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EXECUTIVE SUMMARY

In the past three years, extensive research has been carried out in the REFLEX project focusing on future trends and flexibility requirements in the electricity, industry, transport and heat sectors. This document serves to provide a short but concise overview of the main findings for the different sectors and a bundle of policy recommendations derived thereof.

On the electricity supply side, the assumed strong increase of CO_2 prices towards 2050 drives a fuel switch towards gas-fired power plants. Contrary, up to average renewable shares of 80% across Europe, investments in electricity storage technologies are barely profitable. Ensuring a proper CO_2 price signal as well as support for multi-purpose use of utility-scale electricity storage are therefore crucial in order to steer the future technology mix. Regarding the electricity market design, substantial cross-border effects of the recent uncoordinated introduction of national capacity remuneration mechanisms (CRMs) may occur in the future. Interconnectors should therefore be eligible to participate in CRMs of neighbouring countries in order to avoid market distortions. Alternatively, a coordinated European CRM may be considered.

On the electricity demand side, current conditions are not sufficient to establish functioning markets for demand side management (DSM). The participation of DSM in the reserve markets should therefore be facilitated. Moreover, highlighting existing successful examples of demand flexibility provision may alter the risk perception of companies and raise additional DSM potential.

In terms of energy efficiency, substantial research and development activities need to take place in the coming decade, in order to have new process technologies and innovations for the industry sector ready by 2030.

A bundle of complementary measures is required to support the transition of the transport sector towards low-emission mobility. The introduction of fuel efficiency and CO_2 standards for new vehicles of all kinds represents a fundamental instrument to reduce greenhouse gas (GHG) emissions. Moreover, investments in the rail and public transport systems are needed to increase the attractiveness of these efficient travel modes. Policies supporting electric drive technologies by increasing their financial attractiveness over conventional fuel vehicles include vehicle registration taxes, road charges and fuel taxes. Biofuels and synthetic fuels are less efficient options, yet reasonable for aviation and ships, where mature low-emission drive technologies will not be developed in the near future.

Regarding energy efficiency in residential and tertiary buildings, current EU regulations mainly address new buildings and appliances. However, since refurbishment is a prerequisite for the deployment of renewable energy sources, additional effort is required for the existing building stock. With regard to district heating (DH), significant GHG emission reductions of 60–85% in 2050 are achievable. Particularly in countries with already well-developed DH networks, biomass can play an important role in substituting fossil fuels. With the development of low-energy buildings, DH networks should be expanded in regions where sufficient spatial heat density exists if the current DH demand is to be maintained in the future.

1 Background and Challenges

The transition towards a low-carbon energy system is one of the major challenges the European Union is facing in the coming years and decades. Achieving the targeted emission reductions of 80% to 95% in 2050 compared to the levels of 1990 requires a fundamental transformation of the whole energy sector.

With the Strategic-Energy-Technology-Plan (SET-Plan), the EU is aiming to create an environment that facilitates the evolution of existing and developing new low-carbon technologies to manage the specific needs for a reliable, cost-efficient and sustainable prospective energy supply. In particular, the deployment of renewable energy sources (RES) and energy efficiency in the heat, transport and electricity sector are promoted.

However, the integration of intermittent wind and photovoltaic power poses a major challenge to the energy system and leads to flexibility requirements. This flexibility can be provided by a bundle of technologies including energy storage systems, smart grids, adaptation of flexible power plant technologies, electrification of the heat and transport sectors and demand side management (DSM) across different sectors.

Yet, the increasing importance of sector coupling and the resulting high electricity demand also brings along new challenges for the electricity market. Even if the largest part of the electricity demand is covered by RES and the flexibility potential of the demand side is fully exploited, the patterns of demand and fluctuating production will require utility-scale electricity storage and likely also conventional generation capacities for at least some hours of the year. Therefore, an adequate electricity market design that sets sufficient incentives for investments in low-carbon conventional power plants and storage technologies is crucial.

Against this background, in the past three years, extensive research has been carried out in the scope of the REFLEX project focusing on future trends and flexibility requirements in the electricity, industry, transport and heat sectors. For this purpose, three different scenarios (Mod-RES, High-RES decentralized, High-RES centralized) have been developed, which differ in terms of future electricity demand, district heating (DH) demand, renewable feed-in and technological composition of the renewable electricity generation, the diffusion of electric vehicles and modal shares. Another major difference between the scenarios are the assumed CO_2 prices reaching around 90 EUR/t_{CO_2} for Mod-RES and 150 EUR/t_{CO_2} for High-RES in the year 2050, respectively. For further details on the different scenarios, please refer to Zöphel *et al.* (2019).

