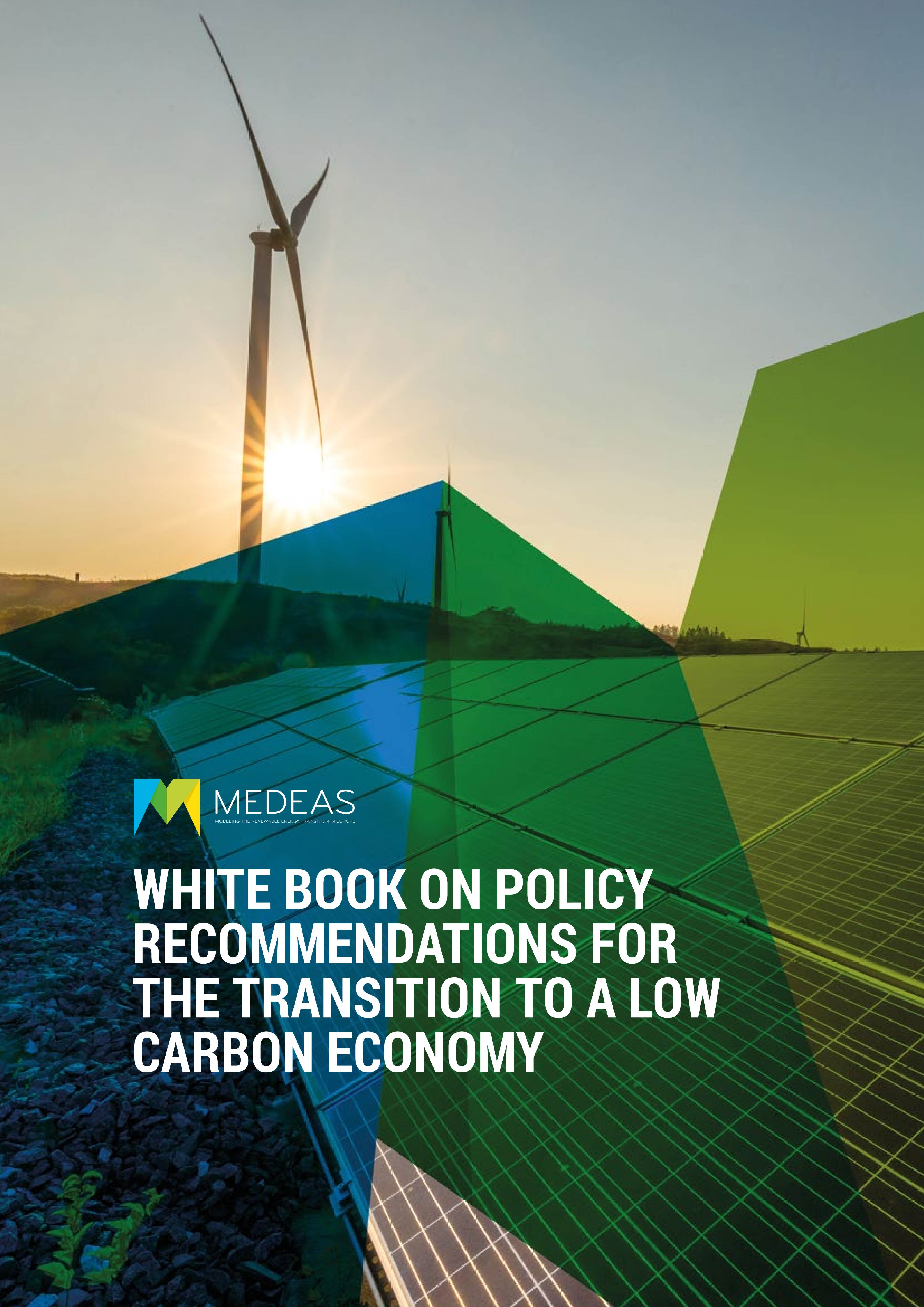

MEDEAS

MODELING THE RENEWABLE ENERGY TRANSITION IN EUROPE

WHITE BOOK ON POLICY RECOMMENDATIONS FOR THE TRANSITION TO A LOW CARBON ECONOMY

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AUTHORING TEAM

The MEDEAS White Book on policy recommendations for the transition to a low carbon economy is developed in the framework of MEDEAS project and has been based on the results of the project throughout its implementation.

Each chapter of this White Book is developed by a specific authoring team, which summarizes the respective policy findings of the project.

Please note that not all MEDEAS partners and stakeholders support all policy recommendations put forward in each of the chapters in this White book.

The overall coordination and organization of the White Book was undertaken by the Centre for Renewable Energy Sources and Saving - CRES (Myrto Theofilidi, Stavroula Papagianni) and Austrian Energy Agency - AEA (Leonardo Barreto, Shruti Athavale).

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LIST OF ABBREVIATIONS AND ACRONYMS

ACER	Agency for the Cooperation of Energy Regulators
BAU	Business As Usual
CAP	Common Agricultural Policy
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CEF	Connecting Europe Facility
COM	Communication
COP 21	21st Conference of the Parties
CSP	Concentrated Solar Power
DER	Distributed Energy Resources
DR	Demand Response
EC	European Commission
EC-GA	European Commission Grant Agreement
EE	Energy Efficiency
EEAG	Guidelines on State aid for environmental protection and energy
EEOS	Energy Efficiency Obligation Schemes
EETS	European Electronic Toll Service
EFSI	European Fund for Strategic Investment
EIB	European Investment Bank
EJ	Exajoule
ENTSO-E	European Network of Transmission System Operators for Electricity
EPBD	Energy Performance of Buildings Directive
EPS	Electric Power System
EPSC	European Political Strategy Centre
ERDF	European Regional Development Fund

EROI	Energy Return on Energy Invested
ESCO	Energy Services Company
ESIF	European Structural and Investment Funds
EU	European Union
EU28	28 European Member States
EU-ETS	European Emission Trading Scheme
EV	Electric Vehicle
FEC	Final Energy Consumption
GDP	Gross Domestic Product
GG	Green Growth
GHG	Greenhouse Gases
GIE	Gas Infrastructure Europe
GW	Gigawatt
HDI	Human Development Index
IEA	International Energy Agency
IEA-PVPS	International Energy Agency Photovoltaic Power System Programme
IPCC	Intergovernmental Panel for Climate Change
IRENA	International Renewable Energy Agency
ISL	Iceland
LCOE	Levelized Cost of Electricity
LNG	Liquefied Natural Gas
LULUCF	Land use, Land Use Change and Forestry
LV	Low Voltage
MEAT	Most Economically Advantageous Tender
MS	Member State
MV	Medium Voltage
MW	Megawatt
NECP	National Energy and Climate Plan
NIMBY	Not In My Backyard

NPP	Nuclear Power Plant
NZEB	Nearly Zero Energy Building
OCGT	Open Cycle Gas Turbine
P2X	Power to X
PCI	Project of Common Interest
PEC	Primary Energy Consumption
PHS	Pumped Hydro Storage
PV	Photovoltaics
RAB	Regulated Asset Base
RE	Renewable Energy
RES	Renewable Energy Sources
RPS	Renewable Portfolio Standard
SRI	Smart Readiness Index
TEN-E	Trans-European Networks for Energy
TEN-T	Trans-European Networks for Transport
TFEC	Total Final Energy Consumption
TRANS	MEDEAS scenario implementing policies at both energy and economic levels to reach a share of RE of at least 90% by 2050 and at the same time drastically reduce CO_2 emissions
TRINE	Solar energy crowdfunding platform in Sweden
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan
UK	United Kingdom
UNEP	United Nations Environment Programme
US	United States
USA	United States of America
VET	Vocational Education and Training
VRE	Variable Renewable Energy
WACC	Weighted Average Capital Cost

Chapter 01.

INTRODUCTION

Climate change represents an urgent threat to societies and the planet, the Paris Agreement sets all countries the goal of keeping global warming well below 2°C, and pursuing efforts to limit the increase to 1.5°C.

The European Union has set several targets to reduce its greenhouse gas emissions progressively up to 2050 and to achieve the binding goals of the 2015 Paris Agreement. At COP 21, the EU committed to keep the increase in global average temperature well below 2ºC above pre-industrial levels, with the aim of limiting the increase to 1.5ºC. The targets set by the European Union are included in three main initiatives: the 2020 Package, the 2030 Framework and the 2050 Strategy. A core virtue of EU action is bringing together a common vision, resources, financing and regulatory regimes to implement coherent policies action across the domestic market.

The **Clean Planet for All strategy**[1] outlines a vision of the long-term deep economic and societal transformations required, engaging all sectors of the economy and society, to achieve the transition to a climate-neutral economy. It addresses the policy aspects that will enable the European Union to fulfil its obligations under the Paris agreement and its objectives under the Energy Union, and reap the economic and societal benefits of a low-carbon transition. The long-term strategy looks into the portfolio of options available for Member States, business and citizens, and how these can contribute to the modernisation of our economy and improve the quality of life of Europeans. The long-term strategy spans in seven strategic areas: energy efficiency, renewable energy, clean, safe and connected mobility, competitive industry and circular economy, infrastructure and interconnections, bio-economy and natural carbon sinks and carbon capture and storage. The clean energy transition would result in an energy system largely based on RES, thereby significantly improving security of supply and fostering domestic jobs.

In the medium term, until 2030, the EU will have to achieve the following targets for energy and climate:

- The Union-wide binding target of at least 40% domestic reduction in economy-wide greenhouse gas emissions as compared to 1990 to be achieved by 2030.
- The Union-level binding target of at least 32% for the share of renewable energy consumed in the Union in 2030.

1. European Commission, 2018. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank on A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, s.l.: s.n.

- The Union-level headline target of at least 32.5% for improving energy efficiency in 2030.
- The 15% electricity interconnection target for 2030.
- Any subsequent targets in this regard agreed by the European Council or by the European Parliament and by the Council for 2030.

The transition to a carbon-neutral economy needs to satisfy multiple (often competing) objectives including: socio-economic competitiveness, protection of the environment, creation of quality jobs and social welfare. Tackling questions such as what this transition involves, which challenges must be overcome and what policies must be implemented is now more important than ever. Policy-makers and other key stakeholders require more holistic tools which do not just focus on the energy sector, but consider the implications of policies on other domains including the economy, society and the environment. The MEDEAS project «Modelling the Energy Development under Environmental And Socioeconomic constraints», supported by H2020, has studied the transition to a low carbon society and economy, through the analysis of different pathways regarding GHG emissions, energy supply and demand as well as biophysical resources required (raw materials, land and water), taking into account physical and social constraints. An integrated assessment model has been developed to analyse variations of the aforementioned pathways and assess policies which could support the transition to a more sustainable European Energy system, based on renewable energy sources and with a minimum impact on society's wellbeing.

MEDEAS conducted a comprehensive scenario analysis across sectors and on basis of this scenario analysis is able to derive policy recommendations. Starting point for the MEDEAS scenario design is the available global carbon budget in order to limit global warming to 2°C, a target agreed by participating countries at the 21st Conference of Partners in Paris (COP21, United Nations, Paris Agreement, 2015). This target is then broken down onto the different geographical levels (World / EU / national) according to the MEDEAS nested model approach.

MEDEAS developed transition scenarios towards a low-carbon economy based on available global carbon budget in order to limit global warming to 2°C and the EU target to reduce absolute annual emissions by 80%. The analysis shows that a strategy to provide greater flexibility to the energy system so that decarbonisation can be achieved in a more cost-effective way is necessary. This transition will allow the EU to fulfil its commitment under the Paris Agreement to contribute to the international effort to keep global temperature rise well below 1.5°C. The decarbonisation of the economy requires integrated planning and operation of energy infrastructure, considering interlinkages across sectors, to ensure that new investments are future proof and minimise overall system costs.

- The MEDEAS analysis shows that an important driver for a decarbonised energy system is the growing role of electricity, both in final energy demand and in the supply of alternative fuels. Higher investment levels in renewables and infrastructures are required to reach full decarbonisation while meeting higher electricity demand resulting from increased electrification of the society.

The MEDEAS White Book highlights the relevance of the issues addressed in the areas of electricity grid upgrade, transport electrification, the role of natural gas, energy efficiency, energy costs, financing cross-border energy infrastructure, price regulation, raw materials and re-cycling, environmental impacts, social and behavioural adaptations, economic development and climate change adaptation. On the basis of the analysis it derives recommendations for long-term policy and policy modelling.

Chapter 02.

ELECTRICAL SYSTEMS UPGRADING POLICY

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2.1 ISSUE DESCRIPTION

One of the seven main strategic building blocks of the EU Clean Planet for All Strategy is to maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply until 2050. The large-scale deployment of renewables will lead to the electrification of the EU economy and to a high degree to decentralisation of electricity production. It will also give an important role to consumers that produce energy themselves (prosumers) and local communities to encourage residential take-up of renewables.

The emission-free energy course as inspired by the climate change is pushing up electricity as the "Number One" energy carrier owing to its potentials to be used in various applications and to its ability to lend to conversion to other types of energy.

Electricity will make up an increasing share in society's future progress to sustainable development as it will replace other types of energy and fuels responsible for the greenhouse gas emissions. Its relative increase in consumption in all sectors – industry, households, trade, services and transport – is already visible on a European and global scale. However, fossil fuels still play a non-negligible role as 41% of Europe's net electricity generation in 2017 was based on coal, gas and oil.

With the increase in renewables and their intermittent nature, regulators face additional challenges for system integration. Countries are driven more and more towards distributed energy resources (DER). Distributed energy resources (mainly wind parks and solar photovoltaics) will become more and more important in the future with the greater penetration of e-mobility and battery storage. These new developments in the electricity market present a challenge for regulators to appropriately handle investments and rates. Clear policies and signals are needed from policymakers to ensure that long-term investments in DER projects will pay off. Policymakers should support these changes through regulatory and market frameworks that also lessen administrative burden, for example through the creation of «one-stop shop» authorities. Business models that could help incorporate DERs in grid ancillary and balancing services attractive to markets have yet to be developed[2]. Further to that, more pressure will be put on the flexibility of grids to accommodate power flow in multiple directions. Greater system flexibility is required to effectively manage large-scale RES in power generation, transmission and distribution systems, storage (both electrical and thermal), demand-side management and sector coupling.

Variable renewable energies call for innovative solutions in terms of technology, business models financial mechanisms and regulatory frameworks.

Substantial progress is needed in system technologies for control and flexibility[3] in order to safeguard power system **security[4] and adequacy**[5]. The ever growing „distributed generation[6]" calls for changes in the low-voltage (LV) and medium-voltage (MV) networks. Integrating high shares of fluctuating power sources into the electricity system also requires substantial storage capacities. In addition, with the increase of RES flows in the grid, the importance of markets for balancing services is likely to continue growing in the future.

The transition to emission-free energy is a long term policy and technology task that each Member State (MS) must fulfil depending on the availability of local resources, technologies, social conditions, economic development and other factors.

Member States were required, under the new "Regulation on the Governance of the Energy Union and climate action" (part of the "Clean energy for all Europeans package") to establish a 10-year national energy and climate plan for the period from 2021 to 2030. The plans also facilitate Member States' programming of funding from the next multi-annual financial framework 2021-2027. In addition, the plans outline trajectories until 2050. Each Member State sets out in its integrated NECP the following objectives and targets:

- The MS's binding national target for GHG emissions and annual binding national limits.
- GHG emissions commitments consistent with the Paris Agreement, other objectives and targets, including sector targets and adaptation goals.
- A contribution to the RES target of the EU in terms of the MS's RES share in gross final consumption of energy in 2030.
- By 2030, the indicative RES trajectory shall reach at least the Member State's planned contribution.
- If a MS expects to surpass its binding 2020 national target, its indicative RES trajectory may start at the level it is projected to achieve.

2. https://www.ieee.org/content/dam/ieee-org/ieee-web/pdf/electric-power-grid-modernization.pdf
3. "Power system flexibility is defined as the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales" (21CPP, 2018)
4. Security is a power system's ability to withstand the risk of massive contingencies in the short term.
5. Adequacy is the power system's ability to meet demand in the long term
6. "distributed generation" refers to electricity generating plants that are connected to a distribution network

- The MS' indicative RES trajectories, taken together, shall add up to the EU reference points in 2022, 2025 and 2027 and to EU's target of at least 32% RES in 2030.

The NECPs are an important instrument to set the foundations for a clean energy transition. "The NECPs play a key role in our governance system to ensure that we join forces and deliver on our objectives together. They should provide as much clarity and predictability as possible for the business and finance sector to stimulate necessary private investments."

In this way the regulatory policy implemented by the Member States will become consistent with the 2030 Climate & Energy Framework designed and systematically updated within the Union, but at the same time it reflects country-specific conditions, traditions, preferences and future opportunities.

2.2 WHY WE NEED TO TACKLE THE ISSUE

Energy policy is at the core of the transition as the successful achievement of the objectives set in the Paris Agreement relies on it. Energy policy is closely related to and directly dependent on the condition of current energy technologies. The growing share of electricity calls for change, both in technologies and **regulations** intended:

- To support technology transformations within the electric power systems (EPS) so as to make possible to coordinate the consumption of electricity in line with the economic limitations, to integrate energy sources with new characteristics, to propose a regulatory frame that will promote new technologies **to balance generation and loads**, in addition to technologies to ensure EPS control in steady-state and transient conditions so as to achieve maximum adequacy, static and dynamic stability and cost-effectiveness.

- To support and guide consumption towards change of the energy carrier, if needed, or change of the organization of consumption.

The regulatory system must balance a number of regulatory instruments, due to the wide variety of technological options and practical solutions. The flexibility of power system is a decisive condition for the successful integration of variable renewable energy (VRE). At an early stage of the VRE integration into the electric power system, to a certain extent, it can cope with their integration using its technological capabilities – reserves and flexible generators and system equipment. As their percentage increases, the need emerges of new technical means of increasing the system flexibility and system stability: demand response, generation curtailments, new storages, shifting demand interchange with neighbouring systems[8] etc.

The energy policy shall include specific regulations for the consumption and for all significant technologies that go into the operation and management of the electrical system, namely:

- All kinds of generators by type of technology according to their technical and operational characteristics, including expected distributed generation (including consumer production) and injection into the network.
- Storage by type of technology according to their characteristics.
- Transmission grid.
- Distribution network.
- Consumption by type of final, consumer, use and technology in accordance with their technical characteristics and their requirements regarding security of electricity supply.

There are several issues on which there are usually differences of opinion among Member States. Regarding the use of nuclear energy, as long as the goals and the deadlines (schedule) for achieving them depend on the national conditions, it is a question of principle, for which several countries have a negative policy and ban included in national documents.

In terms of timing and objectives, there are often major differences between countries that traditionally use their coal to produce electricity – typically the countries of Eastern Europe and some of Southern Europe – and those that do not.

8. Status of Power System Transformation 2018 Advanced Power Plant Flexibility, https://ec.europa.eu/energy/en/studies/identification-appropriate-generation-and-system-adequacy-standards-internal-electricity

2.3 POLICY RECOMMENDATIONS

In the following an overview of the major technology areas in the electric power systems and power grids that need regulatory support to move further towards the EU's 2050 targets is presented.

ELECTRICITY GENERATION

The role of **conventional power plants** is well known: with their flexibility they controlled the frequency and the power exchange and made it possible to control the electric power systems. Nuclear power plants (NPP) were excluded as for economic and technological reasons they had to be limited to primary control, in France – primary and secondary for some NPPs. They did this task successfully in the initial period of the VRE development. However, as they increased, the reduced resources of the conventional thermal power plants had to be made more fast-operating and flexible. The principle of "optimal use of generating capacities" is no longer applicable both due to market relations and technology needs. In many countries thermal power plants, including nuclear power plants, are being upgraded to achieve a wider range of regulation, regardless of their optimum load. However, there exist national problems that need to be addressed in line with EU principles. In the future, however, renewable energy can play the role of the regulation of the electricity system and replace fossil power plants and nuclear energy, providing services of frequency, power and voltage control. For this purpose, a combination of flexible RES power plants, storage, demand response and interconnections will be required.

Coal intensive regions

Using coal for production of electricity is a very serious issue, which cannot be resolved by imposing rigid requirements under the common energy policy documents. The economies of countries such as Poland, Greece, Bulgaria, Romania, the Czech Republic and Slovakia have relied to a significant extent on the utilization of their own coal resources and the immediate forced transition may lead to severe social and economic difficulties. Germany could be added to this list as well, since in its eastern part significant quantities of coal are mined. Following the entry into force of the Paris Agreement, the concerned countries and the European Commission initiated the creation of Coal Regions in Transition Platform[9] to **"facilitate the development of projects and long-term strategies in coal regions, with the**

9. No region left behind, https://ec.europa.eu/regional_policy/en/newsroom/news/2017/12/12-11-2017-no-region-left-behind-launch-of-the-platform-for-coal-regions-in-transition

aim of kick-starting the transition process and responding to environmental and social challenges." The idea behind this Platform is clearly expressed in its slogan "No region left behind!", i.e. the coal intensive countries should be given the opportunity not to lag behind the overall pace of EU development. The aim of the Platform is to support the transition towards clean energy, taking into account the opportunities for developing the economy of the countries and paying more attention to social problems, the necessary restructuring and re-skilling of the workforce. The transition in coal intensive regions must take into account that people in these regions require support to achieve the necessary changes in their economic activities.

