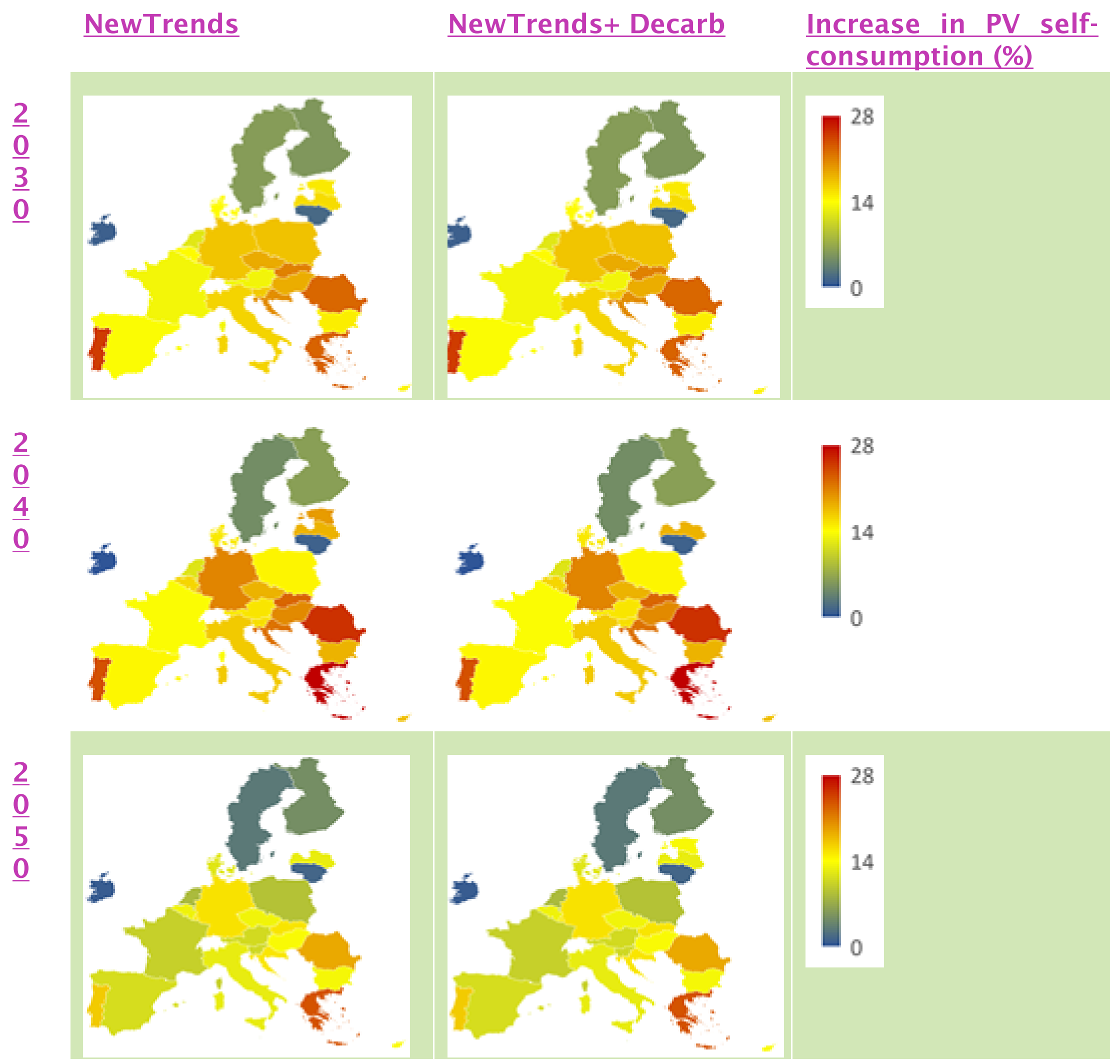
3.4.2.2.2 PV self-consumption

The PV self-consumption describes the amount of consumed PV electricity (PV_{2Load}) compared to the total amount of produced PV electricity ($PV_{generation}$). This metric is only applied to all buildings within a country that have a PV system installed. To get a single value for the whole country, the average of all buildings is taken.

$$PV_{self-consumption} = \frac{\sum \quad PV_{2Load,t}}{\sum \quad PV_{generation,t}}$$

The impact of prosumaging on PV self-consumption is shown in Figure 62 for the two scenarios “newTRENDs” and “newTRENDs+Decarbonisation”. When consumer become prosumager, PV self-consumption increases significantly. Especially southern countries can increase the self-consumption significantly by matching PV production more efficiently to cooling needs (pre-cooling the building). In northern countries the self-consumption of consumers is already relatively high with lower PV production and higher heating demand. Thus, switching to prosumagers does not increase the PV self-consumption as much as in southern countries. Increased renovation rates are the reason behind decreasing PV self-consumption rates from 2030 to 2050. More efficient buildings electricity demand drops, reducing also the possible maximum PV self-consumption rate of prosumagers compared to consumers.

Figure 62 Average increase in PV self-consumption when switching from consumers to prosumers for buildings with PV systems in the EU27 for 2030, 2040 and 2050



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3.4.2.2.3 Load factor

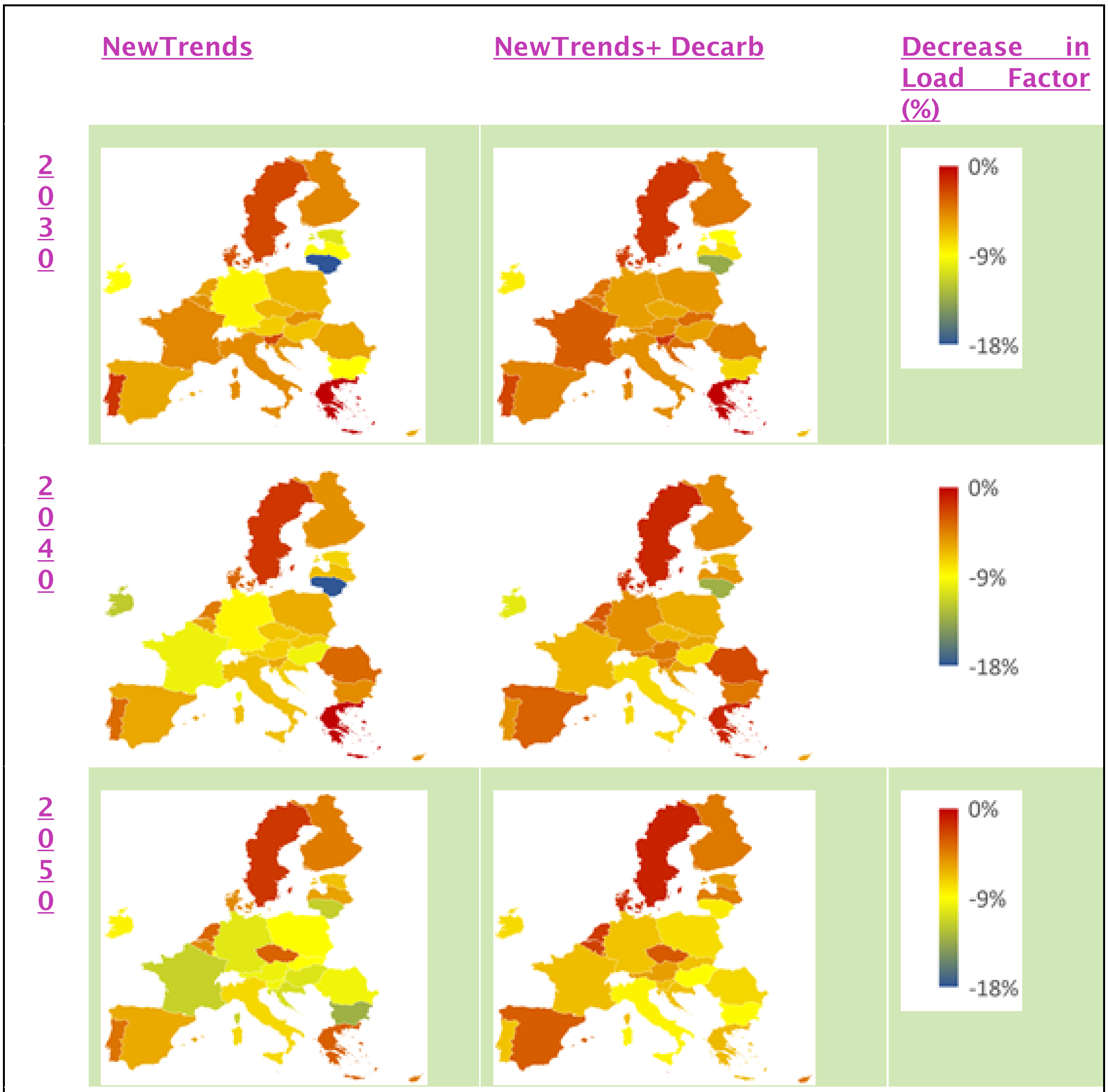
The load factor is a measure to describe the peakiness of a profile by dividing the mean of the profile by its maximum value. In this work we calculate the load factor per day. In both models the load factor is calculated by taking mean of all available days (365).

$$LF = \frac{\underline{P_t}}{P_{max,t}} \quad 1 \leq t \leq 24$$

A high load factor corresponds to a smooth profile whereas a low load factor means that the electricity grid demand of a building has high peaks. In order to focus on the impact on the indicator due to the prosumaging behaviour the load factor will be presented as the difference of the calculated scenarios versus the benchmark load that considers no behavioural changes in terms of load scheduling. This is the same benchmark load used for calculating the load shifting indicator.

Figure 63 shows the average decrease in load factor when households become prosumagers instead of consumers. Naturally, the load factor will drop as the electricity consumption is higher when buildings start to react to a price signal and charge electrical and thermal storages in order to reduce demand at a later time. In addition, the increased PV self-consumption of prosumagers leads automatically to a lower load factor.

Figure 63 Average decrease in Load Factor when switching from consumers to prosumagers in the EU27 member states for 2030, 2040 and 2050



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The decarbonisation of the building stock through an increase of renovation rates leads to a less significant decrease in the load factor through prosumaging compared to the scenario without decarbonisation efforts. Thus, increasing efficiency in buildings additionally benefits the electric grid when the share of prosumagers is going up. Generally, the electricity price influences the change in load factor as it incentivises the prosumagers to shift more load with higher price differences. Nordic countries exhibit small changes in hourly electricity price and therefore also only a small decrease in load factor when switching to prosumagers.

3.4.2.2.4 PV production share

The PV production share describes the total amount of generated electricity ($PV_{generation}$) by rooftop PV systems of all buildings with electric heating systems divided by the total electricity consumption (P) of all buildings with electric heating systems on an annual basis.

$$PV_{share} = \frac{\sum \quad PV_{generation}}{\sum \quad \int \quad P_t \, dt}$$

Figure 64 shows the PV production share for both scenarios in 2030, 2040 and 2050. When switching from consumers to prosumagers the overall PV production share decreases slightly. The total amount of electricity needed by a single household is higher when the household becomes a prosumager due to increased storage losses. Thus, on a country level the electricity demand rises through prosumagers, and the PV production share decreases slightly. This decrease is slightly more visible in the Decarbonisation Scenario where more buildings are electrified than in the Reference Scenario.

Figure 64 PV production-share in each EU27 member state for all buildings with electrified heating systems

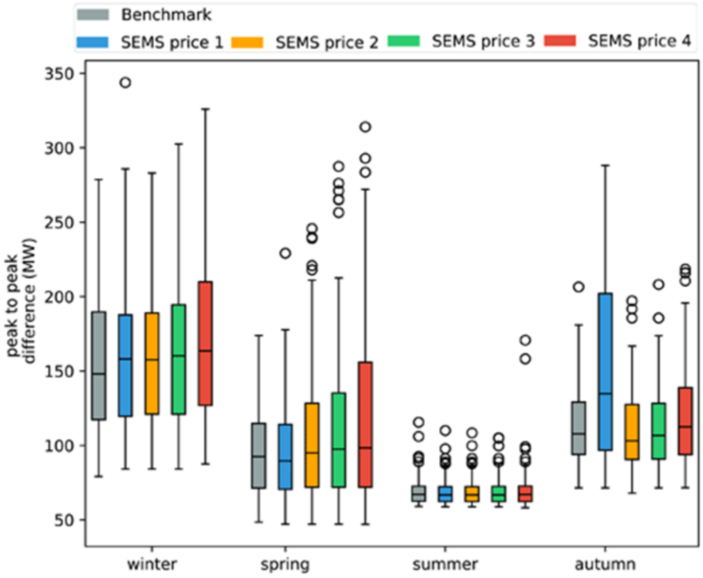
At the same time, the amount of installed PV systems does not increase as much as the share of electrified buildings in the Decarbonisation Scenario. This effect is especially visible in southern countries where the increase in electrified buildings with cooling demand leads to a lower share of PV production, since many buildings are pre-cooled and thus have higher thermal losses. At the same time, there is maximum use of locally produced PV generation. Thus, a decrease in PV production share does not represent a problem that prosumagers cause. Rather, it undermines the fact, that electricity demand can be shifted through the thermal mass of buildings with some losses.

3.4.2.2.5 Daily peak to peak demand

The FLEX model allows to analyse the daily peak to peak demand for EU countries. The FLEX model was used to show the impact of different electricity prices on the peak-to-peak demand of prosumagers in Austria (Mascherbauer et al. 2022). Only single-family houses are considered in this study.

In Figure 65, *SEMS* represent prosumagers who react to four (4) different prices. Price number 1 represents the electricity price from 2021. Because of the price shock prior to the Russian invasion of Ukraine, we can see that the peak-to-peak difference increases drastically due to higher price volatility. The benchmark shows the peak-to-peak difference of the same building stock without prosumagers. The scenario does not consider storages in the households; load is solely shifted through the thermal mass by prosumagers ("SEMS"). This study shows that through the addition of the FLEX model on top of the Invert model the impact of different electricity price schemes can be analysed in detail on a single building level but also on a regional or country level.

