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ABSTRACT

Achieving climate neutrality in Europe is a critical goal, yet there is no model-based assessment detailing the key factors and assumptions of each Member State's National Energy and Climate Plan (NECP). Filling that gap, we evaluated 35 NECPs and simulated them together in a single energy-emissions model, creating a consolidated European National Commitments (NC) scenario. We built a LEAP (Low Emissions Analysis Platform) model covering energy consumption and production in the residential, industrial, agricultural, transport (terrestrial, maritime, aviation), and services sectors. For each fuel type and end use, we calculated multi-pollutant greenhouse gas emissions. Under the NC scenario, significant emissions reductions emerge across all sectors by 2050, driven by energy efficiency gains and cleaner fuel mixes. However, achieving these reductions depends on fully implementing 35 NECPs, which vary substantially in their timelines, ambition levels, data granularity, and fuel-trade assumptions. We highlight these inconsistencies and offer policy recommendations tailored by sector, country, and policy frameworks, providing critical insights to ensure a feasible, holistic and equitable transition.

Keywords: National Energy and Climate Plans (NECPs); Europe; Energy-Emissions; LEAP; Policy Recommendations.

1. Introduction

Climate neutrality, in terms of achieving net-zero greenhouse gas (GHG) emissions, requires multi-sector and multi-country approaches (Brown et al., 2018; Boitier et al., 2023). Energy subsectors' planning (power, transport, industry, buildings) requires close coordination with other sectors, such as agriculture, land management, and uses of appropriate fuel mixes to balance resource flows, curb emissions, and maintain ecosystem health (Khan et al., 2017; Fortes et al., 2022; Alamanos & Garcia, 2024; Koundouri et al., 2024).

Key international commitments, including the Paris Agreement's Nationally Determined Contributions (NDCs) and the UN's Sustainable Development Goals (SDGs), are well integrated into European regulations, such as the European Green Deal (EGD) and "Fit for 55" package, setting binding targets for 2030 (–55% CO_2 vs. 1990 levels) and mandating a climate-neutral economy by 2050 (Koundouri et al., 2024). In this regard, the EU and its Member States are obliged to take necessary measures at EU and national levels to meet the long-term target of climate neutrality, through integrated National Energy and Climate Plans (NECPs). In particular, the NECPs covering 10-year periods should take into consideration the 2030 targets for GHG emission reductions, renewable energy, energy efficiency and electricity interconnection (European Parliament, 2021). The Member States must also submit to the Commission a progress report every two years. In addition, the Member States develop national long-term strategies (LTS) looking forward to 2050, which shall be consistent with their NECPs.

Over 30 European countries, operating within a largely unified internal energy market and common policy framework, offer an ideal regional case study for integrated decarbonization modelling (Luxembourg et al., 2025; Mikropoulos et al., 2025). Numerous energy system models and Integrated Assessment Model (IAM) frameworks have mapped EU decarbonization pathways (Weyant, 2017; Harmsen et al., 2021) with several operational applications, such as the PRIMES model (Capros et al., 2018), or the TIMES-Europe model (Luxembourg et al., 2025). Energy efficiency improvements, increasing use of renewables and electrification are established solutions for Europe's climate neutrality, according to the majority of the existing modelling studies, but complexities in interconnecting sectors and systems are also acknowledged as important challenges to achieve net-zero (Capros et al., 2019; Moreno et al., 2024). Yet, few studies link detailed energy-emissions simulations to the real policy requirements according to the NEPCs.

This is another key aspect and gap of the European energy system's decarbonization, which refers to the individual policies as expressed in each Member-State's NECP. In terms of the NECPs, there have been a few evaluations, but they refer to an analysis of sufficiency elements (Zell-Ziegler et al., 2021), or they focus on aspects of the NECPs related to the dimension of decarbonization in the design and adoption of common European policies and integration issues (Maris & Flouros, 2021), or they assess the quality of EU-mandated public participation in Member-States' NECPs (Oberthür et al., 2025). Moreover, most of the existing modelling studies offer scenario analyses and/or optimal solutions for the EU's energy system, rather than policy analyses on the NECPs and their improvement (van Greevenbroek et al., 2025). There have been country-specific analyses on specific issues, such as the case of renewables for Spain (Ramos et al., 2023), and an analysis of the Italian NECP's review (De Paoli, 2024), but there are fewer multi-country assessments (Geoffron & De Paoli, 2019). In the few available examples, Williges et al. (2022) look at Greece, Austria, and the Netherlands, indicating that the ground is not ready to address the NECPs' objectives. The review by Hyvönen et al. (2024) looks at the North European countries' NECPs (Finland, Estonia, Germany, Sweden, and Denmark), finding them vulnerable to risks related to biomass and global raw material availability for expanding their renewables. However, an assessment of the NECPs of 27 European countries, 5 Western Balkan countries, Norway, the UK and Switzerland with the objective to recommend ways to improve their NECPs as a whole, with regard to their consistency and uniformity has not yet been conducted. We aim to cover this gap by presenting an integrated energy-emissions modelling approach for 35 European countries, simulating each NECP individually. Providing a picture of how the planned net-zero, legally-binding commitments would look like in 2050 is essential to deliver a truly systemic view, revealing sectoral and national challenges with insights grounded on a model-driven analysis, guiding policymakers toward improved national and coherent continental strategies.

2. Context and Challenges in Europe

In this work, we assess Europe as a case study. While we are aware that Europe is interconnected with other regions of the world, it is also important to study it separately as a unit, since there is a common energy policy framework. This intends to harmonize national regulations, and thus to create an integrated, competitive and secure European energy market that facilitates the transition to a net-zero economy. What is more, Europe should operate as a unified energy system to reach the EU's decarbonization targets by creating a more interconnected, resilient, efficient and coordinated energy network, which creates stronger links between different types of energy carriers, energy infrastructure and consumption sectors. So, assessing individual plans and modelling them is a necessary step to provide guidance on how to achieve these objectives.

For our assessment, we consider 35 countries, namely Albania, Austria, Bosnia and Herzegovina, Belgium, Bulgaria, Switzerland, Cyprus, Czechia, Germany, Greece, Denmark, Estonia, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Montenegro, North Macedonia, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia and the UK. These countries are assessed in a cross-sectoral way, considering their current situation, and National Commitments (NC), as we will explain below in the scenario analysis section. This approach of the presented assessment allows us to cover the main challenges and targets among all sectors (residential and services, industry, agriculture, transportation), which share similarities across Europe, but also some differences, as outlined below.

Regarding the residential and services sectors, they account for more than one-third of the EU's energy-related GHG emissions, thus improving their efficiency is critical (European Environment Agency, 2024). However, most European countries struggle with an ageing, poorly insulated building stock (Churkina et al., 2020; Khosla et al., 2021). The required renovation rate is far below targets; the European Environment Agency (EEA) estimates it must double or even triple current levels to meet climate goals (LIFE Unify, 2020; Maduta et al., 2023). Upgrading heating systems (from oil or gas boilers to heat pumps or modern district heating) is a shared goal, but high costs, supply-chain limits and split incentives (e.g., landlords vs tenants) hinder progress (Fattouh & Honoré, 2023; Johnston et al., 2024). So, the main challenges include financing deep renovations, tackling fuel-poor households and dwellings, and decarbonizing heat (e.g., phasing out coal/oil furnaces). Some countries lead with strong building codes or district heating expansion (Nordic and Central Europe), while others still rely on biofuel or gas heating (Abbasi et al., 2021; Elavarasan et al., 2022).

Industry (especially steel, cement, chemicals, manufacturing) is a major emitter and its decarbonization is crucial for Europe (Cavalett et al., 2024; Di Foggia & Beccarello, 2024). The diversity of this sector's processes and supply chains makes its decarbonization challenging to be addressed by single-focus measures, such as only electrification, renewables, energy efficiency or circular economy (Busch et al., 2025; Helm et al., 2025). All those practices are necessary, but in the case of industry in Europe research so far calls for specific roadmaps for each subsector (steel, cement, etc.), with intermediate targets and policies in all NECPs (Meckling et al., 2017). Adoption of new technologies and their costs, as well as integrated power system models accounting for such measures are still necessary for robust planning.

Transport is the EU's largest emitting sector and the one where emissions have flatlined or even risen, with recent research highlighting that all NECPs are "clearly insufficient both in a 2030 and 2050 perspective from a transport point of view" (Transport & Environment, 2019). Most countries set electrification goals (EV quotas, charging networks) and biofuel blends, but these often fall short of the needed pace, while other measures, such as the use of biofuel blends, seem to be overlooked (Transport & Environment, 2019). In practice, uptake of EVs and alternative fuels varies widely among countries (e.g., Norway and Netherlands are far ahead; others lag), and also inequalities emerge due to inherent layouts (e.g., size, population density, topography) and infrastructure levels of different countries (Kaufmann et al., 2024). Modal shift (reducing car travel) is weakly addressed; promoting public transit or active mobility is mentioned only in passing in most plans (Liotta et al., 2023). Freight and aviation decarbonization receive even less attention: hydrogen, synthetic fuels or other solutions are often cited as future potentials without concrete policies (Sharmina et al., 2021; Bergero et al., 2023).