The main findings of the model-based analyses in REFLEX have previously been published and extensively discussed in Zöphel *et al.* (2019) as well as Fraunholz and Keles (2019). In contrast, this document serves to provide a short but concise overview of the main findings for the different sectors and presents a bundle of policy recommendations derived thereof. The following Section 2 therefore contains subsections for the electricity, industry, transport and heat sector, respectively, while Section 3 provides a brief outlook.

2 SECTOR-SPECIFIC POLICY RECOMMENDATIONS

2.1 ELECTRICITY SECTOR

2.1.1 LOW-CARBON SUPPLY TECHNOLOGIES AND FLEXIBILITY OPTIONS

In terms of the future technology mix in the electricity market, Zöphel *et al.* (2019) as well as Fraunholz and Keles (2019) find, that regardless of the implemented electricity market design, a strong fuel switch towards gas-fired power plants can be observed. This result can be attributed to the assumed CO_2 price developments. While the CO_2 prices in Mod-RES are not sufficient to incentivize investments in carbon capture and storage (CCS) technologies, CCS becomes favourable in High-RES between 2040 and 2050 due to the CO_2 prices of up to 150 EUR/t_{CO_2}. Since many conventional power plants in Europe are reaching the end of their lifetime in the upcoming decade, substantial amounts of new generation capacity will be required. Policy makers are therefore strongly advised to continuously monitor the proper functioning of the EU Emissions Trading System (ETS) in order to ensure reasonable CO_2 price signals as early as possible. The introduction of a CO_2 tax could further help to steer the future technology mix towards low-carbon and electricity storage technologies.

With regard to utility-scale electricity storage technologies, the assumed cost decreases of lithium-ion and redox-flow batteries (see Louwen *et al.*, 2018a; 2018b) are not sufficient to bring these technologies into the market when renewable electricity generation contributes to the electricity supply mix at moderate shares of around 60%. Even up to average renewable shares of 80% across Europe, investments in storage technologies are barely profitable and therefore do not play a major role. These findings underline the importance of rapid cost decreases for electricity storage technologies. Moreover, in order to foster the diffusion of electricity storage, policy makers should support multi-purpose use (e.g., providing ancillary services additional to the use on the day-ahead market). An increased diffusion of utility-scale storage could then in turn reduce curtailment of electricity from RES as well as decrease the need for conventional power plant capacity.

A more decentralized or centralized future energy system as compared in the REFLEX High-RES scenarios differ substantially, particularly regarding the interactions of different sectors. Here the role of the residential sector as decentral flexibility source strongly influences the role of further flexibility options (like storages) in the electricity market. To cope with the interactions, integrated cross-sectoral developments should be considered to account for possible trade-offs. When developing instruments to incentivize a desired development of the future energy system, Zöphel *et al.* (2019) state, that besides techno-economic challenges regarding the RES integration, the societal and ecological dimension needs to be included to ensure acceptance and sustainability for the transition of the European energy system. Further interdisciplinary research is therefore required.

2.1.2 Electricity Market Design

In Fraunholz and Keles (2019), the electricity market model PowerACE is applied to a region covering multiple interconnected European market areas with different electricity market designs. Several long-term scenario analyses up to 2050 are carried out in order to quantitatively assess the long-term cross-border effects of capacity remuneration mechanism (CRMs) in the European electricity system. For this purpose, a European energy-only market is compared to a setting with national CRM policies for all three REFLEX scenarios. Additional model runs have also been carried out considering a coordinated European CRM as an alternative market design as well as higher renewable shares.

Concerning the impact of electricity market design on the future technology mix, even under average renewable shares of around 80% across Europe, investments in electricity storage are mainly carried out in countries using a CRM, which is driven by the additional revenues from the CRM. However, due to the technology-neutral approach of a CRM as desired by the European Commission, the profitability of other technologies such as open-cycle gas turbines also increases when a CRM is implemented.