Figure 65 Peak-to-peak difference for the Austrian building stock with single family houses reacting to 4 different electricity prices as prosumagers



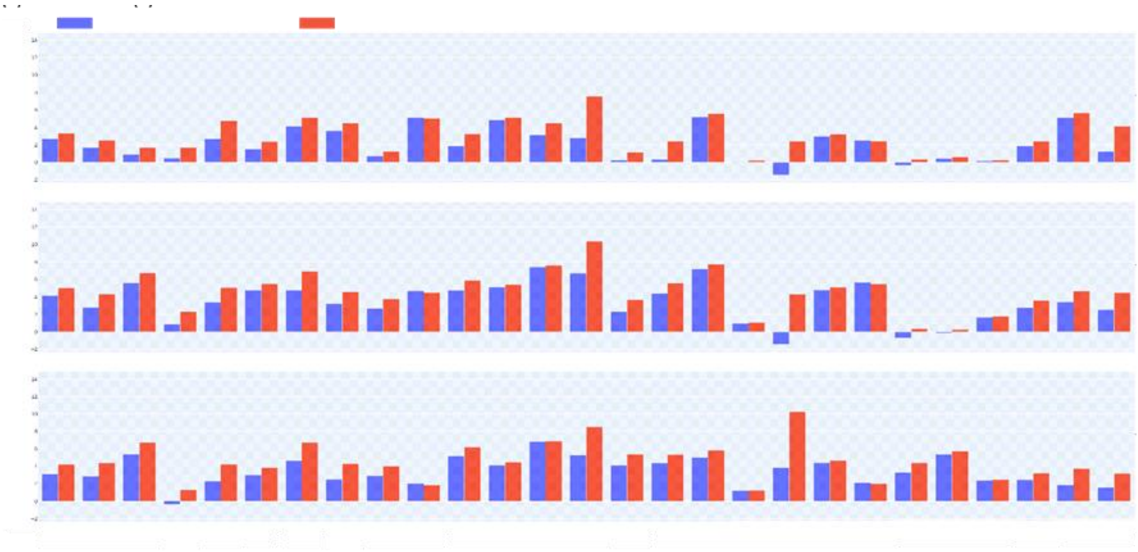
3.4.2.2.6 Impact of prosumaging on total demand (Invert/EE-Lab and Invert/Flex)

As described above, we took the scenarios for the development of energy demand and energy carrier mix in the building stock derived from Invert/EE-Lab as starting point to calculate relevant indicators regarding load shifting in the model Invert/FLEX. We can observe two key effects:

First, prosumaging, if optimised to reduce the operation costs of each building or household, may lead to reduced costs of electrical driven heating systems, in particular heat pumps, if applied in building with correspondingly high thermal inertia or if combined with a thermal storage and more so if combined with on-site electricity generation. This cost reduction could lead to a faster diffusion of these systems and thus might have a related impact on final energy demand and the split energy carriers.

Second, prosumaging scenarios might lead to slightly higher demand, because storage losses are higher than without considering prosumaging and for charging storages, the supply temperature of heat pumps has to be raised. This is the case for heat storage, thermal storage in building mass or electrical storage.

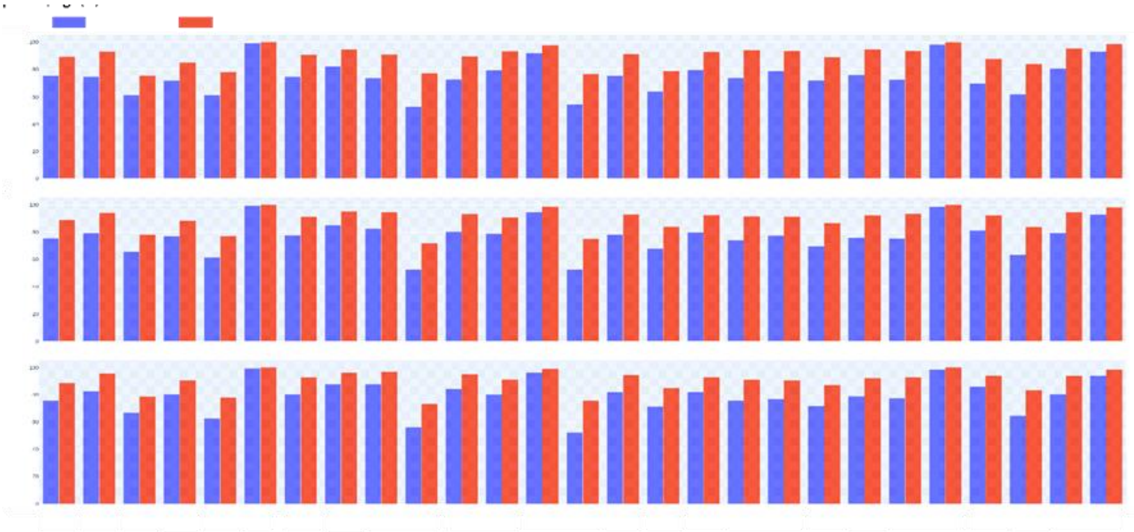
Figure 66 Average increase in the electrified building stock grid demand and load when switching from consumer to prosumager on a country level



Electricity demand of buildings can rise by 1% to 12% on average on a country level through prosumaging (see Figure 66), while PV self-consumption also rises by 10% - 20% on average on a country level (see Figure 67). Therefore, depending on the uptake of PV installations, the total electricity grid demand can be lowered by prosumagers (remarkably high penetration of PV), or may rise slightly compared to the total electricity demand of the buildings (medium to high penetration of PV) or may increase, similar to the total household electricity demand (low PV penetration).

Depending on future electricity prices and the needs of a household for electricity and storage, the reduction of costs ranges from very moderate (or even cost-neutral, if we factor in the uncertainty about the costs of control devices) to highly cost-effective.

Figure 67 Average PV self-consumption for all electrified buildings in each EU27 member state for 2030, 2040 and 2050 under the newTRENDs Decarbonisation Scenario for consumers and prosumagers



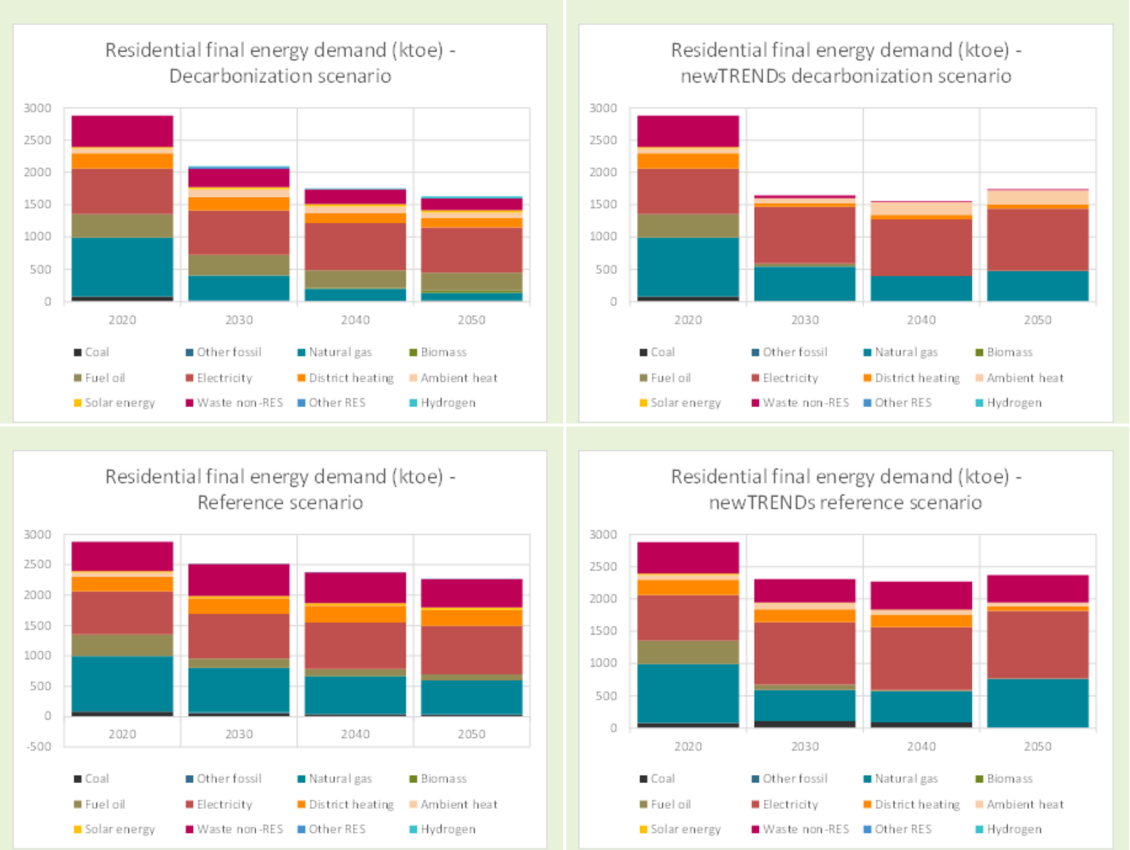
3.4.2.3 PRIMES-Prosumager model

This section focuses on the results of the PRIMES-Prosumager model obtained when applied in the group of scenarios including the newTRENDs. It also presents the results of the group of scenarios without considering the newTRENDs within the projection, i.e. results obtained by applying PRIMES-BuiMo, to the extent that the relevant indicators are available.

Figure 68 presents the evolution of the fuel mix at EU level for the residential sector. In both group of scenarios that consider a reference policy framework, the final energy demand trajectory is characterised by a moderate downward trend. This reflects the impact of existing policies. In a more ambitious framework, however – one that assumes increased uptake of energy efficiency improvements – such as the one considered in the Decarbonisation Scenario group, final energy demand reduces further. This is attributed to the fact that the scenario framework considers policies that drive increased adoption of renovation interventions in the building shell.

In terms of fuel mix, the decarbonisation group of scenarios sees a significant reduction in the use of conventional energy carriers as these are rendered less attractive and renewable sources are promoted. As far as the electricity demand is concerned, the share of electricity is comparable in scenarios within a given policy framework.

Figure 68 Prosumager model: final energy demand (ktoe) per energy carrier for the residential sector in the EU countries across scenarios



Deliverable 5.4 provides an extensive analysis of additional indicators.

The representation of the decision to invest in onsite generation and of the household operation on an hourly basis allows determining the share of the household electricity demand covered by onsite photovoltaic generation (Figure 69) the ‘import’ dependency of the household, that is the share of electricity demand of households covered through grid consumption (Figure 70), as well as the load shifted.

In the case of the newTRENDs Decarbonisation Scenario, introduction of policies facilitating renewables is considered. As a result, higher PV rooftop capacity is installed. This is reflected in the indicators mentioned above: the PV share increases, while the grid dependency decreases. Results at country level vary due to different environmental and economic conditions. Czech Republic in 2050 and southern European countries are the most outstanding cases where the high grid price for electricity (scenario assumption, cf. Mascherbauer et al. 2022) and the high availability of the solar resource, respectively, serve as motives for installing rooftop PV even in the Reference Scenario and with minor need for any support scheme.

Figure 69 Prosumager model: Share of household electricity demand in EU countries covered by onsite photovoltaic generation, 2020 and 2050 newTRENDs reference and 2050 newTRENDs Decarbonisation Scenario

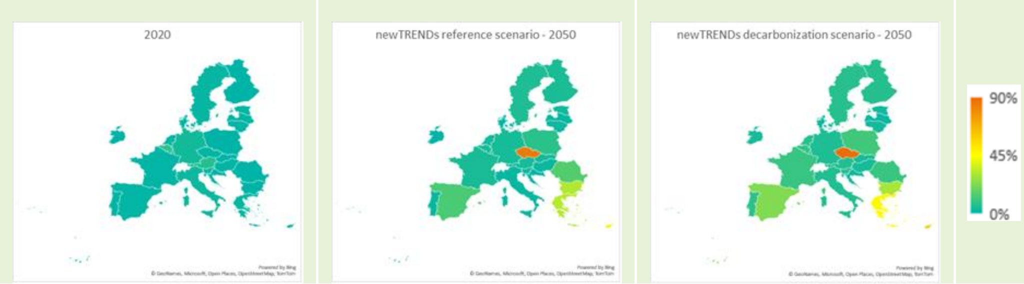
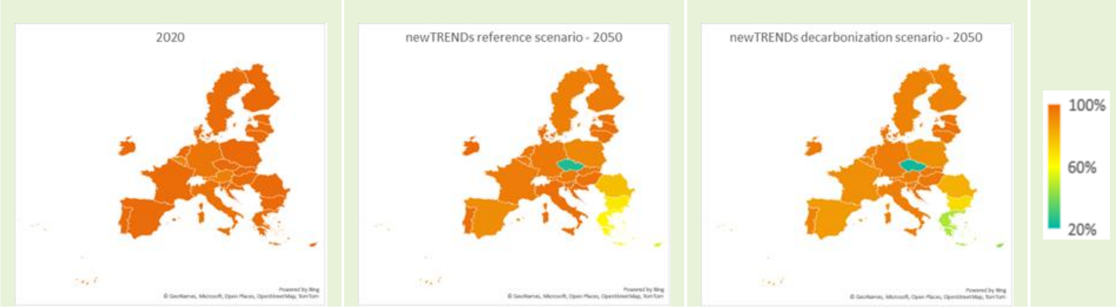
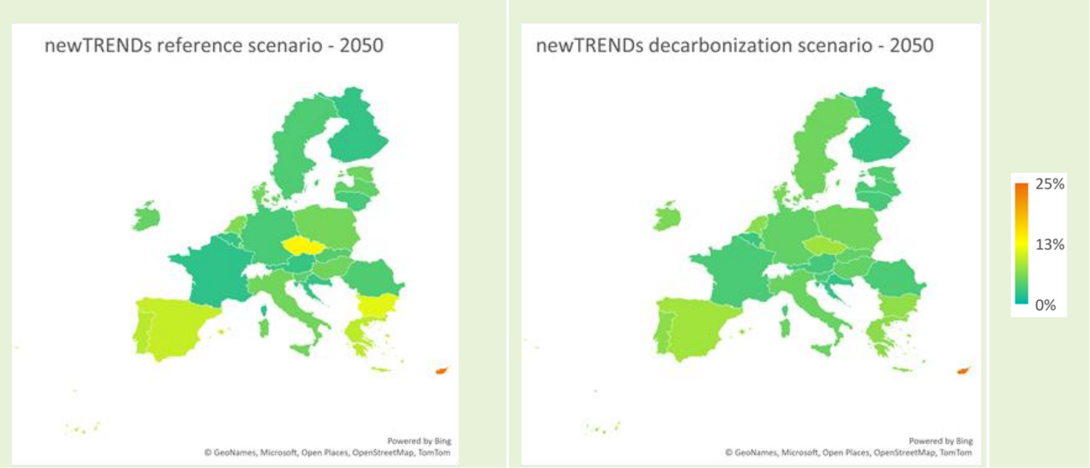


Figure 70 Prosumager model: Share of electricity demand of households in EU countries covered through grid consumption, 2020 and 2050 newTRENDs reference and 2050 newTRENDs Decarbonisation Scenario



Load shifting possibilities are available in both newTRENDs Scenarios, as allowed by the prosumager concept. However, the resulting load shifting is diversified between countries, scenarios and years depending on the combined effects of several factors. Ceteris paribus, the load shifting capabilities are linked to **(1)** the extent to which the flexible uses are electrified **(2)** the volume of the effective demand of these uses as affected by the selected renovation intervention in the building shell and its depth and **(3)** the installation of onsite generation and BESS. For example, in Spain and Portugal high electrification flexible uses and mild implementation of renovation measures occurs, leaving a significant amount of electricity load to be flexibly scheduled, while in Cyprus, Greece and Czech Republic there is increased installation of rooftop PV and BESS. In fact, the highest levels of shifted load are mainly observed in cases where the increased electricity demand is coupled with installation of PV and especially BESS: the existence of PV creates a motive for shifting load to take advantage of the renewable potential, while the existence of BESS allows for flexible use of the onsite produced electricity. Contrary to that, high renovation decreases the total amount of electricity load and the load shifting possibilities, as made evident by the results of the newTRENDs Decarbonisation Scenario, where renovation is higher than in the newTRENDs Reference Scenario.

