European Union: Energy system restructuring towards a long-term low-emission pathway

Where are we?

The EU[1] has been an early mover in the global climate policy landscape and has ratified the Paris Agreement with its NDC target to reduce GHG emissions by at least 40% in 2030 from 1990 levels. The EU energy and climate policy framework has led to a rapid expansion of renewable energy sources (RES) in electricity generation and to a decline of CO_2 emissions by about 20% from 1990 levels. In this context, the EU NDC implementation implies an acceleration of climate policy efforts in the period after 2020 and fits in a pathway to achieve the EU's long-term objective of at least 80% reduction in domestic GHG emissions by 2050. The EU's primary energy mix is still dominated by fossil fuels with oil accounting for 34%, gas for 23% and coal for 17%, while the share of RES has increased from 7% in 2000 to 14% in 2017. The main sources of emissions are energy-related CO_2 emissions (which account for 77% of GHG emissions) while non-CO_2 emissions represent 18% and non-energy related CO_2 emissions 5%. The power generation and transport sectors are the major emitting sectors accounting for 62% of EU CO_2-energy emissions in 2015 mainly driven by high transport activity (which is still largely dominated by oil products) and the electrification of the EU economy.

Recently, the European Commission (EC) presented the "Clean Energy for all Europeans[2]", a package of measures to keep the EU competitive in the context of clean energy transition. The proposed policies and legislation are aligned with the EU NDC commitments to the Paris Agreement and the 2030 policy objectives regarding GHG emissions reduction, renewable energy and energy efficiency. European climate policy can be broadly classified into two categories: (1) the EU Emission Trading System (ETS), the EU-wide cap-and-trade system covering power generation, energy-intensive industry and aviation, and (2) policies targeting non-ETS sectors (buildings, transport, agriculture) including Member State-specific targets for emission reduction (Effort Sharing Decision). The inclusion of all sectors in EU's climate action sets a good practice GHG reduction policy. To reach the NDC target, both policy pillars need to be strengthened after 2020; more specifically, in March 2018 a revision of the EU ETS for the period from 2021 to 2030 was adopted encompassing three key elements: doubling the Market Stability Reserve (MSR) feeding rate in the 2019-2023 period to reduce surplus of allowances; increasing the ETS cap annual reduction rate to 2.2% from 2021 onwards; and invalidating allowances in the MSR exceeding the number of allowances auctioned in the previous year. These measures contribute to achieving the 2030 ETS emission reduction target of 43% below 2005[3]. The Effort Sharing Decision[4] on GHG emissions from sectors not covered by the EU ETS was adopted in May 2018 and would lead to an EU-wide emission reduction of 30% by 2030 relative to 2005; this will be achieved by binding emission limits for each EU Member State by 2030. The policy framework is also complemented with sector-specific measures including the adopted proposal for amending the Energy Efficiency Directive and the Energy Performance of Buildings Directive[5], the regulation to integrate GHG emissions and removals from LULUCF[6] into the 2030 Climate and Energy policy framework, and the EC proposal for setting CO_2 performance standards in light- and heavy-duty vehicles[7]. In 2018, the Energy Union Governance Regulation

[1] We acknowledge funding from the COMMIT project, Climate pOlicy assessment and Mitigation Modeling to Integrate national and global Transition pathways. The project is financed by the European Commission's Directorate-General for Climate Action (DG CLIMATE). More info on: www.pbl.nl/commit-project

[2] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

[3] European Commission (2015) Impact Assessment: Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC. European Commission, Brussels, Belgium

[4] https://ec.europa.eu/clima/policies/effort/proposal_en

[5] Council of the European Union (2017a) Energy efficient buildings – Presidency secures provisional deal with European Parliament

[6] Land Use, Land Use Change and Forestry

[7] https://ec.europa.eu/transport/modes/road/news/2018-05-17-europe-on-the-move-3_en

was agreed, which sets out interim targets towards achieving the 2030 goals of 32% renewable energy and 32.5% energy savings[8]. Recent analyses show that current actions and policy initiatives are not sufficient to meet the Paris Agreement long-term objectives[9], so strengthening of climate ambition is needed towards acceleration of energy system transformation and clean technology uptake. On the other hand, several positive changes have already been observed in the EU, including the implementation of GHG reduction policies at the EU and national-level, the rapid reduction in RES costs, the reduced CO_2 emissions and import dependence, the employment opportunities in RES activities (wind energy, bioenergy, PV installation[10]), and the significant progress made by several EU Member States towards clean energy transition.