With respect to generation adequacy, Fraunholz and Keles (2019) show that the introduction of CRMs is an effective measure substantially shifting investment incentives towards the countries implementing the mechanism. This effect is most pronounced in settings with a moderate growth of the electricity demand (as in Mod-RES), where peak-load power plants are often the most profitable investment option. Consequently, investment in these power plants are carried out in the countries using CRMs, while the remaining countries face significantly lower capacity levels and are therefore confronted with increasing wholesale electricity prices in the long run. If, however, the electricity demand grows stronger (as in High-RES), investments in combined cycle gas turbines are often economically preferable over peak-load capacity. In contrast to peak-load power plants, the profitability of combined cycle gas turbines in countries without an own CRM is less affected by additional investments in neighbouring countries with CRM due to the higher number of running hours than for peak-load capacity. Consequently, the small decline of capacities in the countries without CRM and the strong increase of capacity in countries with CRM may, in the long run, lead to decreasing average wholesale electricity prices also in countries without an own CRM.

Summing up, whether positive or negative cross-border impacts of CRMs prevail depends on the specific setting. However, across all scenarios investigated by Fraunholz and Keles (2019), CRMs seem to generally increase generation adequacy not only in the country implementing the mechanism, but also in the neighbouring countries. This finding indicates that free riding occurs.

In order to avoid these market distortions, a coordinated European approach to electricity market design could be considered as also recommended by Bublitz *et al.* (2019) and Bucksteeg *et al.* (2019). This approach has been analysed by running additional simulations to the ones presented in Fraunholz and Keles (2019). Findings indicate, that a coordinated European CRM is likely to reduce wholesale electricity prices and increase generation adequacy across all countries and is therefore favourable against unilateral, uncoordinated CRMs.

However, since a coordinated European CRM might be difficult to realize, at the very least, the European Commission is recommended to continue carefully evaluating the necessity and design of all planned CRMs prior to their implementation. Moreover, in order to avoid market distortions and reduce the risk of negative cross-border impacts, interconnectors should be eligible to participate in any CRM of neighbouring countries.

2.1.3 Demand Side Management

Within the REFLEX project, we found, that although in some countries favourable regulatory conditions for DSM exist, such conditions are not sufficient to establish functioning DSM markets and attract companies' interest. As of today, particularly small demand units are hardly participating in DSM, although on aggregate level their DSM potential would be high. Lack of (reliable) information and of financial benefits as well as perceived risks have been identified to be relevant barriers against the adoption of more DSM options especially in the tertiary sector.

Specific policy measures are therefore the reduction of barriers across countries as well as country specific. By increasing the implementation rate and the respective compliance with the EU regulation (European Energy Efficiency Directive, 2012), article 15, the varying settings in different countries can be reduced, allowing market players to be active in multiple countries and therefore, attracting business opportunities. Special focus has to be put on the bid size and aggregation of DSM potentials to participate in the reserve markets.

Additionally, by showcasing existing examples of how flexibility providers can benefit from participating in DSM markets, risk perception of companies may be altered, offering additional DSM potentials. As the risk perception differs very much between countries, specific approaches (e.g., from aggregators) are needed to highlight potential economic advantages. Besides market-based transaction schemes, information regarding technical implementation as well as the functionality of DSM have to be provided to small and mid-sized companies as they lack internal relevant know-how. Specific information can be best provided by independent stakeholders such as governmental energy agencies or independent energy advisors.

Larger companies with more standardized procedures regarding energy efficiency and energy demand might adopt DSM models faster and therefore, integrating DSM into energy management systems could support the further roll-out of flexibility options on the demand side. Energy advisors and auditors can help to spread the word of advantages and disadvantages of DSM systems. However, further education for those stakeholders is also required.

2.2 Industry Sector

In the long term, key measures enabling the decarbonisation of the industry sector are radical changes to industrial production systems towards CO_2-neutral production processes and products (e.g., hydrogen processes and large-scale power-to-heat for steam generation), mainly envisaged for implementation in the time horizon after 2030. Before 2030, energy efficiency improvements combined with fuel switching to biomass and progress towards a circular economy are the main mitigation options.

In order to have new CO_2-neutral process technologies and innovations ready by 2030, substantial research, development and innovation activities need to take place in the coming decade supported by the respective known policy measures (e.g., financing of research and development, public procurement, labelling, CO_2 price). Pilot and demonstration plants need to be built as well as new certification processes for new materials introduced. To further promote material efficiency and therefore directly reducing energy demand along the value chain, a broad policy mix is required. Implementing policies to overcome barriers to energy efficiency (energy management schemes, audits, soft loans, and energy service markets) is a prerequisite for other (price-based) policies to work effectively as well (e.g., minimum CO_2 price path to provide clarity for investment decisions, CO_2 tax for companies outside the EU ETS).