Figure 71 Prosumager model: Shifted electricity load for the newTRENDs Reference Scenario and the newTRENDs Decarbonisation Scenario, 2050 (% of total annual load at country level for households with electricity in heat uses)



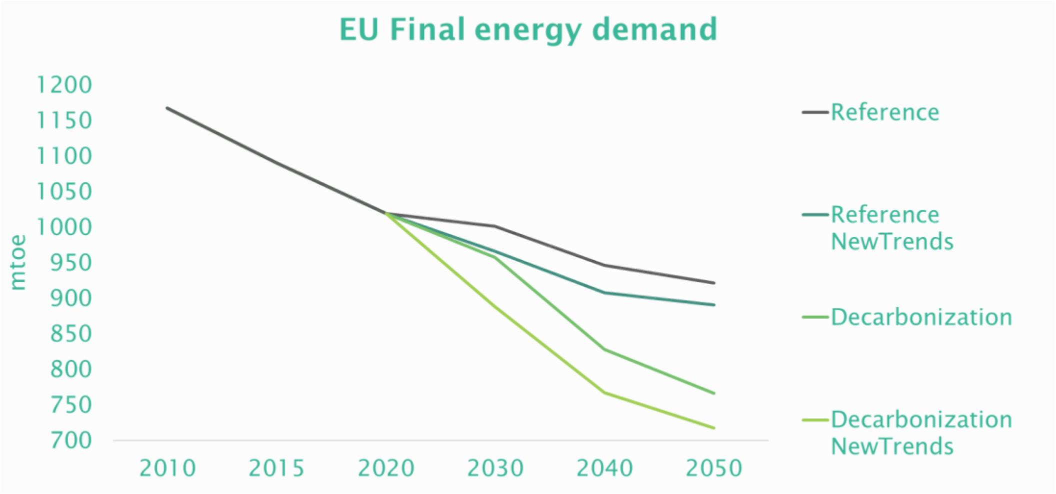
Comparison between different methods is always challenging. This is indeed true for the case of the prosumager model results when compared to the PRIMES-BuiMo results. Even though their scope is the same and they share common ground in terms of typology, the PRIMES-Prosumager model features the option for onsite photovoltaic generation and electricity storage and applies optimisation of both the investment decision and the operation on an hourly basis. Therefore, it assumes the existence of a rational actor that factors several available options in the decision-making process, which influence one another. This approach is in contrast to PRIMES-BuiMo and its nested hierarchical choices that co-exist, each one assigned with its frequency through Weibull distribution. Consequently, even though the interpretation of the results for indicators where a direct comparison of the scenarios with and without newTRENDs is possible, this should be done with proper care, as the two approaches differ in several aspects of their design.

Future work on the topic of prosumaging could focus both on enhancing the representation of the hourly operation and on expanding the model testing on a variety of household types in the effort to capture in more detail the heterogeneity characterising the household consumers. Additionally, deploying the model under different policy frameworks could offer insights into the impact of varying incentives on the behaviour of the residential electricity consumer as well as highlight emerging challenges in managing such a highly distributed flexible resource as the prosumager.

3.5 SUMMARY OF SECTORAL RESULTS

EU final energy demand is projected to decline in all scenarios in the course of the projection period. The adoption of new trends, may it be under a reference or a decarbonisation policy scenario, leads to further reduction in energy demand. As shown in Figure 72 the largest decline in energy demand is achieved under the Decarbonisation_newTRENDs Scenario, where energy demand drops from 888 mtoe in 2030 to 767 mtoe in 2040 and further down to 718 mtoe in 2050.

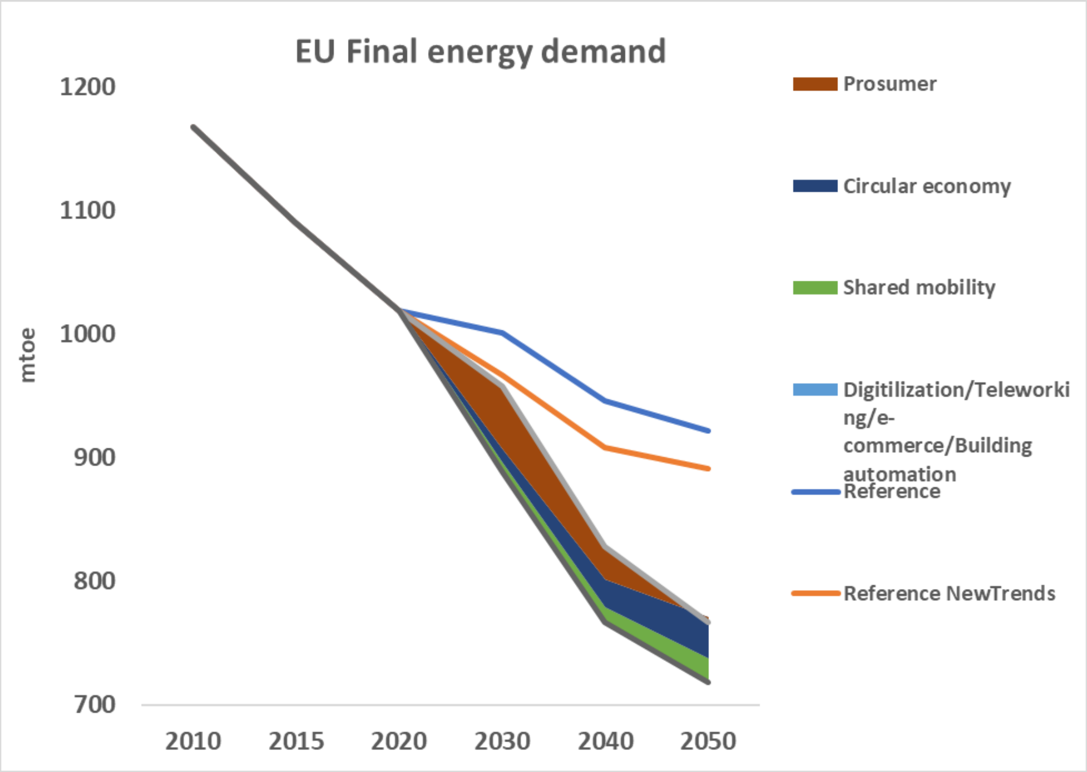
Figure 72 Projection of EU final energy demand under the four scenarios



Taking a closer look at each sector’s contribution to energy demand, we find that of all trends examined, the shift to prosumage brings about the strongest decline in energy demand. The transition to a circular economy and the shift to shared mobility follow suit. Digitalisation has practically no effect.

Which new trend is set to affect energy demand, changes over the projection period. Energy demand is set to fall between 2025 and 2040 driven by the rise of prosumers, however from 2040 onwards, circular economy takes over and is the main factor behind falling energy demand. Shared mobility also picks up and causes energy demand to decline in 2040 and 2050.

Figure 73 Contribution of new trends to EU final energy demand



4. MACROECONOMIC IMPLICATIONS OF NEW SOCIETAL TRENDS

The purpose of this chapter is to offer insights regarding the impact of each new societal trend separately and combined on the macro economy. We introduce output from sectoral models into GEM-E3, a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model and examine the implications on the economy related to the following new societal trends:

- Circular economy of steel and cement in buildings for a low-carbon industry sector (see 3.1),
- Digitalisation/Teleworking,
- Shared mobility and
- Prosumage.

First, we briefly present the simulated scenarios and the type of inputs that have been used by GEM-E3 (Section 4.1) and then we present the results per sector and all together[10].

4.1 GEM-E3: key features and improvements

The GEM-E3 model is a large-scale applied global CGE model that has been extended in order to better capture the trends that are represented by individual bottom-up sectoral models. The model captures all economic agents and their interactions linking all countries and sectors through endogenous bilateral trade flows. The model reflects the production structure, consumer preferences and trade relations as depicted in the base year calibration and dynamically projects those into the future, considering changes in technical progress, population and firm's investment plans.

The GEM-E3 model is an economic model that is used to analyse economic, climate and energy policies and their impacts. The model has a global coverage where the EU27 countries and the countries that are major equipment manufacturers or energy exporters are represented individually. The GEM-E3 model is based on different components that represent various aspects of the economy. These components include the household sector, the business sector, the government sector, and the international/external sector. Each of these components is further divided into sub-components that capture the complexities of the different sectors of the economy. The household sector includes all households in the economy and their consumption and savings behaviour. The business sector includes all firms in the economy and their

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[10] It should be noted that simulations performed with GEM-E3 do not include cost estimates on the adoption of circular mechanisms or the significant productivity improvements that digitalisation brings to the economy (both of these elements could have significant impacts on GDP).

production and investment behaviour. The government sector includes all levels of government and their spending and revenue-raising behaviour. The international sector includes all international trade flows and capital flows. One of the key strengths of the GEM-E3 model is its ability to simulate the effects of different policy changes. For example, it can be used to simulate the impact of changes in taxation, carbon pricing, trade policies, environmental regulations, or infrastructure investments on the economy and the environment.

The global coverage of GEM-E3 makes it possible to analyse the impacts of policies across different regions or countries. It can be used to analyse the impacts of policies in specific regions or countries, as well as the effects of global policies on the world economy and the environment. This makes it a valuable tool for users who want to evaluate the likely outcomes of different policy choices before they are implemented. The GEM-E3 model is also able to analyse the interactions between the economy and the environment. It includes a module that captures the environmental impacts of economic activities, such as greenhouse gas emissions, air pollution, or land use changes. This allows users to evaluate the trade-offs between economic growth and environmental sustainability and to identify policies that achieve both goals.

In the NEWTRENDS study, the GEM-E3 model has been further improved so as to facilitate its link with the sectoral models and in particular with FORECAST – Industry 3.1.1, FORECAST – Tertiary 3.3.1, PRIMES – Prosumager 3.4.1.1, PRIMES – TREMOVE and PRIMES – SHAREM Demand 3.2.1. In particular, the key features of the GEM-E3 model that have been further improved relate to the circular material / material productivity in industry, the calibration of structural shifts in firms fuel mix, the shared mobility options and the ability of the household to become prosumagers of electricity.

4.2 Input data and main assumptions

The inputs had to be mapped to the GEM-E3 sectors and then transposed in a way that would allow linking them with specific GEM-E3 variables and parameters.

The output of FORECAST – INDUSTRY, namely changes in the fuel mix across industrial sectors and material productivity improvements, mainly in steel and cement, are fed into GEM-E3 in order to capture the implications of circular economy. These changes in the fuel mix and in productivity are modelled as the result of behaviour shifts and adoption of technologies that represent mostly ‘low-hanging fruit’ and not of price incentives. Some of these changes require significant restructuring of value chains (i.e. timber construction, increased repair and renovation as well as reuse of building materials and components). However, this is not modelled explicitly due to the limited data availability.

FORECAST – TERTIARY output (changes in fuel mix in the tertiary sector) allows GEM-E3 to assess the effect of digitalisation and teleworking, in particular on the economy and employment. There is a need for further research to fully understand the economy-wide net effects. Specifically, it is important to estimate the effects on residential floor area and final energy demand resulting from the shift of labour as well as the impacts on mobility patterns.

Last, GEM-E3 uses the shares of carpooling and car sharing in order to estimate the effect of shared mobility on economic activity and employment (PRIMES – SHAREDM) and the fuel mix in household energy consumption to assess the effect of prosumage (PRIMES-PROSUMER).

Table 15 Outputs of sectoral models used as inputs in GEM-E3

	Trend Dimensions			
	Circular Economy	**Digitalisation**	**Prosumagers**	**Shared Mobility**
Input from Model:	FORECAST-Industry	FORECAST-Tertiary	PRIMES-Prosumager	PRIMES-SHAREM Demand
Type of Input:	Fuel mix in industry Material efficiency	Fuel mix in tertiary	Fuel mix in household consumption Investment costs for rooftop PV panels per kW	Shares of carpooling, car sharing, car service, mileage and occupation ratio

4.3 Results

To shed light on the socioeconomic implications of the modelled trends, we model each trend individually under a Reference and under a Decarbonisation Scenario. This allows us to break down and better understand the impact of each trend on key macroeconomic variables; also, to grasp the interplay between each trend and reaching climate neutrality by 2050 (or failing to do so). The key macroeconomic variables selected are GDP (and components), sectoral production and employment. Although these indicators do not capture the full impact in terms of welfare, energy security and income distribution, they are key to understanding the main channels through which these trends affect the economy. After simulating each trend separately, we model all trends together for each scenario. The projections express the change that occurs as a result of adopting the new trends described in the introduction of this chapter under the Reference and the Decarbonisation Scenarios. It should be noted that the economic implications of the new trends are considered with a focus on the energy consumption shifts and the mechanisms within.