This analysis is based on the PRIMES model describing in detail the European energy system and markets on a country-by-country basis[11]. PRIMES simulates a multi-market equilibrium solution for energy supply and demand by explicitly calculating prices which balance demand and supply in each sector, while the modelling of agents' behaviour is founded on micro-economics and considers technical and engineering constraints. Two scenarios are explored, i.e. the Reference (including already implemented policies) and the low-carbon scenario assuming strong climate policy action by 2050. The analysis builds on recent modelling improvements including enhanced representation of hydrogen, synthetic fuels, storage and innovative options towards deep decarbonisation and on PRIMES model results from the ASSET project[12].

Where do we want to go?

The EU is on track to achieve its 2020 emission target and is currently legislating policies to reduce GHG emissions by at least 40% in 2030. The policies, legislative instruments and support programmes are expected to put the EU on a trajectory compatible with its NDC, but further measures are needed after 2030 to ensure consistency with the Paris Agreement goal of carbon neutrality in the second half of the century (achieve a balance between emissions and removals of GHGs by human activities). This transition will require deep transformational change to achieve full decarbonisation of the energy system, i.e. going beyond the 80% emission reduction in 2050. The EU has not yet submitted its strategy for long-term low-carbon transition. In July 2018, the EC launched a public consultation on a strategy for long-term GHG emissions reduction reflecting on a vision for a modern low-carbon economy for all Europeans[13]. Recently, eleven EU Member States pledged to meet the Paris Agreement's goal of achieving carbon neutrality in the second half of the century through the Carbon Neutrality Coalition[14]. Various options for decarbonisation and their implications for technology choices and socioeconomic factors are worth to be examined, in an effort to ensure that climate policy creates multiple co-benefits (e.g., reducing air pollution and improving health), but avoids generating adverse side-effects (e.g., deteriorating access to energy). The setting of firm and clear policy directions is required to ensure that near-term choices are aligned with long-term goals, i.e. to ensure sufficient investment in clean energy technologies, and to avoid lock-in to carbon-intensive technologies, processes and infrastructure.

The low-carbon transition pathway requires a significant reduction in GHG emissions towards close to zero net emissions by mid-century. The EU "low-carbon" scenario presented here is considered to be in line with the objective to limit global warming to well-below 2 °C, as cumulative EU CO_2 emissions are 93 Gt in the 2010-2050 period; this is well within the range projected by a number of global models[15] for cost-optimal scenarios assuming a global carbon budget of 1000 Gt CO_2 considered

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[8] The EC anticipates that emission reductions would go beyond 40% below 1990 in 2030, if these new targets are met http://europa.eu/rapid/press-release_SPEECH-18-4236_en.htm. The current analysis does not consider these targets.

[9] European Climate Foundation, Net Zero by 2050: from whether to how, zero emission pathways to the Europe we want, https://europeanclimate.org/wp-content/uploads/2018/09/NZ2050-from-whether-to-how.pdf

[10] https://ec.europa.eu/energy/en/news/over-one-million-jobs-renewable-energy

[11] The analysis does not include emissions from the Land Use, Land Use Change and Forestry sector.