As a result of the Platform's intensive process of exchange of information, research[10], ideas of successful transition, practices, possible solutions, results of pilot regions – Trencin, Silesia and Western Macedonia – support, and Cohesion Fund funding, coal regions are expected to efficiently meet the 2050 targets.

Nuclear energy

The nuclear technology is in operation in 14 EU Member States with about 122 GW installed capacity, 829.7 TWh generation and share in the European electricity production of approximately 25.1% (2016). Despite its moderate capacity, due to its extremely high capacity factor, nuclear has important share in the generated electricity.

Some of the countries have decided or intend to phase out nuclear energy production, while another group of countries, such as the new Member States from East Europe along with Finland and the United Kingdom (UK), are determined to continue using and developing this technology.

A sample division of the countries, maintaining nuclear power capacities, could be made as follows:

- MSs that have set time-frames for terminating the use of nuclear energy: **Belgium** – year 2025, **Germany** - 2022, **Netherlands** - 2035, **Spain** - 2045, **Sweden** - 2045.

- MSs that intend to continue using and developing nuclear energy: **Bulgaria** - Potential building of a new 2000 MW NPP, **Czech Republic** - Target for the nuclear energy share in gross electricity generation in 2040 – 46-58% (29% in 2016), **Hungary** – Construction of two new units by 2030 (1200 MW each), **Romania** – Construction of two more units during the period 2030 – 2040, **Slovakia** - Projected installed capacity

10. Horizon Project Tracer, https://tracer-h2020.eu

in NPP in 2030: 27-35%, possible new plants construction, **Finland** – Construction of one more unit in the late 2020-ies, **France** – 63.1 GWe, 556 TWh gross generation 2016, 50% reduction till 2035, **UK** – Building of new nuclear capacity in the 2030-ies.

These groups reflect the current national intentions. Some of the decisions are taken under political pressure, and in a situation of future scientific and technological achievements, they could change.

In recent years interest in the EU in nuclear energy has declined which is to be attributed to decreasing usability of nuclear power plants, lack of flexibility and difficult adaptation to growing intermittent generation.

As a rule, in the past nuclear power plants had no regulating functions other than primary regulation because of their high fixed costs and low variable costs. By the change of the structure of generation and the progress of VRE, the considerations for effective generation management have given way to the need to use more renewables. In some countries – France, Belgium and Germany – nuclear power plants had to get involved in the regulation of the daily and seasonal power demand. The future use of nuclear power depends on its flexibility and ability to fit into the transition where market relations are in place.

The development of hydrogen energy and the production of renewable fuels by the use of electricity (Power-to-X) could provide new opportunities for the future use of nuclear power in countries that wish to do so. To obtain hydrogen from nuclear power would enable nuclear power plants to balance their load schedules and would allow electricity to expand its already wide field of application as it will penetrate into and, along with the new generation fuels, replace fossil fuels – oil and natural gas.

Variable Renewable Energy generation

The integration of renewable energy sources in the electricity market is necessary to decarbonise the system. It requires increasing the flexibility of the system through several strategies. On the one hand, generation of power plants must be easily controlled. On the other hand, storage capacities must be increased as the share of variable renewable energy is incremented. Moreover, interconnection to other electricity systems is necessary to ensure that demand peaks are covered. In addition, demand response measures are necessary to move demand peaks towards times of the day in which there is sufficient renewable power capacity available. Electricity system flexibility facilitates the management of variability and uncertainty in the system.

The technological development of **VREs** already allows them to play on the electricity market as well as on the system services market; however, to achieve this, a specific political, regulatory and market frame is needed. VREs are already being marketed for system services in a number of electric power systems across the world, including in EU countries. To this end, they abandon the "maximum generation" principles and, operating at lower output provide a possibility to be dispatched upward, whenever necessary. The other option that is also made use of is to let the VREs operate at maximum output on the condition that the output may be lowered should a need emerge to contribute to the balancing.

The coordinated construction of solar and wind farms between different EPSs is another large-scale strategic measure that contributes essentially to the flexibility of the system when the intensity of primary sources 24-hourly is different in the two countries. Depending on the resources in neighbour countries, they may opt for a VRE development path that is most gainful for either. Such cooperation could help substantially decrease flexibility-related costs.

Integrating high shares of fluctuating power sources into the electricity system will require substantial storage capacities in the long term. Storage is necessary at different time scales and capacity ranges and different technologies from grid battery storage to pumped storage power plants have different levels of scalability, reaction times and maturity levels. Storage capacity can be utilized for grid stability purposes. With the increase of RES flows in the grid, the importance of markets for balancing services is likely to continue growing in the future. Storage technologies can provide balancing services to the electricity grid such as voltage and frequency control, spinning and non-spinning reserves, can reduce curtailment of RES electricity and contribute to diminishing the volatility of electricity prices. New technologies are emerging, offering new services and business models in the energy markets. Adapted regulatory conditions and administrative procedures that allow new storage technologies to participate in electricity markets and be remunerated for their flexibility are necessary.

Distributed energy resources (DER) – small generation, demand response, battery etc. – are likewise able to play in the system management by flexibility-enabling services by virtual[11] aggregation for joint participation on the services market. The virtual aggregation of consumers enables them to play together on the electricity market by, most often, the reduction of consumption when needed and upon command from the electrical power

11. An example of DER implementation is the virtual battery Fortum Spring that aggregates the loads of electric storage water heaters Finland, https://www.fortum.com/products-and-services/smart-energy-solutions/virtual-battery-spring

system control centre. Demand Response (DR) develops in the EU (Germany, Denmark, the UK), Japan and the United States (US). By 2030 it is expected for savings in the US to reach $15 billion per year[12].

For these opportunities to be seized it is required that the rules for accession to and participation in the market be subjected to regulatory changes.

ELECTRICITY NETWORKS

The upgrade of the electricity network is necessary to accommodate new generation capacities in the system and ensure security, reliability and stability of the system. The advancement of generation technologies (generators) and integration technologies (network) for the VREs are interconnected and implemented in parallel. The integration of the produced renewable energy requires significant investments and support from the regulatory system. In the initial period of renewable energy sources (RES) development, the political system mainly supported the sources, assuming that the electrical system would be able to be updated according to the requirements of adequacy and sustainability. To support the modernization of the power system with new means of regulating parameters – energy flows, voltages, static and dynamic characteristics it is required to set up a combination of technology solutions and market mechanisms that allow the integration of renewables is a cost-effective manner. It is the continuous upgrade of the electricity system that can ensure the VRE integration while security and efficiency are enhanced. It is imperative that the expansion of the network and the management tools go in parallel while state-of-the-art technologies are employed for smart control and automation of the grid.

Strategic decisions are at the core of this process. For example, interconnections are of great importance for the large EPSs. In Europe, interconnections have helped with the integration of regional electricity markets. The enhancement of the exchange potential in the Ten-Year Network Development Plan (TYNDP) of ENTSO-E is suggested to reach a 15% target, based on installed generation capacity for 2030. This measure makes it possible to substantially decrease the costs of balancing and higher reliability of the integrated systems and to achieve significant savings.

Distributed electricity generation calls for major changes in the main facilities and tools to control and safeguard the distribution networks throughout Europe and around the

12. Smart Electric Power Alliance, Utility Demand Response Market Snapshot, September 2019, https://sepapower.org/resource/2019-utility-demand-response-market-snapshot/thank-you/

world. The previous distribution networks and, to a large extent, the current distribution networks are as simple as possible because of the **foreknowledge of the energy flow direction**. This is valid for both, the main equipment and the controls, relay protections and automation. Distributed VRE generation requires a major upgrade of these networks that by their reach and access to every consumer have huge core assets and the investments to upgrade them can be very high – even as high as the level of investment in VREs.

The regulatory system must ensure the use of advanced technologies of devices and equipment with particular attention to the equipment to store energy, the balance of the diurnal consumption (electric cars), the improvement of controls, including the power flows so as to achieve high security and adequacy and upgrade the medium-voltage and low-voltage networks in line with the development of distributed renewable generators.

The slowdown in the development of VREs in some European Union Member States is to be attributed to the delays in the network upgrade resulting from their desire to maintain low electricity tariffs for social reasons.

ELECTRICITY STORAGE

Electricity has modest storage capabilities – capacitive, inductive, mechanical, superconducting magnetic – but it has abundant possibilities for conversion into other types of energy – water, mechanical, compressed air, chemical energy – that are easier to store and that have developed inasmuch as needed for the electric power systems and some limited technical applications.

The great development of intermittent RES leads to intensive production of both batteries for network services and small storage devices for the developing electric vehicle transport. Rechargeable technologies are continually improving; lithium-ion batteries in particular are making progress leading to higher efficiency and output.

It is of particular importance for the electric power system to provide opportunities to charge transport batteries during the slots of a surplus of operating intermittent capacities and, in certain cases, the use of batteries in the event of shortages. This tallies with the interest of car manufacturers that invest to open charging stations.

And here comes the question of sustainability. It is well known that the deposits of metals that are required for battery production are globally limited and scarce. End-of-life products might be used to extract the expensive metals though this is unlikely to lead to their sustainable use. The future development of technologies towards emission-free energy calls for a simple and natural solution.

HYDROGEN TECHNOLOGY

Hydrogen has significant potential for decarbonisation of the energy system in the long run. It is versatile and can meet demands in several sectors such as transport, heating, steel production and electricity generation, for instance through the use of fuel cells. It can be produced from several fuels, among other renewables. Hydrogen can be also used as a way to store variable renewable electricity and as a complement to electricity, replacing a number of fuels in transport and other sectors. Electrolysis, the decomposition of water into hydrogen and oxygen, is besides natural gas reforming, a cost-effective paths for hydrogen production and can enhance the opportunities for the uses of renewable electricity. Other hydrogen production paths from renewables are still not mature enough for commercial application.

Owing to its relatively high energy density value hydrogen is capable of replacing fossil fuels in vehicles and machines. Hydrogen is a chief component of liquid and gas fossil fuels and this close affinity makes it possible to use the hydrogen obtained by means of renewable energy in their artificial production without any loss of energy. The fuels that are produced in this way do not differ in their basic qualities from the fuels that are derived from oil and natural gas and can effectively replace them, together with the expected second and third generation renewable fuels.

Hydrogen fuels can be transported and stored in the already developed infrastructure for oil fuels and natural gas.

Hydrogen and electricity are versatile and clean and can be used in a number of applications. Hydrogen, for example, can be used in several sectors in which electricity is not a cost-effective way of reducing greenhouse gas emissions such as aviation, shipping, iron and steel production, chemicals manufacture, high-temperature industrial heat and long-distance road transport. The opportunities for converting electricity and hydrogen into one another eliminate the restrictions on renewable energy applications in activities and technologies, such as cargo machines, maritime transport, etc. These opportunities are in the phase of development and in the future – 2030, 2040 – will open up a new era in application and transformation of renewable electricity.

Integrating renewable energy carriers and energy flows through mutual transformation is a way off using solar resources. The report "International Aspects of A Power-To-X Roadmap"[13] has pointed out the opportunities that establishing a global PtX industry

13. WEC Germany, International Aspects Of A Power-To-X Roadmap, 2018

could bring and "explain the need for international PtX production and trade on a global scale, explore potential PtX producing and exporting countries around the world and identify major pillars and milestones of a roadmap towards a global PtX market."

It can be assumed that renewable hydrogen will first find application in the industry where it is used though produced from non-renewable electricity. Replacement with renewable hydrogen will enable to test the first steps towards using it in other sectors as well[14].

For the time being hydrogen energy is underdeveloped which is only natural given the very short distance covered towards carbon-free energy, the insufficient progress in VRE development and in efficient consumption. The future rapid development of hydrogen energy will require cooperation between the EU and countries with high solar radiation in Africa, Asia and even Australia as, given the high energy content, the transportation costs are acceptable. The high wind potential of the Arctic Ocean coast will be most likely appropriate to be used for hydrogen production.

As an example of future developments, the Austrian government's Hydrogen Initiative[15] that has been joined by most European countries is an encouraging step towards the future development of hydrogen energy.

POLICY RECOMMENDATIONS DERIVED FROM MEDEAS MODEL

Having run a number of simulations in MEDEAS_eu model, several key policy recommendations for EU low-carbon transition in the area of electricity system can be highlighted. These are summarized below.

To achieve at least 80% GHG emission reduction by 2050, corresponding to EU commitment to Paris agreement, it is crucial to work simultaneously in the following directions:

- Higher reliance on electricity in the final energy demand. The electricity share should substantially increase (e.g. reaching 43% in our recommended scenario by 2050). On the other hand, the increase needs to be limited mainly to the applications with high efficiency of substitution of the replaced energy carrier.
- High reliance on low and non-carbon energy resources. The electricity generation need to become carbon-free by 2050, meaning that it relies only on renewables and nuclear. In our recommended scenario, for example, their shares are respectively 91% and 9%.

14. WEC the Netherlands, Hydrogen – Industry as Catalyst the Netherlands Accelerating the Decarbonisation of Our Economy to 2030
15. http://h2est.ee/wp-content/uploads/2018/09/The-Hydrogen-Initiative.pdf

- Rational use of energy. Without substantial decrease of energy intensity, it would be very expensive to move to carbon-free generation, due to the increasing marginal costs of electricity from renewables. In our recommended scenario, the final energy demand intensity decreases by 54% in 2050 compared to 2020.

- The model results show that the majority of the RES-related costs of the recommended scenario, reaching 64% by 2050, refer not to RES capacity, but to the additional investments necessary to cope with RES variability, mainly balancing costs. It is important, therefore, to stimulate both R&D in storage and P-to-X technologies, and investments in non-intermittent (or less intermittent) sources, such as biomass, hydro, oceanic and geothermal.

- A (nearly) linear RES growth would result in much (about 15%) lower RES-related costs, compared to initial sharp RES increase, followed by a moderate increase later. Such a (nearly) linear RES increase would result in only slightly (about 0.5%) higher cumulative GHG emissions, compared to the sharp initial increase.

In the future, the model should be able to consider the effect of regulations, without which it is not possible to assess the effect of a given regulatory system. The degree to which each considered policy mix affects the barriers and market failures will be identified and introduction of additional policies to minimize the barriers could be improved.

The modelling of energy policy in the MEDEAS model is done through a set of regulatory parameters that represent simple ratios reflecting the impact of regulatory policy on the assessment of the studied scenario. The model has great potential for enrichment in this direction.

Chapter 03.

TRANSPORT

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3.1 ISSUE DESCRIPTION

Transport uses nearly one-quarter of global primary energy and is the world's largest air pollutant which additionally contaminates every day the world ocean with huge amounts of pollutants from oil tankers and other different types of watercrafts.

Its development goes in parallel with the progress of human development - from primitive life to modern civilization. It is at the root of all human activities and is especially growing with the advancement of technology because it is inseparable from every human activity - social life, technological and economic development - and is growing. Market mechanisms are unable to make transport sustainable. Especially given the greenhouse gas (GHG) emissions, the drastic oil price fluctuations, and the increasing number of vehicles in use.

The European Union has always attached utmost importance to transport, improving safety and reducing energy consumption and emissions. A number of official documents laying down the objectives and the associated achievement methods were developed especially following the publication of the Roadmap to a Single European Transport Area in 2011[16], wherein, specifically for the transport sector, a 60% emission reduction target compared to 1990 levels is set to be accomplished by 2050. A strategic approach to lower emissions from mobility needs to fully exploit the potential for improving vehicle efficiency, in both conventional and alternative fuel vehicles.

The Clean Planet For All Strategy (COM 2018/773) emphasizes the need for a rapid scale-up of technological innovations in all major sectors including transport. The deployment of renewable electricity also provides opportunities for the decarbonisation of the transport sector, for example through the direct use of electricity (e-mobility) or through indirect use by producing e-fuels through electrolysis. It stresses that rail freight needs to become more competitive compared to road transport, since it is the most energy efficient solution for transporting freight over medium- to long distances. Aviation and the maritime industry need to shift to advanced biofuels until electric solutions become more cost-effective for these sectors. The technology developments related to digitalisation and data sharing should be integrated on a more widespread basis to allow for smarter traffic management and better regional infrastructure planning. This change will be primarily driven through behavioural changes by individuals and companies. More emphasis needs to be placed on developing transport-related infrastructure (ex. completion of the Trans-European core

16. COM(2011) 144 final, Brussels, 28.3.2011, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system

network TEN-T by 2030) and maximizing the synergies between the transport, electricity as well as the digital networks.

In order to support the transformation towards more environmentally-friendly and sustainable mobility solutions, the European Union has introduced a number of policies to target the transport sector. In addition to these policies, Member States have also introduced financial incentives (purchase premiums and exemptions from motor-related insurance tax) and non-financial measures (exemptions from short-term parking zones and shared use of bus lanes). This section will take a closer look at the current policies and regulations in place on the EU-level:

The Car Labelling Directive (1999/94/EC), which helps consumers buy cars that use less fuel and encourages manufactures to reduce the fuel consumption of new cars, was recently reviewed by the Commission in order to check its effectiveness. The conclusion was that the Directive continues to be relevant, but that the Directive could be simpler in order to increase its efficiency and coherence.

The Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles (2009/33/EC) aims at a market introduction of environmentally-friendly vehicles through public procurement tenders. The Directive requires that both energy and environmental impacts linked to the vehicle over their entire lifetime are taken into account in the purchase of road transport vehicles. Unfortunately, the Commission's evaluation of September 2015 found three main problems affecting the effectiveness of the Directive, namely the application of the monetisation methodology and its ability to reduce GHGs and pollutant emissions[17]. An amendment to the Clean Vehicles Directive is currently being discussed in the European Parliament (latest information as of April 2019).

The EU adopted the Alternative Fuels Infrastructure Directive in 2014, which recommended the introduction of a minimum level of infrastructure for charging electric vehicles across Europe, i.e. one public charging point for every 10 EVs. Other directives such as the Energy Performance of Buildings Directive also sets out specific mobility-related targets. This Directive requires that at least one electric charging point be included in all new non-residential buildings and in existing buildings undergoing major renovation that have over ten parking spaces[18]. Additionally, it requires the Member States to implement common standards, as well as a common plug for electric vehicles to promote EU-wide interoperability, and to roll-out infrastructure for alternative fuels.

17. http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/614690/EPRS_BRI(2018)614690_EN.pdf
18. http://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637895/EPRS_BRI(2019)637895_EN.pdf

The European Strategy for Low-Emission Mobility[19], published in July 2016, lays out the main initiatives that the Commission is planning to undertake in the coming years and highlights existing cross-sectoral synergies. The main components of the Strategy are (a) the increase in efficiency of the transport system, (b) the further deployment of low-emission alternative energy sources for transport, and (c) the acceleration of the transition towards low-and zero-emission vehicles. The Strategy emphasizes the need for cities and local authorities to step up actions in the transport sector by introducing incentives for renewable energy sources and alternative vehicles and by promoting mobility schemes as well as public transportation. Furthermore, the Strategy identifies key priorities to support the European transition to a low-carbon economy, including scaling-up research and innovation in new mobility solutions and providing clarity for investors through concrete policies.

The European Commission submitted the «Europe on the Move» legislative package in May 2017 aimed at making Europe a leader in clean mobility. This package consisted of mobility-related measures that were introduced in three phases (May 2017, November 2017, May 2018). The following legislative proposals were included in each of the phases:

- **Europe on the Move I**[20]: (a) Smarter Road Infrastructure Charging; (b) promotion of the European Electronic Toll Service (EETS); (c) better access to the EU road haulage market; (d) review of the Directive on the Use of Hired Goods Vehicles; and (e) enhancement of workers' rights in road transport.

- **Europe on the Move II**[21]: (a) new CO_2 standards to help manufacturer invest in innovation and supply low-emission vehicles; (b) promote clean mobility solutions in public procurement tenders; (c) trans-European deployment of alternative fuels infrastructure; (d) promotion of the combined use of different modes for freight transport; (e) stimulate the development of bus connections; and (f) battery initiative.

- **Europe on the Move III**[22]: (a) new road safety policy framework for 2021-2030, vehicle and pedestrian safety, and infrastructure safety management; (b) communication on connected and automated mobility; (c) CO_2 standards for heavy duty vehicles and an action plan on batteries; (d) digital environment for information exchange in transport; and (e) streamline permitting procedures for the implementation of projects in the core trans-European transport network (TEN-T).

19. https://ec.europa.eu/transport/themes/strategies/news/2016-07-20-decarbonisation_en
20. http://europa.eu/rapid/press-release_MEMO-17-1445_en.htm
21. http://europa.eu/rapid/press-release_IP-17-4242_en.htm
22. https://ec.europa.eu/transport/modes/road/news/2018-05-17-europe-on-the-move-3_en

In the recent years, electric mobility (e-mobility) has emerged as one of the most promising solutions on the pathway towards a more sustainable energy system and the numbers are set to increase dramatically. Although the cost of electric vehicles as well as of e-mobility solutions has already decreased, further improvements in battery performance and increase in infrastructure (i.e. number of charging stations) will help to drive the uptake of e-mobility forward.