4.3.1 Circular Economy / Industry

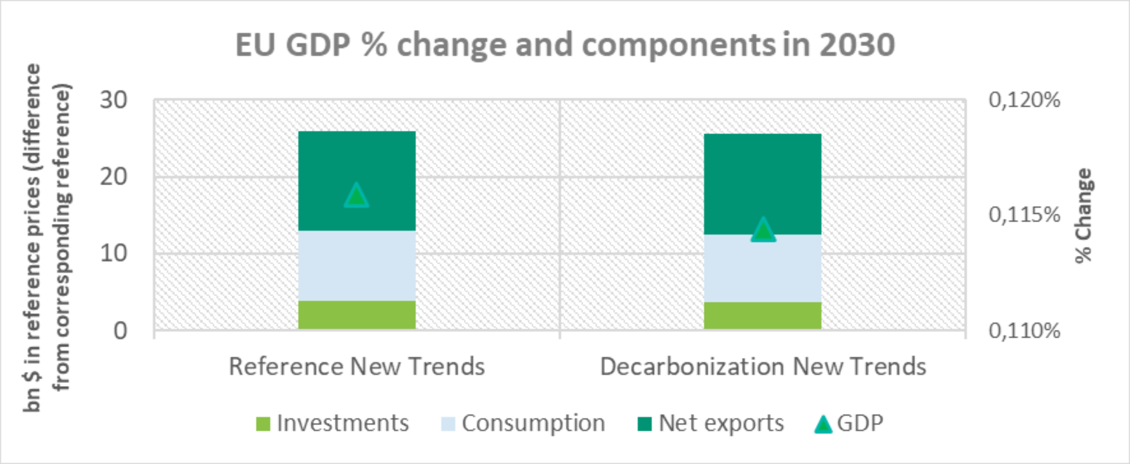
We start off the analysis by looking at the adoption of circular economy practices for steel and cement in buildings and its impact on the industry sector in the coming decades under a Reference and a Decarbonisation Scenario. According to the projection, transitioning to a circular economy for buildings alone positively affects GDP, while decarbonisation does not seem to act on this development in some way.

Circularity fosters resource efficiency, as products and materials are continuously reused and recycled. In turn, resource efficiency minimises waste generation, reduces the demand, production and imports of raw materials. As a result, upstream sectors reduce their production costs, improve profit margins, and increase their competitiveness overall.

In 2030, the transition to a circular economy for steel and cement in buildings is projected to drive GDP up by 0.12% and 0.11% in the Reference and Decarbonisation Scenarios respectively; and in 2050 by 0.31% and 0.30%. The increased uptake of circularity in buildings in the period 2030-2050 has a positive effect on the economy - in 2050, the efficiency is by assumption higher.

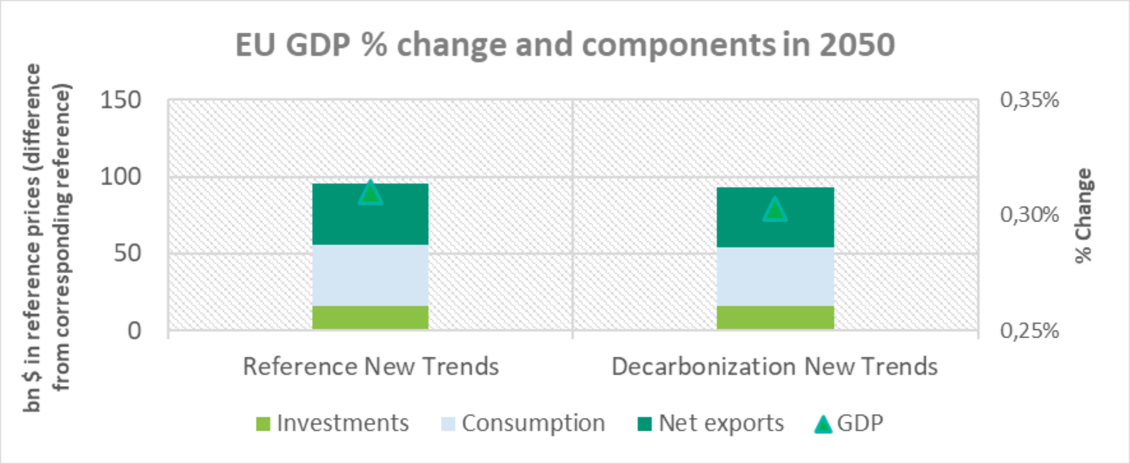
Net export growth (net exports = exports *minus* imports) is the key driver behind GDP growth. Net exports increase for two reasons. First, because imports of raw materials decline. The boost in material efficiency in EU buildings means that it becomes less dependent on raw materials imports. Second, because EU exports rise. Adopting circular economy practices for steel and cement in buildings helps upstream sectors in the EU, lower their production costs and gain in competitiveness vis-a-vis their counterparts in the rest of the world. Second most important driver of GDP growth is consumption.

Figure 74 EU GDP% change and components in 2030



Source: GEM-E3

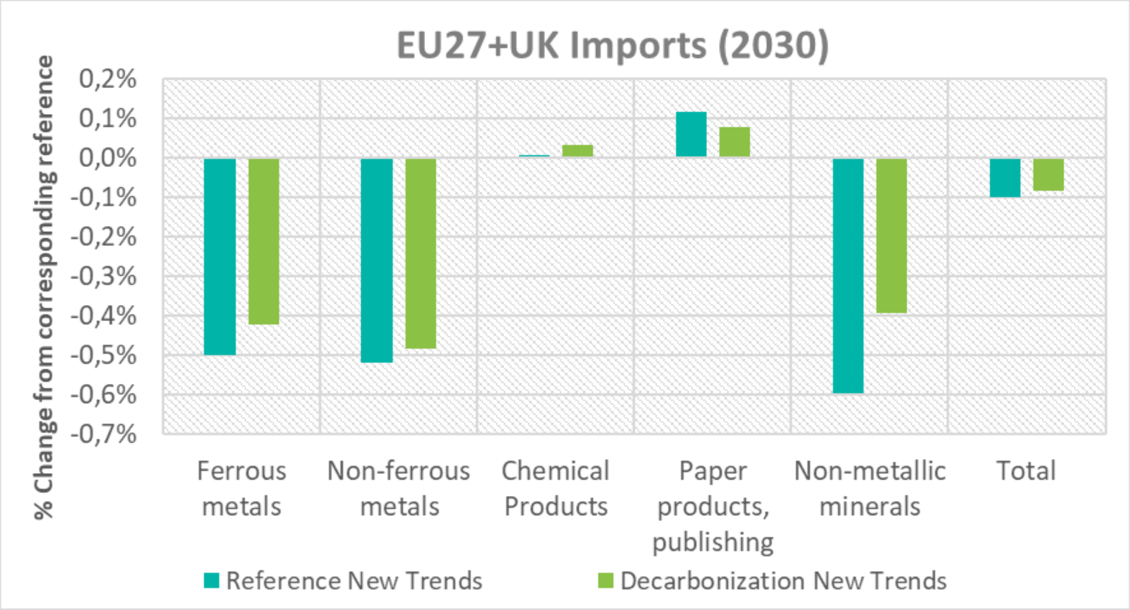
Figure 75 EU GDP% change and components in 2050



Source: GEM-E3

With more recycling and reuse of building components and materials, imports that were intended to meet domestic demand for raw materials drop. There is less need for imports of specific raw materials, such as ferrous, non-ferrous metals and non-metallic minerals, because these are recovered through more recycling and reuse that takes place domestically. Overall, total imports decrease by ~0.10 % in 2030 and ~0.13% in 2050. As we move from 2030 to 2050 and towards the end of the projection period, increasing levels of circularity in buildings lead to stronger effects toward the end of the projection period.

Figure 76 Impact of circular economy on imports in 2030 (EU27+UK)



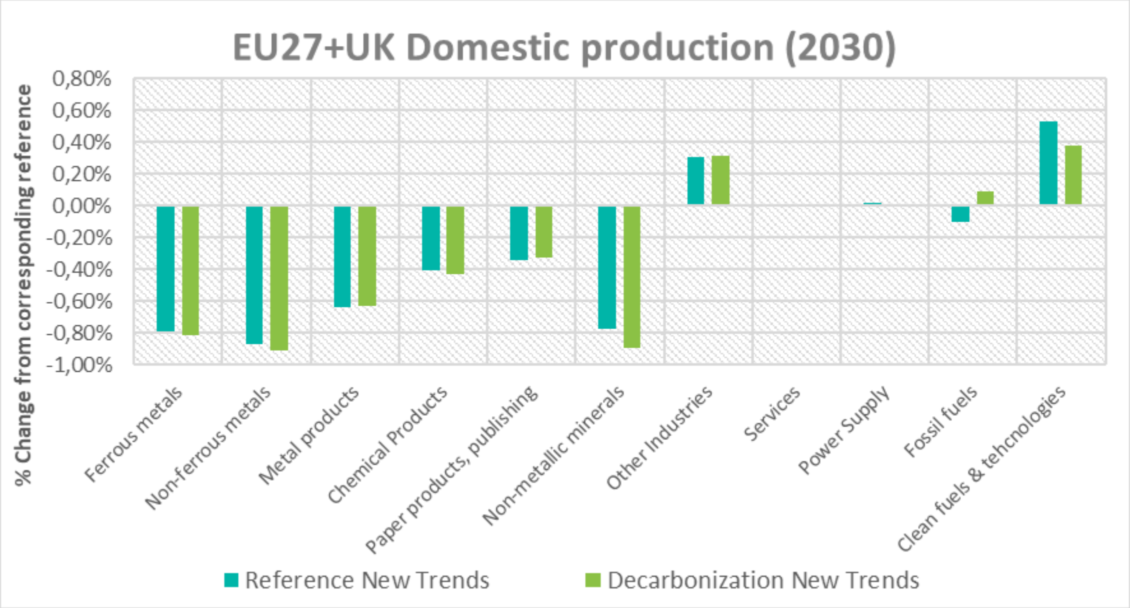
Source: GEM-E3

Material efficiency mitigates demand for raw materials. Consequently, production but also imports in downstream sectors drops.

Meanwhile, domestic production increases in upstream sectors (services, other industries) because by leveraging material efficiency, these sectors have managed to lower their production costs. Computer, electronic and optical products, electrical equipment, machinery etc. exhibit the highest increase in percentage change due to high trade openness and gains in competitiveness.

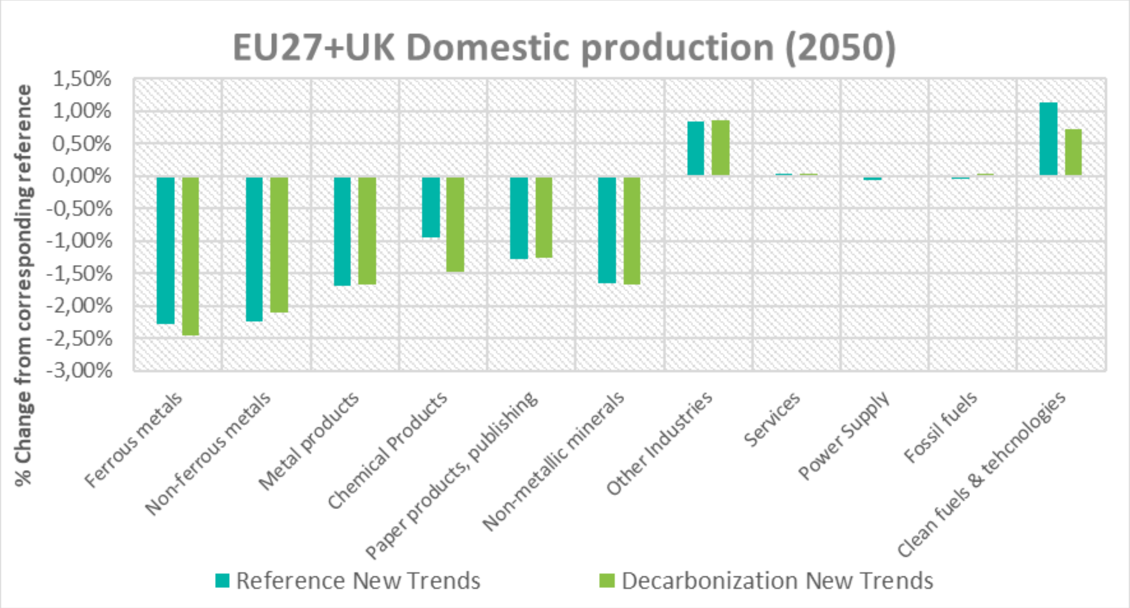
The outlook of domestic production in 2030 is similar to that of 2050. As we move towards the end of the projection period and decarbonisation accelerates, the impact of the transition to a circular economy for steel and cement in EU buildings becomes more pronounced.

Figure 77 Impact of circular economy on domestic production in 2030 (EU27+UK)



Source: GEM-E3

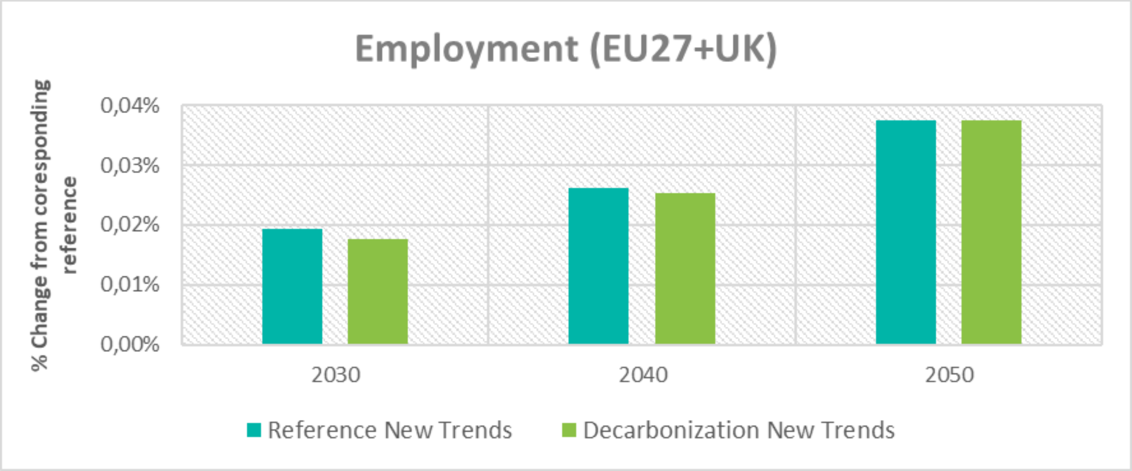
Figure 78 Impact of circular economy on domestic production in 2050 (EU27+UK)



Source: GEM-E3

Changes in GDP (and sectoral production) shape the trends in employment. Notably, higher economic activity induces more demand for labour. According to projections, new employment opportunities will be created in sectors with growing domestic production (mostly upstream sectors) that have managed to boost competitiveness by lowering their production costs. These sectors are included under "other industries" e.g. machinery and equipment, electronic equipment etc. Meanwhile, in sectors with diminishing production, like ferrous metals, and non-metallic minerals, employment will drop as well.

Figure 79 Impact of circular economy on employment in 2030-2050 (EU27+UK)



Source: GEM-E3

4.3.2 Shared Mobility / Transport

Examples of shared mobility include ridesharing, carpooling, bike-sharing, e-scooter sharing etc. By encouraging ridesharing, shared mobility reduces the number of private vehicles on the road, leading to lower fuel consumption and greenhouse gas emissions. A decrease in the demand for largely imported fossil fuels will have positive implications for the GDP.