[12] ASSET project, https://ec.europa.eu/energy/en/studies/asset-study-sectorial-integration

[13] https://ec.europa.eu/clima/news/public-consultation-strategy-long-term-eu-greenhouse-gas-emissions-reduction_en

[14] https://www.euractiv.com/section/climate-environment/news/europes-2050-climate-strategy-takes-shape/

[15] The range of EU cumulative CO_2 emissions over 2010-2050 from global models is [91-111] Gt in the 1000 Gt global carbon budget scenario and [90-102] Gt in the 400 Gt global carbon budget scenario, for additional information: McCollum DL, et al (2018) "Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals," *Nature Energy*, doi: 10.1038/s41560-018-0179-z.

equivalent to likely below 2 °C and it is also in line with global models' scenarios assuming a global carbon budget of 400 Gt CO_2 over 2010-2100 (equivalent to 66% probability to limit global warming to 1.5 °C). The EU low-carbon scenario leads to a 95% reduction in CO_2 emissions from 1990 levels implying a near complete decarbonisation of the energy system by 2050. All sectors need to contribute to the low-carbon transition according to their technological and economic potential, with an almost complete decarbonisation of both energy supply and demand (Figure 1). The energy supply and transport sectors are the major contributors to emission reductions, driven by extensive expansion of wind and solar PV in power production and large-scale deployment of electric vehicles, hydrogen and advanced biofuels in transport modes. The industry and buildings sectors have high CO_2 abatement potential, through accelerated energy efficiency, electrification and reduced carbon intensity of energy use. Closing the gap towards the long-term decarbonisation pathway can be achieved with a renewed and more ambitious NDC (strengthening action in the medium term)[16]; suitable near- and long-term climate strategies targeting the key emitting sectors; appropriate carbon pricing mechanisms and other policy measures; and appropriate finance to facilitate uptake of clean energy technologies.

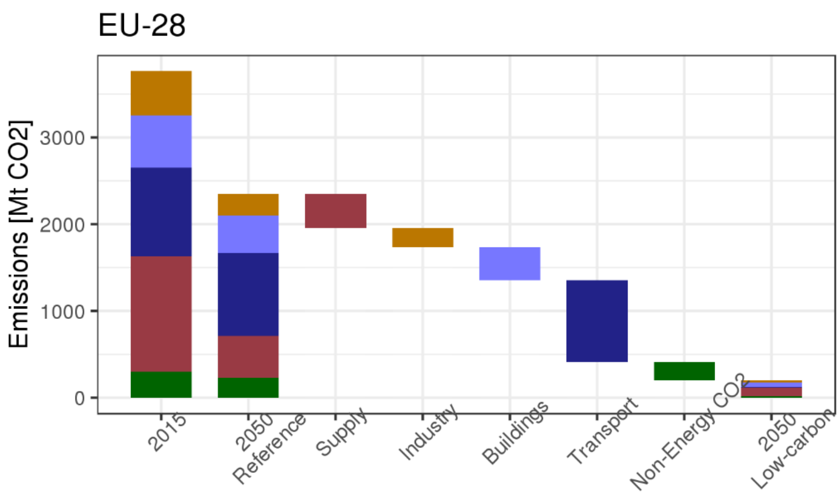

Figure 1: Greenhouse gas emissions in 2015 and by 2050 in the reference scenario, emission reductions between the reference and low-carbon scenarios by sector (energy supply, industry, residential and commercial buildings, transport, non-energy CO_2), and 2050 emissions in the low-carbon scenario (consistent with 1000 $GtCO_2$, i.e. 2 °C). Non-energy CO_2 includes emissions from industrial processes.

How do we get there?

Several studies[17] have identified the key role of energy efficiency, expansion of renewable energy and fuel switching away from carbon-intensive options and towards electricity and bioenergy in end-use sectors to achieve large cuts in GHG emissions. RES expansion is driven by significant cost reduction due to accelerated technical progress, while transport decarbonisation requires large-scale deployment of electric cars and increased use of advanced biofuels in non-electrifiable transport modes. The role of electricity is central in the low-carbon transition; electrification of final energy demand (both in stationary and transport uses) complemented with decarbonised power supply plays a critical role for the cost-efficient low-carbon transition (Figure 2). Power generation is projected to undergo a profound restructuring towards the dominance of variable renewables, with the share of solar PV and wind increasing from 12% in 2015 to 58% in 2050. In parallel, gas-fired capacities are required for balancing and reserve to complement expansion of intermittent RES. In the longer term, the massive RES deployment in