E-mobility offers the possibility for a radical transformation of a sector, which has traditionally been focused on the use of fossil fuels. Such a change would enable security of supply and a significant reduction in CO_2 emissions as well as in air pollution, thereby helping countries to reach their environmental targets. «Electric vehicle 'tank-to-wheels' efficiency is a factor of about 3 higher than internal combustion engine vehicles.»[23]

At the moment, the EU market for e-mobility, especially for electric vehicles, is in its early stages and therefore primarily dependent on support policies to stimulate growth. The limited offer of electric vehicles in comparison to conventional fossil-fuel powered vehicles also limits consumer enthusiasm. EU policies and the level of ambition of these policies (e.g. emission regulations) will also shape the e-mobility landscape[24].

E-mobility not only increases the security of supply, but also allows for the integration of further renewable energy sources into the electricity grid, since electric vehicles (EVs) can support grid management. By using smart charging technologies, consumers are able to charge their EVs outside of the peak demand times. This provides consumers with economic returns, while helping balance demand and increase flexibility in the electricity grid by feeding excess energy back into the grid during high demand times[25]. However, from a technical point of view there is still a long way to go.

3.2 WHY WE NEED TO TACKLE THE ISSUE

Transport is the only sector that is increasing its energy consumption and is gradually taking the first place in the European Union's energy balance. According to the figures of Eurostat, the share of the transport sector in the EU's final energy consumption has grown from 25% in 1990 to 31% in 2017. Road transport consumption is dominating considerably over that of the other transport sectors.

23. https://ec.europa.eu/transport/themes/urban/vehicles/road/electric_en
24. http://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637895/EPRS_BRI(2019)637895_EN.pdf
25. https://www.platformelectromobility.eu/wp-content/uploads/2018/02/EMobility-Platform-Brochure-2019-web2.pdf

The European transport has started reducing its emissions only after 2007; however by 2017 they remained above the 1990 level, with 70% of them being due to road transport.

Between 1990 and 2016, GHG from transport increased by 18% in the EU28+ISL.

The expansion of the economic activities imposes increasing domestic and international transport activity. The restrictions on commercial and other transport communication in Europe and in the world are gradually being abolished. The freedom of movement is one of the most valued freedoms of the European citizens and the basis of economic development. However, this requires transport connectivity - roads, vehicles, and management systems.

3.3 POLICY RECOMMENDATIONS

The current changes in energy and climate policy, imposed by climate change, require a technological revolution that encompasses the development and implementation of new technologies for the production, conversion, storage, and use of energy. The European Union is convincingly demonstrating how they can be put into practice - through an initial supportive energy policy that could attract inventors, developers, manufacturers, and users. The success of this policy so far needs to be stepped up with even greater activity in order to consistently resolve technological issues that were previously considered impossible but which should lead to the success of the Paris Agreement.

PROGRESS DIRECTIONS

The progress towards low-emission mobility is an integrated process that could be divided into four priority actions:

- Low-emission means of transport.
- Efficient organization of the mobility system.
- Infrastructure, i.e. completion of the Trans-European main network (TEN-T) by 2030 and of the comprehensive network by 2050.
- Speeding up the deployment of low-emission alternative energy for transport, such as advanced biofuels, electricity, hydrogen and renewable synthetic fuels and removing obstacles to the electrification of transport.

The momentum in these areas requires research, development and demonstration promoted through appropriate regulatory and legal policies - a continuation of the EU's successful past policy, which, through its various regulatory instruments, has shown its strength and has successfully passed the first test – the development of intermittent energy sources at acceptable costs and market prices.

Despite the significant progress made in developing the e-mobility sector in Europe, there are still a number of measures that the European Union could undertake to further support the transition. Steps should be taken to properly design the market to support technological solutions (i.e. smart charging, plug standards) coupled with innovative financing schemes. Until now, the focus has been mainly on implementing policies for passenger vehicles. In the future, the European Commission should actively try to develop policies to target long haul and heavy duty travel in order to integrate e-mobility solutions into this sector. Other sectors that could offer enormous potential is the electrification of the maritime and aviation sectors as well as the cargo transport sector.

POLICIES AND TECHNOLOGIES

The close relationship between technological development and its supporting policies is mandatory for the moving towards zero-emission transport. Regulatory policy should actively promote the commercialization of **new vehicles and fuels** having in mind all technological perspectives that are now known and are in different stages of development - such as improved vehicle efficiency, advanced biofuels, electricity, hydrogen and renewable synthetic fuels. Innovation, not only significantly improving transport efficiency but also facilitating the active replacement of fossil fuels with renewables, including second- and third-generation biofuels should be encouraged.

Subject to the requirements of the European Union and depending on its national conditions and needs, technology requirements and choices, each Member State will decide what transport policy to follow. The national policy should be designed based on:

- European transport policy and the latest EU documents[26], including the three Mobility packages require full commitment and efforts by the Member States to make progress towards green transport.

- Technological perspectives in light of the research, development and demonstration guidelines.

26. COM(2018) 773 final. Brussels 28.11.2018

- Capabilities of the regulatory system given the successful commercialization of renewable energy sources.

- Prospects for development of efficient zero-emission vehicles of all types .

- Link between transport and the development of economy, trade and civil activity. Contribution of low and zero-emission transport in achieving sustainable development.

- Technological guidelines: electricity, advanced biofuels, hydrogen and renewable synthetic fuels and removing obstacles to the electrification of transport.

- Intermediate role of natural gas in the replacement of liquid petroleum fuels. Natural gas and its subsequent replacement with artificial gas or other energy sources may have a role in ensuring a reduction of carbon emissions. Compared to petroleum-fuelled vehicles, Natural Gas Vehicles (NGVs) have lower CO_2 emissions[27] and lower (or much lower compared to diesel) NOx and Particulate Matter emissions. This is especially important for urban areas where gas can replace diesel in city buses and utility vehicles, but also in private transport.

- Member States' National Energy and Climate Plans (NECP).

- The increasing participation of electricity in transport and the related development of batteries. Contemporary studies and prospects for new technologies featuring a substantially higher energy density compared to the existing battery technologies.

- Potential for technology development of the hydrogen energy that can provide remarkable interchangeability with electricity in meeting efficiently and cost-effectively all transport needs.

- Future role of Power-to-X (PtX) in the production of clean fuels for transport.

The information on the modern transport system makes possible to draw conclusions about its imperfections and from there to make inference about its future modifications and refinements as a consequence of the EU transport policy.

Initial information about the EU Member States' transport policy towards 2030 and further

27. Looking at the whole lifecycle of the natural gas, studies (e.g. IEA, 2017. World Energy Outlook 2017) indicate that there are substantial additional GHG emissions from extraction and transportation. The European Commission is considering different measures to substantially reduce these additional emissions (e.g. replacement of pipes). The natural gas role may therefore depend on the effectiveness of these measures.

to 2050 might be obtained from the NECPs. It is observed substantial differences between the objectives and plans of the member countries, most often based on the economic development of the countries, the state of logistics, social policy and technological opportunities. Some shortcomings are obvious, such as the inefficient structure of transport systems in the Member States, in which road freight transport dominates over rail and water transport. The neglecting of rail transport for medium and long haul of oversized loads, at the expense of road transport, whose efficiency is significantly lower, is apparent. Water transport is similarly neglected.

The attractiveness of fuel and mobility alternatives in the European Member States depends largely on national legislations and regulations, tax rates and incentives. The large variety across Europe also makes it hard to directly replicate situations in one city to another.

One of the biggest challenges is the financing gap in supporting the transition to e-mobility solutions across the EU. Due to the high level of risk and high upfront capital investments needed to switch to alternative mobility options, many road companies face barriers to raise the necessary funding[28]. Further investments are needed in Europe in order to boost the research and development in further cost-effective e-mobility solutions. In this context, NECPs could play an important role in increasing investors' confidence and drawing more private investments towards the e-mobility sector.

Cities and municipalities should also be encouraged to integrate urban planning with efficient free mobility solutions and infrastructure and allow them only the possibility to travel within environmentally-protected areas and to add charging stations at the entrance of these zones.

Another major barrier going forward will be the limited availability of resources within Europe. The raw materials needed for the production of batteries must be imported from China or from the Democratic Republic of Congo. The production of batteries within Europe is not yet competitive and thus limited to the supply in these other countries. One potential solution to the shortage of raw materials is the end-of-life recycling of batteries. In order to reap the full environmental benefits of EVs and e-mobility in general, the European Union should take steps to develop battery recycling capacities. There are currently not many regulatory incentives for the collection and recycling of electric batteries, a fact that would need to change with the expected e-mobility transformation. Recycling certain elements from batteries can help reduce environmental impacts and CO_2 emissions by

28. https://www.eib.org/attachments/pj/access_to_finance_study_on_innovative_road_transport_en.pdf

avoiding raw material extraction. This could open new job opportunities in the recycling and extraction sector.

ELECTRICITY AND HYDROGEN TRANSPORT

Electric vehicles are a technology that supports the integration of VRE into the electric power systems and at the same time, contributes to the reduction in emissions from transport. To make them more attractive, many European Union Member States should introduce additional policy instruments to boost the uptake of EVs across Europe. Countries that offer generous incentives coupled with good charging infrastructure have larger market shares of EVs[29]. Various regulatory instruments are used for that purpose:

- Increased taxes on fossil fuels.
- Tax breaks.
- Free public parking for EVs.
- Standardisation (uniform plugs, parking spaces, billing and invoices, access to chargers, fleet standards, etc.).
- Exemption from paying vehicle registration tax or reduced fee.
- Exemption or minimum rate of road tax, pollution tax, etc.
- Increase in available purchase grants.
- Additional possibilities for EVs to use bus lanes.
- Public procurement and public-private partnerships.
- Car sharing schemes that exclusively offer electric vehicles.
- Support for the development of publicly-accessible charging stations.
- Retrofitting of housing complexes to include e-mobility solutions.

More funding will need to be provided to rapidly expand (rapid) charging infrastructure including overhead lines and inductive charging. Retrofitting of housing complexes to include e-mobility solutions is currently a major topic that will need further exploration. The growth in the carsharing industry should be expanded to include electric carsharing

29. https://www.acea.be/statistics/article/interactive-map-electric-vehicle-incentives-per-country-in-europe-2018

options and related measures, including the provision of free parking places for electric vehicles. In the future, topics related to electric mobility, such as the disposal or recycling of old batteries, the used car market and the range of EVs, will continue to be pressing issues.

Unfortunately, the existing technologies for electric energy storage are of limited capacity, i.e.:

- Not suitable for important applications: heavy-duty transport vehicles, water transport, aviation, bus transport.
- Fail to meet the sustainability criterion.

Low-volume/weight, high-capacity and high-efficiency storage batteries with acceptable operative lifetime are required. But more importantly, for the manufacture of such batteries rare metals are used, and even though the potential for their recycling, the technology does not comply with the requirement for sustainability. Active research is being conducted in this direction, to allow new technologies to replace the existing chemical batteries. New technologies without the commonly used liquid electrolyte will have many times higher specific accumulation and Cycling stability, which will significantly reduce the dependence of vehicles on the location of battery stations. The first significant achievements in this area are however expected after 2020.

Research into new energy storage technologies gives a lot of hope for multiple increases in the energy density, while avoiding the disadvantages of the now best storage batteries.

A combination of electricity and hydrogen that owing to its simplicity appears to provide fundamental solution to achieving the ultimate goal of sustainable carbon-free energy.

More information on electricity-hydrogen interconnection is provided in Chapter 2: Electrical systems upgrading policy.

SUSTAINABLE BIOFUELS

Development of sustainable technologies for production of liquid fuels are facing constraints, however it is expected to have them boosted up after 2025. Fuel consumer associations show interest in this filed. Major oil companies have expressed their interest in the achievements in this field and undertaken actions as they deem necessary to keep pace with current trends. The EU should continue to play a key role in their promotion by adopting a number of policies:

- More stringent sustainability and quality requirements.
- Increasing targets for biofuel share in transport.
- Support for research, development, and demonstration activities, and development of infrastructure, especially for the aviation, in line with the European Advanced Biofuels Flightpath.
- Introduction of voluntary schemes to ensure sustainability.

MODAL SHIFT

Due to the required technological development, it may take decades for the individual automotive transport and aviation to become sustainable. Modal shift, on the other hand, represents a readily available measure with a great potential to save energy and emissions. Some demand segments can easily and quickly change to more sustainable modes.

Both the EU and national policies need to support the definition of modal shift targets and priorities, the establishment of a level-playing field for all modes of transport, improve infrastructure planning, and support monitoring and information exchange.

Other possible measures would be:

- Incentives to marine and railway freight transport.
- Increase taxation on aviation sector.
- Incentives to railway passengers transport.
- Improving public transport offer and geographic coverage.

Chapter 04.

NATURAL GAS INTERMEDIATE ROLE

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4.1 ISSUE DESCRIPTION

The majority of the gas supplied in the EU is imported from outside the EU (74.4 per cent in 2017). Limits to European production capacity and import infrastructure (with over half of pipelines operating at monthly peaks above 80%) may contribute to market tightness over the coming years, particularly if Asia continues to absorb the ramp up in global LNG liquefaction capacity. For a number of years, Russia has been the largest supplier of natural gas to the EU and the EU's high dependence on one supplier is a main political concern. A key part of ensuring secure and affordable supplies involves diversifying gas supply routes.

Large investments are required for supply infrastructures in a changing framework of commercial and contractual relationship with producers. In the long run, there are several key issues that may have an impact on gas security in the European Union: how gas can flow within the EU; how patterns of demand might change in the future; and what role gas infrastructure might play in a decarbonising European energy system.

Storage plays a traditional and important role as one of the pillars of gas security of supply. Storage capacities were increased with the growth of gas markets, mostly because of the dominant share of heating in gas demand.

Natural gas currently plays an important role in balancing the electricity system and has many applications in final energy consumption. The balancing role will change in the long term, as the electricity system becomes increasingly renewables - based. Also, in the future, decarbonised gaseous fuels (biogas, but also hydrogen and e-gas) could provide clean energy to industry, buildings and transport. Today, gas does not have a decarbonisation strategy. The success of such a strategy will obviously depend on its economic and technological feasibility.

Renewable gas is a low-carbon option to „green" the gas grid. Through upgrading and injection of biogas or bio synthetic natural gas, renewable gas could replace natural gas, and also support a long term future for gas in space heating.

The regulatory system has always been decisive in the process of European development because of the extreme complexity of its management. The regulatory systems of three dozen countries, created in a variety of circumstances, political regimes and economic conditions, had to be restructured to reflect the process of social development, technology, and environmental changes. The current transition period requires particularly focused and correct solutions due to the high stakes - the environment and climate.

The transition to emission-free energy sources necessitates replacement of the organic fossil fuels by renewable ones. The main problem emerges in power systems where the basic energy source is coal – often low-grade coal, especially in East Europe – with high relative emissions. And since the main renewable energy sources (RES) – sun, wind - are intermittent, the power systems need changes in the control technologies. There arises the need for power plants with significant dynamic capacity that would permit to control the frequency, voltage and the power flows while following the demand trajectory.

Gas-fuelled power plants meet these requirements to a great extent. They use simpler technology and have lower investment costs for their construction than the coal-fuelled ones. Besides, there is less carbon in the chemical composition of natural gas and the carbon dioxide emissions are about 40% lower as related to primary energy.

For these reasons as well as due to the huge deposits existing in many regions around the world, natural gas can take on a special transitional role in the European and global policy of replacing the coal and oil, until electricity becomes "greener" and the production of synthetic fuels is wider developed. Most of the regions rich in natural gas - in Russia, Iran, Algeria, Qatar, Turkmenistan – are near Europe, so it can be delivered through pipelines. The increased production of shale gas in the United States also provides opportunities for import of liquefied natural gas (LNG) in Europe which can increase and take a serious share in the European energy balance.

Natural gas is not a sustainable solution because it releases greenhouse gases in the combustion process, and its extraction and transportation are accompanied by leakages, not really great - about 2-3%, - but with high greenhouse effect.

Replacement of the energy source is necessary also in the consumption of coal and liquid fuels for heating, especially in the countries of Southeast Europe where the low solvency of the population forces people to use coal – usually imported – for heating with low-efficiency – not exceeding 30% - household appliances. In the rest of EU this problem does not exist due to the traditional use of natural gas.

Use of natural gas during the transition, its flexibility, potential in all applications – industry, households, power sector, services – will largely alleviate the difficulties that could be met due to giving up of coal and oil.

The balance between advantages and disadvantages leads to an energy policy that gives an intermediate role to natural gas – its use during the transition, in order to make it more balanced, without any drastic changes in technologies and investments that have no prospects in the future emissionless energy.

4.2 WHY WE NEED TO TACKLE THE ISSUE

NATURAL GAS SUPPLY

Natural gas constitutes about 23.9% of EU's primary energy demand in 2016 and is used for generation of electric power, heating, fuel for transport vehicles and feedstock for the industry. Due to its scarce resources the EU covers all its demand for natural gas by supply from remote regions through pipelines or as liquefied gas by gas tankers (gas carriers). In 2017 it was 398 384 ktoe of which 77.9% was imported[30]. About 30% of it goes for power and heat generation. An increase in these two directions should be expected over the next years till 2030, in parallel with decommissioning of the coal-fuelled power plants and increasing variable renewable energy (VRE).

Natural gas, along with electric power, is an energy carrier of the transition and the security of supply attains paramount importance. In the complicated environment of economic and political interrelations the energy markets, the need for large long-term investments, the energy policies of EU as well as of each individual country attain an extremely great weight. Building of gas lines requires political decisions from states with different government systems and interests. Reliable guarantees of demand, as well as supply in the future are needed. Europe has often witnessed the difficulties with ensuring such conditions.

A complex, balanced policy of EU as well as of its member countries is required, as far as it is within their competencies and capabilities, to diversify the **sources and routes of supply** for the purpose of reliable gas supply at acceptable prices. The New Policy Scenario of International Energy Agency (IEA), for example, shows that in the period till 2040 the future competition between Russia and the United States of America (USA) will permit to contain price increases. However, they can switch the direction of their interests. By the end of 2019 Russia will start export of natural gas through the gas line „Power of Siberia" to China, while the USA are expected to turn to Asia in search of more advantageous markets.

The 2009 Third Energy package, improved the functioning of the EU energy market and brought progress for consumers, addressing both the electricity and gas markets. The Directive 2009/73/EC concerning common rules for the internal market in natural gas, part of the Third Energy Package, established provisions for the unbundling of energy suppliers from network operators, third-party access, non-discriminatory tariffs and

30. IEA WEO 2018 foresee 82% gas import dependency of EU in 2025

transparency requirements and promoted an increase cross-border cooperation. The directive adressed barriers to the sale of gas on equal terms and without discrimination in the EU. In particular, non-discriminatory network access and an equally effective level of regulatory supervision in each Member State.

Further measures were taken to ensure transparent and non-discriminatory tariffs for access to gas transport. Where a storage facility or ancillary service operates in a sufficiently competitive market, access can be allowed on the basis of transparent and non-discriminatory market-based mechanisms.

Security of gas supply is a shared responsibility of natural gas companies, Member States, and the Commission within their respective areas of activities and competence. Moreover, customers using gas for electricity generation or industrial purposes may also have an important role to play in security of gas supply through their ability to respond to a crisis with demand-side measures. In 2017 a new Security of Gas Supply Regulation was introduced, which requires EU countries to cooperate with each other in regional groups to assess common supply risks together (common Risk Assessments) and to develop and agree on joint preventive and emergency measures (to be reflected in their Preventive Action Plans and Emergency Plans). The regulation also introduces the solidarity principle: EU countries must help each other to always guarantee gas supply to the most vulnerable consumers even in severe gas crisis situations

In 2019, the Council adopted an amendment to the so-called gas directive which aims at closing a legal gap in the EU's regulatory framework and boosting competition in the gas market. The rules governing the EU's internal gas market will in future also apply to gas pipelines to and from third countries.

Today, the EU internal gas market is functioning relatively well. around 75% of gas in the European Union is consumed within a competitive liquid market, in which gas can be flexibly redirected across borders to areas experiencing spikes in demand or shortages in supply.

There is considerable variation in the number, size and structure of electricity and gas network operators throughout Europe. However, network operators are natural monopolies requiring regulation by national regulatory authorities.

On 8 November 2017, the EU Commission proposed a targeted amendment of the 2009 Directive. The update aims to extend the application of the core principles of EU energy legislation (third party access, tariff regulation, ownership unbundling and transparency) to all gas pipelines to and from third countries, up to the border of the EU's jurisdiction.

POWER GENERATION FROM NATURAL GAS IN EU

Over the recent years, electricity generation from natural gas in Europe has been growing. The latest solutions with efficient gas turbines are applied. The transition to emission free energy and the 2030 targets necessitate deployment of that process - construction of new gas plants whereby the frequency can be controlled, and the base load can be covered in the RES basic load during renewable energy minimum. Two types of capacities are needed for that purpose: Natural gas Open Cycle Gas Turbines (OCGT) and Natural gas Closed Cycle Gas Turbines (CCGT).

Natural gas Open Cycle Gas Turbines with 35 – 40% efficiency for larger turbines have about twice lower emissions than coal-fired plants, 2-3 times shorter construction times and considerably smaller investments. They are indispensable for the balancing the electricity power system (EPS) keeping in mind their high dynamism and potential in the primary, secondary and tertiary regulation, to cover a load almost without any delay or to be stopped without significant energy losses.