Moreover, many shared mobility services rely on electric vehicles (EVs), which have lower operating costs and emit no tailpipe emissions, reducing further the carbon footprint of these services. Shared mobility can also complement public transportation by providing first and last-mile connectivity to transit stations. This integration encourages more people to opt for public transport and so rely less on private vehicles and save energy.

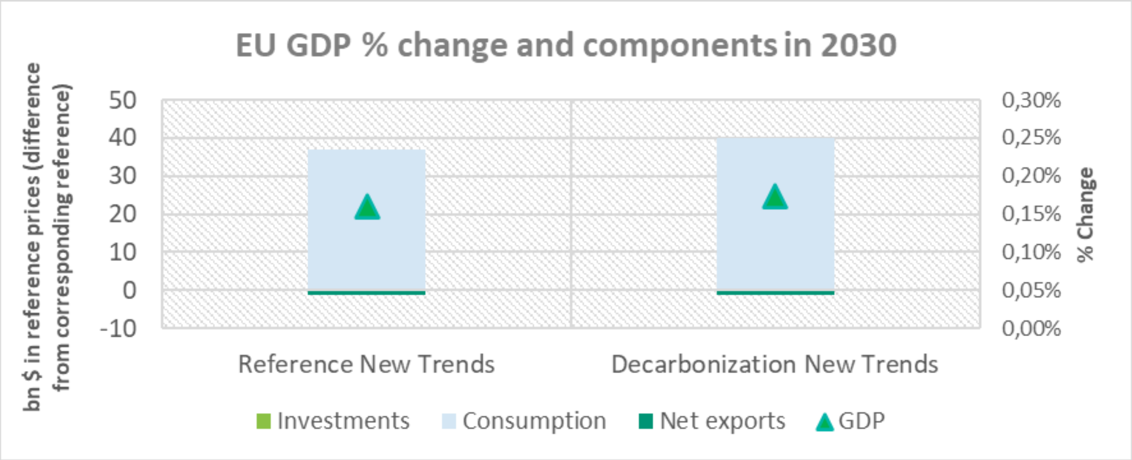
As shown in Figure 80, the growing adoption of shared mobility will positively affect GDP in the coming decades, with the impact being practically the same under the two *new trend* scenarios, i.e. including shared mobility. Towards the end of the projection period, higher adoption levels of shared mobility pushes GDP further up.

Traditional commuting involves single-occupancy vehicles while shared mobility services promote a more efficient use of vehicles since more passengers share a single vehicle (carpooling) or the same vehicle (car sharing).

Not buying private cars results in an increase in disposable income of households, which is directed towards other purposes, mostly services. The services sector contributes more to the creation of value added, since it relies less on the import of goods compared to sectors like transport equipment, where the indicator of imports/demand is much higher. This boosts domestic production and thus GDP.

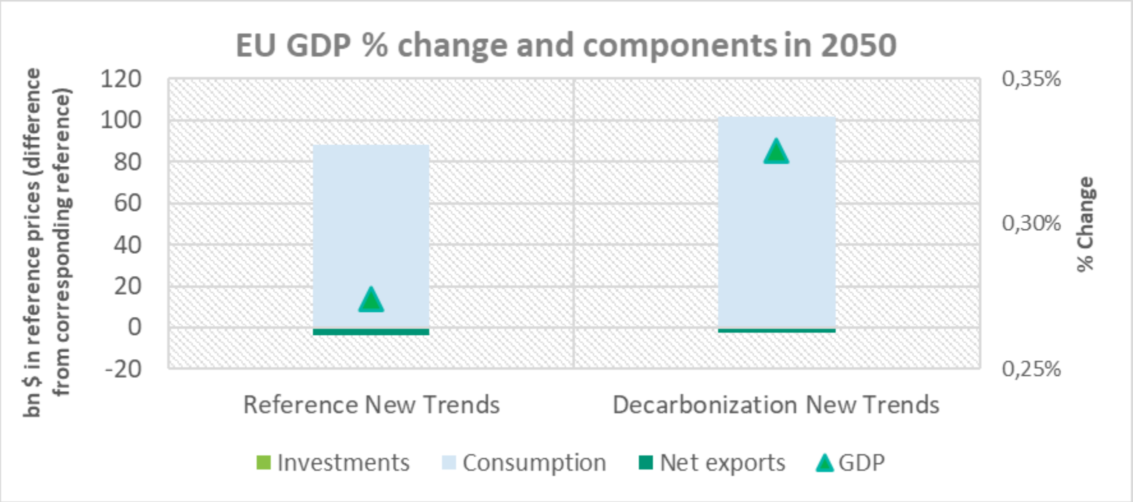
Furthermore, the output multiplier of sectors related to the production of vehicles is lower than the output multiplier of services, which means that to redistribute 1€ of demand from transport equipment to services will result in increased output for the economy.

Figure 80 EU GDP % change and components from shared mobility in 2030



Source: GEM-E3

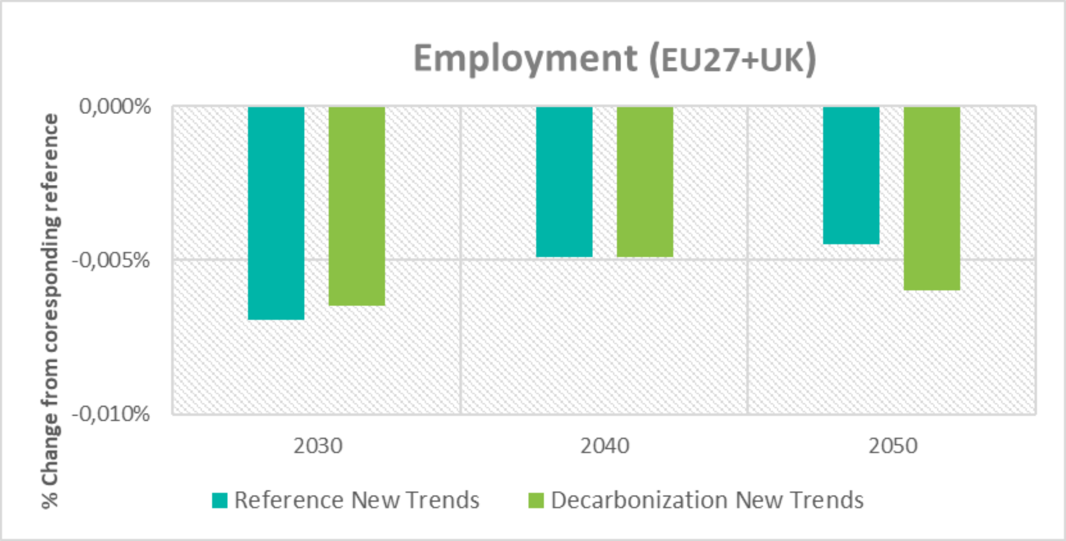
Figure 81 EU GDP % change and components from shared mobility in 2050



Source: GEM-E3

With demand for private cars going down, their stock reduces and so does the activity in sectors that provide equipment to produce cars. As a result, employment in these sectors drops. Meanwhile, more jobs are created in sectors like services, for which demand is going up. New employment opportunities open up in sales, customer service, fleet maintenance, product, and technology management. Nevertheless, the total effect of shared mobility on employment is marginally negative.

Figure 82 Impact of shared mobility on employment in 2030-2050 (EU27+UK)

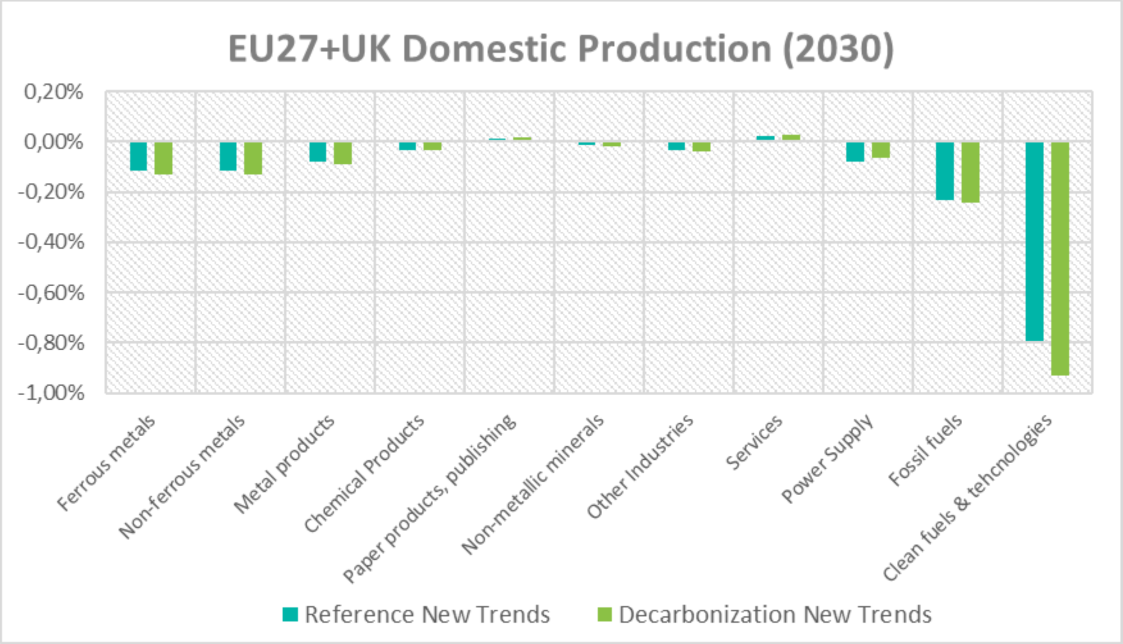


Source: GEM-E3

The impact of shared mobility on the outlook of domestic production in 2030 in the EU is the same between the two *new trends* scenarios. The production of clean fuels and technologies, which include among others EV transport equipment, batteries, and e-fuels, is projected to go down. This is because with the uptake of shared mobility, the demand for (and production of) cars, including EVs, will decrease.

Likewise, with fewer cars, the demand for fossil fuels will drop. On the other hand, domestic production of services will increase; despite the small percentage change reflected in the graph, the services sector occupies a large share of the overall domestic production.

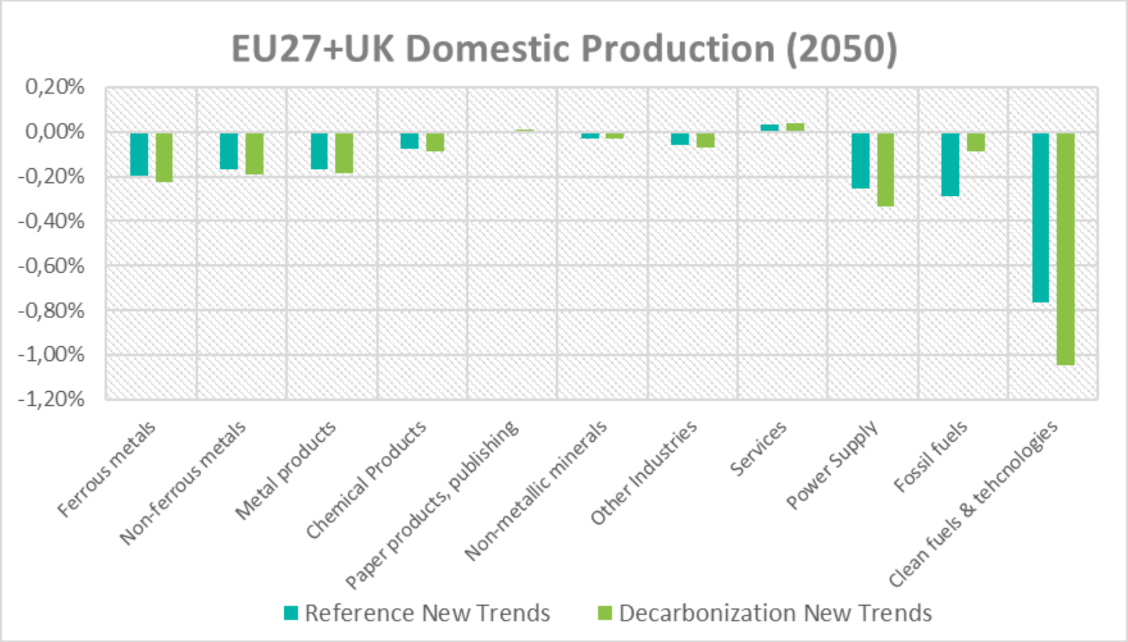
Figure 83 Impact of shared mobility on domestic production in 2030 (EU27+UK)



Source: GEM-E3

The projection for 2050 resembles that of 2030. The main difference is that in 2050, shared mobility will have a more pronounced effect on final energy demand, including electricity production. Shared mobility will trigger a stronger decline in fossil fuel production in the Reference Scenario compared to the Decarbonisation Scenario, because the latter already foresees fewer conventional cars. Also, domestic power supply is set to drop because the use of EVs drops too in a context of reduced mobility activity.

Figure 84 Impact of shared mobility on domestic production in 2050 (EU27+UK)



Source: GEM-E3

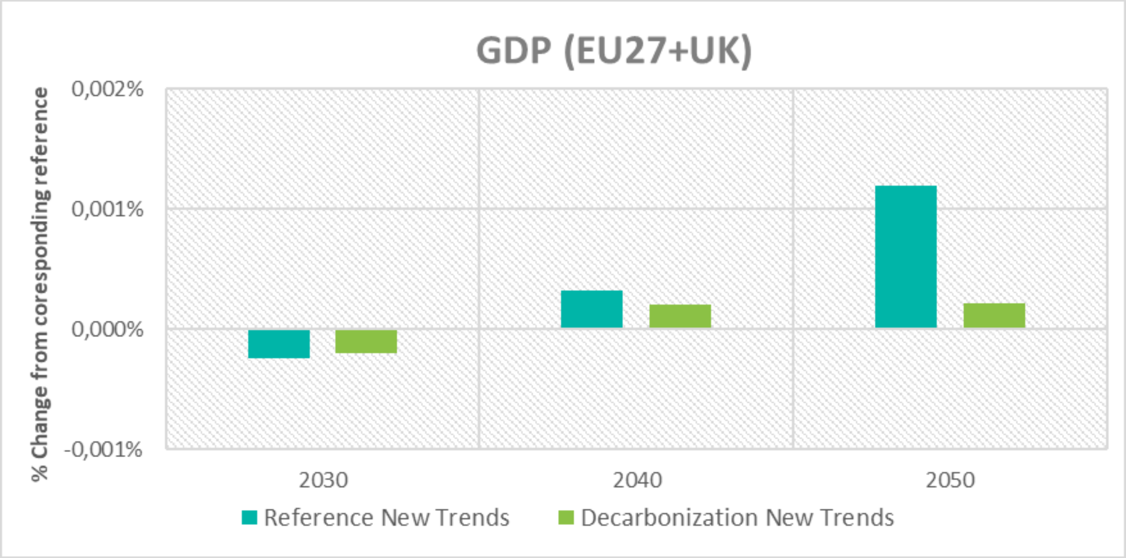
4.3.3 Digitalisation / Tertiary

Moving forward, we examined four (4) new trends in the tertiary sector and their macroeconomic implications. We found these trends to have a small effect on final energy demand.