Across Europe's NECPs the agriculture section (including energy and non-energy uses, livestock, crops, etc.) tends to be shallow. Common measures cited include improved manure management, biogas from waste and some efficiency gains, but overall ambition is low (Stid et al., 2025). A recent review finds NECPs "do not reflect sufficient ambition" for agriculture and land use (Frelih-Larsen et al., 2024): They virtually ignore food consumption (diet) changes and mainly rely on LULUCF measures (afforestation, soil carbon projects) to offset farming emissions. Also, agriculture exhibits visible differences across Europe, as other countries have larger livestock sectors (e.g., Eastern countries), others have a large cropping production (South), and so on, with the national policies differing accordingly. In terms of broader land use management, NECPs commonly include afforestation and forest-management plans to boost removals, and some address peatland rewetting. A common objective is that urbanization should stay around existing centers, and avoid agriculture or forest land losses, with reforestation being often a target (Senf & Seidl, 2021).

So, an integrated analysis combining different measures and NECPs comparisons is expected to be a useful exercise for all those sectors.

3. Methodology

The energy-emissions model

Our modelling approach consists of the Low Emissions Analysis Platform (LEAP) (Heaps, 2022) for the simulation of the energy consumption and the associated GHG emissions of multiple pollutants. LEAP is a software tool for long-term integrated energy, climate mitigation, and air pollution planning and analysis, developed over the last 40 years by the Stockholm Environment Institute (SEI). It has been developed as a scenario-based modelling tool that explores how emissions may change in the future. LEAP has been employed in numerous applications globally, from local municipalities to national governments (Fall & Mbodji, 2022). The model's flexibility enables it to accommodate various methodologies, including bottom-up end-use accounting and top-down macroeconomic modelling, making it suitable for integrated resource planning and GHG mitigation assessments (Fall & Mbodji, 2022). This functionality allows for the simulation of specific policies as modelling scenarios, enabling detailed evaluation of their impacts and trade-offs. The model's ability to simulate different scenarios has been particularly useful in exploring future conditions and/or ways for decarbonization (Liu et al., 2021; Xu et al., 2024).

To address the considerable heterogeneity across the NECPs regarding the level of detail that they entail in their description of the planned interventions, we developed two modelling approaches within LEAP. The first approach calculates the energy demand (D) as the product of an activity level (AL) and an annual energy intensity (EI, energy use per unit of activity), according to LEAP's Final Energy Demand Analysis method (Equation 1) (Heaps, 2022). In addition, this approach allows for the simulation of multiple different uses within each core sector (residential, industry, agriculture, transportation, and services). This makes it very suitable in cases where we have sufficient data, that allows the examination of sector-specific policies and scenarios.

$$D_{sector,scenario} = AL_{sector,scenario} \cdot EI_{sector,scenario} \tag{1}$$

In contrast, to deal with cases where we faced data scarcity, we developed a second modelling approach that is based on LEAP's Total Energy Demand method (Heaps, 2022). This means that the main required input is the total final energy consumption for each sector. This second approach simulated the same sectors as the first, but with a lower level of detail (i.e., fewer energy uses). Table 1 below offers a one-on-one comparison of the two approaches.

LEAP's energy supply-side module simulates the resources (representing the availability and characteristics of primary and secondary energy forms), and transformation processes (simulating how energy is converted, transmitted, and distributed through technologies like power plants, refineries, and grids). The supply system ensures alignment with the per sector demand-side inputs and can simulate constraints, imports, exports, and system losses, offering detailed insights into energy flows. Again, there are some differences between the two approaches, reflecting data availability (Table 1). The main difference is that the second approach considers fewer fuel types than the first approach. This is achieved by classifying the fuel types used in the first approach into less fuel categories (aggregation) in order to comply with cases with insufficient data.

Table 1. The main types of inputs in the LEAP model, for each sector.

Simulated sectors/ parameters	Modelling Approach 1	Modelling Approach 2
Energy Demand		
Residential	**Method**: Final Energy Intensity Analysis **Activity Level**: Population divided into urban and rural. **Uses**: Space Heating, Space Cooling, Water Heating, Cooking, Lighting, Appliances	**Method**: Total Energy Demand **Uses**: Residential as a whole
Agriculture	**Method**: Final Energy Intensity Analysis **Activity Level**: Value added	**Method**: Total Energy Demand
Industry	**Method**: Final Energy Intensity Analysis **Activity Level**: Value added **Sub-sectors**: Food & Tobacco, Textiles & Leather, Wood & Wood Products, Paper Pulp & Printing, Chemicals, Rubber & Plastic, Non-Metallic (excluding cement), Basic Metals (excluding steel), Machinery, Transportation Equipment, Other Manufacturing, Mining, Construction, Cement, Steel	**Method**: Total Energy Demand **Sub-sectors**: Industry as a whole
Aviation, Maritime & Terrestrial Transportation	**Method**: Final Energy Intensity Analysis **Activity Level**: ktoe per Passenger-km **Sub-sectors**: Cars & Light Trucks, Freight Trucks, Motorcycles, Buses, Trains, Freight Trains, Domestic Airplane, Maritime	**Method**: Total Energy Demand **Sub-sectors**: Terrestrial Transportation, Aviation, Maritime
Services	**Method**: Total Energy Demand **Sub-sectors**: Services as a whole	**Method**: Total Energy Demand **Sub-sectors**: Services as a whole
Energy Supply (fuels' generation & transformation processes)		
Primary Resources	Solar, Hydro, Wind, Geothermal, Solid Waste, Biomass, Crude Oil, Lignite, Other Coal, Natural Gas	Renewables (includes: Solar, Hydro, Wind, Geothermal), Biomass (includes: Biomass, Solid Waste), Crude Oil, Coal (includes: Lignite, Other Coal), Natural Gas (includes: Natural Gas, CNG)
Secondary Resources	Electricity, Hydrogen, Synthetic Fuels, Heat, Biogas, Refinery Feedstocks, Diesel, Petroleum Coke, Fuel Oil, Kerosene, CNG, LPG, Gasoline, Other Petroleum Products	Electricity, Hydrogen, Synthetic Fuels, Heat, Biogas, Refinery Feedstocks, Petroleum Products (includes: Diesel, Petroleum Coke, Fuel Oil, Kerosene, LPG, Gasoline, Other Petroleum Products)
Transformation Processes	Transmission and distribution, synthetic fuel production, generation of hydrogen, electricity, heat, oil refining – with the associated losses	Transmission and distribution, synthetic fuel production, generation of hydrogen, electricity, heat, oil refining – with the associated losses
GHG Emissions		
Type of Pollutants	CO_2, CH_4, N_2O, PM2.5, Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6), Black Carbon (BC), Organic Carbon (OC)	CO_2, CH_4, N_2O, PM2.5, Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6), Black Carbon (BC), Organic Carbon (OC)
Validation		
	For the current account, both energy consumption and fuel supply results were	For the current account, both energy consumption and fuel supply results were

	validated with data from a single source (EUROSTAT).	validated with data from a single source (EUROSTAT).
Countries	Albania, Bulgaria, Czechia, Greece, Hungary, Montenegro, North Macedonia,	Austria, Bosnia & Herzegovina, Belgium, Switzerland, Cyprus, Germany, Denmark, Estonia, Spain, Finland, France, Croatia, Ireland, Italy, Lithuania, Luxemburg, Latvia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia, UK

To ensure that our results, and thus our conclusions, are not sensitive to the choice of modelling approach, we tested the implications of the two approaches for selected countries. Namely, we implemented both modelling approaches to countries with sufficient data, and we compared their results. Our analysis showed that the results of total and per sector energy consumption, total energy production and emissions remain the same, as we detail in Koundouri et al. (2025). Moreover, using the "Modelling Approach 2" was proved to be a very useful and trustworthy solution in cases of data scarcity. Finally, note that the results of both approaches were validated for the current account (i.e., year 2022) using data from EUROSTAT.

The GHG emissions are then estimated based on the emission coefficients of the IPCC's Fifth Assessment Report (IPCC, 2014), in order to estimate emissions per sector, use and fuel type. In particular, LEAP's "effects" menu provides the option to select different sets of Global Warming Potential (GWP) values corresponding to one of the IPCC Assessment Reports. LEAP includes 20, 100 and 500-year GWP values. These values reflect the relative potential of each effect over each period. Each value is specified in units of tonnes of CO2 equivalent per tonne of pollutant (T CO2e/T). That is, the GWP values measure the warming potential of a tonne of each gas relative to a tonne of CO2.

The National Commitments Scenario

Our assessment is based on the **NC** (National Commitments) scenario, reflecting the legally binding objectives for each country. For the LEAP model, these are explicitly expressed through each individual NECP and are detailed per sector.

Unavoidably, the NECPs are the most central part of this 'NC' analysis, as they include all sectors and set specific technology and fuel-related goals per country. So, a necessary step for our assessment was to carefully review all 35 countries' NECPs under specific criteria to facilitate their simulation in LEAP. The outcome of this process is summarized in the Annex, Table A1, and is discussed after the results, in order to put the review-finding into the broader context.

The NECPs of the 27 EU countries are available at the European Commission's website (European Commission, 2025), and the NECPs of the 5 Western Balkan countries, namely Albania, Bosnia and Herzegovina, Montenegro, North Macedonia and Serbia, are available at the Energy Community's website (Energy Community, 2025). Norway's Climate Action Plan for 2021-2030 is available at its government's website (Norwegian Ministry of Climate and Environment, 2021), and Switzerland's long-term climate strategy to 2050 is available at the website of its Federal Office for the Environment (FOEN, 2025). As far as the UK is concerned, it should be mentioned that the UK, although it is not a member of the EU anymore, submitted its NECP to the Commission shortly before the end of 2020.