Closed Cycle Gas thermal power plants (Combined cycle base-load gas TPP) have also high flexibility and efficiency about 20% higher than the best coal-fired plants (about 65%.)

These benefits determine the expected increase in natural gas consumption until 2030, both in the EU and in the world, although depending on the improvement of energy efficiency and the expansion of RES, the absolute consumption of natural gas is expected to be limited.

Construction of gas capacities for power generation sets complex requirements towards the regulatory system. The reason is that they are in a competitive environment with investments in RES (VRE) which enjoy certain privileges. The high gas prices in comparison to the falling prices of RES that can avail themselves of other advantages as well, render the economic substantiation of a new gas capacity difficult. This is especially true with respect to CCGT. An investigation shall take into consideration other parameters beside the energy output, for example the **services** that a dynamic gas system can provide to the EPS. Some other factors also have to be considered, such as plans for new RES capacities, possible construction of electric power storages which are competitive with the regulating capacities of CCGT or OCGT.

4.3 POLICY RECOMMENDATIONS

NATURAL GAS CONSUMPTION POLICY

After the beginning of massive introduction of RES in the power generation, a number of European countries started and renovated their thermal coal-fired plants in order to make them more flexible, with a deeper minimum, thus helping to integrate the VRE without significant investments. This solution permitted them to postpone large investments in thermal capacities, while the intermittent generation is diversified.

The next 10 years are years of power generation "rearming" in many European countries. The coal-fired plants that have reached the end of their service life will be decommissioned and replaced by gas-fired plants[31]. An energy policy stimulating replacement of the solid and liquid fossil fuels is needed:

- Construction of OCGT - high flexibility gas modules – to ensure adequate generation and stability of the power system in an environment of significant intermittent generation.
- Replacement of coal basic generators by CCGT needing significantly lower investment and having much better flexibility and efficiency. The construction of such plants takes about two years, while the open-cycle gas module can be ready and commissioned in less than one year.
- Development of gas-fuelled heating systems - regional, urban and individual - with fuel that is significantly more convenient and cleaner than oil and coal for use in everyday life and services.
- Replacement, where necessary, of direct burning of wood in low efficiency appliances - to reduce air pollution with fine particles and flying ash.
- Specific processes in the industry to replace the use of liquid fuels and coal.
- Replacement of petrol by natural gas in cars which is already widespread and the potential for increasing gas use is enormous with significant positive impact.
- Penetration of LNG in heavy-duty road transport and shipping.

31. Construction of new coal-fired TPPs without carbon capture & storage (CCS) would be possible only in special circumstances, for example in some of the countries from the group of Coal Regions in Transition.

Each country chooses its policy in depending on its national conditions, in conformity with the objectives set by EU.

On the basis of the information here above, the respective plans for development of the transmission and distribution gas systems are developed. System reliability, probable supply interruptions and their impact are taken into account.

SECURITY OF GAS SUPPLY

The gas infrastructure forms a network without national borders. Failure of one part of the network can spread over other areas potentially including several countries. That is why all users, generators, transmission operators and, most of all consumers, gain from its reliable operation.

The energy policy with respect to natural gas supply is guided by various considerations which shall **be viewed in development till 2050 in order t**o avoid sunk costs:

- Reliability – supply diversification, contracts with suppliers, cooperation with neighbouring regions for exchange of information on issues relating to security of the gas supply and other current gas-related matters, mutual assistance.
- Sufficient capacity of the gas storages, possibilities for their expansion or construction of new ones.
- Prospects for production of renewable gas from electric power or from other resources and capacities of the gas storages to accommodate **the increasing production of renewable gas.**

The gas infrastructure is „critical", which leads to high requirements for adequacy and security, and need for common basic risk level for the security of this network throughout Europe. The rules applying to risk are mandatory and subject of Regulation 2017/1938 of 25 October 2017[32]. Gas Infrastructure Europe (GIE) - the association representing the interests of European natural gas infrastructure operators – has created a Security Risk Assessment Methodology[33], containing requirements for security of natural gas supply.

Security of gas supply is a shared responsibility of natural gas companies, Member States, and the Commission within their respective areas of activities and competence.

32. REGULATION (EU) 2017/1938 of 25 October 2017 concerning measures to safeguard the security of gas supply and repealing Regulation (EU) No 994/2010
33. https://www.gie.eu/download/2015/GIE_Security_Risk_Assessment_Methodology_May2015.pdf

Customers using gas for electricity generation or industrial purposes may also have an important role to play in security of gas supply through their ability to respond to a crisis with **demand-side measures**. EU countries will cooperate within regional groups to assess common supply risks together (Common Risk Assessments), develop and agree on joint preventive and emergency measures, and guarantee gas supply to the most vulnerable consumers even in severe gas crisis situations.

EU rules in the third energy package impose separation of the supplier from the operator, third countries' access, tariff regulation and transparency with respect to security of supply. The latest negotiations with the main current and future suppliers - Russia, Azerbaijan – demonstrated that these rules successfully serve as basis for the negotiations.

The energy policy shall ensure the highest degree of energy system reliability. The EU and all member countries are extremely sensitive to the probability of supply limitation. A number of EU and member-country documents are dedicated to reliability in the event of crisis, to the measures mitigating the probability of supply fluctuations. They cover prevention and emergency action plans for various consumer groups, depending on the level of adequacy and security required by them[34].

The operators of transmission systems and gas distribution networks are responsible for elimination of the limitation or interruption risk by means of **network and market**-related measures. The plans envisage prevention of emergency arising or deterioration, restriction of user categories, protection of the power system security, as well as realization of the opportunities for regional cooperation between natural gas suppliers for the sake of reliability of the gas system.

NATURAL GAS TRANSMISSION SYSTEM

The gas transmission system is well interconnected across EU's Member States, and allows for efficient transport of any gaseous fuels over long distances. Gas storage facilities offer large-scale storage solutions for sustainable energy, thereby ensuring security of supply through physical availability of gas and providing up and running flexibility tools for intra-hourly up to seasonal operational needs to the benefit of an overall robust and resilient energy system.

In the future, investments in gas infrastructure would mainly be driven by development of renewable gas, and flexibility needs to ensure the **adequacy and operational reliability** of the overall energy system. Obviously, the transmission system will undergo serious changes. Natural gas deposits will gradually lose their importance. The regions rich in

34. Regulation (EU) 2017/1938 of 25 October 2017

solar and wind energy will produce hydrogen, the transportability of which is times higher than that of liquid fuels.

In this context, the industry needs to examine both its assumptions and investments in relation to the carbon footprint of natural gas and explore how it can change to be in line with a fully decarbonised energy system. Depreciation rules for gas infrastructure assets may need to be revised to properly take into account the specific risks related to the changing gas demand and supply patterns. Projects should be evaluated on the basis of their added value for the global energy system, including impact on system adequacy and operational reliability.

GAS TRANSITION TO 2050

Natural gas, being the fuel of transition, offers a remarkable convenience: its replacement by renewable gas can be done gradually, without requiring any change in the technologies of its utilization. The transmission and distribution infrastructure will only need rehabilitation in order to accommodate the higher hydrogen content. By 2030 natural gas demand in Europe will grow, at a moderate pace, due to the steadily growing efficiency of consumption. At the same time, the technologies for hydrogen production will develop and it will be, together with electricity, a key element of the future carbon-free energy. The leading member countries – Austria, France, Germany, the Netherlands - as well as the large energy companies in Europe and the world, are aware of that and direct their energy policies to that prospect.

As a consequence of the renewable energy transition portrayed by MEDEAS scenarios, two main developments can be observed that affect the gas infrastructure: first, the overall gas consumption is declining, and second, the remaining gas demand will be supplied from biogenic resources, thus becoming a renewable energy carrier. Gas operates as a transition fuel, enabling the way towards a renewable-based energy system. The blending of biogas quantities in the gas distribution grid, reduces the quantity of fossil based natural gas, therefore, providing low carbon distributed gas to the final consumers.

As a result of the increasing electrification of the economy in the MEDEAS analysis, more integrated planning and operation of gas and electricity infrastructure is needed.

After 2030 the technological development will allow increasing participation of hydrogen in the gas energy till the final replacement of natural gas. In parallel, its participation in electric power generation will decrease, leaving just enough to guarantee the EPS adequacy.

This policy requires wider international cooperation of EU with countries rich in renewable energy – solar to the south of EU, wind to the north.

Chapter 05.

ENERGY EFFICIENCY

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5.1 ISSUE DESCRIPTION

Energy efficiency (EE) involves actions on both the supply and the demand side. Considerable progress has been made, with EU primary energy consumption (PEC) having peaked in 2006. The efficiency of PEC, measured as a ratio of final to gross energy consumption, reflects both the efficiency of the transformation of primary energy and the structure of the energy balance. PEC efficiency in the EU increased from 0.700 in 2000 to 0.719 in 2017, but there is a great variety among the individual Member States – from 0.509 (Estonia) to 0.972 (Luxembourg) – indicating potential for further improvement.

The energy intensity of the final energy supply (FEC), the ratio of final inland energy consumption and gross domestic product (GDP), offers even greater improvement potential. In this regard EU has already achieved remarkable success - between 1990 and 2016 FEC energy intensity decreased by 36%, corresponding to an average annual decrease of 1.7% per year. The energy intensity reduction can be attributed not only to technological improvements, but also to structural change, such as outsourcing of energy-intensive production to countries outside EU[35].

Key factors for energy efficiency investment include the policy and regulatory environment, the development of a supportive energy efficiency industry and financial ecosystem and addressing persistent barriers for financing. A combination of policy and financial know-how is needed to facilitate new business and financing models on the ground to realise investment opportunities on energy efficiency. It is also necessary to give a clear signal to investors that energy efficiency is a growth sector for the future. Therefore, it is necessary to deploy financial instruments and innovative business models to attract private finance to energy efficiency

Energy efficiency is strong driver to achieve the 2020 and 2030 climate targets and also a key building block for the Commission's Clean Planet for All Strategy. According to a report from the Commission,[36] "increases in economic activity continue to push energy consumption up. Energy savings have helped offset the impact of these increases, leading to gradual improvements in energy intensity. However, in recent years, energy savings

35. Arto, I., Capellán-Pérez, I., Lago, R., Bueno, G., Bermejo, R., 2016. The energy requirements of a developed world. Energy for Sustainable Development 33, 1–13. https://doi.org/10.1016/j.esd.2016.04.001
36. REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL 2018 assessment of the progress made by Member States towards the national energy efficiency targets for 2020 and towards the implementation of the Energy Efficiency Directive as required by Article 24(3) of the Energy Efficiency Directive 2012/27/EU. https://ec.europa.eu/commission/sites/beta-political/files/report-2018-assessment-progress-energy-efficiency-targets-april2019_en.pdf

were not high enough to offset the impact of the growth in economic activity, possibly also due to the delays in implementing energy efficiency policies in some Member States". In the long term a substantial decline of the energy intensity is necessary.

Therefore, substantial efforts are still required, including consumer behaviour, innovative financial measures, awareness raising, standardisation, information and training and combination of energy efficiency with renewable energy sources to tap synergies and achieve the EU targets in the most resource-saving way.

Energy efficiency is one component of resource efficiency, using the planet's limited resources in a sustainable manner while minimising impacts on the environment. Resource efficiency is a fundamental condition for a sustainable, low-carbon, and climate resilient society. Besides energy efficiency, MEDEAS touches upon other aspects of resource efficiency such as materials use and environmental impacts of energy technologies as described below.

5.2 WHY WE NEED TO TACKLE THE ISSUE

Energy efficiency can result in multiple benefits – environmental, financial, energy security, employment, poverty alleviation, health and wellbeing, and many others. It is increasingly taking its key place in the context of achieving sustainability targets, such as economic growth, security of supply, competitiveness and environmental sustainability. In this context, energy efficiency is given the highest priority in EU, as confirmed by the "energy efficiency first" principle in EC Energy Union Strategy.

During the last decades, the EU economy registers notable GDP growth of nearly 2% per annum and forecasts indicate similar growth rates in the future. Decoupling FEC and economic growth is therefore inevitable if Europe is to reduce its energy use and emissions. Improving energy efficiency can reduce EU energy consumption by half compared to 2005 and will therefore play a key role in achieving net-zero greenhouse gas (GHG) emissions by 2050[37]. Policies, legislation and programmes to develop energy efficiency markets as well as implementation of relevant EU directives (Energy Efficiency Directive, Energy Performance of Buildings Directive, Ecodesign directive, among others) are required to set the European Union along an energy efficiency path, an essential component of a sustainable energy future.

37. https://ec.europa.eu/transparency/regdoc/rep/1/2018/EN/COM-2018-773-F1-EN-MAIN-PART-1.PDF

Although energy efficiency makes good sense in many cases, it is often difficult to get consumers and other decision-makers to take action and achieve effective implementation over a long period. There is a number of barriers that hinder energy efficiency improvement, so relevant policy instruments need to be introduced to address them. Some of the main barriers include:

- Inertia – people are inclined to accept the status quo, even if this choice is not rational.
- Policy and regulatory barriers.
- Lack of information and awareness of EE potential.
- Lack of incentives to promote energy management in industry and commerce.
- Lack of capacity to identify, appraise, develop and implement EE measures.
- Lack of easily accessible financing.
- Technological barriers.

Additionally, to lower energy consumption and emissions, the rebound effect, both direct and indirect, need to be addressed. The rebound effect is particularly high in households, where its value for EU-27 is estimated between 73.62% and 81.16%[38]. This effect is high in the transport sector and in several industrial sub-sectors too. Therefore, the rebound effect is an important factor that needs to be taken into account explicitly when designing energy policies.

As a complement to energy efficiency and deployment of renewables, demand response needs to be fully integrated in EU energy markets. Its goal is to enable active participation of commercial/domestic consumers in the market through the provision of consumption flexibility services to different players in the power system and measures to facilitate the participation of demand response in electricity markets should be improved in the EU.

38. Freire-González, J., 2017. Evidence of direct and indirect rebound effect in households in EU-27 countries. Energy Policy 102, 270–276. https://doi.org/10.1016/j.enpol.2016.12.002

5.3 POLICY RECOMMENDATIONS

Energy efficiency is a broad area, covering a wide range of approaches and policies in each sector. This section, therefore, focuses only on selected policies – either sectoral or horizontal – with high importance.

ENERGY EFFICIENCY TARGETS

The 2012 Energy Efficiency Directive (2012/27/EU) established a set of binding measures to help the EU reach its 20% energy efficiency target by 2020. The new amending Directive on Energy Efficiency (2018/2002) updated the policy framework to 2030 and beyond. It sets the headline target of at least 32.5% reduction of energy intensity to be achieved by 2030, compared to the 2007 projection for 2030. The directive requires Member States to use energy more efficiently at all stages of the energy chain, including generation, transmission, distribution and end-use consumption. The Directive requires at least 0.8% reduction of final energy consumption annually. This target would require substantially higher annual investments compared to the current ones. It also included a possible upward revision clause, which increases the level of ambition compared to efforts required to meet the 2020 targets.

Using MEDEAS_eu model, a number of simulations assuming different energy efficiency ambition for 2050 have been produced, where the energy intensity dynamics until 2030 follows EUCO3232.5 scenario. The results clearly show that for the period 2031 – 2050, the energy intensity need to continue its sharp decline and maintain the projected average annual decrease for the period 2009 – 2030. The energy intensity dynamics for each sector is shown in the table below.

Table 1 : Energy intensity dynamics, (2000=100)

SECTOR	2009	2030 (EUCO3232.5)	2050 (extrapolated)	Average annual change
Industry	88.8	60.0	46.0	-1.32%
Residential	91.0	51.0	37.3	-1.55%
Services	92.9	56.0	42.1	-1.41%
Transport	93.9	60.0	47.5	-1.17%

The 2050 extrapolation is based on very ambitious average annual energy intensity change in the respective sector (last column), which is notably higher than the historic change. MEDEAS model results indicate that lower rates of energy intensity improvement after 2030 would require excessive cost for EU to meet its 2050 commitment for GHG reduction in relation to Paris Agreement. This is so, because the additional energy consumption would need to be covered mainly by renewable sources (RES). First, the marginal cost of utilizing the RES potential are increasing, due to the necessity to use less attractive sites and utilize more expensive renewable sources. Second, a higher RES share in electricity generation would require disproportionally higher balancing costs. Therefore, less ambitious energy efficiency policy would not only increase the total energy cost, but also the energy price. These threaten the affordability of energy for the European consumers.

ENERGY EFFICIENCY IN BUILDINGS

Buildings are responsible for the largest share of European final energy consumption (approx. 40%) and they represent the most significant potential to save energy.

An ambitious approach to energy efficiency is needed across all the sectors, but the major challenge of the next decade is buildings.

Buildings are a key element of the energy strategy of the EU, due to their high share in the energy consumption and high energy saving potential. The minimum energy performance for new and existing buildings needs to become stricter, in parallel with the cost reduction trend of the respective measures. While the requirements for new buildings have improved substantially, more emphasis needs to be put on the existing building stock. The existing buildings offer much greater energy saving potential, but their renovation still faces many barriers. The key barrier is financing. Member States need to move from traditional to innovative instruments to ensure more efficient financing and to mobilize private funding. Financial programmes need to set a higher ambition and support deep retrofit.

The Energy Performance of Buildings Directive (Directive 2010/31/ provided a framework to improve energy efficiency in buildings. Specifically, the EPBD set minimum energy performance requirements for new buildings and major retrofitting and defined lists of national financial measures to improve the energy efficiency of buildings. It also established Energy Performance Certificates and inspection schemes for heating and air-conditioning systems.

The EPBD gives discretion to Member States when designing their building codes and implementing technical requirements regarding renovations, building certificates and technical building systems.

Directive (EU) 2018/844 amended Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency and entered into force on 9 July 2018. The revised EPBD covers a broad range of policies and supportive measures that will help national governments in the EU boost energy performance of buildings and improve the existing building stock in both a short and long-term perspective. Among others, it establishes the following measures:

- All new buildings must be nearly zero-energy buildings (NZEB) from 31 December 2020.
- Long term renovation strategies for Member States, aiming at decarbonisation by 2050, with a solid financial component (effective use of public funding, aggregation, de-risking), and a clearer link between energy efficiency and financing are necessary.
- EU countries must set cost-optimal minimum energy performance requirements for new buildings, for the major renovation of existing buildings, and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls.
- A common European scheme for rating the smart readiness of buildings (Smart Readiness Index, SRI), will be introduced.

The requirements for the operation of technical systems, especially heating and cooling ones, in both existing and new buildings will also need to become more stringent, in terms of efficiency and automation.

Buildings need to increasingly support electromobility by provision of parking places and recharging points.

Investors often use credit ratings to help assess credit risk and to compare different issuers and debt issues when making investment decisions and managing their portfolios and still consider energy efficiency a high-risk undertaking. One possibility of streamlining transactions and increasing the reliability of projected energy savings is the standardisation of energy efficient investment projects in the buildings sector. This standardisation refers both to the estimation of energy savings and the risk assessment conducted by financial institutions. Standardisation can contribute to build a marketplace for energy efficiency projects. It allows individual projects to be aggregated and traded by large investors in financial markets.

- The MEDEAS project has the following recommendations for policies in the buildings sector: Raising awareness about the potential of energy efficient buildings, heating and cooling.

- Assessment and development of business models for energy service providers (ESCO).
- Conducting training courses for administration officials, companies, energy service providers, architects and engineers on Nearly Zero Energy Buildings (NZEB).
- Design and implement demonstration projects on energy efficient buildings and renewable cooling.
- Strengthen networks of practice for know-how, best-practice and experience exchange between stakeholders.
- Implement the recommendations of the Comprehensive Assessments.
- Member States must promote the implementation of the Smart Readiness Index (SRI) for smart buildings.
- Increment activities in the field of smart buildings and digital Building Energy Management Systems.
- Implement the requirement of the buildings directive that at least one electric recharging point be fitted into all new non-residential buildings, and in existing buildings under major retrofitting.

ECO-DESIGN AND ENERGY LABELLING

Eco-design and labelling has proved to be a strong instrument in setting product standards and have been a strong driver for innovation. Their role will become even higher in the future, due to the increasing share of appliances consumption.

The 2019 Eco-design and Energy Labelling Package, expected to save 5% of EU electricity consumption after 2030, is a big step towards policy simplification (merging regulations, energy label re-design), higher energy efficiency requirements, and better (wider) product coverage. Ecodesign and labelling contribute to EU circular economy and climate objectives. Measures have been included to support reparability and recyclability of products. Moreover, existing requirements on durability (for lighting), water consumption (for dishwashers and washing machines) and marking of chemicals were also revised and adapted as appropriate. Ecodesign measures facilitating products repair by ensuring the availability of spare parts have been enacted.

In the future, the efficiency requirements will be regularly increased in parallel with technology development. Europe needs to encourage such a development and enhance its position of one of the global technology leaders.

CO-GENERATION, DISTRICT HEATING AND COOLING

High-efficiency cogeneration, district heating and cooling have a notable potential to contribute to primary energy savings. District heating systems is heterogeneous in the EU. The largest proportion of district heating system can be found in Northern and Eastern European countries. A number of systems is still fossil-based. Renewable energy district heating and cooling systems can replace fossil fuel boilers and district heating. Implementing measures to facilitate the deployment of renewable district heating and cooling systems necessitates financing mechanisms, business models and technologies that combine energy efficiency and renewable energy in a smart way. Thermal storage, heat pumps and other technologies can improve flexibility of the heating system. The new renewable energy directive requires Member States to achieve an annual increase of 1.3% per year in the share of RES heat and cooling and encourages the use of waste heat. Inter alia policy must support national, regional and local authorities with heating and cooling planning, provide capacity building for market actors and provide measures to streamline authorisation procedures, etc.