To assess the macroeconomic effects of these trends, we first used only the change in fuel mix as input to the model. This however did not account for costs and efficiencies associated with these trends, which explains why the effect of these trends on GDP appears to be marginal in Figure 85.

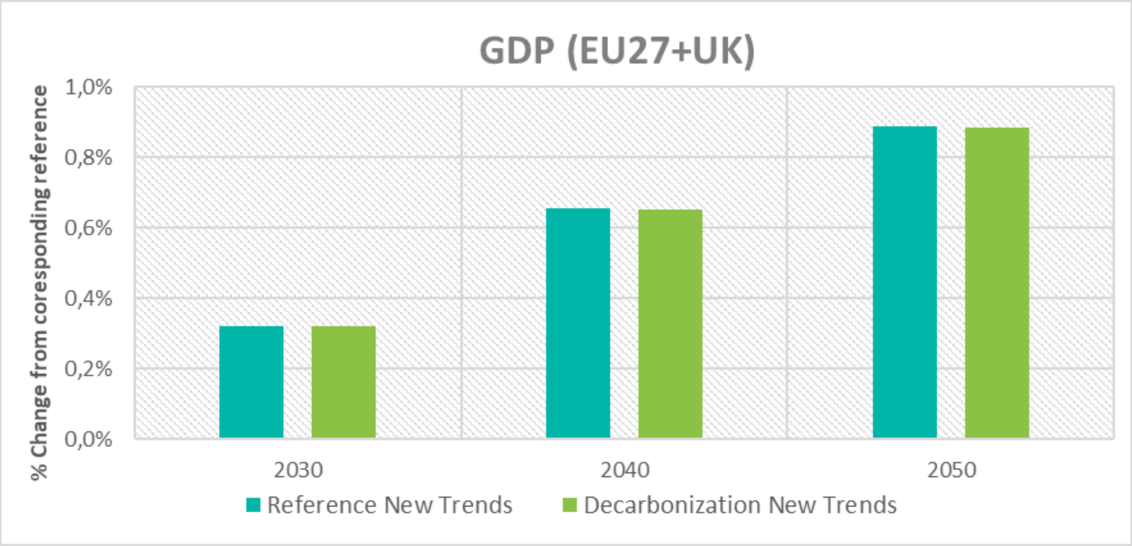
Considering the changes in floor area cost in the residential and tertiary sectors caused by teleworking and also the labour productivity enhancements gained through e-commerce, the impact on the economy is significant, as shown in Figure 86. In fact, labour productivity contributes three times as much as floor area change in GDP (Figure 87).

Figure 85 EU GDP % change from digitalisation in 2030-2050 (EU27+UK) considering only the fuel mix change in the tertiary sector



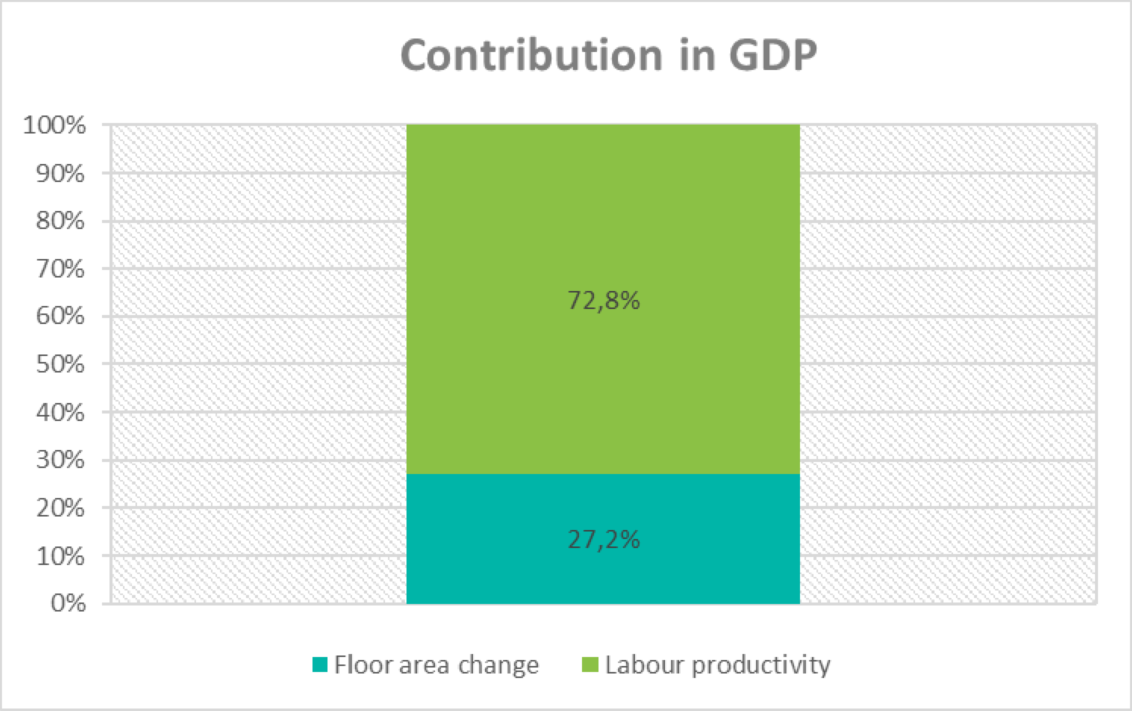
Source: GEM-E3

Figure 86 EU GDP % change from digitalisation in 2030-2050 (EU27+UK) considering changes in fuel mix, floor area costs and labour productivity from e-commerce in the tertiary sector



Source: GEM-E3

Figure 87 Contribution of labour productivity and changes in floor area costs in GDP in 2030-2050

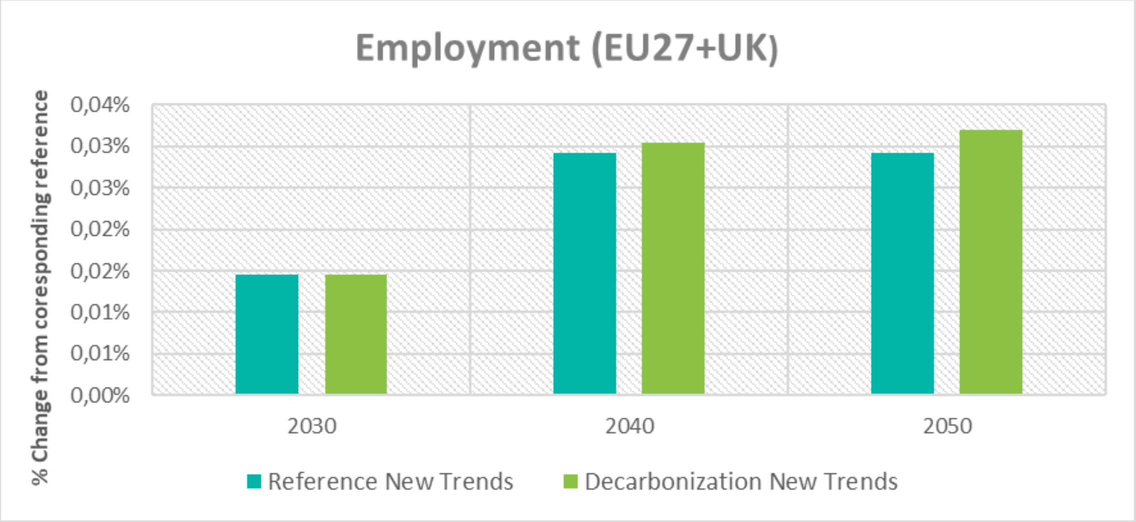


Source: GEM-E3

Digitalisation reduces employment in the tertiary sector (fewer workers are needed to produce the same output because of e-commerce). But because digitalisation has a positive effect on the economy overall, economic activity increases, and so does demand for labour. Hence, the effect of digitalisation on total employment is positive.

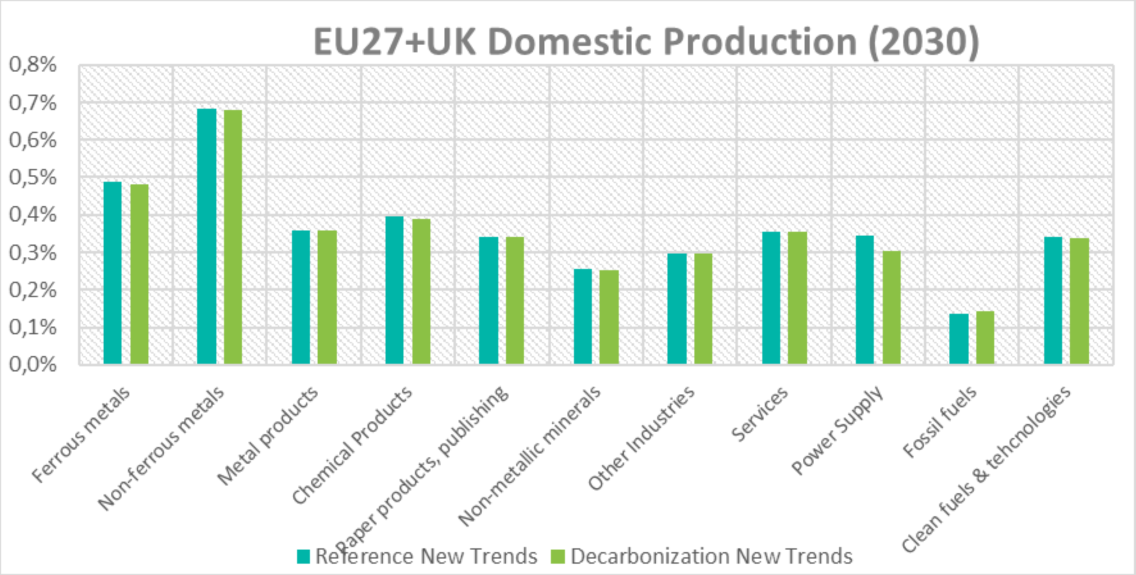
The economy is projected to become more productive with digitalisation and all sectors benefit from this boost in productivity throughout the projection period, as shown in Figure 89 and Figure 90.

Figure 88 Impact of digitalisation on employment in 2030-2050 (EU27+UK)



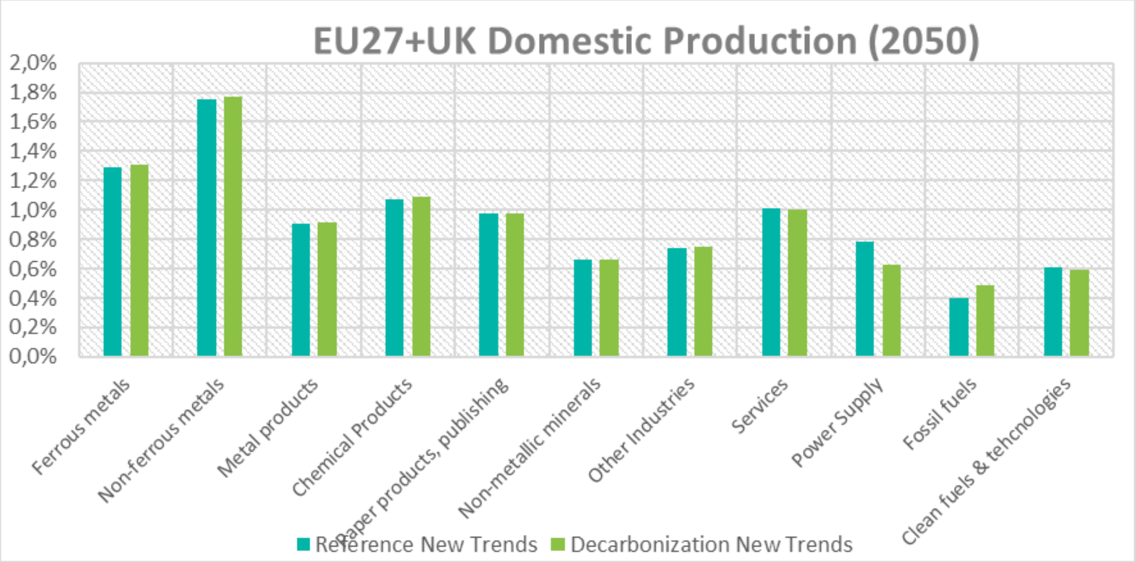
Source: GEM-E3

Figure 89 Impact of digitalisation on domestic production in 2030 (EU27+UK)



Source: GEM-E3

Figure 90 Impact of digitalisation on domestic production in 2050 (EU27+UK)



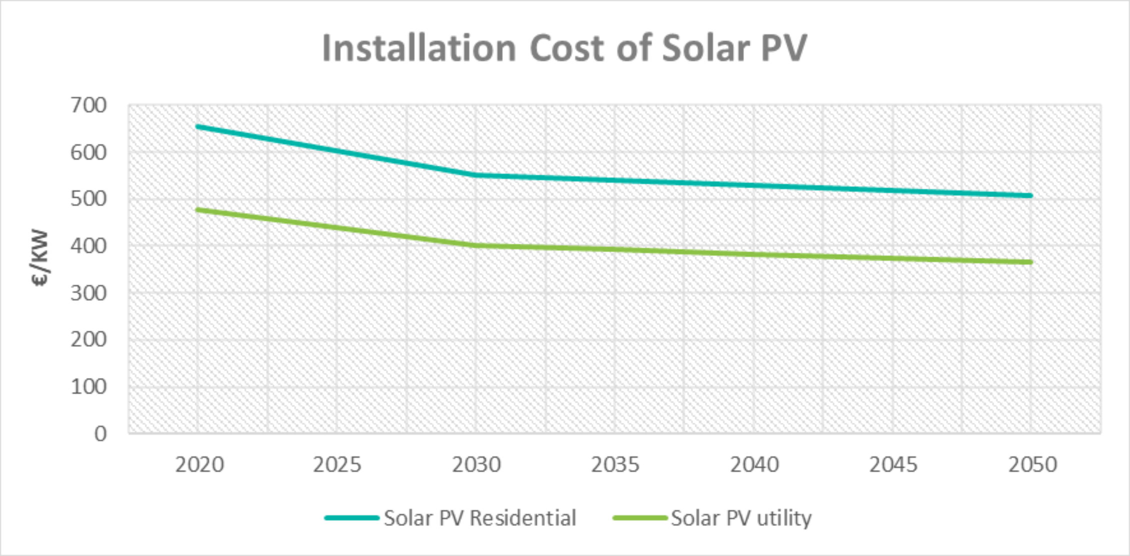
Source: GEM-E3

4.3.4 Prosumagers / Residential

In this section, the analysis focuses on prosumers, i.e. households that produce and consume their own electricity for heating and cooking, using installed roof solar PV panels. Prosumers do not pay for the electricity they produce. If they consume more than what they produce, they obtain this excess electricity from the grid.