Our analysis focused on the following criteria:

a) The level of NECP readiness of each country, namely checking whether the countries have submitted a draft or a final version of their NECP.

b) The planning horizon of each NECP, as some countries set their objectives for 2040 or 2050, providing a long-term strategy.

c) The approach considered in the NECPs in terms of emphasizing on a "supply-management" (more fuel- and technology-focused), or a "demand-management" (more efficiency- and consumption-focused), or on a seemingly balanced approach.

d) The level of detail on how to achieve decarbonization targets, as some NECPs provide more detail and data-driven analyses, projections and specific breakdowns of measures, while others tend to be more descriptive.

e) The GHG emissions reduction targets (e.g., the percentage reduction in GHG emissions compared to 1990 or 2005 levels).

f) Data on renewable energy in final energy consumption and electricity generation. The NECPs consider renewables and electrification as major drivers for net-zero, so we noted which countries provide explicit numbers on the renewable energy shares in the final energy consumption and energy generation by 2030 and/or 2050.

g) The reliance on imports and/or exports of each country. Some NECPs include explicit projections for their expected imports and/or exports of specific fuels (e.g., fossil fuels, biofuels, hydrogen, etc.), so we noted whether this data is included, as well as the respective available information.

Having taken into account these criteria while reading the official translated in English version of the NECPs, and manually translating specific parts of the original-language NECPs whenever necessary, we gathered all relevant data that we found in the NECPs and created a summary comparative table, which we attach as an Annex. These criteria were necessary for their LEAP simulation, but we also consider them central for the identification of potential areas for further coordination and collaboration among European countries, and the provision of sectoral and international recommendations.

4. Results

The model runs under a simulation period, from 2022 to 2050, at an annual time step. The BAU (business as usual) period 2022-2025 was used for model validation, while after 2025 the model assumes that the NC scenario is implemented as mentioned above, to capture the legally binding targets for GHG emissions. The NECPs, as defined by each country's Ministry of Energy (and Environment in some cases), assume certain interventions per sector. These refer to improvements of energy use efficiencies and cleaner energy mixes. So, for all sectors, the NC scenario - expected energy consumption - led to the respective energy intensities assumed in this simulation. Also, for each sector, the NC's expected fuel mixes (phasing out fossil fuels and replacing them with cleaner ones) were simulated.

Note that for the energy consumption, fuel mix and the associated GHG emissions of the transportation sector, there is an important difference between the NECPs. On the one hand, several NECPs focus only on domestic transportation (i.e., terrestrial, aviation, and navigation). On the other hand, there are countries that consider international transportation (i.e., aviation and navigation) as well. To ensure consistency in our analysis, we adopt the latter approach for all countries by filling the missing data in the first group of countries based on reasonable assumptions about the growth rate of international transportation and the corresponding fuel mix. Finally, economic instruments like the EU Taxonomy, Circular Economy rules, or the ETS serve as supporting frameworks to finance or incentivize investments, but they do not themselves set or alter sectoral quotas or consumption benchmarks. Therefore, omitting them from our analysis does not overlook additional mandatory commitments, since we do not present an economic model here (this is our future-research plan).

The parameters that are changing according to the specific NECP recommendations, include the fuel mix shares serving the demand (increasing the share of cleaner fuels), and improvements in energy efficiencies per sector and use. Table A2 in the Appendix provides a summary of the planned interventions per sector under the NC scenario. Note though that this does not mean that all interventions listed in Table A2 are adopted by each of the 35 NECPs. Although there are specific countries that plan to adopt all listed measures, most countries aim only at a subset of those interventions.

The results for Europe as a whole under the NC scenario indicate a steady decline in energy demand (meaning consumption) from 2025 to 2050, driven by decreases in all major sectors. Most notable reductions are observed in the transportation (red) and residential (green) sectors, while services (blue) and industry (yellow) also contract gradually (Fig.1a). One of the main reasons for the modest decrease in energy consumption in the tertiary sector, despite the adoption of similar to the residential sector measures, is the increasing role of data centers, which leads to high demand for electricity. Demand-side emissions drop sharply due to the shift from fossil fuels to clean energy sources (Fig.1b). On the supply side (Fig.1c), oil refining (dark brown) contracts significantly, while electricity generation (brown) gradually expands to become the dominant supply source by 2050, accompanied by a gradual increase in hydrogen generation (green), while traditional heat generation (dark green) remains stable over the whole planning horizon. Supply-side emissions from the energy generation processes fall dramatically from around 1,000 $MtCO_2e$ in 2022 to roughly 200 $MtCO_2e$ by 2050 (Fig.1d), reflecting the transition to low-carbon technologies. These results underscore Europe's NECPs expected progress toward decarbonization, driven by reduced demand and a shifting supply mix, yet also highlight persistent emissions from remaining generation and refining activities, emphasizing the need for continued policy support and technology deployment.

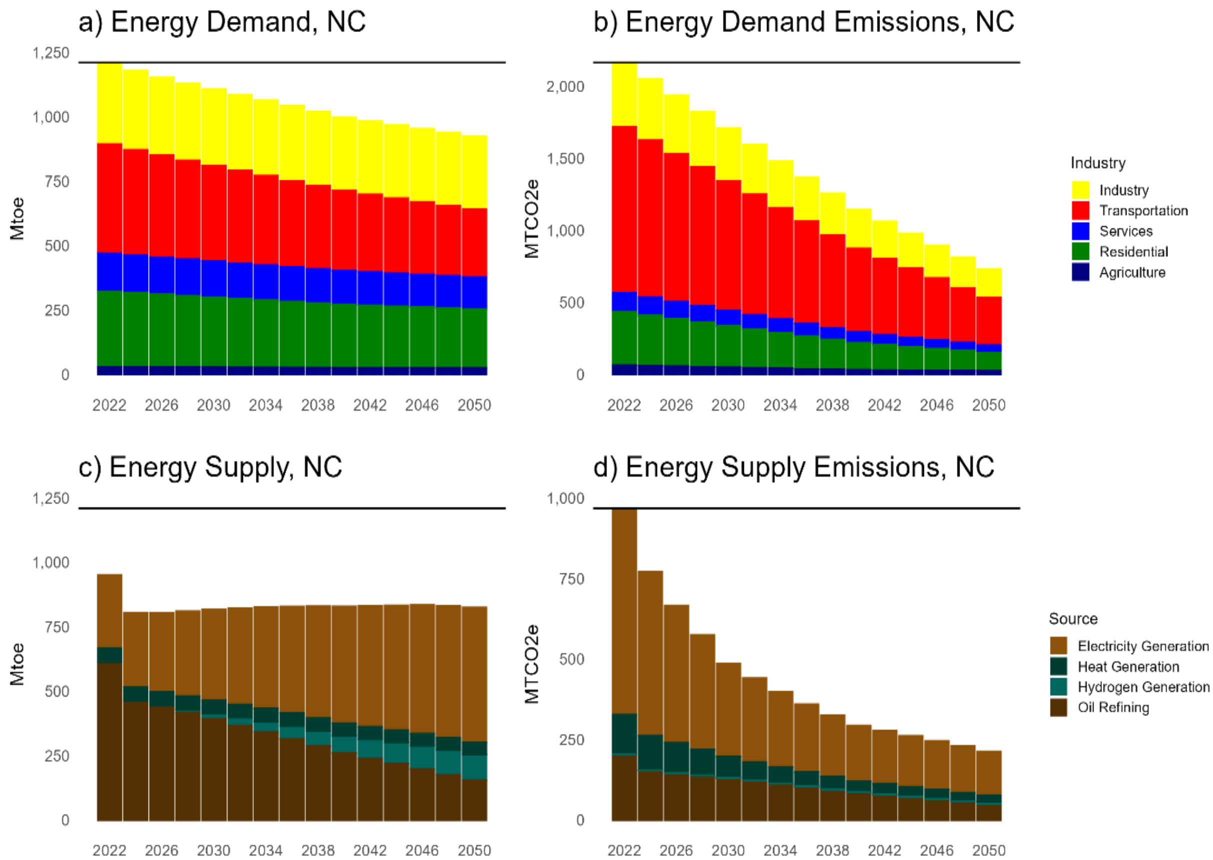

Figure 1. The overall results of the European NC scenario, including: (a)Total energy consumption per sector, with (b) the respective GHG emissions (100-Year GWP). (c) The amount of energy supply per source, with (d) the respective GHG emissions (100-Year GWP).

Figure 2 shows the per country results of the evolution of energy consumption and the associated GHG emissions. In 2025, as expected, larger economies (Germany, France, the UK, and Italy) display higher total energy consumption. Industry (yellow) and transportation (red) dominate in Central and Western Europe, whereas Southern and Eastern countries (e.g., Greece, Poland, Romania) show relatively larger residential (green) and services (blue) shares. By 2050, our pie-chart diameters shrink uniformly (normalized to their respective minimums/maximums in the legend), reflecting overall declines in projected demand under the NC scenario. The sectoral mix shifts modestly: industrial shares reduce slightly, while services and residential shares remain more stable. Geographically, Northern Europe (Sweden, Finland) maintains a noticeable industrial component despite lower total volumes, whereas Mediterranean countries exhibit pronounced transportation and residential slices, underscoring persistent reliance on mobility and building energy. Commitment dates (shaded 2040 or 2050, depending on the NECPs' planning horizons) do not radically alter pie-sizes, but they indicate that earlier-committing nations generally exhibit somewhat smaller 2050 pies relative to later adopters. In 2025, emissions are higher in Germany, Poland, and Italy, driven by substantial transportation (red) and industrial (yellow) shares (in line with the respective consumption). Western countries like France and Spain have comparatively smaller pies due to larger renewable uptake. Northern states (Sweden, Finland) show small but significant residential (green) and services (blue) emissions. By 2050, pie sizes shrink dramatically across all countries, reflecting the aggressive NC decarbonization, yet transportation remains a consistent share, especially in Southern Europe. Eastern EU members (e.g., Bulgaria, Romania) still display sizable industrial emissions slices, indicating slower phase-out of fossil-heavy processes. Notably, early-commitment countries (shaded lighter grey) achieve more pronounced emission reductions by 2050 than those committing in 2050 (darker shaded grey), highlighting the impact of earlier policy implementation on decarbonizing national energy consumption.