[16] http://europa.eu/rapid/press-release_SPEECH-18-4236_en.htm
[17] EC Energy Roadmap 2050, Capros et al, 2014, European decarbonisation pathways under alternative technological and policy choices: A multi-model analysis, https://www.sciencedirect.com/science/article/pii/S2211467X13001053

the electricity system is supported by development of batteries, hydro pumping and chemical energy storage (power-to-gas, hydrogen). To achieve ambitious GHG emission reduction targets, the low-carbon scenario includes several policy measures:

- Strengthening of the ETS cap in power generation and energy intensive industries
- Measures for accelerating energy efficiency in the buildings sector
- Regulatory emissions standards for Light Duty Vehicles aiming at low emissions mobility
- Promotion of Best Available Techniques in industry
- Facilitation of renewables' deployment in energy supply and demand sectors.

The large-scale adoption of these mitigation options and policy measures would lead to GHG emissions reduction of about 80% in 2050, leaving unabated emissions from the transport, industry and building sectors. To achieve further GHG reductions, it is necessary to further augment the intensity of sectoral measures and achieve a higher level of sectoral integration mainly through the deployment of hydrogen and clean synthetic fuels (next section).

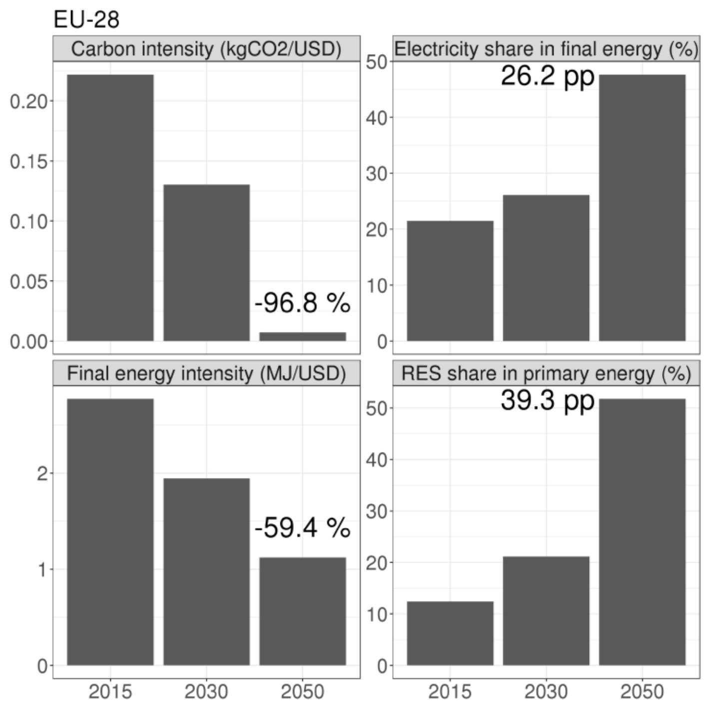

Figure 2: Energy system transformation towards decarbonisation (key transition indicators). Numbers in graph indicate change between 2015 and 2050 (intensity indicators: %, share indicators: percentage points, pp)

The transition would entail several challenges to all sectors that need to decarbonise, i.e. energy-related costs for households and firms shift to CAPEX, away from OPEX, posing challenges to low income classes. On the other hand, significant opportunities may also emerge as the energy transition would improve security of energy supply, air quality and human health. The energy efficiency gains, together with the shift towards RES, would reduce the need for imported fossil fuels and lead to a large decline in the EU energy import bill. The low-carbon transition can bring a wide range of additional benefits for EU citizens (clean air, less traffic and city congestion, avoided climate damages), better living environments, reduced energy import bill, and increased resilience of the EU economy. The model-based analysis supports the feasibility, technically and economically, of the NDC targets for 2030 and the long-term low-carbon transition with opportunities for strengthened climate action through low-cost options, like coal phase-out, energy efficiency measures and RES expansion in electricity production. The EU Climate policy framework can facilitate the effective market coordination between consumers, policy makers, technology and infrastructure developers towards the cost-efficient decarbonisation of the European economy.