2.3 Transport Sector

In comparison to all other sectors, the transport sector increased its GHG emissions since 1990 (European Commission, 2011). By 2050, these emissions need to be reduced by at least 60% relative to 1990 (European Commission, 2011). This minimum goal for the transport sector was affirmed in the European Strategy for Low-Emission Mobility. According to this strategy, emissions should be clearly on the path towards zero by mid-century and air pollutants harming our health need to be drastically reduced without delay (European Commission, 2016). Considering the continuous growth of passenger and freight transport demand, strong and timely responses are required at the policy level. Within the REFLEX project, a reference scenario (Mod-RES) and two ambitious policy scenarios (High-RES) were simulated with the ASTRA model[1] under special consideration of global learning for batteries and flexibility potential provided for the electricity sector. Results indicate that a bundle of complementary measures is required to support and accelerate the transition. The main findings and policy recommendations are described in the following, categorized by the three main European strategies for the decarbonisation of the transport sector.

[1] ASTRA (ASsessment of TRAnsport Strategies) is an integrated assessment model applied since more than 20 years for strategic policy assessment in the transport and energy field. The model is based on the System Dynamics approach and covers all EU28 member states plus Norway and Switzerland. A more detailed description of the ASTRA model can be found in Fermi *et al.* (2014) or on the ASTRA website (www.astra-model.eu).

2.3.1 ENERGY EFFICIENCY

A central principle that should be applied is "Energy efficiency first" to reduce the overall energy demand. The introduction of fuel efficiency and CO_2 standards for new vehicles represents a fundamental instrument to reduce overall GHG transport emissions. These standards should not only be tightened for cars and vans but also extended to heavy duty vehicles, buses and airplanes. Such standards force the automotive industry to become innovative and to change their product portfolio to vehicles with alternative zero- and low-emission powertrains. Setting intermediary as well as long-term targets beyond 2030 ensures that investments kick-start soon and are maintained based on the stability and long-term direction provided. These standards have the advantage to promote innovation while staying technology-independent which is relevant for those transport modes for which several competing technologies are under development.

In addition, modal shifts to more efficient modes can contribute to decarbonisation. Instead of using individual cars, options for passengers include public transport and non-motorised modes. High-speed train connections can replace flights. For freight, transport on railways and inland waterways are more efficient transport solutions. To achieve these shifts, investments in the rail and public transport systems are needed. Sustainable transport modes should be made more attractive and convenient, for example by urban planning measures and infrastructure provision in favour of active modes, by increasing spatial coverage and frequency, and by developing and promoting an ICT-based, integrated and transparent multimodal mobility system. It is fundamental to sustain modal shift especially for short-distance passenger transport where the vast majority of trips are concentrated. Indeed, urban areas show the most pressing congestion challenges but have also the highest potential for behavioural change and technology transition. Modal shift was mainly achieved for the High-RES decentralized scenario on the local level for passengers. For freight, a part of road transport share was shifted to rail and inland waterways, in particular due to respective investments in railway and waterway infrastructure, in multimodal freight terminals and increased taxation of fossil-fuel based road transport. However, road share increased again towards 2050 with the diffusion of low-emission fuel cell and battery electric trucks, thus showing a rebound effect.

Complementary measures aiming at increasing car occupancy rates and optimizing the city logistic chain can support the achievement of the decarbonisation target at urban level.

The diffusion of shared mobility schemes in European cities, enhanced by the wide spread of information and communication devices, is becoming an alternative to individual transport means thus partly alleviating the problems related to congestion, air pollution and GHG emissions by reducing the number of vehicles in circulation. Within the REFLEX scenarios, car sharing and car-pooling policies have been tested and showed interesting results for local mobility (especially in the High-RES decentralized scenario).

On the freight side, the development of integrated logistics can make a more efficient use of freight vehicles, enabled also by the diffusion of digital technologies. Measures related to urban freight logistic include a huge variety of different transport operations and logistics activities ranging from road network and parking strategies, terminals and modal interchange facilities, pricing strategies, ICT-based vehicle control systems, logistics information systems, etc. Within REFLEX, this type of policies has been simulated in the High-RES scenarios, contributing to the reduction of CO_2 emissions at urban level.

2.3.2 *Electrification of Road Transport*

Subsidies for low-emission vehicles are required in the first years of technology market entrance, when vehicle prices are still relatively high. Battery electric and plug-in hybrid electric vehicles are expected to contribute to a widespread electrification of passenger transport, as they will soon become competitive with conventional oil-based cars thanks to learning effects and economies of scale in global battery production and as public charging infrastructure is deployed. Thus, subsidies for vehicles as purchase incentives or bonus-malus (or so-called feebate) systems seem only reasonable within the next few years. Furthermore, monetary advantages for homeowners with rooftop photovoltaic system, generating electricity for self-consumption can contribute to the diffusion of battery electric vehicles. This factor would become more relevant if the electricity system develops in a more decentralized way.