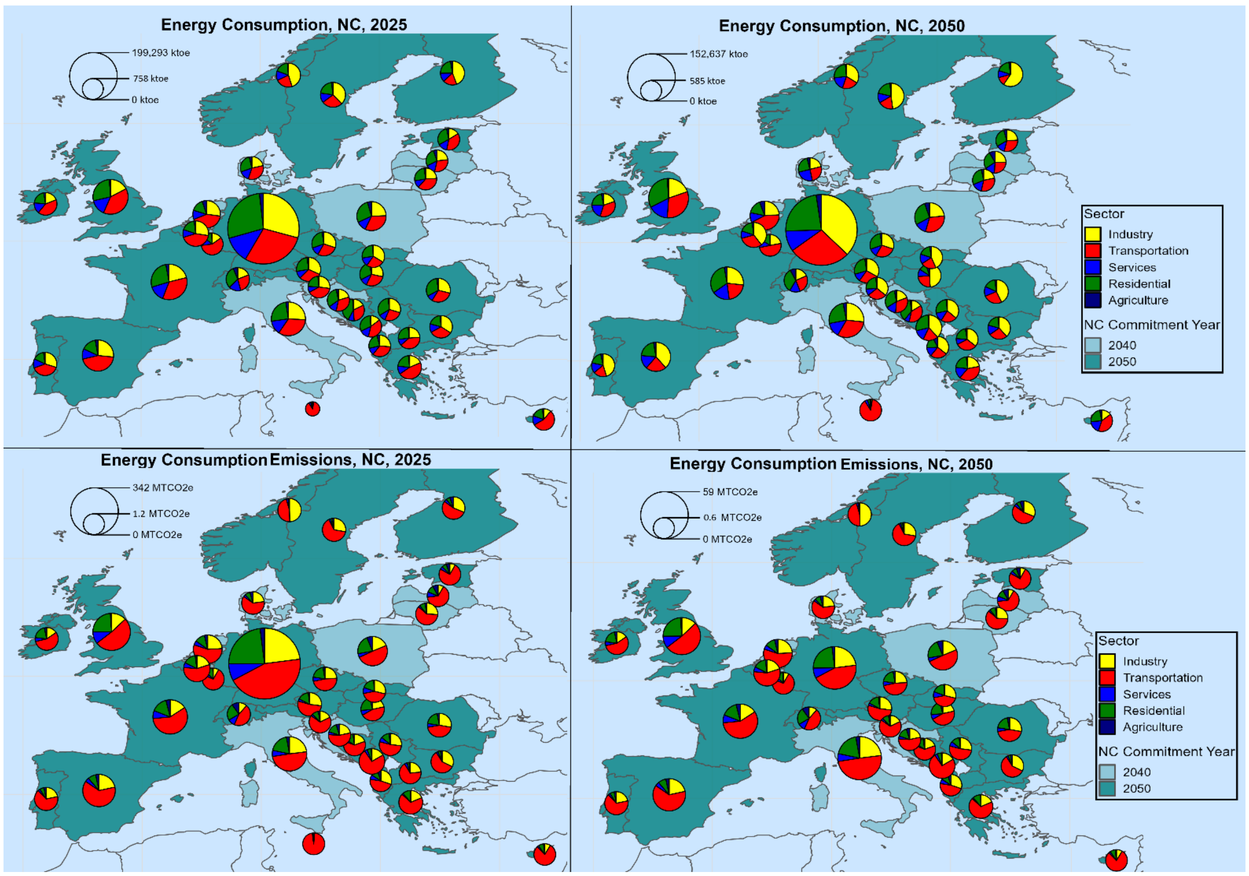

Figure 2. The evolution of energy consumption, according to the NC scenario: In 2025 (upper left) and 2050 (upper right), along with the respective GHG emissions in 2025 (bottom left) and 2050 (bottom right), per sector. To accommodate the scale of the pie charts, they were normalized according to their min and max sizes, as indicated in the legend.

Figure 3 shows the per country results of the energy supply sources and their associated emissions. In 2025, Europe's largest energy suppliers (Germany, France, UK) exhibit sizable electricity generation shares (brown), while Baltic and Scandinavian countries display notable heat generation (dark green). Oil refining (dark brown) remains significant in Eastern and Southern countries (Poland, Italy, Spain, Greece), reflecting persistent domestic refinery activity. Green Hydrogen production (teal) is minimal overall. In 2025, supply-side emissions peak in Germany, Poland, and Italy, where electricity generation (brown) drives most CO_2 output, due to the large share of coal and natural gas in the electricity generation mix. Oil refining contributes substantially in Eastern Europe and the UK.

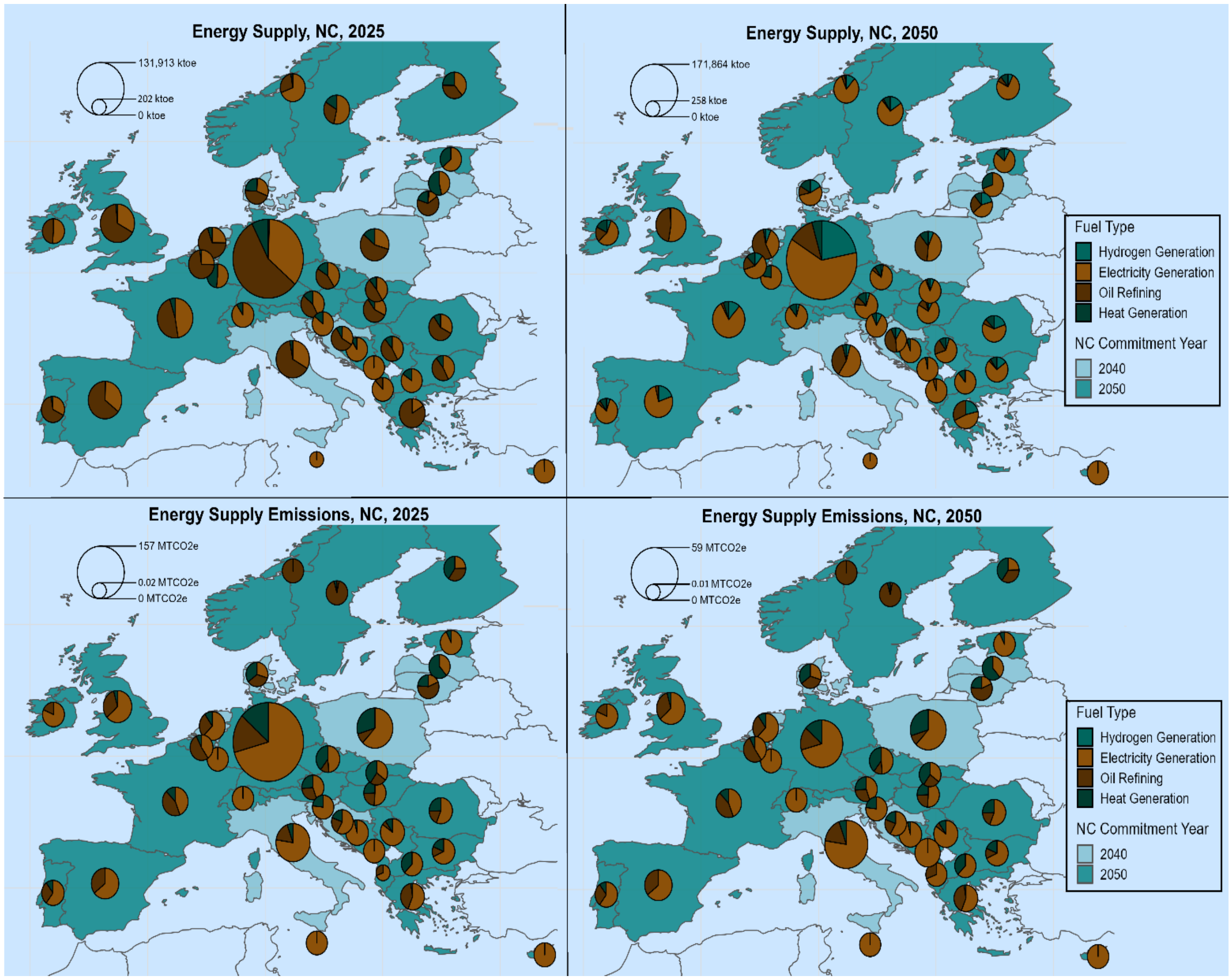

Figure 3. The evolution of energy generation from the main supply sources, according to the NC scenario: In 2025 (upper left) and 2050 (upper right), along with the respective GHG emissions in 2025 (bottom left) and 2050 (bottom right), per sector. To accommodate the scale of the pie charts, they were normalized according to their min and max sizes, as indicated in the legend.