The role of hydrogen and clean gas towards deep decarbonisation

Transport and heat decarbonisation are key ingredients towards the low-carbon transition, but are challenging without structural innovations. Energy efficiency improvements and electrification of final energy uses would reduce CO_2 emissions, but the deployment of hydrogen and clean synthetic fuels would be required to enable full decarbonisation complemented with innovative technologies providing flexibility and storage services. Assuming high learning for these options in the long-term, the low-carbon scenario (presented above) would have the following characteristics (Figure 3):

- Mix of hydrogen up to 15% in the gas distribution grids, together with bio-methane and clean methane (produced from hydrogen and CO_2 captured from the air); the share of each option reaches 15-20% in 2050;
- Use of electrolysis-produced hydrogen to feed fuel-cell powertrains in large vehicles (trucks, buses, etc.) and long distance travelling cars coupled with hydrogen refuelling infrastructure hubs;
- Use of hydrogen directly in high-temperature furnaces to decarbonise industrial processes which are difficult to electrify, including in iron and steel, the chemical industry and other sectors;

Power-to-H_2 technologies would need to be developed to provide electricity storage services at a large-scale, needed to maximise the use of renewables, and produce hydrogen and clean methane used by consumers. The decarbonisation of transport is achieved through a combination of mitigation options; electric vehicles are massively deployed in the passenger car stock, battery-charged vehicles combined with fuel cell powertrains are used for heavy-duty and high mileage travelling vehicles, while advanced biofuels are mainly used in aviation and maritime sectors. Despite the significant increase in the volume of electricity required to produce hydrogen and clean synthetic fuels, electricity prices would not increase owing to the market integration and the interconnected energy system allowing access to remotely located renewables, flexibility provision, and an effective sharing of balancing resources. The hydrogen-based storage of electricity would contribute to smoothing the load curves, maximising RES capacity factors, and to shifting RES-based electricity to time periods when renewable power production is in deficit. Hydrogen, clean gas and bio-methane would cover almost half of total consumption of gaseous fuels by 2050, with natural gas (equipped with CCS) mainly used in power generation and industrial applications. Energy security has long been a major concern in the EU as most Member States rely to a large extent on imported fossil fuels. The low-carbon pathway reduces EU's energy import dependence significantly, from 56% in 2015 to 27% in 2050, driven by the expansion of domestic renewable sources (including advanced biofuels) and the domestic production of gaseous fuels from electricity and hydrogen.

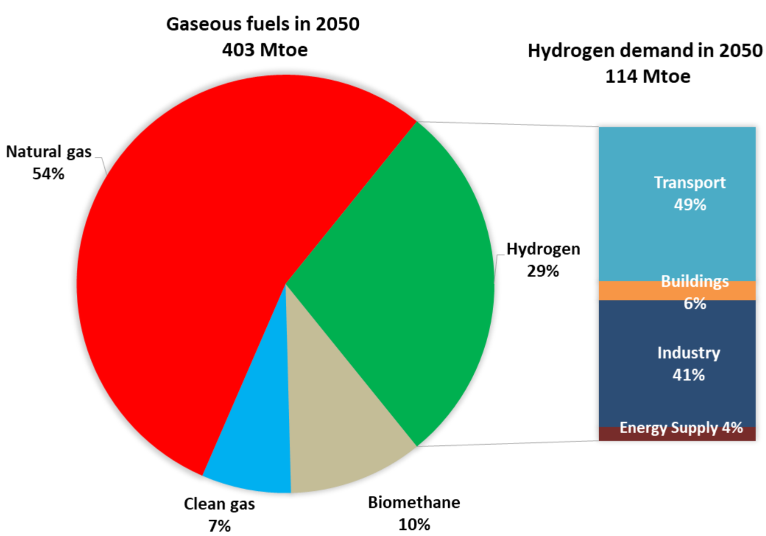

Figure 3: Deployment of hydrogen and clean gas in EU deep decarbonisation scenario in 2050