To better grasp the effect of prosumage on GDP, we first need to consider the costs of installing the PV. Figure 91 shows the investment cost for installing 1 KW solar PV panels by households and by utilities. It is important to note at this point that the figure does not account for power line losses and power grid investments.

Figure 91 Installation cost of solar PV for households and utility



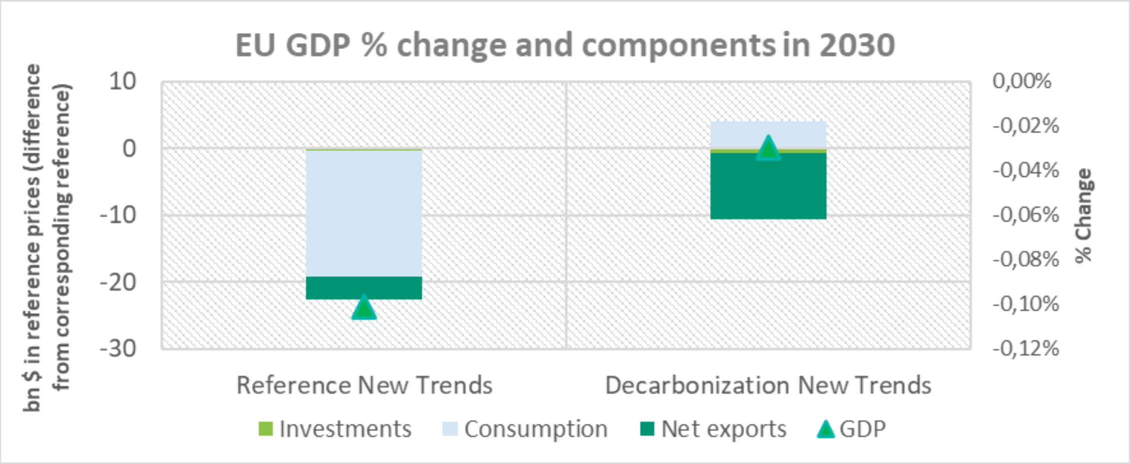
Source: PRIMES – PROSUMER

Overall, the impact of prosumage on GDP is projected to be negative. Households shift demand from the power supply sector to the manufacturing of PV panels, which is a heavily imported technology, resulting in money flowing outside of the EU. This has a negative effect on GDP. In addition, it is more expensive for a household to install solar PVs, which adversely affects GDP. In fact, the costs associated with installing PV panel systems are greater than the gains from falling electricity costs for households. However, this negative trend recedes in the future, as prosumers are projected to reap cumulative gains for all the years that PV capacity has been operating.

Comparing the two scenarios, we find that the negative effect of prosumage on GDP is milder under the Decarbonisation Scenario, because, in a decarbonisation context, electricity costs are higher. For this reason, households that produce and consume their own electricity are better off.

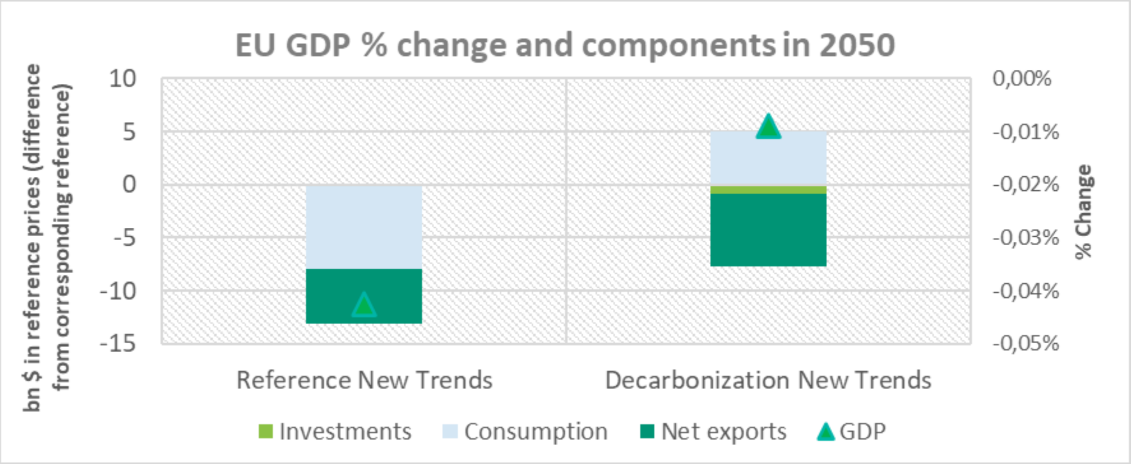
In a decarbonisation context, where more prosumage takes place, there is a need for more PVs. As a result, imports increase and net exports decrease. The contribution of net exports to GDP change is thus higher. Furthermore, prosumage in a decarbonisation context leads to higher income savings, which in turn triggers an increase in household consumption compared to Reference conditions.

Figure 92 EU GDP % change and components from prosumagers in 2030 (EU27+UK)



Source: GEM-E3

Figure 93 EU GDP % change and components from prosumagers in 2050 (EU27+UK)

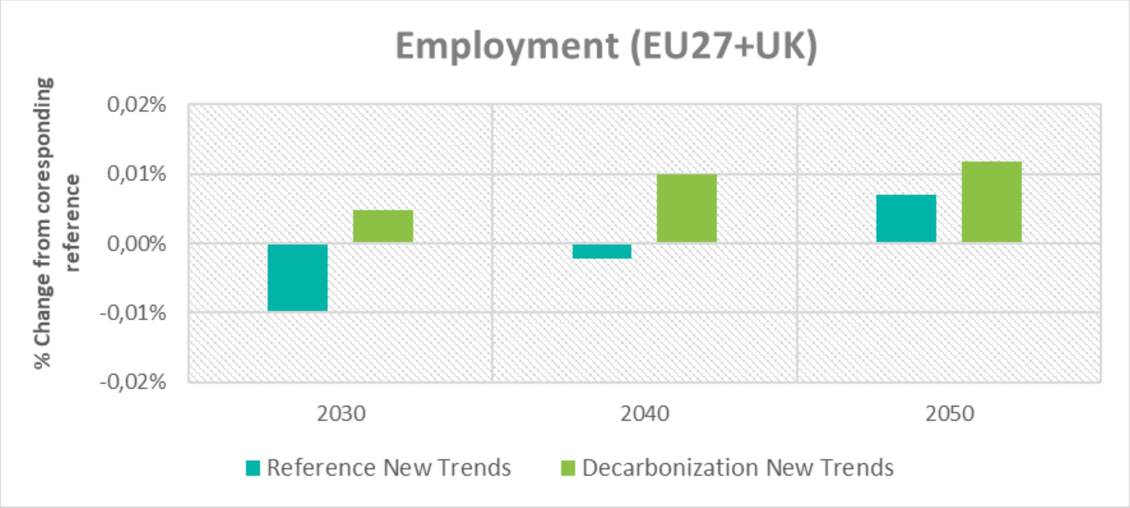


Source: GEM-E3

Investing in solar rooftop PV creates more demand in PV panels and construction sectors. This boosts employment in these sectors. At the same time, in the early years of installing a solar PV panel, the capital costs exceed the income savings (from lower electricity bills). Assuming the 100% self-financing of PV panels, households are projected to consume less of other goods and services, which will then face a decrease in activity and employment. Yet, in the course of time, prosumers are projected to benefit from higher return on capital for the years that the PV capacity has been operating. In which case, prosumer households will not be compelled to consume less of other goods / services.

These contrasting (positive and negative) effects on employment are depicted in both scenarios. In the Reference Scenario, the negative prevail over the positive effects in 2030 but this trend is later reversed. Whereas, in the Decarbonisation Scenario, where electricity costs are higher, prosumers will achieve additional cost savings and the effect on employment will be positive and will remain unchanged until the end of the projection period.

Figure 94 Impact of prosumagers on employment in 2030-2050 in EU27+UK



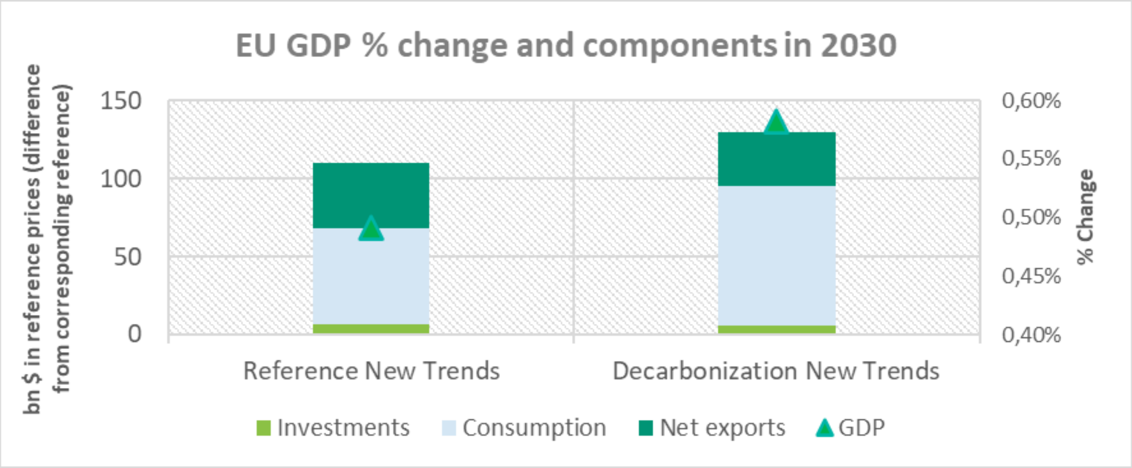
Source: GEM-E3

4.4 Full Trends

This subsection explores the combined macroeconomic effects of the described new societal trends by integrating sectoral results under the two scenarios.

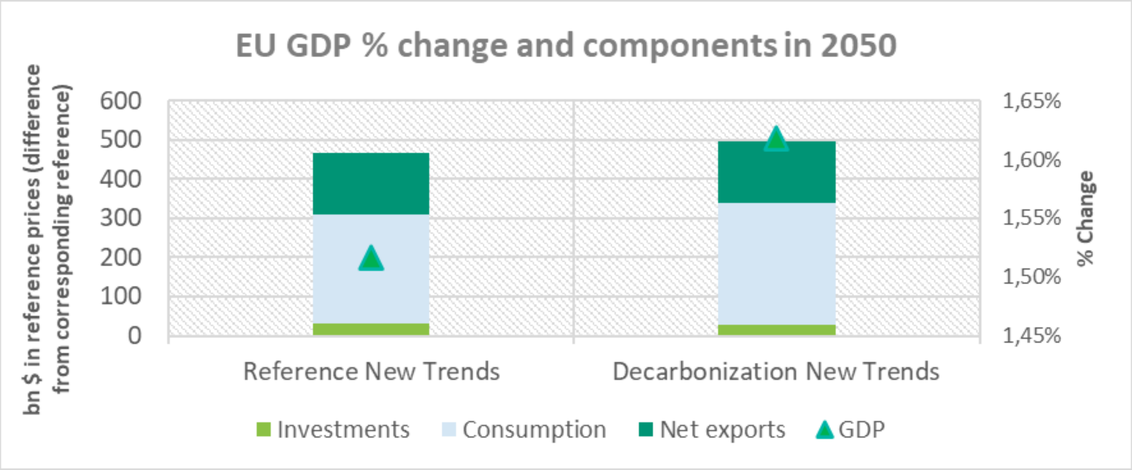
As shown in Figure 97, digitalisation is the main driver of the positive effect on GDP, followed by the transition to a circular economy for buildings and the uptake of shared mobility. In 2030, under the Reference Scenario *new trends* bring about a rise in GDP of ~0.49% and ~1.52% in 2050. Under the Decarbonisation Scenario, GDP grows by ~ 0.58% in 2030 and 1.62% in 2050.

Figure 95 Combined effect of new trends on EU GDP % change and components in 2030



Source: GEM-E3

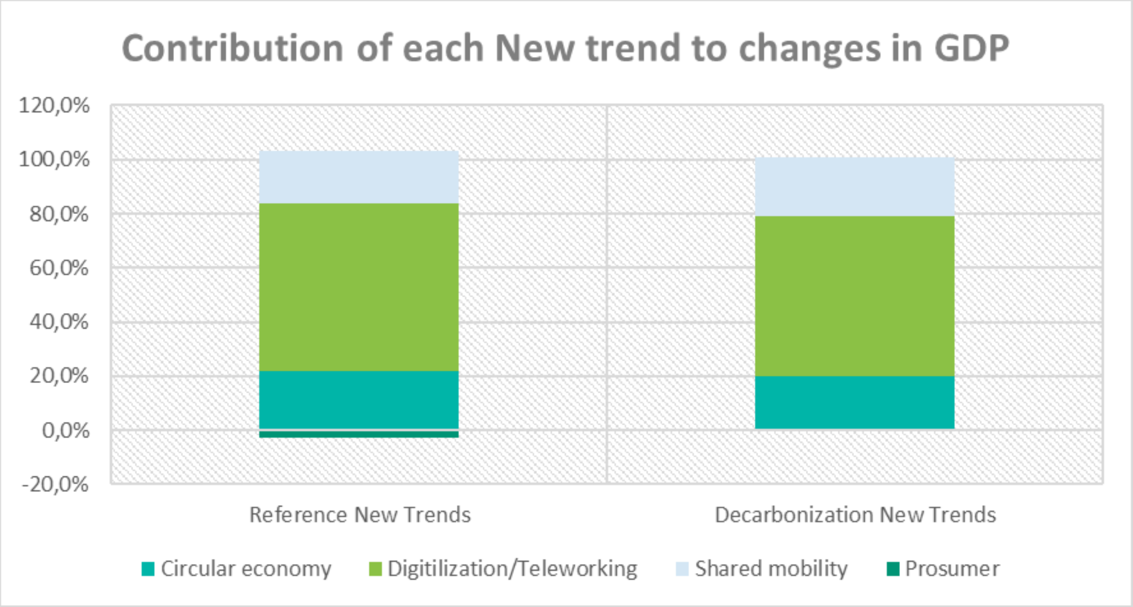
Figure 96 Combined effect of new trends on EU GDP % change and components in 2050



Source: GEM-E3

The highest positive contribution to GDP comes from digitalisation and is ~60%. Circular economy and shared mobility follow suite with 20% each. Prosumagers' contribution is negative, yet small.