By 2050, the NCs project a general grow in the share of hydrogen, especially in Northern Europe (Sweden, Finland) and Central Europe (Germany, Austria), indicating a regional pivot toward hydrogen. Electricity generation remains dominant in all countries, while the share of oil refining decreases significantly. Eastern and Southern countries still rely more on oil refining in 2050 compared to their Northern peers, highlighting divergent decarbonization speeds. The respective NC-projected emissions in 2050 are significantly lower than the 2025 levels, (pie-sizes are normalized to min/max), with Germany and the UK reducing electricity emissions most, while Northern European nations use renewables and have minimal remaining emissions. Eastern and Southern states (e.g., Poland, Romania, Greece) still have visible oil refining emissions, indicating lagging decarbonization. Hydrogen's clean production yields near-zero emissions, so countries with larger hydrogen slices in 2050 (e.g., Sweden) exhibit negligible supply-side emissions compared to fossil-dependent peers.

In general, regarding the total GHG emissions, the primary driver of the reductions in the total emissions (both from energy consumption and energy generation) is the significant decrease in fossil fuel use across the residential, industrial, and transportation sectors, which is one of the core recommendations of the NECPs. Additionally, the adoption of renewable energy sources in electricity production further contributes to these reductions.

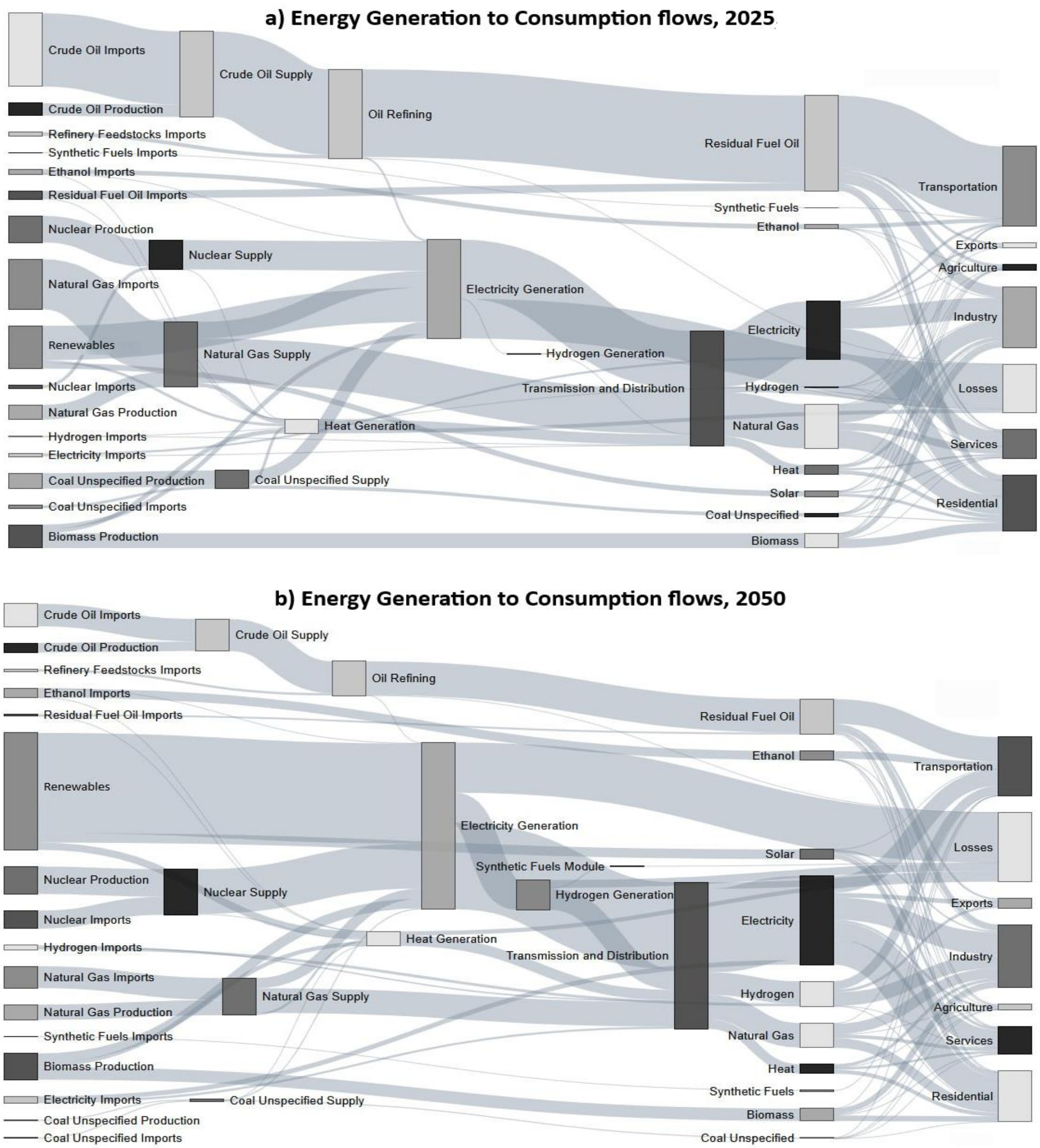

Figure 4. Sankey diagrams for the energy generation and consumption flows in (a) 2025 and (b) 2050, following the NC scenario based on the NECPs' projections, for the Europe as a whole.

Under the BAU period, up to 2025 (Fig.4a), Europe's energy system remains heavily reliant on fossil imports (crude oil and natural gas flow into large refining and gas-fired power plants), supplying transport, industry, and buildings with residual fuel oil, natural gas, and a modest share of renewables and nuclear. Electricity generation is dominated by gas and nuclear, with renewables playing a secondary role, and hydrogen is negligible. In contrast, the NECP 2050 projection (Fig.4b) reveals a dramatic transformation: renewables supply the bulk of electricity, displacing gas and oil; solar and biomass enter the end-use mix; hydrogen generation ramps up alongside a new synthetic fuel module; and oil refining shrinks to serve niche transport segments. Electricity becomes the primary carrier for residential, services, and industry, while transport increasingly uses hydrogen and synthetic fuels. Imports of fossil feedstocks vanish, reducing supply-side emissions. These flows underscore the feasibility of deep decarbonization (provided massive investments in renewables capacity, grid expansion, hydrogen infrastructure, and synthetic-fuel facilities are achieved) and highlight the need to phase out legacy fossil assets, bolster system flexibility, and secure supply chains for low-carbon fuels.

The assessment of the National Energy and Climate Plans (NECPs)

As mentioned, the core policy framework at the national level that is designed to address climate neutrality is the NECP. Table A1 in the Annex summarizes the 35 NECPs reviewed in a comparative way. This review reveals both elements of coherence, but also elements that need further attention to avoid policy inconsistencies.

Regarding the degree of readiness (Final/Draft plans), of the 35 countries that we examined, 28 have developed and submitted a final NECP. Only 7 of them, namely Bosnia and Herzegovina, Belgium, Estonia, Croatia, Montenegro, Poland and Slovakia, have not yet submitted a final NECP. It is noted that both EU Member States and the Energy Community members had the obligation to submit their final NECP, having taken into consideration the assessment and recommendations of the Commission and the Energy Community Secretariat, by 30 June 2024.

As far as the planning horizon is concerned, we found that the majority (19) of the countries (Albania, Austria, Bosnia and Herzegovina, Belgium, Bulgaria, Switzerland, Czechia, Germany, Greece, Estonia, Croatia, Hungary, Ireland, Italy, Montenegro, North Macedonia, the Netherlands, Romania and Serbia) have set in their NECP 2050 targets. Ten (10) countries, namely Denmark, Finland, Lithuania, Luxembourg, Latvia, Malta, Portugal, Sweden, Slovenia and Slovakia, provide in their NECPs projections until 2040, whereas 6 countries, namely Cyprus, Spain, France, Norway, Poland and the UK include in their NECP 2030 projections, but have or are developing their long-term strategy (LTS status) for 2050.

While assessing the 35 NECPs to simulate them in LEAP, we observed that there were some differences in the approach they follow towards net-zero. Some countries emphasize their "supply-side", the primary consumption per fuel, including mainly electricity, natural gas, renewables, hydrogen (6 countries, namely Albania, Czechia, Estonia, Croatia, Portugal and Romania); Some countries emphasize their "demand-side", the reduction of energy consumption per sector (9 countries, namely Bosnia and Herzegovina, Finland, France, Lithuania, Montenegro, North Macedonia, Malta, Sweden and Slovakia); A more "balanced" analysis of the energy supply and demand sides across multiple sectors, including buildings, households, industry and transport, is provided by most countries (19 countries: Austria, Belgium, Bulgaria, Switzerland, Cyprus, Germany, Greece, Denmark, Spain, Hungary, Ireland, Italy, Luxembourg, Latvia, the Netherlands, Poland, Serbia, Slovenia and the UK). Finally, Norway follows an emissions-based approach as it mainly focuses on the reduction of GHG emissions, without discussing explicitly supply- and/or demand-side measures.

Similar differences are observed in the planning of imports/exports. Figure 5 summarizes the simulated evolution of energy imports/exports according to the NECPs, focusing indicatively on electricity (a potential product of renewable energy), and green hydrogen (an emerging green fuel). The NC scenario can shift electricity trade patterns between 2025 and 2050. France and Sweden emerge as net exporters (blue), while Italy and Germany run significant deficits (red), reflecting combinations of heavy demand and less domestic low-carbon capacity. By 2050, France's surplus grows even larger as other countries decarbonize, while Germany remains a major net importer despite expanding renewables. Southern states (Spain, Italy) reduce their deficits moderately, aided by solar and wind growth. Regarding hydrogen, 2025 shows early exporters like France and the Netherlands (blue), contrasted by Germany's deep import needs (dark red) as it builds demand before scaling domestic production. By 2050, France becomes the main green hydrogen hub, followed by the Scandinavian countries and the Netherlands. Overall, we observe that the total electricity deficit more than doubles (54 TWh in 2025 vs 115 TWh in 2050), while the corresponding deficit in green hydrogen sharply increases as well (11 TWh in 2025 vs 79 TWh in 2050). This raises significant concerns about the feasibility of the existing NECPs.