The REFLEX High-RES scenarios assumed that fuel cell electric vehicles would lead the technology transition for long-haul trucks. Although hydrogen production is less energy-efficient compared to direct electrification, fuel cell electric trucks are assumed to become a real decarbonisation option, as hydrogen production has the potential to provide flexibility to the electricity system that has to cope with fluctuating production of renewables. Hydrogen could be produced in times of electricity oversupply and could be reconverted to electricity if needed. Research and development as well as subsidies for fuel cell technology seem still required to achieve competitive prices.

Policies that support the transition to new drive technologies by increasing their financial attractiveness compared to conventional fuel vehicles are vehicle registration taxes, road charges and fuel taxes that all depend on the respective CO_2 emissions.

While prices for battery electric vehicles decline, range anxiety is currently one of the biggest barriers to the purchase of electric vehicles. Therefore, it will have to be ensured that sufficient public charging infrastructure, including stations for fast charging, are timely deployed.

If low-emission vehicles do not diffuse fast enough regardless of the implemented measures due to soft factors of technology acceptance, phase-out decisions for pure fossil-fuel based cars (in particular gasoline, diesel and liquefied petroleum gas) have to be made to accelerate the speed of transition towards low- and zero-emission vehicles. Announcing a phase-out in about 10 years would also be beneficial for vehicle manufacturers and suppliers as they could focus research and development in alternative fuel technologies with a secure timeline. In addition to the measures already described, banning pure fossil-fuel cars from cities could be a promising measure to prepare and support the phase-out. Within the High-RES scenarios, the phase-out was introduced for buses and vans in 2035 and for cars in 2040 and was one of the main drivers for the diffusion of low-emission vehicles.

2.3.3 Alternative Fuels

Biofuels and synthetic fuels based on electrolysis and additional treatments, i.e., power-to-gas (PtG) and power-to-liquid (PtL), are less efficient options, as production requires biomass as resource and renewable electricity for production with low degrees of efficiency in internal combustion engines. However, they should be used for modes for which mature low-emission drive technologies will not be developed in the near future and this is the case for aviation and for ships. Alternative fuels also play at least an intermediate role for road transport, if battery range anxieties result in a higher diffusion of plug-in-hybrid cars for longer distances. Moreover, new technologies for trucks might not become adequate for certain special purpose vehicles by mid-century. A clear strategy for using sustainable biofuels and synthetic fuels is then needed. Adequate allocation of biomass to different demand sectors could be aligned to use resources as best as possible. The production of advanced biofuels should be supported. When sustainable production can be ensured for certain quantities, blending quotas of biofuels and power-to-X (PtX) fuels could be established.

2.3.4 Conclusions and Further Outlook

Achieving the 2050 target of 60% GHG emission reduction for transport compared to 1990 is challenging and requires ambitious policy measures. All three described strategies to decrease CO_2 emissions should be combined. Several pathways exist by adopting these strategies to different extents and with different configurations. Thus, the contribution to GHG emission reduction of the individual strategies can vary. In the investigated High-RES scenario simulations, the main drivers of CO_2 emission reduction are the diffusion of low-and zero emission road vehicles (achieving 26% reduction in 2050 relative to 1990), efficiency improvements (adding up to 44% reduction in total), and alternative fuels, in particular for aviation and navigation (reaching 58% in total). Policies aiming at modal shift to active modes, public transport and new mobility services (e.g., car sharing, mobility-as-a-service systems, autonomous cars) can contribute in particular on the local level. Although for the overall transport system the impact in the analysed scenarios was less compared to the other strategies, these policies still contribute to CO_2 emission reduction for about 10%.

GHG emissions reduction in the REFLEX scenarios is obtained assuming that transport performance grows with increased gross domestic product, income and population until 2050. Future research and policies might focus also on measures investigating how demand can be reduced while still meeting citizens’ needs, for example by spatial planning measures and opportunities appearing with increasing digitalisation. The three mobility packages presented by the European Commission (2018) set the right direction. Their principles should be enhanced and adopted as binding directives either on European or on national level to ensure implementation.