Figure 97 Contribution of each new trend to changes in EU GDP



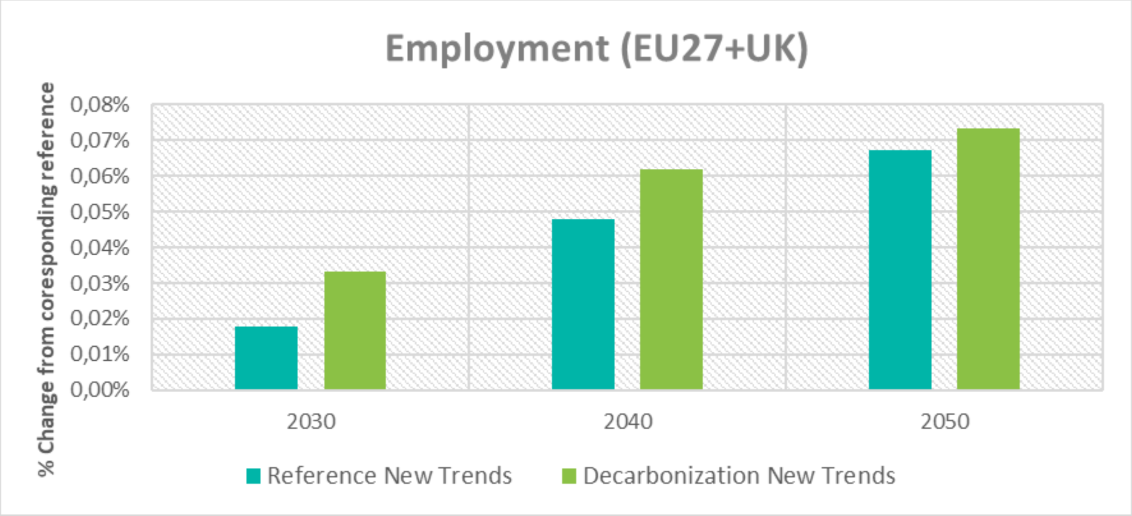
Source: GEM-E3

Overall, the studied new societal trends affect employment in a positive, yet not even, manner across sectors. Most jobs are created in “other industries”. This is attributed to the uptake in material efficiency and production levels, brought about by the transition to a circular economy for buildings.

Moreover, many jobs are created in the construction and equipment for PV sectors, driven by investments of prosumager households. On the other hand, the projection points to a loss of jobs in downstream sectors (e.g. ferrous metals, non-metallic minerals etc.) due to material efficiency, which lowers demand for raw materials. Likewise, a reduction in employment will be caused in sectors related to the production of vehicles due to shared mobility.

Digitalisation reduces employment in the tertiary sector (less employment is needed to produce the same output because of e-commerce). But because digitalisation’s effect on the economy overall is positive, economic activity and, therefore, the demand for labour increases. That said, the effect of digitalisation on total employment is positive.

Figure 98 Combined effect of new trends on employment in 2030-2050 in EU27+UK



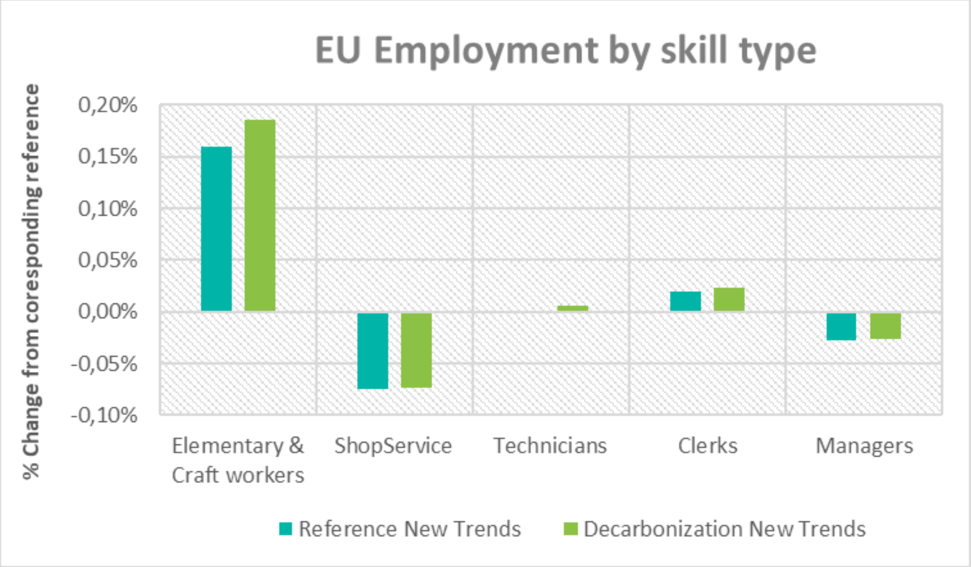
Source: GEM-E3

Sectoral employment is affected in different ways by the various new trends. For example, transport equipment is positively influenced by the circular economy for buildings and negatively by shared mobility. To gain an in-depth understanding of the effect on employment by skill type, we take a close look at the sectors impacted the most.

Downstream sectors face the most significant risk of job losses, in particular, EV transport equipment, trade (wholesale and retail) and services. Sectors benefiting from new trends are construction, equipment for PV panels, machinery and equipment, and electrical equipment.

In these sectors, most occupations are related to craft and trade and elementary, which explain the rise in this subsector. Trade and services sectors occupy more service and sales workers, mapped within the shop service category, decline (Figure 99).

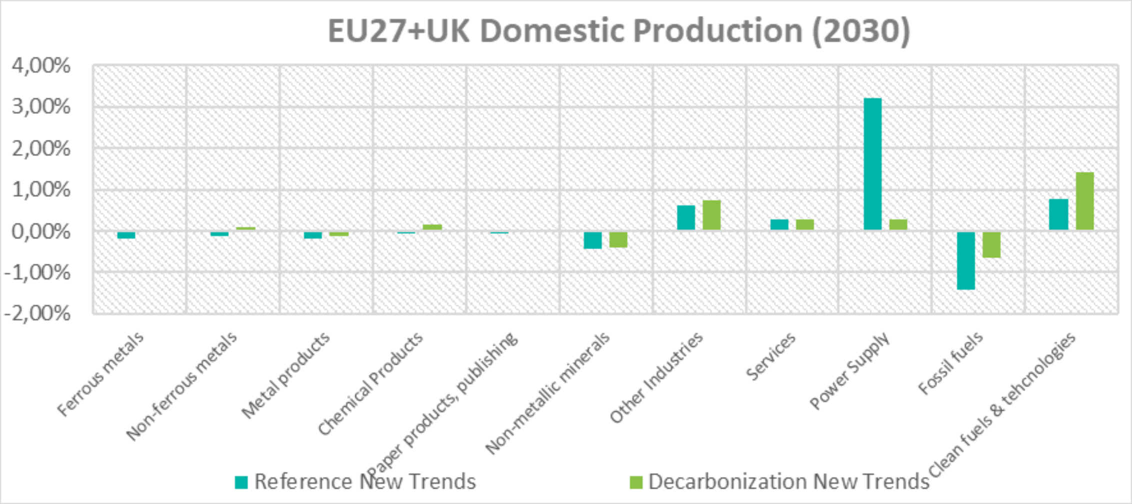
Figure 99 Combined effect of new trends on employment by skill type in 2020-2050



Source: GEM-E3

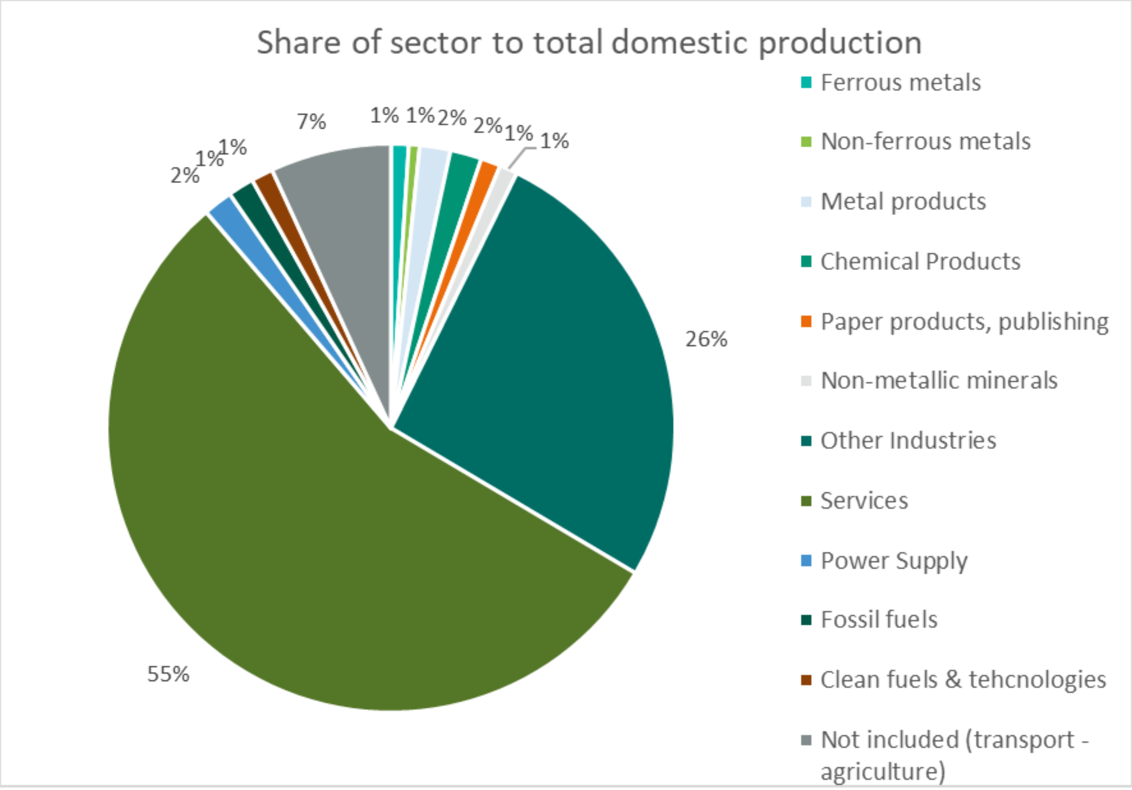
Digitalisation boosts domestic production throughout the economy by introducing more efficient production processes. In addition, the transition to a circular economy causes domestic production from downstream sectors (e.g., ferrous metals, non-ferrous metals etc.) to decline and production from other industries to rise, even though some sub-sectors are negatively affected by shared mobility (e.g., transport equipment).

Figure 100 Combined effect of new trends on domestic production in 2030 (EU27+UK)



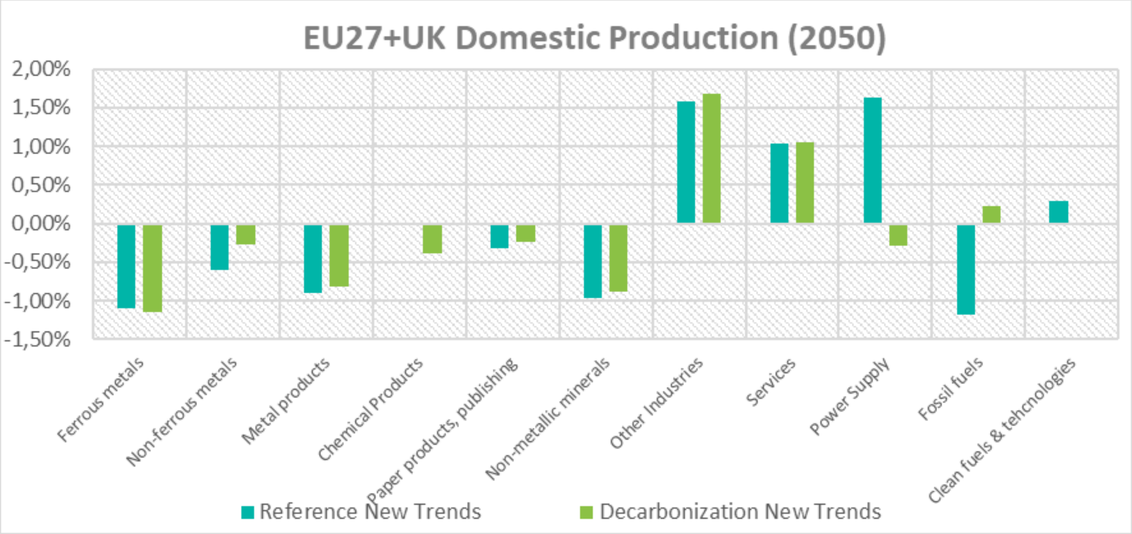
Source: GEM-E3

Figure 101 Breakdown of total domestic production per sector (share %)



Source: GEM-E3

Figure 102 Combined effect of new trends on domestic production in 2050 (EU27+UK)



Source: GEM-E3

5. CONCLUSIONS

The report at hand presents the main findings of the newTRENDs project regarding the impact of new societal trends on energy demand in each sector and the macro economy.

The project has developed four scenarios to assess this impact under different policy contexts (Reference vs. Decarbonisation) using bottom-up and macro economy models. The strongest decline in energy demand is achieved under the scenario where new trends are adopted within a decarbonisation context.

The rise of prosumagers brings about the strongest decline in energy demand, followed by the transition to a circular economy in buildings and the uptake of shared mobility, while digitalisation has a minimal effect.

The analysed new trends have a mixed effect on activity and employment, since they operate through different channels. New trends, such as digitalisation, in particular, which stimulate EU domestic activity (and / or activities with high multipliers) have a positive impact on aggregate GDP and employment.

Digitalisation has a strong positive effect on GDP, by boosting labour productivity and reducing floor area costs in the tertiary sector. Circular economy for buildings and shared mobility are also favourable trends for the EU economy, since they increase efficiency and productivity, and trigger demand-driven economic growth.

Prosumagers foster the RES potential of the economy and could be seen to act in a complementary way to mitigation measures in hard-to-abate sectors. However, the rise of prosumagers is associated with fragmented installation, which increases costs, and increased demand for PV panels, a heavily imported technology.

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