We have also observed several inconsistencies between projected installed capacity, generation, consumption and expected net imports/exports of electricity and green hydrogen by 2050 in four (4) countries, namely Croatia, Denmark, Lithuania, and Poland. The reasons for these inconsistencies vary. Croatia seems to underestimate the necessary net electricity imports to support domestic electricity consumption and planned green hydrogen generation. The Netherlands seems to expect to switch from net electricity importer to net exporter without building (or analyzing the progress for) the necessary capacity to meet demand. In the case of Lithuania, there is an expectation to become net exporter in both markets (electricity and hydrogen), but based on the planned investment in power generation capacity this is feasible only in one of the two markets. Finally, Poland underestimates its net exports potential in both markets, implying that they cannot exploit the full potential of the projected installed electricity capacity.

Regarding the level of detail in the different NECPs, on data and ways to achieve the long-term net-zero emissions target, we observed again differences. Only seven (7) countries (Albania, Bulgaria, Czechia, Greece, Hungary, Montenegro, and North Macedonia) have conducted a very detailed analysis in their NECPs, providing extensive data to support their policies and measures toward climate neutrality by 2050. On the other hand, nine (9) countries (Bosnia and Herzegovina, Belgium, Germany, Estonia, Finland, Latvia, the Netherlands, Poland, and Sweden) have not provided a detailed analysis or sufficient data. In addition, nine (9) countries (Spain, France, Croatia, Ireland, Italy, Lithuania, Norway, Slovakia, and the UK) have followed a descriptive approach in their NECPs, supplying the least amount of relevant data. These patterns largely reflect differing institutional and financial drivers, with Southern-Eastern countries being more "finicky" than Northern-Western ones. The former countries, still integrating EU frameworks or reliant on Cohesion and Just Transition Funds front-load, tend to detail technical data to demonstrate compliance and "absorption capacity" and justify external funding (Streimikiene et al., 2007; Dani & Haan, 2008)[1]. In contrast, wealthier, long-standing EU members tend to house their deep sectoral analyses in specialized energy and climate strategies outside the NECP itself (e.g., Germany's Energiewende documents, Sweden's green transition plans). Their NECPs serve more as high-level roadmaps, with granularity delegated to parallel plans, hence the descriptive format and apparent "lack" of data, even though highly granular analyses may exist elsewhere (Oppermann et al., 2021).

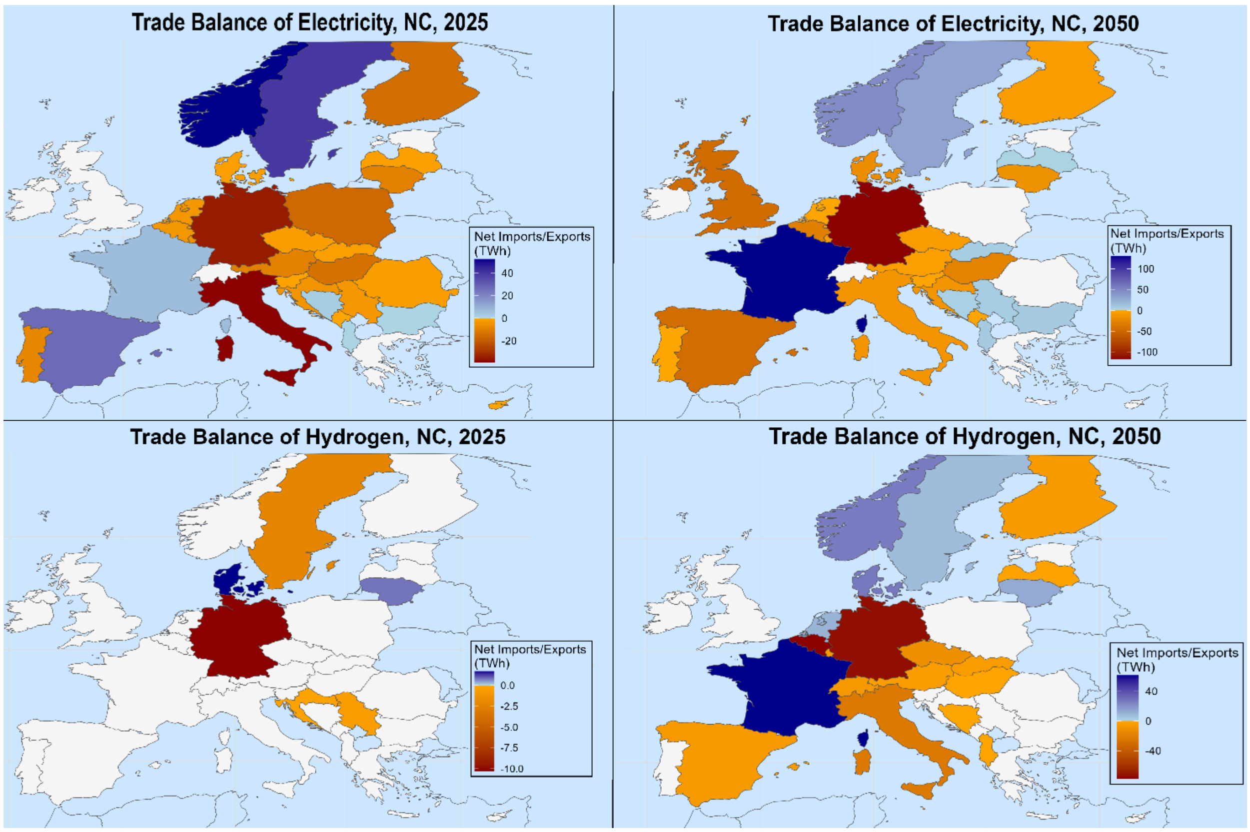

Figure 5. Trade balance maps, indicatively in 2025 and 2050, for electricity (upper row) and green hydrogen (bottom row).

Furthermore, from our analysis we have identified some geographic patterns. For instance, the 'wealthier' countries of Western and Northern Europe (Germany, France, the Netherlands, Belgium, Denmark, Sweden, Finland, Austria, Ireland, and Luxembourg) have set very ambitious GHG emissions reduction targets, compared to the Southern and Eastern ones. Germany stands out as the only country bound to achieve climate neutrality by 2045. Denmark is also aiming to reduce its GHG emissions by 110% in 2050 compared to 1990 levels. These countries generally benefit from robust technological readiness and secure infrastructure: high-capacity grids, sophisticated energy storage, and mature supply chains for renewables and hydrogen (IEA, 2024). Their strong trade relations also help absorb shortfalls or export surpluses of low-carbon technologies (Den Elzen et al., 2022). Consequently, they can adopt more

[1] Bulgaria, Hungary, Greece and Czechia rely heavily on EU grants for infrastructure upgrades, so they need more robust analysis to secure support from the Modernization Fund, Just Transition Fund, and recovery grants. In essence, "detail" becomes a way to make a stronger case for external financing.

aggressive targets with confidence that domestic manufacturing, interconnection capacity, and import–export frameworks will support rapid deployment, grid stability, and resilient supply chains through 2050.

5. Limitations, gaps, and policy implications

The examined policies face challenges due to differing planning horizons, target years, and implementation responsibilities. As noted, there are even inconsistencies across the different NECPs. Such fragmented approaches can lead to scattered efforts and potential inefficiencies in achieving Europe's sustainability goals.

Limitations

First, it is important to acknowledge the limitations of our effort to simulate the NC from an integrated modelling lens. Specifically, we treated Europe as a single, closed system; however, it is a realistic (and necessary) way to explore its NC, as expressed under a common framework for all Member States, the NECPs. Also, in our current setup, countries are modeled independently within LEAP, without any simulation of cross-border energy flows (e.g., imports/exports). This approach, however, mirrors the way NECPs conceptualize Europe, with each country outlining its national targets and strategies without accounting for specific import/export dynamics. While the presented integrated modelling approach overall aligns with the structure of the NECPs and thus realistically reflects their framing, it inherently restricts the analysis by omitting the interconnected nature of real-world energy markets. So, practically, no economic data, such as prices and other market data, were considered. There is also lack of modelling of biofuels, land requirements, water analysis, and potential assessment of other economic policies. This is, however, the objective of our ongoing and future research, with the development of a CGE model to complement and extend the energy system model presented here. In addition, several assumptions were necessary due to the lack of detailed data within many NECPs, particularly regarding sector-specific technological pathways or timing of investments. Lastly, the NC scenario simulation is based on the assumption that the NECPs are fully implemented, which in turn requires certain behavioural changes (e.g., adoption of technologies to improve energy efficiency and mixes of cleaner fuels). Even if this is achieved, it is worth noting that not all NECPs achieve complete decarbonization by 2050, there are still emissions, but significantly lower.

NECPs among different countries

The NECPs across Europe exhibit differences in planning horizons, emission targets, granularity of analysis, and treatment of cross-border flows. While some countries set short-term milestones to 2040 or 2045, others extend goals only to 2030 or broadly to 2050, leading to misaligned timelines that complicate regional coordination. Targets themselves vary often, reflecting differing domestic priorities rather than a unified EU strategy. Moreover, wealthier Member States frequently submit high-level, narrative plans with limited data, whereas newer or less affluent members provide detailed projections but focus solely on national supply and demand without addressing imports or exports. This patchwork of approaches undermines collective progress, as energy markets and infrastructure inherently transcend borders.