Member States are required to carry out regularly a comprehensive assessment of the national potential of cogeneration and district heating and cooling, as well as a cost-benefit analysis of the potential of using cogeneration in specific cases. The new renewable energy directive 2018/2001 requires Member States to carry out an assessment of their potential of energy from renewable sources and of the use of waste heat and cold in the heating and cooling sector. To improve the effectiveness of the comprehensive assessments, the future ones should have more emphasis on concrete policies that address the market imperfections identified in the cost-benefit analysis. While in many Member States co-generation is adequately supported, this is not so for district heating. Public policy shall recognize the benefits of sustainable district heating solutions and provide more incentives for this sector to move in the right direction.

DEMAND RESPONSE

Demand response is part of the strategies to increase the flexibility of the electricity grid and can contribute to energy efficiency. A number of provisions dealing with demand side participation in the electricity market as a form of increasing flexibility are stipulated in various EU policy documents, specifically the Electricity Directive (2009/72/EC) and the Energy Efficiency Directive (2012/27/EU). Member States should also ensure that national energy regulatory authorities encourage the participation of demand side resources, such as demand response, alongside supply in wholesale and retail markets. Demand response needs to be fully integrated in EU energy markets. Its goal is to enable active participation of commercial/domestic consumers in the market through the provision of consumption flexibility services to different players in the power system and measures to facilitate the participation of demand response in electricity markets should be improved in the EU.

REBOUND EFFECT

The effectiveness of energy efficiency policies to reduce energy consumption can be significantly improved, especially in buildings and transport, if the rebound effect is considered explicitly. The rebound effect can be addressed by additional policies, such as communication and awareness of the consumers, regulations and/or energy taxes.

Energy or emission taxation, including carbon pricing, is the most powerful instrument to mitigate the rebound effect. The taxation increases the energy price and the energy efficiency cost savings would be offset by this increase, thus ensuring that the demand of the service remains unchanged. To minimize the indirect rebound effect, the taxation must be applied economy-wide and cover the energy or emissions embodied in internationally traded goods. The experience in the last decade shows that various barriers and political economy factors hinder, or at least delay the introduction of adequate taxation. Therefore, taxation must be complemented by other policy instruments where the rebound effect is explicitly addressed - regulations, information programmes, and others.

Despite the importance of the rebound effect, still there is insufficient research on policies to address it, so it is recommended to give it a higher priority. Additionally, the consideration of the rebound effect can be enforced through an obligation to assess it in policy plans and implementation reports.

ENERGY EFFICIENCY OBLIGATION SCHEMES

The Energy Efficiency Directive requires Member States to set up an energy efficiency obligation scheme. This scheme requires energy companies to achieve yearly energy savings of 1.5% of annual sales to final consumers. The new directive extends this oblgation scheme til 2030. The energy efficiency obligation schemes (EEOS) take advantage of the fact that energy suppliers, retailers, and distributors are best placed to identify and realize energy savings with their customers. EEOS proved to be very advantageous, e.g. have high cost effectiveness , so their role should substantially increase.

There are many positive recent policy developments in the area, such as higher targets, wider sector coverage, wider scope of energy efficiency improvement measures, high degree of flexibility, and development of more stringent control on the obliged parties. These trends must continue in the future to ensure that EEOS becomes highly effective.

In the context of the EEOS, Member States can make use of renewable energy generated on or in buildings for own use as a result of policy measures promoting new installation of renewable energy technologies to achieve the target (up to 30%).

Chapter 06.

ENERGY COSTS

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6.1 ISSUE DESCRIPTION

The construction of power plants requires upfront energy investments, providing energy returns only over the lifespan of the facility. Additionally, the large-scale replacement of fossil fuels with renewable energies will require additional energy investments related with the management of their variability (storage, overcapacities, overgrids, etc.). Hence, it is important to dynamically estimate the net returns during the transition to avoid potential «energy trap» scenarios, i.e., increasing gross energy output while decreasing the net energy delivered to the society. In fact, from a societal/metabolic point of view, the relevant dimension is the energy available to the society (Net energy), not the energy produced by power plants. A favourable ratio of energy delivered from a process divided by the energy required to get it over its lifetime (i.e., Energy Return On Energy Invested, EROI) over the long-term (energy surplus) has been associated in fields such as biology or anthropology as a key driver of increasing complexity and evolution for plants, animals and humans. The energy literature is quite rich with papers and books that emphasize the importance of energy surplus as a necessary criteria for allowing for the survival and growth of many species including humans, as well as human endeavours, including the development of science, art, culture and indeed civilization itself[40].

The results obtained in this first MEDEAS approach[41] indicate that achieving high penetration levels (75-100%) of renewables in the power system by 2060 consistent with the Green Growth narrative would decrease the EROI standard of the entire global system from current ~12:1 to between ~3 and 5:1 by the mid-century. These EROI levels are well below the thresholds identified in the literature required to sustain high levels of development in current industrial complex societies. This would translate into a substantial energy overdemand reaching a peak of +35% during the transition for the case of 100% RES; i.e. the production of energy would need to increase by 35% in order to supply the same level of net energy to society during the transition to RES. The increase in energy investments would imply a higher primary energy consumption which in turn would intensify the issues of environmental impacts and resource depletion. Hence, if not properly managed, the transition to RES could imply a strong reduction in the net energy available for society.

40. Hall, C.A.S., Balogh, S., Murphy, D.J.R., 2009. What is the Minimum EROI that a Sustainable Society Must Have? Energies 2, 25–47. https://doi.org/10.3390/en20100025
41. Capellán-Pérez, I., de Castro, C., Miguel González, L.J., 2019. Dynamic Energy Return on Energy Investment (EROI) and material requirements in scenarios of global transition to renewable energies. Energy Strategy Reviews 26, 100399. https://doi.org/10.1016/j.esr.2019.100399

Considering these results we proposed a more ambitious yet more sustainable scenario than the Green Growth (GG), the TRANS scenario, which implements policies at both energy and economic levels to reach a share of RE of at least 90% by 2050 and at the same time drastically reduce CO_2 emissions. On the one hand, it imposes a quasi-stabilisation of the economic production to the levels before the transition, and on the other hand, it enforces the electrification of all sectors and improvements in energy efficiency. Indeed, it combines energy and economic policies with the expectation to progressively reduce the energy intensities, while maintaining current standards of living.

In a scenario of rapid increase of RE capacities, the economy is expected to slow down at first, due to the large monetary resources and energy investments required. However, when the transition is successfully completed and if the renewable energy supply meets the energetic demands of the future society, unless new regulations are implemented, the economy will continue to expand at the current exponential rates, continuing to aggravate the depletion of resources (water and materials) and the occupation of land, the destruction of habitats and extinction of species. To avoid taking the same catastrophic path again, in the TRANS scenario, the per capita annual GDP growth expectations have been set to a much lower 0.4%, which corresponds to a doubling time of 173 years.

The causality between economic growth and energy consumption has been the subject of many studies since the late 70's. However, while some studies found a unidirectional causality running from GDP, others reported a bidirectional relationship. Few others have reported evidence of neutrality of energy consumption and economic growth. Whatever the situation, the causation between energy consumption and economic growth has significant implications in policy making.

6.2 WHY WE NEED TO TACKLE THE ISSUE

The issues to be considered are split in two parts, following the two MEDEAS scenarios: Green Growth and TRANS.

Green Growth scenario:

The assessment of energy investments during the energy transition with the MEDEAS model and following the GG scenario has three main implications:

- In terms of planning the transition to RES, it is usually assumed that the only relevant constraints are political and economic (i.e. political will and monetary investments).

- However, the results presented in this work show that the EROI of the system is also a relevant factor to be considered when assessing the best choices for the deployment rates of RES technologies. There is a trade-off between urgent climate mitigation and viability of the system. Moreover, decreasing (monetary) learning rates might not correspond to real technological improvements.

- From the point of view of the efficiency of the system, the results show that a fast transition to RES would imply very large energy investments with the potential to counteract future efficiency improvement trends. For example, in a scenario targeting 100% renewables by 2060 the total final energy intensity (defined as TFEC/GDP) by 2055 reaches the level attained in the mid-2020s, while in the case of not accounting for the EROI variation feedback, the total final energy intensity would steadily decrease over the simulated period (cumulated reduction of ~40% between 2020 and 2060).

- From a policy perspective, the aforementioned factors such as the resulting EROI of the system being well below the range of the thresholds identified in the literature as necessary to sustain high levels of development in current industrial and complex societies, as well as the evidence of the strong re-materialization required to perform the transition towards RES energies in the electricity sector (instead of absolute decoupling), put into question the consistence and soundness of the Green Growth paradigm as it is being currently presented.

Most models used for advising policy (e.g. IEA, IPCC, national governments, etc.) neglect the energy investments related with the construction and operation of the RES power plants, as well as the implications on the full energy system. It is necessary for energy modelling to complement classical monetary costs with biophysical quality indicators such as the EROI.

TRANS scenario:

Simulating the transition under the hypothesis defined in the TRANS scenario highlighted the following challenges:

- The 2030 EU target for energy efficiency improvement is 32.5% relative to the 2007 modelling projections. Simulations experiments were run setting 15%, 25% and 50% efficiency improvement targets for 2050. Those percentages were calculated from the efficiencies of the transport sector of 2014 and from values for 2005 for the remaining sectors. Therefore, the obtained results cannot be directly used to evaluate the likelihood of meeting the 2030 EU energy efficiency targets.

- Nevertheless, it is worth noticing that none of the efficiency gains imposed, not even a 50% improvement, allowed meeting the EU energy consumption target by 2030 (40 EJ or 949 Mtoe).Therefore, the desirable reduction of energy consumption may not be achievable exclusively by defining energy efficiency targets.

- Most importantly, the large amount of energy required to make the TRANSition does not allow to reach the 2030 final energy consumption target (target=949 Mtoe or 40 EJ, TRANS=1306.5 Mtoe or 54.7 EJ). The same happens for the reduction of CO_2eq emissions with respect to those of 1990 (target=40%, TRANS =2.47%). In fact, model projections show that embarking on the energy transition results in rising energy consumption and GHG emissions at first, until enough renewable capacity is available, which highlights the potential negative impacts of imposing very restrictive short-term energy consumption targets and carbon budgets.

- Model projections indicate that unless the progressive electrification of all economic sectors is accompanied by similar rates of growth of renewable electricity generation, primary energy demand may increase due to growing transformation losses (from fossil fuels to electricity).

- Simulation experiments showed that delaying the phase-out of oil for electricity and head production to 2100, did not prevent a period of energy scarcity and the subsequent shrinkage of the economy by 2030. Nevertheless, the imbalance between supply and demand was less pronounced in that case than if the phase-out of oil is imposed earlier (i.e. 2060 or 2040).

Despite the previous challenges, the significant decrease in the energy demand achieved with the TRANS scenarios, in most part resulting from the stabilisation of the economy, represents a step in the right direction in order to guarantee energy security, given the uncertainty on the energy that could potentially be generated with the future mix of renewable technologies.

Moreover, in spite of the reduction in the energy demand, the total primary energy use per capita obtained with the TRANS scenario for the global model, remains above the considered minimum required to fulfil the acceptable standard of living (30-40 GJpc), and for the European model it is above the 106 GJpc[42] threshold to reach high development (HDI>0.8).

42. Arto, I., Capellán-Pérez, I., Lago, R., Bueno, G., Bermejo, R., 2016. The energy requirements of a developed world. Energy for Sustainable Development 33, 1–13. https://doi.org/10.1016/j.esd.2016.04.001

Also, in the TRANS scenario the average EU share of renewables with respect to the energy consumption reaches 30.7% by 2030, which is close to the 32% target for the EU.

In addition, simulation experiments show that significant extra energy savings can be achieved by halving the size of the air transport sector. This possibility was suggested by García-Olivares et al[43], who argue that the service the aviation sector provides in relation to its energy costs, would justify dividing its size (hence its energy consumption) by two in a future carbon-free society. Model projections show that halving the size of the aviation sector by 2050 results in extra savings of 2 EJ/year, which corresponds to ca. 12% of the energy demand of the whole transport sector (17 EJ in the TRANS scenario), and a non-negligible 4% of the total final energy consumption of the EU.

Finally, although the 2030 emissions reduction target is not reached with the TRANS scenario, by 2050 the carbon budget is almost met (target: 29.3 GtCe, TRANS: 30.05 GtCe).

6.3 POLICY RECOMMENDATIONS

The main recommendations that can be derived from the discussions above in order to design policies for the reduction of the energy costs of the transition are summarised hereafter:

1. Larger energy cuts must be made on sectors providing low service to society with regards to their energetic (and environmental and social) costs (e.g. aviation sector, tourism).

2. The energy costs of the inland transport need to be minimised by reducing the size of the vehicle fleet, moving all freight transport from roads to railways and promoting car sharing. Fossil fuels should be replaced by renewable gas and/or hydrogen for long distance travel.

3. Energy consumption must increase in the short term (hence carbon emissions) to allow building the infrastructure required to make the transition. Short term carbon budgets and energy efficiency targets might inadvertently penalize countries taking the lead in the transition and discourage countries with the lowest penetration of RES.

43. García-Olivares, A., Solé, J., Osychenko, O. 2018.Transportation in a 100% renewable energy system. Energy Convers. Manag. 158, 266–285.

4. The supply of fossil fuels must be guaranteed in the initial stages of the transition (supply security).

5. Country-specific shares of RES are the most effective measures to reduce carbon emissions. These shares must be determined based not only on the actual RES potential of each country, but also on the degree of externalisation of their economic activity in order to set realistic and fair targets.

6. The interconnectivity of the electric grid will be key for homogenizing RES supply across all EU countries.

7. Storage will be key to guarantee a stable supply with RES. More investment is required in order to develop higher capacity and less resource intensive storage technologies.

8. Electrification and storage and RES capacity must be planned altogether to tackle supply intermittency and to be able to supply the progressively growing demand of electricity of all economic sectors resulting from their growing electrification. Unbalances between the three might result in intermittency of supply, increased demand for fossil fuels and increased overall energy consumption due to transformation losses.

9. High EROI RES technologies must be privileged whenever possible. Otherwise an overcapacity will be required to meet the increased net energy demand.

In general, MEDEAS results have indicated that slowing down economic growth not only reduces environmental impacts and materials costs but it also decreases energy consumption levels and thus the required energy investments during the transition. Similarly a planned and progressive demographic reduction would have similar effects and would complement the reduction of economic activity. Energy efficiency gains do not necessarily lead to reducing the overall energy consumption (Jevons paradox).

Chapter 07.

FINANCING CROSS-BORDER INFRASTRUCTURE

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7.1 ISSUE DESCRIPTION

One of the key elements of the Energy Union is to create a well-connected, modern energy grid to guarantee the security of supply, contribute to sustainable development as well as provide clean and reliable energy to all citizens.

Cross-border interconnectors are a multi-purpose investment. In the past they have been used mainly as a back-up of national energy systems in cases of emergency shortages or surpluses, whereas their socioeconomic value has only been lately ascertained. The European Commission has supported the implementation of fundamental energy infrastructures and has recognized the need for enhanced cross-border infrastructure and interconnections in the gas and electricity network as a step towards common energy markets (Internal Energy Market).

Nevertheless, being a cost-intensive and regionally critical investment, the construction of cross-border interconnectors is often associated with several technical, economic and political complications. Crucially, securing the funds and ensuring a seamless planning, permitting, construction and commissioning of cross-border infrastructure can be challenging. Certain issues related to both technological barriers and the governance of these projects often impede their timely completion.

One of the main hypotheses for the reasons why there are insufficient investments in new cross-border infrastructure or delays in existing projects is the lack of sufficient capital and access to funding. Furthermore, the different actors involved may disagree concerning the value added from such an investment. That is, the long-term economic benefits of one involved country may outpace those of the counterpart country, leading to increasing national concerns on the overall cost and benefits of the investment. One of the most important challenges, however, is the inadequacy of national policies and sound regulatory frameworks (discrepancies and changes in national policies and unharmonised national policies lead to market distortions and instabilities) and the permitting procedure (which leads to delays and large administrative costs and the time that mediates between the investment decision and its realization), all of which lead to barriers regarding public acceptance.

While developing such projects, planners should ensure that cross-border infrastructures do not negatively affect low-income groups of citizens or inadvertently create isolated communities. Systematic approaches are needed to develop infrastructure projects that are strongly backed by the public. It is critical that governments address concerns surrounding a project, while also widely conveying the benefits (e.g. direct and indirect employment, better living conditions, etc.) it will bring. A lack of strong public acceptance has proven to be a major barrier to large infrastructure projects. In some cases, projects are hindered due to the perceived loss of sovereignty as a result of compromises needed to implement the project in the first place. Further funding mechanisms need to be available to finance cross-border infrastructure projects across Europe.

7.2 WHY WE NEED TO TACKLE THE ISSUE

The anticipated transition to a low carbon economy involves a series of reforms in the global and European energy system that are potentially critical for securing and safeguarding seamless supply of energy to consumers. Among these reforms, the mass deployment of renewable energy sources and the increased requirements on energy security – especially for less carbon-intensive fuels, such as natural gas – require significant investments in infrastructure, both in electricity and gas sectors. The electricity grids will need to accommodate much higher shares of variable electricity than today, which requires substantial grid enhancement, increased cross-border interconnection and coordinated regional cooperation.

Furthermore, among the many benefits of enhanced and reliable cross-border infrastructure, especially in conjunction with its energy and climate strategy and goals, the EC brings forward security of supply and the reduction of energy dependency, lower risk of electricity blackouts, reduced requirements for new power plants, efficient supply and use of energy, easier management of variable renewable power sources such as solar and wind, increased competitiveness, increased opportunities for employment, enhanced sustainability and better regional cooperation at European level. Moreover, it is argued that through efficient interconnections there will be a wholesale price reduction due to the flexibility and the availability of a larger number of suppliers and the better use of complementarity across several production mixes. This can further lead to a reduction in consumer prices. According to a 2013 study, the amount of savings for EU consumers because of the energy market integration can reach 12-40 billion EUR on an annual basis.

The European Commission, having acknowledged the several benefits of enhanced cross-border infrastructure has taken appropriate actions to incorporate interconnectors in its strategy for climate and energy. In its Internal Energy Market Strategy, cross-border interconnections are recognized as important to facilitate the coupling of national energy markets with increasing demand for energy trade between Member States. Moreover, the Trans-European Networks for Energy (TEN-E) strategy aims to connect the energy infrastructure of EU Member States and complete the internal energy market, by identifying, selecting, prioritising and supporting the realization of the projects that are essential for the interconnection of the European network. This also includes the Connecting Europe Facility (CEF), which aims to provide financing in order to develop the trans-European network. The TEN-E strategy includes nine priority corridors for infrastructure development (four for electricity, four for gas and one for oil) between at least two EU countries, which will connect isolated energy markets, enhance cross-border interconnections and integrate renewables.

The European Council has in addition set an electricity interconnection target of minimum 10% of each MS's installed capacity by 2020, which has been extended to 15% by 2030. This target aims to guide policy makers and lead to actions by all relevant actors, such as Member States, project promoters, TSOs, regulators and transmission system operators and to address the challenges and issues related to new projects.

In order to complete the internal energy system of the EU and achieve its energy and climate objectives, several projects of common interest (PCIs), mainly key cross-border infrastructure projects are realized, the list of which is renewed every two years. A project is considered a PCI when it is necessary for at least one priority corridor or area, as identified in the TEN-E strategy, has significant impact on the energy markets of at least two EU countries by improving and enabling market integration, enhancing competition and integrating renewables, and the potential benefits outweigh the costs, based on a thorough cost-benefit analysis.

7.3 POLICY RECOMMENDATIONS

The design, selection and combination of policies in order to promote cross-border infrastructure projects and leveraging the appropriate funding for their realization is multifold. It spans from political will and regional cooperation among the interested Member States to European-wide implementation of tools to support and eliminate financial barriers for projects deemed critical for meeting EU goals on climate and energy.

IMPROVEMENT OF NATIONAL REGULATORY ENVIRONMENTS AND REGIONAL COOPERATION

The insufficiently stable and predictable regulatory environment is considered one of the most important challenges for cross-border infrastructure financing, especially on behalf of financing institutions. Investors, both on equity and on debt side are generally more hesitant to take risks or ensure longer-term returns within frequently changing regulations, as this creates high uncertainty in the evaluation of long-term investments, such as the realization of cross-border interconnector.

Furthermore, since investment returns that are regulatory determined are generally low, investors do not usually have sufficient incentives for cross-border projects. This concerns not only external equity investors (such as public shareholders, pension funds or large infrastructure funds), who normally require higher internal rates of return, but also internal equity investors, who are not likely to risk their assets in a relatively less profitable investment. This adds up to the difficulty in raising additional external equity financing in the cases of Member States, in which the TSOs are still largely state owned.