2.4 Heat Sector

2.4.1 *Energy Efficiency in Buildings*

In the buildings sector (residential and tertiary), the potentials for energy efficiency are even higher than in industry. Currently, low building renovation rates limit the fast uptake of energy efficiency potentials and the switch to renewable heat sources. Efficiency progress in the buildings sector is mainly driven by EU regulations like the Energy Performance of Buildings Directive (EPBD) and the Ecodesign Directive. However, these directives mainly address new buildings and appliances. Therefore, tapping additional efficiency potentials in the existing building stock requires additional efforts (e.g., subsidies, incentives, binding targets as well as removal of barriers and changes of personal preferences). To reduce these, combined efforts in refurbishment rates, depths and technology change are needed. Refurbishment is a prerequisite for the deployment of RES. For an effective diffusion of RES for space heat supply, the regulatory frame needs to be adapted to make RES cost-competitive compared to fossil-based solutions.

DH can be a facilitator to decarbonise the heat sector. To allow for a more centralized provision of renewable heat, financial incentives as well as connection regulations and strategies are needed to tap the full potential of DH networks and cold networks (anergy networks). DH networks allow among others integrating excess heat from industrial activities. Respective system integration needs to be supported by regulations towards connection management and excess heat disposal. Policies can additionally support the uptake by e.g., hedging high risks in individual projects, regulating excess heat release in national emission control acts, strengthening local heat planning and providing investment grants. The management and support of specific geothermal potential zones as well as further cost reductions is needed to achieve major growth of large-scale heat pump installations for DH supply.

2.4.2 *District Heating Networks*

The development of the DH systems in EU in the future depends on the DH demand, which varies in the REFLEX scenarios. This demand increases in the High-RES centralized scenario whereas in the Mod-RES and High-RES decentralized scenarios it is expected to be lower than today. The other factors influencing the modelling results are prices of CO_2 emission allowances on the EU ETS market, techno-economic parameters of processes employed in DH systems as well as potential and costs of fuels and energy resources.

The results show that significant GHG emission reductions are possible in the DH generation sector from 60% to ca. 85% in 2050 depending on the REFLEX scenario. As a response to increase in CO_2 prices, bioenergy (mainly biomass) capacities are growing significantly. Therefore, biomass can play an important role in substituting fossil fuels in DH generation in particular in the EU member states where the DH networks are already well developed. Natural gas is still used due to high flexibility also in terms of the power-to-heat (PtH) production ratios.

Seasonal and short-term heat storages help to smooth the generation profiles and increase the heat production in summer times. The use of PtH technologies including large heat pumps depends on electricity prices but certainly helps to manage the RES electricity surplus that otherwise would be curtailed.

With decreasing DH demand and with a simultaneous increase in electricity demand – as in the case of the High-RES decentralized scenario – it is impossible to maintain the current relative share of electricity produced in cogeneration while meeting the cogeneration efficiency goals. In fact, in this scenario the share decreases from the current 12% to 7% in 2050.

In general, DH costs are increasing in future years. This is mainly due to the investments in new capacities, rising CO_2 prices and increasing fuel costs. Therefore, it is necessary to maintain the existing or new implemented policy measures that will guarantee necessary profits for generators and keep the DH end-user prices at competitive levels. With the development of low-energy buildings, DH networks should be expanded in regions where sufficient spatial heat density exists in order to maintain the current DH demand.

Otherwise, with decreasing DH demand, as e.g., in case of the Mod-RES and High-RES decentralized scenario, combined heat and power plants are exposed to lower DH sales but also to lower electricity sales. In case of the High-RES centralized scenario, the increased DH demand has to be associated with developments of new DH systems. It is also important to design them for low-temperature sources such as renewables. The transition towards higher use of bioenergy (mainly biomass) requires sustainable organizational (logistic) solutions that will minimize energy and CO_2 emissions embedded in processing and transportation.

3 Outlook

The presented results of the extensive analyses across various energy-related sectors carried out within the REFLEX project show that both a more decentralized (High-RES decentralized scenario) and a more centralized (High-RES centralized scenario) low-carbon European energy system have the potential to achieve significant CO_2 emission reductions of 80%.

However, in order to raise this potential, a combination of various measures within different sectors will be required. General measures across all sectors include strengthening the EU ETS and potentially supplementing it with a CO_2 tax, increasing energy efficiency and transitioning towards electricity from RES as main energy carrier.

Besides techno-economic challenges, it is crucial to also consider the societal and ecological dimensions to ensure acceptance and sustainability for the transformation of the energy system. For this reason, integrated assessments as in the REFLEX project should be further intensified also in future research.

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