Policy coherence

Achieving climate neutrality across sectors presents a significant challenge for European countries, particularly within the framework of NECPs. Sectoral efforts can be challenging, requiring the coordination of policies between different governmental entities, such as Ministries of Environment and Energy, Ministries of Transportation, Ministries of Economics, along with divergent interests among private stakeholders (Mercure et al., 2016). These fragmented governance structures have been hindering progress and integrated action to several member states (Jensen et al., 2020). This is because they can create siloed communication channels, challenging effective collaboration and integrated policy execution, and resulting in misaligned priorities and policy incoherence (Buylova et al., 2025; Lah, 2025). Overall, although climate neutrality requires to couple cross-sectoral planning in a unified framework (Brown et al., 2018), governance innovations (e.g., the EU's Cities Mission) that aim at bridging these silos often struggle in practice due to vague coordination mechanisms and lack of political will (Buylova et al., 2025).

6. Recommendations

Drawing upon the findings of this assessment, we summarize the main policy recommendations in Table 3. These recommendations are categorized as sector-related, country-related and regulatory-related.

Starting with our sectoral-related recommendations, we highlight that, to achieve deep decarbonization, Europe must move beyond isolated technological improvements and adopt sector-specific strategies. The most challenging sectors, such as heavy industry, transport, and agri-food, require tailored, multi-faceted roadmaps that prioritize electrification, energy efficiency, clean fuels, transformative agricultural practices, and cross-sectoral integration of energy, services, and transit systems.

Also, country-targeted interventions are essential, especially in Southern and Eastern Europe. These may include expanding public transport, supporting industrial retrofits, and facilitating refinery transitions, all while aligning local investment with broader EU goals. Early action, holistic water and land use planning, and targeted funding for less affluent economies are also crucial to ensure an equitable and effective transition.

Table 3. Policy recommendations considering sectors (first colour-block), countries (second colour-block), and regulatory frameworks (third colour-block). The order is indicative, and all recommendations are complementary.

Category	Recommendation
1. Industry sector, Energy	**Develop more comprehensive & diversified measures for industry sub-sectors:** Recognize the diversity of industrial subsectors by creating tailored roadmaps for steel, cement, chemicals, and other high-emission industries. Each roadmap should combine electrification, renewable power sourcing, energy-efficiency upgrades, and circular-economy practices. Encourage policymakers to move beyond single-technology fixes toward coordinated portfolios of measures that address each subsector's (e.g. steel, cement, etc.) unique energy and emissions profile.
2. Transportation sector, Energy	**Invest in public transport infrastructure:** Address policy fragmentation between development and transport portfolios by prioritizing large-scale rail upgrades, bus rapid transit corridors, and urban tram expansions. Strengthening government coordination, such as joint transport-land use planning, will speed

	up necessary infrastructure investments. Enhanced public transit networks will reduce reliance on private cars, cutting transportation emissions and alleviating urban congestion.
3. Transportation sector, Energy	**<u>Promote adoption of cleaner fuels in transportation with equity:</u>** Introduce incentives and regulatory mandates to increase the use of clean fuels (e.g. biofuel blends) in shipping and aviation. For instance, establish national blending requirements for sectoral transportation fuels and offer tax credits or direct compensation to airlines that integrate sustainable aviation fuels. This will ensure that biofuels help decarbonize hard-to-abate transport modes while meeting emerging emissions standards.
4. Agri-food sector, Energy	**<u>Transformative agricultural practices beyond technology fixes:</u>** Move from incremental improvements (e.g. optimized feeding and fertilizer application) to systemic changes that include dietary shifts and large-scale organic or regenerative farming. Integrate incentives for crop diversification, agroforestry, and reduced meat consumption into CAP and rural development schemes.
5. Cross-sectoral, Energy	**<u>Integrate residential, services, and transit sectors within NECPs:</u>** For example, synchronize funding for thermal retrofits of residential blocks with the rollout of district heating or rooftop solar, and coordinate this with public transit improvements. Adopting integrated energy–economy–urban planning models will ensure that efficiency measures, grid investments, and zoning regulations reinforce one another rather than being implemented in isolation.
6. Southern Europe, Energy	**<u>Strengthen transport decarbonization in Southern Europe:</u>** Southern Europe is marked by high private vehicle ownership, tourism flows, and limited rail networks, so transportation remains a challenge. Prioritize the expansion of intercity and urban public transit systems (e.g., regional rail, bus rapid transit). Introduce vehicle-scrappage incentives tied to electric or low-emission models, and coordinate road-pricing or low-emission zones to discourage fossil-fuel cars. Align infrastructure grants with local municipal transport plans, ensuring that new bus depots and charging hubs serve dense corridors to maximize ridership and slash tailpipe emissions.
7. Eastern Europe, Energy	**<u>Target industrial emissions in Eastern Europe:</u>** Key Eastern EU industries (steel, cement, chemicals) are large emitters. Many facilities are owned by foreign multinationals or joint ventures, driving an outsourcing trend by lower labor and environmental costs. Mandate comprehensive emissions reporting and introduce sector-specific decarbonization roadmaps, requiring annual reduction milestones (e.g., 10% CO_2 cut per five years). Offer tiered funding for clean-tech retrofits, while conditioning EU funds on visible progress. Strengthen labor retraining programs to support workforce transitions in high-emission subsectors.
8. Southern & Eastern Europe, Energy	**<u>Refinery transition in Eastern and Southern Europe:</u>** Despite declining demand, many Eastern and Southern European countries will still depend on oil refining in 2050. Target these refineries with dedicated support packages, low-interest loans or grants, to retrofit units into biorefinery hubs that process waste oils, biomass, or produce green hydrogen.
9. Cross-country considerations	**a)** **<u>Accelerate action:</u>** Early-commitment countries achieve more pronounced emission reductions by 2050. Accelerate commitments in lagging Member-States. **b)** **<u>Urban-driven sustainable growth:</u>** Urban-dominated countries (especially those with high population densities) should urgently upgrade water distribution systems and align future city growth with sustainable, resilient water sourcing strategies. **c)** **Smart land use in densely populated countries:** Compact nations such as Belgium and the Netherlands should prioritize rooftop, floating, and agrivoltaic solar to reduce land-use conflicts with agriculture, urbanization, and conservation. **d)** **<u>Support smaller economies with renewable investment needs:</u>** Countries with smaller GDPs require targeted EU and international funding support to meet solar and wind expansion goals without straining public budgets.
10. NECPs1	**<u>Unified 2050 planning horizon and deepen modeling:</u>**

	All Member States should align their NECPs on a common 2050 endpoint for climate neutrality. Critically, countries must explicitly model cross-border trade in electricity, fuels, and low-carbon technologies (e.g., hydrogen). Harmonized timelines and richer data are highly recommended.
11. NECPs2	**Cross-border infrastructure and policy collaboration:** Governments must establish regular dialogue with neighboring countries to coordinate grid interconnections, shared renewable energy projects, and joint infrastructure investments and trade. This collaborative approach ensures that new capacity serves multiple markets efficiently and supports balanced electricity flows, ultimately lowering costs and enhancing grid stability across Europe.
12. NECPs3	**NECP transparency:** Member States should treat NECPs not just as funding applications but as fully transparent roadmaps[2]. Every country, regardless of GDP, EU-seniority, or administrative capacity, must include detailed sectoral data (e.g., technology costs, capacity trajectories, policy impacts, cost-benefit analyses) to enhance credibility and enable rigorous EU-wide assessments.
13. Equity considerations	Western and Northern European countries tend to set more ambitious net-zero goals, relying on robust technological readiness, secure grid infrastructure, and mature supply chains. In contrast, Southern and Eastern Member States often lack these advantages, making it harder for them to commit to or achieve equally stringent goals without additional support. **a)** **Targeted EU Funding:** Allocate a dedicated share of the EU's Just Transition and Recovery Funds to upgrade grids, storage, and renewable manufacturing in Southern and Eastern Member States, enabling them to build the infrastructure that underpins deeper decarbonization. **b)** **Technology transfers:** Establish pan-European purchasing consortia for solar panels, electrolyzers, and other clean-energy technologies, enabling poorer countries to benefit from bulk-purchase discounts and shared R&D. **c)** **Capacity-building:** Create specialized training and technical assistance centers funded by wealthier Member States or EU programs, to provide expertise in project development, permitting, and grid integration for renewables in lagging regions, supported by monitoring and accountability mechanisms. **d)** **Cross-border renewable projects:** Launch EU co-financing for interconnection projects and shared renewable installations (e.g., offshore wind farms serving neighboring grids), ensuring less-resourced nations gain access to low-carbon electricity without bearing the full infrastructure cost alone.

Overall, our overarching recommendations highlight the need for all Member States to align their NECPs on a unified 2050 horizon, enhance cross-border collaboration, ensure full transparency, and direct EU funding, technology transfer, and capacity-building to less advantaged countries, laying the foundation for a fair and resilient pan-European energy transition.