Considering the above challenges, it is important to set up an appropriate regulatory environment for cross-border infrastructure projects which should provide transparency, stability, long-term predictability and attractiveness to investors through improved returns on investment, shorter payback periods and lower risks.

What is of major importance, since at least two Member States are involved in cross-border projects, is to harmonize national rules and policies, possibly starting at EU level. This harmonization should first consider the benefits and costs and the interests of all relevant actors and Member States during the interconnection in order to enhance the integration of the energy market.

The regulatory environment should also foresee and be accompanied by improved cooperation among all relevant actors, from national authorities and EU to system operators and investors, in order to reduce the complexity in the project implementation and increase transparency.

IMPROVEMENT OF PERMITTING PROCEDURES

Parallel to the insufficiently stable and transparent regulatory environment, a barrier for investors to commit to cross-border infrastructure projects is the complicated and lengthy permitting procedures involved. Apart from the creation of uncertainty regarding the different stages of project construction and completion related to the project commissioning date, investors are hesitant to invest due to a high risk posed to the project's cost. In specific, lengthy permitting procedures usually correspond to longer periods required for the generation of revenues, which are necessary to recover the initial costs, such as interest, loans, depreciation and other expenses. Moreover, the permitting procedures become more complicated when different permit regimes and priorities among different Member States are present.

Recognising this, the European Commission has already introduced certain rules in the permitting procedures of Projects of Common Interest, which are to profit by fast-track permit granting with a binding limit of 3.5 years. Nevertheless, in practice the average duration of permitting is approximately 4 years, whereas ACER has found that for 20% of the projects the expected permit granting process will exceed 5 years and for two of these even more than 10 years.

To streamline the permitting process and optimize its duration and complexity, it is important to improve the national permit regimes and consider commonly agreed harmonization rules. Mutual permitting procedures should be developed and specific criteria and steps of permitting should be agreed at regional level to minimize unpredictability and the duration between the investment decision and the project completion.

IMPROVEMENT OF ACCESS TO FINANCE

Among the major barriers for the increased realization rates of cross-border interconnectors, access to finance is of major importance. As already mentioned above, investors have to face several barriers that may pose extra financial burden to the projects, such as the economic consequences of changing regulatory environments and lengthy permitting processes. In addition to these, the initial capital cost, being rather high for cross-border infrastructure, has to be undertaken by either the TSO in a regulated model, or by external investors in a merchant model. In some cases, the investment volumes required surpass certain TSOs' capacities, the latter even being in greater need for additional interconnections.

In the regulated model the recovery of the investment takes place through an interconnector use payment, which usually refers to regulated tariffs on top (or as share) of the consumers' energy prices. In the regulated model, the most common source of financing is corporate financing, which means that the cross-border interconnector is part of a group of projects on the TSO's balance sheet with company level financing. Apart from the vulnerability of insufficient capital on the TSO's side, passing on the cost recovery to consumers may also pose political and social opposition.

On the other hand, merchant projects, for which the financing of cross-border infrastructure happens on a fully commercial basis, are financed through project finance. This means that the project does not belong to the balance sheet of the respective TSO, but to that of a separate company, with the TSO usually being a shareholder. Revenues are determined directly in the market and the income from the congestion rents is used for project refinancing. The financial risk of the investors is higher than in the regulated model, leading to an increased project specific level financing. Although such models are rather common outside the EU, for a cross-border interconnector to be implemented under the merchant model in the EU, certain exemption from EU Regulations are required.

Like most large investments, the main financing sources for interconnection projects are debt, equity and grants. Debt comes from international financing institutions (e.g. EIB) with favourable conditions for granting loans to TSOs (such as long maturities), corporate bonds and commercial banks. A planned decrease in the total lending volumes of EIB and the limitations on lending volumes for individual companies (such as the TSOs) as well as the constraints of commercial banks on offering long-term lending impose another challenge for investments in energy infrastructure. Equity financing can be either internal from the TSOs' own cash flows or external, such as pension funds. At EU level various grants are available for cross-border infrastructure investments, the predominant being CEF Energy, which is the EU fund intended for PCIs and mainly supports implementation of studies over works. Apart from CEF funding, PCIs can also apply for funding under other EU programmes, such as the European Fund for Strategic Investment (EFSI) and InvestEU, and the European Structural & Investment Funds (ESIF) - in particular the European Regional Development Fund (ERDF) and the Cohesion Fund. Although European grants are still an essential tool for raising capital in cross-border infrastructure investments, volume-wise they play a limited role.

To overcome the barriers related to access to finance, it is important first of all to support the sound preparation and securing of interconnection projects' bankability to attract investors. In terms of debt, appropriate measures should be implemented to increase the lending volumes of international financing institutions, such as the EIB, and to increase the lending volumes of individual TSOs if involved in critical cross-border infrastructure projects. On the equity side, public grants should be commenced, especially due to the public ownership of many TSOs. Complementarity among financing sources should be stimulated and flexibility in selecting the most appropriate approach for financing (corporate or project) and the most beneficial investment model should be granted, including elements of both the RAB and merchant investment model, to facilitate the incorporation of external equity. Furthermore, since certain European TSOs do not have a credit rating, it should be considered to introduce incentives to obtain credit ratings by international rating agencies to improve their debt financing opportunities for commercial bank loans.

Finally, to secure the funds required and mitigate risk and complexity of cross-border infrastructure projects, priority premium schemes could be considered, which refer to remuneration on top of the foreseen returns to investors, whether they are internal (TSOs) or external equity providers. This can be applied to selected critical projects.

PROMOTION AT EU AND REGIONAL LEVEL

Cross-border infrastructure projects are characterized by a high degree of complexity, which is intensified by the involvement of more than one Member states, national authorities and stakeholders associated with various stages of project implementation. Moreover, public acceptance can impact significantly the realization of cross border infrastructure projects, since sensitive political issues are difficult to handle. Although according to the EC cross-border infrastructure and cross-border trade can increase the net economic and social welfare gains for the EU as a whole, the individual countries involved, may end up profiting or losing from such an investment, depending on the national energy prices. To overcome this and ensure that the investment in cross border infrastructure can provide gains and be profitable for all involved parties, regulation, incentives and facilitation of access to finance are required, as described earlier.

Nevertheless, the interconnection target and the PCIs should be further promoted not only to the interested stakeholders (investors, TSOs, lending institutions, project developers, etc.), but also to the general public, by stressing the importance of such projects and the long-term benefits in the framework of the European climate and energy strategy. Moreover, it is important to enhance communication among stakeholders and promote regional cooperation to ensure agreement on the necessity of cross-border infrastructure among involved Member States and to facilitate investments by ensuring investors trust and political will.

Chapter 08.

PRICE REGULATION

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8.1 ISSUE DESCRIPTION

The use of pricing as a tool, i.e. acting in the market by influencing the energy prices, to support transition in the energy sector has been widely used in the past. Prominent examples have been price regulations to support the decarbonization of the national power systems, as well as to contribute to the mitigation of energy-related greenhouse gas (GHG) emissions in all sectors of the economy.

In the past 10 to 15 years we have seen an impressive deployment of renewables in the electricity and other sectors, which, in Europe, was largely based on the significant reduction of technology costs (e.g. for wind and photovoltaics), the respective increase of efficiencies, as well as the implementation of rather favourable and effective policies and support measures for investing in renewables. These parameters, among others, have boosted the integration of renewables in the European electricity system and have set the grounds for the complete decarbonization of the electricity sector. Nevertheless, the cost-optimality of their implementation has been widely questioned and criticized, with the European Commission addressing the issue anew implementing new guidelines and regulations.

On the other hand the EU strategy towards a carbon-neutral economy by 2050 identifies that in the future energy system, primary energy supply will largely come from renewables and the European economy will be vastly electrified and at a high degree decentralized. According to the EC, by 2050 more than 80% of electricity will come from renewable energy sources, a fact that calls for drastic policies to support this decarbonization of energy sector. Parallel to that, MEDEAS projections, and in specific the scenario of a 100% RES economy by 2050 (TRANS scenario), indicate that although such a pathway is technically feasible, the deployment rates of RES are significantly higher compared not only to the current ones, but also to the deployment rates assessed in slightly less ambitious scenarios[44]. The investment requirements for the transition in the EU range up to 0.7 trillion $/year, which is roughly 5% of the EU GDP (model projected) for year 2030 in TRANS scenario. Even if framed within all energy-related costs it is much lower than the energy costs associated with conventional technologies, referring mainly to imports of fossil fuels. This translates to a need for decisive policies to allow the investors modify the current economic monetary flows and shift from the BAU scenario (in which, for instance, fossil fuels are subsidized) to the TRANS evolution in which high RES penetration is projected. If such measures are not addressed as in BAU scenario, model

44. Buchmann, K. et al., 2019. MEDEAS Deliverable 6.3 «Impacts: Challenges in the transition»

projections show that fossil fuel scarcity around 2030 will conduct to an economic crisis and recession.

8.2 WHY WE NEED TO TACKLE THE ISSUE

The aforementioned discussion raises questions as to at which extend we need to implement pricing policies, which sectors are more relevant and what combination of pricing tools is the most beneficial for the transition to a low carbon economy.

The anticipated increased deployment rates for renewables and the desired mitigation of GHG emissions in all sectors of the economy has been highlighted by the EU, through various regulatory packages to guide Member States on making the most of public funds, focusing on the reformation of existing support schemes and the effective design of new ones.

The EC has in the past promoted the implementation of financial support schemes and incentives to facilitate investments in renewable electricity technologies, at a time in which it was impossible for them to compete fossil fuels. This support has played a decisive role in their maturing, driving research and innovation to technological advancements, ensuring public acceptance, involving large players and investors, which all led to substantially growing renewables share in the power mix. Nevertheless, support schemes have not always been considered positive for the overall social welfare. The main reasons for that relate to:

- The overcompensation received by certain technologies that was a consequence to the unforeseeable abrupt technology cost (such as in the case of solar PV).
- The subsequent surcharges imposed to final electricity consumers, from which a large part of the renewables remuneration originated and which led to rising electricity costs.
- The need for retroactive actions to correct distortions of the support schemes, such as decreasing feed-in tariffs, which have unsettled investors' trust.

That led the EC to reassess the support principles for renewable technologies by encouraging the gradual phasing out of certain support measures for mature technologies (such as onshore wind and solar PV) and endorsing their gradual exposure to the electricity market.

As found in the individual reviews of leading countries assessed in MEDEAS project[45], most of them have initially employed powerful support tools to uptake renewables in their national power mix, but were soon adjusted to the aforementioned provision of the EC for integrating renewables in the electricity market, mainly by converting to market premium schemes and introducing competitive bidding processes to minimize the overall cost burden.

On the other hand, carbon pricing policies, although in economic theory are considered as the most powerful and cost-effective tool to decarbonize the energy sector, in reality it was proven to be less efficient than anticipated. The analysis carried out in the frame of MEDEAS project, on two main schemes – cap-and-trade system (EU-ETS) and carbon tax – showed that although the reduction of GHG depends on a variety of reasons and cannot be only attributed to a carbon pricing policy, the countries that had applied such policies did not exhibit any noteworthy result. It is important to note that carbon tax payers, usually being large utilities or industries with the power to influence decision making, in view of the anticipated decrease of their competitiveness, have imposed significant political barriers. To overcome these, regulation had to partly accommodate the demands of emitters, such as combining a carbon tax with reductions in other taxes.

8.3 POLICY RECOMMENDATIONS

The design, selection and combination of policies for the decarbonisation of the energy sector must entail a careful consideration of all interdependencies of the economy, not disregarding the economic situation, priorities and individualities of each Member State and overcoming several economic, institutional, political, legislative, social and environmental barriers.

Pricing tools to promote decarbonization must in general be part of a well-balanced mix of policies. These policies should span from technological measures, such as grid expansion and storage development, regulatory measures such as streamlining of authorization and permitting processes to pure financial measures, including subsidies and innovative financing tools. This essentially means that support schemes should be perceived as climate policies and not as opportunistic subsidies to investors, as has unluckily been observed for some cases in the past.

Furthermore, it has to be stressed that during the policies setting process, it should

45. Radulov, L. et al., 2019. MEDEAS Deliverable 7.1, Annex 3, “Role of market conditions and political support for the transition”

be ensured that multiple scopes are served. This means that support schemes of RES technologies should not only aim at the vast deployment of the respective technologies, but also, indicatively, to safeguard final consumers total burden in the energy bills, upgrade their role as prosumers and facilitate dispersed grid integration.

A good example of policies combination can be found in several cases in which the revenues of carbon pricing schemes, including EU-ETS, were tied to other clean-energy support schemes, as for instance, using the revenues earned from carbon pricing to compensate the financial support provided to RES technologies. This can not only add to cost effectiveness of the designed policies, but contributes to the improvement of carbon pricing public acceptance.

The main policy recommendations that are extracted from MEDEAS findings are summarised in the following:

MARKET INTEGRATION OF RENEWABLE ELECTRICITY AND REGULAR RE-EVALUATION OF LCOE FOR VARIOUS TECHNOLOGIES

As communicated by the EC, as well as the findings of MEDEAS project, renewable electricity technologies should progressively be integrated into the electricity market, complying with its rules and undertaking all respective responsibilities, such as balancing responsibilities.

The designed policies should consider the maturity degree of technologies, in the sense that as technologies cost drop, their competitiveness increases and a guaranteed fixed support becomes progressively less required. Thus the considered technologies could be gradually exposed to the market and transit from being granted guaranteed price levels centrally determined (such as in the case of feed-in tariff schemes) to market premiums or other market-based schemes.

This has already happened in most Member States for technologies that have reached a certain degree of maturity, mainly solar PV and on- and off-shore wind, with a shift from feed-in tariffs to market premiums or other support schemes which give incentives to producers to respond to market prices.

Premium models consist of two remuneration components; the wholesale electricity market price obtained at a certain point in time that the produced electricity is sold in the market and an additional market premium paid on top of the wholesale electricity price.

The market premium usually results from the difference between an administratively determined adequate support level and the electricity wholesale power market price on an average basis. It can have several forms, the most common of which are fixed premium, sliding premium and cap-and-floor premium.

While market premium schemes still guarantee a reasonable and safe return on investment, it also exposes RES generators to market price signals, which is the main difference from the feed-in tariffs scheme, in which producers receive a fixed price per electricity produced, independently of the market price. It is important to stress out that market integration of renewables fosters demand-orientated electricity feed-in, a fact that becomes increasingly important for the overall functioning and stability of the electricity system, especially in view of the increasing demand for renewables in the transition to a low carbon economy.

Nevertheless, to effectively reform support schemes and expand this to all technologies, their maturity degree must be precisely assessed. This is a prerequisite to ensure both that the respective technologies can still recover their investment costs without risking investor trust and technology public acceptance and also that overcompensation is avoided and cost-effectiveness is reached in the system as a whole.

Further to that, it is still important to design financial support schemes and other subsidies for less mature technologies in a manner that allows relatively high returns in the beginning to compensate for higher capital costs, but ensures a timely pull-back once maturity is reached. A tool to support this process is the re-evaluation of renewable energy financial support level by assessing their respective levelized cost of electricity (LCOE), on the basis of updated production costs at regular intervals.

The general consensus is that any financial support should be granted to renewable technologies as long as it is required and in view of their gradual phasing out in a coordinated way. The timing for the phasing out will consider parameters such as their ability to compete conventional technologies, to fairly participate in the electricity markets, complying to their rules and undertaking their responsibilities, and safeguarding that the overall cost burden of the national electricity systems are minimized.

COMPETITIVE DEPLOYMENT OF RENEWABLE ELECTRICITY

The EC brings competitiveness at the front of its climate and energy strategy and this expands to both energy demand and supply. Since the electricity supply is expected to be dominated by renewables by 2050, at a share of more than 80%, their competitiveness must be endorsed and ensured. This will partly happen through the continuation of granted market-based support and their gradual integration in the electricity market, as mentioned earlier. Nevertheless, additional tools should also be implemented to ensure that the overall cost burden is minimized.

As highlighted by the Commission one way to achieve cost-effectiveness of RES projects is by fostering competition among RES producers. Operating support granted through a competitive bidding process (either auctions or tenders) has been increasingly brought forward, as a volume-based support scheme, in which administratively set required volumes of production are auctioned instead of guaranteed revenues for production (such as the feed-in tariff schemes). Following the provisions of the EEAG[46], many Member States have already implemented competitive bidding processes renewable electricity production, on the basis of clear, transparent and non-discriminatory criteria, mainly for technologies that have already reached a certain degree of maturity and larger projects. Tender or auction schemes are usually implemented in combination to other support schemes, such as market premiums.

Auctions or tenders are widely considered as an option to reduce costs of RES-support, but also control the quantity of new RES installations.

The way each national authority may design their auction or tender schemes involve many different elements, which can be used to further promote the competitiveness of renewable electricity from different technologies. These involve the type of tendering procedure, the price paid to bidders, the award criteria, the technologies concerned, special conditions for involvement of small actors and others.

One way to ensure competitiveness is to choose a dynamic auction over static auction, allowing for competitors' reaction, provided though that no distortions of the process can arise. As opposed to static auction, which involves sealed bids, in a dynamic auction a quantity is offered by the bidders considering a pre-established ceiling price, which is then decreased to allow for new bids until the desired quantity is reached.

Furthermore the decision on what the paid price approach will be – i.e. either pay-as-bid or uniform price to all bidders – can introduce further competition to the process.

The agreed award criteria could be also used to foster competition and even succeed in a economically and technologically most advantageous project, by either leaving price as

46. European Commission, 2014. Communication from the Commission on Guidelines on State aid for environmental protection and energy 2014-2020 (2014/C 200/01)

the only award criterion or involving additional ones, such as specific grid requirements, depending on the specific process's requirements.

Finally, although currently most of the Member States analyzed in MEDEAS project have implemented technology specific tenders, cost-efficiency and maximization of benefits could be potentially achieved by setting up technology-neutral tenders, as long as, maturity is met for more technologies.

Similarly to earlier, a regular re-evaluation of renewable energy production costs is imperative to consider in designing competitive bidding processes for the support of renewable technologies.

INCORPORATE ALTERNATIVE SCHEMES, STRENGTHENING THE ROLE OF PROSUMERS

As highlighted in the long-term European strategy for a carbon-neutral economy by 2050 the power sector is expected to be highly decentralized and at the same time "…measures will be put in place to facilitate the participation of citizens in the energy transition through self-consumption and energy communities…". This imposes a requirement for strengthening the role of prosumers.

For this to happen, appropriate self-consumption schemes should be developed. These refer usually to onsite production and consumption of renewable electricity, typically applicable to small-scaled systems. The most common self-consumption scheme, widely adopted in the EU, is the net metering scheme, under which the excess electricity produced by an onsite RES plant and injected into the grid can be used at a later stage to offset consumption, in case the onsite renewable electricity production does not suffice. This concept practically uses the grid as a virtual storage system for excess renewable energy production and was initially implemented to favour demand side management. Nevertheless, according to the European Commission[47], although net metering schemes have been proven beneficial for jump-starting distributed generation, are attractive and easy to apply and to understand from the consumer's perspective, they have been increasingly criticized from a system perspective. In case of wide deployment of the scheme, there are concerns regarding the overall system cost-effectiveness, as the remuneration of the excess electricity absorbed by the grid was usually made at the retail electricity price, normally higher than the onsite generation cost.

46. European Commission, 2015. Commission Staff Working Document on Best practices on Renewable Energy Self-consumption

Nevertheless variants of this scheme could be designed, such as the net billing scheme, in which the cost of excess electricity production is calculated at the time of production, or simple self-consumption schemes.

According to the findings of MEDEAS project, certain Member States that had introduced net metering schemes have already reformed their schemes, by either using a net billing approach, or allowing netting on an hourly basis only, or limiting a lot the system's size.

Other ways to strengthen the role of prosumers and energy communities is to implement schemes of direct investment grants or specific tariffs for end-users of evolving technologies with still high initial cost but also high potential and for self-consumption schemes. This should be combined with special provisions for facilitating their access to finance.

Finally, another option involves combining self-consumption schemes with peak vs. flat pricing, which refers to the application of a different pricing strategy, in response to the need for smoothing the electricity demand throughout a day by charging higher prices at peak hours. As found by Kök et al[48], distributed generators are motivated to invest in solar energy with peak pricing policies, since they usually sell the generated electricity at the high daytime retail price and therefore increase their profit.

48. Kök, A. G., Shang, K. & Yücel, S., 2016. Impact of Electricity Pricing Policies on Renewable Energy Investments and Carbon Emissions. Management Science, pp. 1-18.

Chapter 09.

RAW MATERIALS AND RECYCLING

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9.1 ISSUE DESCRIPTION

The lower power density of renewable energies in comparison to fossil fuels translates into a substantially higher (in quantity and diversity) material demand to build the structures for harnessing renewable energy flows. The large-scale replacement of fossil fuels with renewable energies will require large amounts of materials for the construction of the new power plants. Moreover, although metal recycling and technological change may contribute to the future materials supply, mining is expected to continue growing for the foreseeable future to ensure demand fulfilment in an expanding economic system. Recent works highlight the dependence of the current economic system and alternative technologies on minerals.