[2] The European Commission's Assessment of the NECPs itself discusses how several Member States use the NECPs as funding tools, especially those eligible for EU Cohesion Policy and Just Transition Fund support, which often requires detailed project pipelines and cost-benefit justifications. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0564

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Annex

Table A1. The summary for the NECPs assessment and comparison

Country	Final/Draft (F/D) - Publication date	Plan-ning Horizon	Status of long-term strategy (LTS)	Fuel-focused (supply) / Consumption-focused (demand) / Balanced	Level of detail on achieving net-zero target	Reduction in GHG emissions target for 2030 (%)	GHG emissions target for 2050	Renewable energy share in total energy consumption by 2030 (%)	Renewable energy share in total energy consumption by 2050 (%)	Renewable energy share in total electricity generation in 2050 (%)	Total energy consumption in 2050	Account for reliance on imports (Y/N, quantity)	Export targets by 2050
Alb	F - 31 October 2024	2050	embedded in the NECP	Imports in fossils, exports in electricity	Very detailed	10.21	2.2 Mt CO2-eq. (excluding LULUCF)	59.4	73	93	111.7 PJ	600 ktoe=7 TWh in Fossils (oil+NG)	570 ktoe in Electricity
Aus	F - 20 December 2024	2050	currently updating the 2019 LST	balanced	Moderately detailed	48 compared to 2005	24,9 Mt CO2-eq. (excluding LULUCF)	56.8			884 PJ (data reported also per sector)	Y (1 TWh in 2050)	
Bosnia & Herz	D - 30 June 2023	2050	December 2020	consumption - focused	Little detail	53% compared to 2014	80% compared to 1990, 4.19 Mt	28	43	85	129 PJ	Y (12 TWh in fossils)	–
Bel	D - 4 December 2023	2050	March 2020		Little detail	15 compared to 2005	85% compared to 1990	22.6	56.6				
Bul	F - 15 January 2025	2050	submitted in 2022	balanced	Very detailed	10 compared to 2005	climate neutrality	34.96	85.50 (4 893 ktoe)	60 (80303 GWh)	6 544 ktoe (data reported also per sector)	Y (4.9% in 2050)	6010 GWh
Swi	F(Long-Term Climate strategy and Supplement) - 27 January 2021 and 29 January 2025	2050		balanced	Moderately detailed	65 compared to 1990 in 2035	net zero emissions			45,000GWh		N	
Cyp	F - 20 December 2024	2030	September 2022	balanced	Moderately detailed	32 compared to 2005	zero emissions	33.2	95		1996 ktoe		

Cze	F - 20 December 2024	2050	December 2019	fuel-focused	Very detailed	68.4 compared to 1990	96% reduction compared to 1990 (7.98 Mt CO2ek)	30	65	52	Graph 117	Y (hydrogen imports 36.7 TWh in 2050)	2.8 TWh (2043-2047)
Ger	F - 29 August 2024	2050	February 2019	balanced	Little detail	55 compared to 1990	GHG neutrality by 2045 - total GHG emissions with LULUCF 153 Mt CO2-eq.	41	88.8 (green hydrogen imports) 80.5 (hydrogen imports from exclusively non-renewable sources)		6,238 PJ (data reported also per sector)	Y (38.7% - 31311 MW in 2050)	28368 MW
Den	F - 1 July 2024	2040	December 2019	balanced	Moderately detailed	70 compared to 1990	110 compared to 1990	60 for EU target of 45%	2653,7ktoe in 2040 (82,3%)		17798 ktoe in 2040	Y (1969ktoe in 2040)	160 PJ
Est	D - 17 August 2023	2050	April 2017	fuel-focused	Little detail		95% reduction compared to 1990	65				Y	
Gre	F - 7 January 2025	2050	2019	Fuel-focused	Very detailed	58% reduction compared to 1990	98% reduction compared to 1990	43	95.8	100.8	13412 ktoe	Y (very detailed for all fuels)	424 ktoe in electricity
Spn	F - 26 September 2024	2030	December 2020	balanced	descriptive	55 compared to 2005	climate neutrality (at least 90% reduction compared to 1990)	48 (37.295ktoe)		100			
Fin	F - 1 July 2024	2040	April 2020	consumption - focused	Little detail	50 compared to 2005		62	464ktoe in 2040		21927ktoe in 2040	Y (4300GWh electricity in 2040)	
Fra	F- 10 July 2024	2030	March 2020	consumption - focused	descriptive	50 compared to 1990	net zero emissions		No estimated share of renewable beyond 2030.		decrease by 50 % compared to 2012		
Cro	D - 4 July 2023	2050	June 2021	fuel-focused	descriptive	50.2 compared to 2005	9 Mt CO2	42.5	65%	93	6334 ktoe	Y, fossils	
Hun	F - 16 October 2024	2050	updated 2021	balanced	Very detailed	50 compared to 1990 (47,5 Mt CO2e)	climate neutrality	30	62	32 TWh		Y	
Ire	F - 22 July 2024	2050	updated in 2024	balanced	Moderately detailed	42 compared to 2005	net zero emissions	43			11,541 ktoe	Y (60% in 2040)	
Ita	F - 1 July 2024	2050	February 2021	balanced	descriptive	43 compared to 2005	85 Mt CO2	38.7	42.3	69	95400	Y(54% in 2040)	
Lit	F - 7 October 2024	2040	update in 2021	consumption - focused	descriptive	≥70 compared to 1990	100	55	95			Y	43.000 tonnes of

														green hydrogen
Lux	F - 24 July 2024	2040	November 2021	balanced	Moderately detailed	55 compared to 2005	climate neutrality	37			29 168GWh in 2040	Y (60,7% electricity dependancy in 2040)	
Latvia	F - 15 July 2024	2040	2019	balanced	Little detail	65 compared to 1990	climate neutrality	62	82,7 (2040)		3331 ktoe (2040)	Y (19,6% in 2040)	
Mont	D - December 5th, 2024	2050	embedded in the NECP	consumption - focused	Very detailed	27 compared to 2022	0.40 Mt CO2	39.17	50.7	100	614 ktoe	Y (fossils)	n
North Mac	F - 31 May 2022	2050	embedded in the NECP	consumption - focused	Very detailed	51 % compared to 1990	3.3 MtCO2	35	57.2	95.9	2517 ktoe	Y (fossils + 8% electricity)	N
Mal	F - 7 January 2025	2040	October 2021	consumption - focused	Moderately detailed		carbon neutrality	24.5				Y in 2030	
Neth	F - 26 June 2024	2050	December 2019	balanced	Little detail	46-57 compared to 1990	95% reduction	30.5			55046 ktoe	Y (72% in 2040)	
Nor	F - 8 January 2021	NECP 2030, long-term strategy (LTS): 2050	October 2020	emissions focused	descriptive	50-55 compared to 1990 (Norway's target of being climate neutral from 2030 onwards)	90-95 reduction compared to 1990					N	
Pol	D - 5 March 2024	2030	not submitted	balanced	Little detail	35 compared to 1990		29.8				Y (2030)	
Port	F - 10 December 2024	2040 NECP, 2050 LTS	June 2019	fuel-focused	Moderately detailed	43	carbon neutrality (2045)	51	88	100		65% in 2030	
Rom	F - 16 October 2024	2050	embeded to NECP	fuel-focused	Moderately detailed	85% compared to 1990	13.8	36.2	86.1	86.9	16512	Y (Renewables)	NG+ oil products = 82%
Ser	F- 25 July 2024	2050	embeded to NECP	balanced	Moderately detailed	33.3 compared to 1990	13.2	33.6	64.53	90.6	9537 ltoe	Y (35%)	Oil products
Swe	F- 1 July 2024	2040	December 2019	consumption - focused	Little detail	50 compared to 2005		67				Y	
Slovn	F- 7 January 2025	2040	March 2020	balanced	Moderately detailed	35-45 compared to 2005	0 (Figure 83)	33 (with a view to significantly increasing the share of RES by 2040 (and 2050) at the next update of the NECPs)				Y	

Slovk	D- 6 September 2023	2040		Demand	descriptive	~55% compared to 1990	16.25	not available data	32.7	no data for electricity generation	6910 (estimated)	Y(fossils)	–
UK	F - 31 January 2020	2030	Energy and emissions projections 2023 to 2050 report (December 2024)	balanced	descriptive		net zero emissions	22-29				Y in 2050	

Table A2. Summary of the planned interventions per sector according to the NECPs, reflecting the NC scenario.

Interventions/Sectors	Description
Energy Demand	
Residential	i) Substitute fossil fuels (diesel and natural gas) and biomass (wood) with heat pumps and/or modern district heating. ii) Substitute fossil fuels (diesel and natural gas) with electricity in cooking. iii) Increase the use of heat pumps in space cooling, substituting A/C units. iv) Improve energy efficiency in buildings.
Services	i) Substitute fossil fuels (diesel and natural gas) and biomass (wood) with heat pumps and/or modern district heating. ii) Increase the use of heat pumps in space cooling, substituting A/C units. iii) Improve energy efficiency in buildings.
Agriculture	i) Substitute fossil fuels (diesel and natural gas) with biofuels and electricity. ii) Improve energy efficiency.
Transportation	i) Substitute petroleum products with electricity, biofuels, hydrogen and synthetic fuels in aviation, navigation and terrestrial passenger and freight transportation. ii) Shift from private (cars & motorcycles) to public (buses & trains) modes of transportation.
Industry	i) Substitute fossil fuels (petroleum products, coal and natural gas) with electricity, hydrogen and synthetic fuels. ii) Improve energy efficiency.
Energy Supply (fuels' generation & transformation processes)	
Electricity Generation	i) Increase renewable power generation capacity. ii) Substitute fossil fuels (petroleum products, coal and natural gas) with renewable energy sources.
Hydrogen Generation	i) Increase electrolysis capacity. ii) Increase green hydrogen production to meet domestic demand (and exports). iii) Use hydrogen to produce fuels like, ammonia, methanol, etc.