Results obtained in MEDEAS indicate that achieving high penetration levels of renewables in the electric system by 2060 consistent with the ***Green Growth*** narrative[49] Ref would require a substantial amount of minerals relative to the current estimated levels of reserves and resources, driving in fact a substantial re-materialization of the economy which would exacerbate eventual mineral risk availability in the future. In particular, estimated cumulated extraction demand would surpass the current level of reserves in GG-100% for tellurium, indium, tin, silver and gallium. Following these results, the most affected technologies by mineral scarcity would be some solar PV technologies (tellurium, indium, gallium, silver, manganese), solar CSP (silver, manganese) and Li batteries (lithium, manganese). Wind technologies would be much less affected. Notably, gallium and indium also belong to the list of 14 critical minerals identified by the Raw Material Initiative of the EU[50].

On the other hand, simulations with the TRANS scenario reach comparable shares of RES than the GG scenario with an imposed 100% penetration of RES, with much lower material costs. This comes as a result of two main hypotheses included in the TRANS scenario: 1) a slowdown of economic growth, which results in a smaller demand for raw materials of all economic sectors, fewer electric vehicles and a smaller overall energy consumption (hence smaller RES capacity, electric grid and fewer EV batteries); 2) a 5% annual growth of the recycling of all materials included in the model.

The materials that appear to be more critical under the TRANS scenario are those required

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49. Capellán-Pérez, I., de Castro, C., Miguel González, L.J., 2019. Dynamic Energy Return on Energy Investment (EROI) and material requirements in scenarios of global transition to renewable energies. Energy Strategy Reviews 26, 100399. https://doi.org/10.1016/j.esr.2019.100399

50. Commission of the European Communities, 2008. Communication from the Commission to the European Parliament and the Council - The raw materials initiative : meeting our critical needs for growth and jobs in Europe, s.l.: s.n.

in the manufacture of PV solar cells. This is a consequence of the great importance that solar PV is given in the TRANS scenario, which produces more than 55% of the total electricity and 40% of the total energy demand by 2050. Wind onshore and offshore combined make up 33% of the total electricity production and hydropower covers 5.3%. The remaining production is shared between geothermal, oceanic, bioenergy and CSP.

9.2 WHY WE NEED TO TACKLE THE ISSUE

Given that for many minerals the cumulated primary demand surpasses the current level of reserves and even resources for a significant number of critical minerals[51], the results obtained put into question the consistence and viability of the Green Growth narrative at global level. Moreover, the results obtained also indicate that the extraction of the minerals required to fuel a global GG development will likely intensify the current socio-environmental conflicts related with the expansion of the extraction frontier globally. Impacts associated with the mining of key metals used in renewable energy and storage include pollution and heavy metal contamination of water and agricultural soils, and health impacts on workers and surrounding communities. The assessment of the potential impacts generated by the development of new mines could be the focus of further work (identification of the most vulnerable countries and communities, etc.). Certification schemes looking to ensure responsible sourcing of minerals could be extended to all minerals creating a minerals 'Fair Trade' (Earthworks, Fairtrade International). However, analyses of with current schemes point that they generally have little benefit for the poor producers.

On the other hand, and for the sake of example, according to IRENA and IEA-PVPS (2016) estimates, the recycling or repurposing of solar PV panels at their EOL can unlock an estimated stock of 78 million tonnes of raw materials and other valuable components globally by 2050.

Therefore, and according to all the previous discussion, accounting for the material requirements of the energy transition and their potential recycling allows to design more robust transition pathways.

51. Capellán-Pérez, I., de Castro, C., Miguel González, L.J., 2019. Dynamic Energy Return on Energy Investment (EROI) and material requirements in scenarios of global transition to renewable energies. Energy Strategy Reviews 26, 100399. https://doi.org/10.1016/j.esr.2019.100399

9.3 POLICY RECOMMENDATIONS

The Resource-efficient Europe is also part of the Europe 2020 Strategy and the Roadmap to a Resource-Efficient Europe sets the framework for the design and implementation of future actions, and outlines the structural and technological changes needed up to 2050. It proposes ways to increase resource productivity and decouple economic growth from resource use and its environmental impact.

In the same line, in 2015, the Commission adopted the Circular Economy Action Plan, which includes measures aimed at stimulating Europe's transition towards a circular economy, boosting global competitiveness, fostering sustainable economic growth and generating new jobs. This action plan included 54 measures covering production, consumption, waste management and the market for secondary raw materials and a revised legislative proposal on waste, and target dates for their accomplishment. Other initiatives were adopted by the European Commission in 2018, regarding the reduction of the impact of certain plastic products on the environment and the regulation on minimum requirements for water reuse. Also in 2018, a revised legislative framework on waste entered into force, setting targets for the reduction of waste and establishing long-term goals for waste management and recycling. Three years after adoption, the Circular Economy Action Plan is fully completed.

Also, within the framework of the Resource-Efficient Europe, the Commission publishes the Resource Efficiency Scoreboards, which are a set of indicators used to illustrate the progress towards increased resource efficiency of individual Member States and the European Union as a whole, and are based on the most recent statistics from Eurostat, the European Environment Agency and other internationally recognized sources.

In this work we tested the impact on the demand for raw materials of increasing the recycling rates of the materials used in RES technologies and batteries, increasing the durability of EV batteries and increasing the lifespan of PV solar cells.

The main policies that can be derived for the minimisation of the raw materials costs by combining the results obtained with the two simulated scenarios are summarized hereafter:

52. European Commission, 2011. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and The Committee Of The Regions on the Roadmap to a Resource Efficient Europe, s.l.: s.n.
53. European Commission, 2011. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and The Committee Of The Regions on the Roadmap to a Resource Efficient Europe, s.l.: s.n.

1. Combined with other policies, slowing down economic growth is the most effective way to reduce both materials and energetic costs of the transition.

2. Securing the supply of raw materials is essential in order to meet the growth in demand that the energy transition will bring.

3. Research must be financed to develop more resource efficient and durable RES technologies, and to find replacement materials for the most critical ones. The more durable the new technologies, the later a new technological change will be required once the materials that are used in current technologies become scarce.

4. Batteries are among the most material intensive energy storage technologies. Diversification of the storage capacity using a combination of different technologies (PHS, P2X, etc.) is advised to diminish the demand for critical materials.

5. The EU should be accountable for all impacts generated for the extraction of raw materials and the manufacturing of the end use products consumed within its borders, even if they take place in other world regions.

6. A recycling-friendly design of products and technologies is key to make possible high recycling rates in the future[54]. To that end, the end of life management strategy of RES technologies must be developed during their design-phase. Targets must be set for manufacturers in terms of recyclability, reusability and waste generation. Planned obsolescence practices must be banned and condemned. All this should be complemented by a cultural change in which citizens contribute to recycling.

7. Increasing recycling of raw materials and improving the energy efficiency of the mining sector are essential to maintain acceptable EROIs for RES technologies.

8. Developing action plans to tackle the increase of e-waste that the transition will bring. Limit externalisation of waste and incentive recycling, reuse and repurposing of waste within the EU borders (circular economy).

As a bottom line, it is noted that the 2050 energy mix should be planned and designed taking into account the expected demand for raw materials, their respective resources and reserves, their economic importance, the international context in which they are being produced, their embedded energy, their recyclability and the environmental impacts along their life-cycle.

54. UNEP, 2013a. Metal recycling: Opportunities, limits, infrastructure. International Resource Panel. United Nations Environment Programme. Valero, A., Valero, A., Calvo, G. & Ortego, A. Material bottlenecks in the future development of green technologies. Renew. Sustain. Energy Rev. 93, 178–200 (2018).

Chapter 10.

ENVIRONMENTAL IMPACTS

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10.1 ISSUE DESCRIPTION

Renewable energy development is a necessary instrument which helps to reduce the use and burning of fossil fuels and limits the risks related to climate change. At the same time, it is clear that each type of electricity and heat or transport fuel production has some environmental impact, including renewable energy sources. It is therefore necessary to find a balance between the renewable energy development on one side and the nature protection, sustainable forestry and agriculture on the other.

The environmental impacts of the development of individual types of renewable energy sources can be summarized as follows:

Wind power (both onshore and offshore): Bird and bat collision with components of a wind power plant present the highest risk for this technology. Also, disturbance and displacement - habitat loss for birds and bats caused by the operation and construction of a wind power plant are possible risks, next to the more “soft” impact of disturbing the landscape character.

Hydro power: The most serious impacts include changes in river morphology and riverine habitats, next to creating barriers to migration and dispersal of protected species.

Forest biomass: As the need for the biomass usually causes excessive logging, it also leads to soil degradation and biodiversity reduction.

Agricultural biomass: It creates pressure on land use change by agricultural usage of high carbon stock areas (wetlands, peatlands and forests). Further to that, if the management is not sustainable with aim to maximize biomass yield, other impacts are relevant for this energy source: soil degradation and erosion, ground water pollution and biodiversity degradation.

Utility scale solar photovoltaic: Large areas are impacted by the loss of habitat, fragmentation and indirect land use change (with increased risk of erosion in case of improper location of the power plant)[55].

Extension of the transmission and distribution system related to the development of renewable sources: Power lines require the clearance of land and the removal of surface

55. Van de Ven, D.-J., Capellán-Pérez, I., Arto, I., Cazcarro, I., De Castro, C., Patel, P., González-Eguino, M., 2019. The potential land use requirements and related land use change emissions of solar energy. Under review.

vegetation, resulting in alteration, damage and fragmentation or destruction of existing habitats.

Within MEDEAS model, the environmental limits related to nature protection are not considered in much detail, as they would need to be included in the individual models of each member state. Although some of the limits, as climate change impacts, available land or resource stocks influencing the renewable energy sources development, already are in the model and therefore, regardless of the model limitations, we have used the MEDEAS scenario TRANS to analyse the impacts of the RES massive deployment in a 100% renewable socio-economy in the land uses, water requirements and recycling materials needs and so, the reduction of waste associated to RES technologies. The MEDEAS model allows framing the environmental impacts that, as mentioned above, should be analysed with more detail at country geographical level.

10.2 WHY WE NEED TO TACKLE THE ISSUE

Most of the mentioned environmental impacts can be limited to an acceptable level, often at the cost of a relevant reduction in the renewable energy sources development and energy production. This requires substantial improvements in energy efficiency as well as demand response strategies that, when combined with local renewable energy production and storage options, can significantly reduce peak demand, resulting in energy and cost savings for stakeholders throughout the energy supply chain.

The development of energy efficiency can improve the environment in several respects: higher energy efficiency leading to reduced energy demand could lead to reductions in water demand and land use. It can also contribute to reduce emissions of local air pollutants and consumption of materials. Measures to improve energy efficiency naturally lead to reductions in energy demand and thus consumption of fossil fuels. Reduced consumption of fossil fuels implies reduced emissions of greenhouse gases[56].

It is very likely that in practice the environmental constraints will shift the potential of renewable resources to lower use of the technical potential. For example, in MEDEAS EU TRANS scenario which counts with a significant reduction of energy consumption, technological potential for hydro power production is 36% above the actual level and the potential for on-shore wind is tripled compared to the actual realization in 2018. Part of this potential estimate very probably includes projects which will come into conflict with

56. European Commission. The macro-level and sectoral impacts of Energy Efficiency policies. https://ec.europa.eu/energy/sites/ener/files/documents/the_macro-level_and_sectoral_impacts_of_energy_efficiency_policies.pdf

nature protection (e.g. building of hydro power plants in protected areas). This problem becomes more visible on regional level – there are places with very suitable technical conditions for wind or hydro power plant but the protection of the natural and cultural heritage actually makes the project impossible.

Some of the technologies analysed (third generation biofuels, certain storage technologies, most marine energy except for tidal barrages and offshore wind) are still in the development phase and not commercially available. Their impacts are therefore mostly unknown.

Moreover, the frameworks to evaluate environmental impacts of these new technologies are also being developed. For instance, it is difficult to quantify the impacts of marine technologies on biodiversity since baseline data of biodiversity in seawater is scarce.

From the perspective of carbon balance, it is clearly harmful to e.g. turn virgin forests into the agriculture land for growing biofuels, as the loss of high carbon stock areas mean more CO_2 in the atmosphere[57], thus negating the originally good idea of replacing the fossil fuels with renewable energy. Further to that, extensive logging for energy sector could cause other serious environmental problems such as erosion, drought or harming biodiversity. Even so, the excessive logging in the European forests would jeopardize their production capacity in the coming decades, which in the future would mean a reduction in the amount of biomass available for energy purposes, thus influencing the real energy potential in the future.

This is why a set of sustainability criteria were included in the Clean Energy for all Europeans package[58], although they remain rather vague. It is necessary to define more conditions, especially in the individual member states with their specifics, to ensure that the energy transition does not go against the nature protection and that renewable energy sources´ limitations are clearly recognized and described.

Further to that, the public support is also an important precondition for the development of the renewable sources. Cases of death of birds[59] or fish due to the inadequately realized projects without environmental assessment in the planning phase (including cumulative effects) or damage to the sites of great natural or cultural significance are detrimental to the development of renewable resources.

57. Stephenson, N. L. et al., 2014. Rate of tree carbon accumulation increases continuously with tree size, Nature 2014/01/15/online. https://www.nature.com/articles/nature12914
58. EU DIRECTIVE 2018/2001 on the promotion of the use of energy from renewable sources (2018), https://eur-lex.europa.eu/eli/dir/2018/2001/oj
59. like in Kalikra area in Bulgaria, where the European Court of Justice ruled against the project which was harmful to birds in NATURA 2000 protected location: European Court of Justice, 2016. Decision published on January 14th 2016.

10.3 POLICY RECOMMENDATIONS

When comparing the existing policies and the practise in the individual member states, it is obvious that most of the recommendations would be given on the level of the individual member states, rather than on EU level. The Clean energy for all Europeans package sets the important limits and goals, while leaving enough space for the countries to decide on their specific measures to achieve the energy sector transformation. This also well respects the fact, that almost each member state begins at a different starting point, taking into consideration not only historical development, current energy sources mix, but also natural and societal possibilities and limitations. Natura 2000 on the other hand lays out the important measures to protect the natural heritage, fauna and flora. The member state compliance to the existing policies is crucial and so the monitoring processes (incl. citizens and public associations) and adequate penalties for breaching the EU directives are of utmost importance.

Among all reviewed RES technologies, hydropower and biofuels (especially the first generation) account for the highest direct environmental externalities, due to their enormous land footprint and water usage. Onshore wind seems the RES technology with the least environmental impacts.

As for all new infrastructures, impacts on the environment will be minimised if the new infrastructure is built in already degraded landscapes or close to urban areas. The same is true for the plantation of crops for biofuels, which will be less damaging for the environment when produced in marginal lands (although the yields may also decrease). However, it is clear that especially bioenergy production is very demanding from land use point. Renewable energy deployment under TRANS scenario leaving less than 2% of the total EU soil unaffected by human activities and available as animal habitat and plants (currently it is around 16%).

What still could be improved are the rules and conditions for nature preserves and national parks. Common definitions and rules could be set up on the EU level, giving specific guidelines (and bans) for the development of any renewable sources of energy in these areas.

The new EU Common Agricultural Policy (CAP) should be focused on the improvement in the areas of biodiversity and soil protection. At least 50% of CAP support fund under first and second pillars should be earmarked for climate and biodiversity related measures.

The final general recommendation would be to search for, gather and promote working solutions and best practise in the member states, providing knowledge transfer and experience sharing for the others. Examples worth sharing are numerous (during our work in MEDEAS Task 7.3c, mainly Bulgaria and Austria were studied), among them a Bulgarian example of "optical fence" for large solar PV installations, where no physical fence is constructed, but cameras and monitoring system are installed instead. Or, the practise of acceleration of the authorization process for smaller onshore wind projects is a sharable practice from Austria.

Another set of technology-specific recommendations addressed to the individual member states are described below:

ONSHORE WIND

There is a rather broad agreement that a landscape capacity assessment, spatial planning and appropriate site location are the key preventive instruments of negative impacts of wind power plants, especially the risk of bird and bat collision. It is very important to identify precisely the areas where the construction is inadmissible. Also, it is highly advisable to involve bird protection experts in the identification of excluded zones.

The specification of exclusion zones gives the wind power plant developers very clear information where the projects will be acceptable. At the same time, it enables the acceleration of the authorization process in areas earmarked for construction. The practice of accelerated process for wind parks with capacity less than 20 MW can be recommended under three conditions: a) careful exclusion zones specification, b) appropriate legislation, and c) authorities experienced with the simplified procedure.

Exclusion zones specification principle is also an applicable measure to avoid the negative effects on landscape scenery and potential Not in My Backyard Phenomenon (NIMBY) causing citizens' resistance in the area.

Generally, excluding the wind power plant construction from the national parks and nature preserves is recommended. It is not necessary to automatically exclude all Natura 2000 sites as some subjects of protection are not in conflict with wind power plant development. However, in Natura 2000 sites related to birds protection, the wind power plants should be constructed only exceptionally: in case the construction and operation of wind power plants is not a disruptive factor for the subject of the protection.

OFFSHORE WIND

Recommendations for minimization of offshore wind power plants environmental impacts are similar to those related to onshore: a careful site location is the key preventive measure to avoid seabirds and marine species collision with wind the turbine. Long-term monitoring of offshore wind power plants needs to be considered as a condition for the approval of the project, so that the evaluation of the impact on population of marine species is enabled.

HYDRO POWER

In the case of yet undisturbed rivers, it is recommended to exclude the sections where it is possible to protect near-natural hydro morphology from hydropower development (to prevent affecting river valleys, waterfalls, cascades floodplains and related habitats). Generally, hydropower development should be excluded on river sections flowing through protected areas (national parks, Ramsar sites, biosphere reserves, Natura 2000 areas or nature preserves).

Rules for operation of the existing hydropower plants should take into account the necessity of sufficient water flow during all seasons of the year.

As for the fish migration, a requirement to build fish-passes should become a part of hydro power development in Europe.

FOREST BIOMASS

Sustainable forest management is essential to guarantee that biomass used for energy purposes is sustainable. The utilization of forest biomass for heat or electricity production is possible only under the condition of a sustainable forest management, where the specific sets of criteria should be implemented on the national level. The most basic criteria include a) the annual harvest should not exceed the yearly increment to forest biomass stock, b) limitation of the amount of biomass removed from the forest after timber harvesting (it is crucial to maintain the soil quality and biodiversity), c) proof of origin of the feedstock (to prevent the power generation from wood which could be processed with a higher added value instead).

Forests in the national parks and nature reserves should be managed according to special plans and left to natural development in selected zones without exceptions.

Natural rejuvenation is widely recommended in Natura 2000 areas, as it maintains autochthonous genetic material, increases resilience and creates near-to-nature habitats. As a principle, age-classes of trees should be mixed in Natura 2000 forests.

Removal of brushwood and harvest residues should be permitted only for specified forest types (with low level of soil damage). The remaining trunks, trees with hollows and selected mature trees should be left to live and decant in at least 5 trees per hectare in adult stands[60].

The new RES directive established sustainability criteria for solid biomass which aims at ensuring that biomass is produced sustainably, irrespective of its geographical origin. Electricity from biomass in large scale plants (equal or above 20 MW) must be produced through high-efficient cogeneration technology and meet the EU sustainability and GHG criteria for contributing to the EU RES target and receiving public support. Member States must require economic operators to show that the sustainability and greenhouse gas emissions saving criteria laid down in Article 29(of the new RES Directive have been fulfilled. In addition, the verification of the sustainability sustainability criteria takes place either through a) national rules/schemes (involving Member States' authorities) or b) voluntary schemes (national/international) recognized by the Commission.

The forestry sector is also covered by the policy on emissions and removals from LULUCF (Land use, Land Use Change and Forestry). In 2018, the LULUCF-Regulation set the binding commitment that total emissions from this sector are in balance and do not exceed CO_2 removals. The LULUCF accounting system is part of the EU sustainability criteria for bioenergy.

According to the governance regulation, measures on bioenergy promotion must take into account biomass availability, including sustainable biomass considering domestic potential and imports from third countries as well as biomass uses by other sectors (agriculture and forest-based sectors); as well as measures for the sustainability of biomass production and use.

Financial support of bioenergy production from forest biomass should be made conditional on compliance with sustainability criteria laid down in the Renewable Energy Directive (2018/2001/EU) and State Aid guidelines[61]: usage of forest biomass is acceptable from the areas where monitoring or management systems can ensure the legality of harvesting operations, forest regeneration of harvested areas, maintenance of soil quality and biodiversity and maintenance of the long-term production capacity of the forest. The compliance with the sustainability criteria in practice will need to be verified through certification systems. Further specific set of sustainability criteria should be designed at member state level individually.

60. FSC Česká republika, Brno 2015. Komentovaný Český standard FSC, FSC STD CZE-03-2013, http://www.czechfsc.cz/data/standard_FSC_2015.pdf

61. Guidelines on State aid for environmental protection and energy 2014-2020, (2014/C 200/01), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014XC0628%2801%29

AGRICULTURAL BIOMASS

Each member state should develop an agricultural strategy with the aim to achieve balance between the production of food, feedstock and energy crops and determine the best possible level of farming intensity and crop rotation. Environmental requirements on the conventional crops grown for bioenergy production are the same as the requirements on crops for food production: prevention of soil degradation and erosion, prevention of ground water pollution and protection of biodiversity.

It is also necessary to ensure that growing bioenergy crops does not create any pressure on undesirable land use change by agricultural usage of high carbon stock areas (wetlands, peatlands and forests). Potential land use change is the most important environmental limit for special energy crops like perennial grasses or short rotation coppice. Growing of these crops on agricultural land should lead to biodiversity improvement.

The financial support of bioenergy production from agricultural biomass should be made conditional on compliance with sustainability criteria laid down in the Renewable Energy Directive and State Aid guidelines for environmental protection and energy: a) usage of agricultural waste has to respect management plans in order to address the impacts on soil quality and soil carbon, b) raw material obtained from land with a high biodiversity value or high carbon stock is not eligible for bioenergy production.

As a example, the Austrian practice of regulating the agriculture in Natura 2000 areas by individual contracts between regional authorities and landowners has proven positive effects and could be recommended for application in other countries.

SOLAR PHOTOVOLTAIC

Plants integrated in buildings (roof or facade) should be the priority of any support schemes as they have only negligible impact on the environment. However, attention should be paid to the decomissioning and dismantling of used PV panels at the end of their lifetime. Policy that requires solar panel manufacturers to have a recycling plan for their products is necessary to avoid substantial amounts of waste due to the decommisioneed PV panels. In addition, it is important to take account of the fact that hazardous materials are being used for their production.

The installations of utility scale solar photovoltaic plants have to avoid risks of habitat loss and land use change with possible carbon release as the consequence of stripping vegetation and disruption of soil. Both mentioned risks of impact of utility scale solar plants can be reduced or prevented by appropriate siting. Brownfields and degraded land are optimal for the large solar PV installations. Solar PV installations in Natura 2000 areas are generally possible under the conditions of no conflict with the subject of protection and avoiding of the use of chemical substances for managing the site.

TRANSMISSION AND DISTRIBUTION LINES

Optimizing tracing from a nature and landscape conservation perspective is the only way to limit the impact of increasing demands on transmission and distribution system capacity.

Chapter 11.

SOCIAL AND BEHAVIOURAL ADAPTATIONS

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11.1 ISSUE DESCRIPTION

This chapter focuses on social and behavioural adaptations in relation to renewable energy adoption and energy intensity, with a special focus on two dimensions of labour demand and labour skill relevance.

First, the effects of the low-carbon transformation on labour demand have been claimed to be considerable, which is crucial for social acceptance. The focus on labour dimensions is supported by several empirical findings. Appropriate labour skills have been found to be a critical bottleneck in the low-carbon transformation. This requires education policies to anticipate upcoming demand. Even when cost-efficient and highly competitive, renewable energy technologies require the labour skills necessary for their adoption and maintenance.

Second, labour skills are also crucial in relation to energy intensity across sectors. Energy intensity concerns the efficiency of energy utilisation in relation to economic output. Labour skills are not only relevant to enable the adoption of renewable energies, but also important to increase energy efficiency and reduce energy intensity in the broader economy, including a number of energy-intensive industries, irrespective of the adoption of renewable energies.

MEDEAS project analyses reveal that a continued transition to renewable energy implies a considerable potential to generate more jobs domestically through the renewable energy transition in the case of coal-based economies. In all analysed countries (including Austria, Germany, UK, Czechia, Poland and Bulgaria), the prevalence of male workers remains stable – electricity-related sectors are usually characterised by 2/3 of male employment. Low skilled labour contributes only minor parts of the labour demand effects. MEDEAS analyses show that the labour demand increases considerably in coal-based economies to facilitate the low-carbon transformation. The analyses also demonstrate that labour skills are crucial for improving energy efficiency and reducing energy intensity across a large number of energy-intensive sectors.

The policy conclusions are embedded in a broader transition framework. The relevance of structural adjustment assistance as a forward-looking, albeit narrow transition policy frame is highlighted. Forward-looking structural adjustment assistance is fundamental to overcome resistance and anticipate labour demand. This includes education assistance, as well as public goods provision for labour skill development.

11.2 WHY WE NEED TO TACKLE THE ISSUE

The potential gains in terms of labour demand are significant, but ambiguous. In the case of early adopters, the continued transition to renewable energy would not increase domestic employment. Conversely, in the case of coal-based economies, there is a considerable potential to generate more jobs domestically through the renewable energy transition. The situation is usually balanced for medium and high skilled labour, with low skilled labour contributing only minor parts of the labour demand effects. The results have to be interpreted with caution however, since there may be significant economies of scale, when wider deployment of renewable energy sources takes place. In the research, the changes in employment patterns induced by the renewable energy transition itself were distinguished from the other effects. Therefore, MEDEAS analysis does not calculate with effects of economic growth (which could possibly boost the job gains), nor any other factors that could possibly influence the overall labour demand effects, such as working time reduction, work automation, changes in labour supply (changes in demographic structure of the population), or, for example, changes in production patterns in the renewable power sectors.

Furthermore, statistical support for the high relevance of labour skills in improving energy efficiency and reducing energy intensity across a large number of energy-intensive sectors was found. A conclusion was made that education policies that take into account coordination between industries and education, such as in vocational training, may be especially fruitful to enable renewable energy adoption and simultaneously reduce energy intensity across industries, thereby providing a double dividend in the low-carbon transformation.

MEDEAS project analysis aimed to shed light on the compatibility of the EU climate and energy targets with the Union’s goals regarding employment and labour policy. Whereas in the case of early adopters, including Austria, Germany, and the UK, the continued transition to renewable energy would usually mean some employment losses (at least domestically), in the case of coal-based economies, there is a potential to generate more jobs through the renewable energy transition. The comparison of Poland and Czechia indicates that even though both countries are depending largely on coal and are not having a contingent governmental plan for coal phase-out, the coal industry is facing decline. The costs of coal use as well as environmental impacts are some of the reasons for growing social opposition. Especially lignite mining at certain locations is contested by social resistance in various forms and thus makes future prospects of lignite mining limited. Programs supporting the transition of coal regions at the European level have been introduced in both countries relatively recently, which could create opportunities for growing public acceptance of the transition.

11.3 POLICY RECOMMENDATIONS

The EU 2020 strategy highlights the complementarity of the employment and energy transformation goals. According to the strategy, “[the goals] are interrelated and mutually reinforcing” so that “educational improvements help employability and reduce poverty”, “R&D/innovation and more efficient energy use makes us more competitive and creates jobs”, and “investing in cleaner technologies combats climate change while creating new business or job opportunities”. More generally, also Eurofound, the European Foundation for the Improvement of Living and Working Conditions states on its website that “European social policies aim to promote employment”. The social policies of the EU are motivated by “technological progress, globalisation and an ageing population”, and aim to promote employment, sustainable (economic) growth and greater social cohesion. Specifically, the policies covering equal opportunities, but also appropriate skills for the changing labour markets are relevant for MEDEAS policy recommendations.

The policy conclusions concerning employment, labour skills and education, as explained below, were embedded in a broader transition framework, which has been proposed to describe different types of policies in the context of the low-carbon transformation. This framework describes four ideal types of policy approaches, separated along the lines of their scope (broad versus narrow), and along the lines of their orientation in time (forward versus backward looking). MEDEAS focus is on structural adjustment assistance as forward-looking, but narrow policy orientation, which emphasizes monetary or monetary-equivalent public good provision and incentives. This includes wage subsidies, subsidised education, assistance for relocation of workers, but also subsidies for households to support investments in energy-efficient and low-carbon technologies. The subsidies can also extend to infrastructures, innovation, and skills development in the sense of providing public goods.

The policy conclusions exclude any policies which focus on monetary compensation to those agents who lose from the transition and provide monetary support for any monetary losses incurred. The orientation of this policy direction is narrow, and usually backward-looking. Typical examples are targeted unemployment compensation schemes or early retirement in the context of labour effects. Examples in other areas are household compensations or subsidies for increased living costs or compensation of industries for replacing lost assets incurred by low-carbon technologies. Also exemption policies were put aside, which usually have a broader scope, but remain back-ward-oriented. The typical examples of exemption policies are grandfathering, postponed and graduated implementation. Exemption policies have been used to implement tradable emission allowances. Exemption policies are backward-looking as they try to maintain the status quo of actors but are broader than pure monetary loss compensation. Finally, MEDEAS project does not consider policies of holistic adaptive support, extending to non-financial losses, including intrinsic values or even mental effects. Adaptive support policies include transition planning, counselling, support for re-employment and investments in social and cultural goods.

The focus on labour demand, education and skills investment, chosen in MEDEAS project analyses, belongs to the narrow, but forward-looking policy category. This does not imply that holistic measures may not be important for the transformation. While acknowledging the relevance of holistic support approaches, the analyses do not allow deriving any conclusions concerning holistic support measures. The recommendations are therefore focused on the education policies and the effects of investments into labour skills for the low-carbon transformation. The focus is on three education-related policy recommendations, which appear to provide the most leveraging effects for the transformation, and also provide a double dividend:

A key pillar for the transformation is vocational training, which is lacking in most liberal market economies. The renewable energy sector in the UK lacks a skilled workforce, as has been shown in a report of the Imperial College London developed for Shell. Missing vocational training and manufacturing bases prevents the UK from realizing its potential in the low-carbon transformation.

In the **first policy conclusion, it is therefore recommended upscaling the experiences from coordinated market economies which have vocational training structures with close collaboration between industries, education and research.** Although uniform approaches to renewable energy policies exist, this coherence is currently lacking for vocational training and labour skills development more broadly. MEDEAS analyses have revealed that such education policies that take into account coordination between industries and education, as in vocational education and training (VET), may be especially fruitful to enable renewable energy adoption while simultaneously improving energy intensity across industries.

The demands of the renewable energy transition for high- and medium- skilled labour are clearly in line with Europe's 2020 strategy goal to promote higher education. Moreover, the call for supporting skills development is also mutually coherent with the qualification requirements for the transition to 100% based renewable electricity production. More generally, a successful energy policy for renewable energy diffusion at the EU level requires developing capacities at the national level that are sensitive to the context of liberal and coordinated market economies.

The **second policy conclusion** concerns more general recommendations for education.

As numerous examples of social resistance indicate, however, any technology- and engineering-oriented education policy needs to be accompanied by more general education concerning the social dimensions of the transformation. Building on the Council conclusions and the progress report, emphasizing the multi-dimensional importance of collaboration on VET, **the suggestion is, in addition to balancing the strong gaps in some countries, a focus on education for renewable energy adoption, to anticipate increased expected sector-specific labour demand.**

A more general **third policy conclusion concerns forward-looking implementation capacity to roll-out low-carbon policies across EU member states** once stronger political consensus emerges, and, on a global, multi-lateral level, to pursue unilaterally induced reciprocity.

These conclusions have been derived from a number of related case studies. Although some of the case study insights are not easily transferrable, others provide guidance and lessons learnt. In the context of trade liberalization and also in the case of immigration policies, gradualism has been important. Given the time pressure of realizing the low-carbon transformation, such gradualism becomes increasingly less feasible. Similarly, reciprocity among countries could profit from gradualism in those cases. Luckily, several countries have already generated experiences with a gradual introduction of low-carbon transformation policies. In these cases, some forms of reciprocity could be developed within the multi-level governance structure of multi-lateral agreements, but also among cities. The gradual phase-in of carbon taxes or cap-and-trade regimes has been practiced in several countries, but many countries will have to leap-frog this policy process. The fast implementation of more fundamental transformation policies, however, will likely create stronger resistance, and therefore requires more fundamental solutions. Building on a nascent literature, strengthening adaptation capacity is suggested, in order to be prepared for implementation once a stronger consensus develops. Second, unilaterally induced reciprocity it is recommended to speed up cooperation. Taxing the carbon emissions of imports appears fundamental to prevent carbon leakage, as well as labour and investment migration. The consumption-based perspective on carbon emissions building on input-output analyses clearly demonstrates the fundamental role of non-domestic emissions induced by consumption. These findings also have considerable implications for labour demand and labour skills as part of the adaptation capacity of a country.

Chapter 12.

ECONOMIC DEVELOPMENT

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12.1 ISSUE DESCRIPTION

The strategic vision report of the European Commission "A Clean Planet for All" called for "achieving net-zero greenhouse gas emissions by 2050 through a socially-fair transition in a cost-efficient manner" in the EU. A successful transition in electricity and basic materials industries are essential for achieving this goal, especially when taking into account the long investment cycles of these industries. Moreover, this transition will happen in a highly competitive and dynamic international market, where many of the basic materials are traded. The low-carbon transformation requires fundamental structural change throughout the economy. One of the top challenges identified by the MEDEAS project is the buy-in and engagement of the private sector since many of the needed investments are not currently considered to be attractive opportunities for the private sector. Several sectors are dependent on fossil energy provision, being suppliers to the energy sector or directly or indirectly profiting from fossil energy supply.

While renewable energy policies have been analysed and reviewed extensively, including the effectiveness of emission trading schemes and carbon taxes and renewable energy support schemes[62], there are considerably less studies that analyse the drivers and barriers of the transformation across sectors. Policies concerning the phase-out of fossil energy sectors are crucial to enable the transformation, but an extended view on the linked and dependent sectors may turn out as significant as focusing on the energy sectors directly. That is, indirectly dependent sectors could compromise the transition as well.

This chapter derives policy strategies to gain acceptance of the necessary sector-level adaptations for the low-carbon energy system transformation. The outcome is a proposal of socially just, economically viable and environmentally smart economic policies for the transformation period. The chapter derives policy conclusions concerning critical sectors that could compromise the transition, and sectors that could directly and indirectly profit

62. Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy 33, 2123–2137.
Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation–explaining the German diffusion of renewable energy technology. Energy Policy 34, 256–276.
Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R., Stern, N., 2018. Making carbon pricing work for citizens. Nat. Clim. Change 8, 669–677. https://doi.org/10.1038/s41558-018-0201-2
Lipp, J., 2007. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. Energy Policy 35, 5481–5495. https://doi.org/10.1016/j.enpol.2007.05.015
Negro, S.O., Alkemade, F., Hekkert, M.P., 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. Renew. Sustain. Energy Rev. 16, 3836–3846. https://doi.org/10.1016/j.rser.2012.03.043
Venmans, F., 2012. A literature-based multi-criteria evaluation of the EU ETS. Renew. Sustain. Energy Rev. 16, 5493–5510. https://doi.org/10.1016/j.rser.2012.05.036

from the transition. The recommendations draw on results from an extensive analysis of sectoral value-added effects to identify which sectors could indirectly gain and which sectors could indirectly lose in the transition by being dependent either on fossil or renewable energy sectors, respectively. Within MEDEAS research, the input-output methodology was used to identify those sectors that are directly and indirectly benefiting or losing from the low-carbon transformation, because of an increase in renewable electricity production. The calculated value-added effects for each sector that is directly or indirectly linked to electricity production. As the results reveal, the value chains of fossil fuel industries and renewable sectors differ considerably, but there are also potential synergies in the transition that could be politically facilitated.

12.2 WHY WE NEED TO TACKLE THE ISSUE

During MEDEAS research, the input-output analysis revealed the sectors that are affected by the low-carbon transformation:

- Losses are expected in the sectors strongly linked to the non-renewable sources of electricity production. The first sectors losing out are obviously the fossil fuel sectors, and the directly linked primary sectors of mining and extraction.
- Interestingly, other negatively affected sectors comprise of retail trade, wholesale trade, and supporting and auxiliary transport activities.
- The gaining sectors obviously include the renewable electricity sectors that contribute to the transformation.
- More important however, are the indirect effects on linked sectors: Agriculture with crop cultivation is an obvious sector gaining directly from biomass processing for electricity generation.
- Sectors related to biomass and biogas electricity production would grow – biogasification of sewage, cultivation of crops, production of electricity from bioenergy itself, as well as forestry and logging occupy the first four places among the winners.
- Interestingly, the pulp-and-paper industry seems to gain from the transformation. This seems counter-intuitive, as woody biomass use for energy purposes competes with material uses. Yet, the re-processing cascading use could be a crucial candidate for a circular economy.

- Also transmission, distribution and trade of electricity are gaining significantly. Whereas electricity infrastructure is usually considered a significant barrier and cost for the transformation, the utility infrastructure sectors are gaining in terms of value-added effects.

- Finally, private households gain from the renewable energy transformation in terms of value added and also labour demand. Households are strongly involved in solar PV and wind projects, especially in the case of rooftop installations of solar PV.

Thus, there is an urgent need to design economic instruments that are capable of leveraging private investments at the scale needed for the necessary energy transition. Also, effective economic instruments further scale-up technological innovations in energy, buildings, transport, industry and agriculture sectors, with circular value chains which are robust and efficient, and with the smart integration of the energy and industrial sectors. These instruments typically refer to government policies that affect the behaviour of producers and consumers by causing changes in the relative prices to be paid for goods or services.

The gaps for a successful energy transition exist across a broad range from the creation and acceleration of new low-CO_2 production processes, to innovation that can prevent the decline of energy return over energy invested (EROI) in the overall system of energy production (Task 7.2a of MEDEAS). Currently, many of the most promising low- CO_2 technologies remain at the pilot or even earlier stage (Tasks 7.2a and 7.2b of MEDEAS).

The feasible TRANS scenario (Task 7a, > 90% of Renewable Energy Sources share by 2050 with more controlled use of resources), requires an average energy investment over the period of 2020-2050 of 11.7% (World) and 15.8% (EU) of the total final energy consumption. The scenario requires an increase of up to 50 times the current demand for Lithium, and more than 30-fold for Indium, Gallium, Tellurium, Vanadium, Cadmium and Manganese. The CO_2 prices in the EU-ETS will not be sufficient to cover the cost difference between low-CO_2 production routes and the incumbent ones. Other barriers to market entry include the existing standards or unused opportunities in procurement and the lack of information on life cycle assessments of products.

The transition to a net-zero greenhouse gas emissions economy by 2050 requires a significant increase in investments. Business companies will only make these investments if the following enabling conditions are present: technologies are mature enough for industrial scale production, a market for low-CO_2 solutions is growing, and there is access to reliable, green and competitively priced energy as well as infrastructure. As CO_2 intensive production installations after 2020 are highly likely to be operational up to

2050, it means that some of these investments will lock-in emissions and lead to higher mitigation costs in the 2030s and 2040s.

12.3 POLICY RECOMMENDATIONS

The protests of the yellow vest movement in France have brought the socio-economic dimensions of climate change mitigation to the forefront again. A vast majority of an internet sample of French people supported the movement in a survey in 2018[63]. Despite the fact that France has already one of the highest taxes on fuels and tax shares more generally, this policy proposal seemed to have provoked a tipping point of resistance in society. Although further research is necessary on the actual process dynamics, there are some fundamental insights that provide lessons learnt for socio-economic acceptance. One such key lesson is that, whereas economists focus on the demand effects of carbon taxes on fossil fuels, most citizens focus on the way how the revenues raised by such a tax are actually used (recycled), without considering their “elasticities of demand”. Framing of carbon taxes is fundamental. The neglect of this insight has probably contributed to the social unrests in France.

Pure economic analysis suggests that carbon pricing is the most cost-effective approach for decarbonizing an economy. However, political lobbying and resistance have led to relatively moderate carbon prices in most jurisdictions, including EU countries, which have implemented emission trading systems and/or carbon taxes. To compensate the weak effectiveness of the under-priced carbon trading system, many governments have implemented a combination of pricing mechanism, sector-specific standards, subsidies, and investments and can now serve as a best practise for others. Also, any fundamental policy concerning the low-carbon transformation of societies needs to anticipate and study the potential social reactions that matter, including the different sectors that are gaining or losing economically from the transition. The policy recommendations are developed to strengthen the coalitions across sectors that are indirectly profiting from the transformation, while, simultaneously, providing structural adjustment assistance to those sectors that could otherwise become losers in the transformation. All coalitions and strengthened collaborations between sectors can also create new innovation potential for a circular economy, as the strategy to support a “competitive EU industry and the circular economy as a key enabler to reduce greenhouse gas emissions” suggests.

Taking the losing sectors into consideration, the **first policy recommendation concerns**

63. Grillmayer, D., 2019. Emmanuel Macron und die Krise der politischen Repräsentation, in: Frankreich Jahrbuch 2018. Springer, pp. 11–20.

adaptive measures to make the trade and transportation sectors fit for the renewable energy transition. This includes targeted research and innovation support as well as facilitating cooperation with the renewable energy sectors, but specifically addressed to trade and transportation related to renewable energies. Most support schemes focus on renewable energy sectors. In addition to facilitating the adaptation of the sectors themselves, this strengthened coalition could be a precondition for the projects in order to enable pro-active adaptive measures. This would require a scoping study of best practice approaches that potentially already exist, and an institutional analysis of up-scaling potential.

As an extension of the strategic long-term vision of the European Commission, "A Clean Planet for All", the strategic building block to "Embrace clean, safe and connected mobility" should be complemented to include connected, smart and sustainable transport logistics that could facilitate the renewable energy transition by transport sector adaptation.

With regard to the gaining sectors, the **second policy recommendation focuses on the electricity infrastructure and households.**

Electricity network infrastructure is usually considered a significant cost for the transformation, and related infrastructure investments are also communicated this way. On the other hand, the infrastructure is at the same time fundamental to facilitate the renewable energy adoption (this is also suggested within one of the building blocks of "A Clean Planet for All": strategy to "Develop an adequate smart network infrastructure and inter-connections" is said to be crucial) and so the previous perspective should always be complemented by the fact that the utility infrastructure sectors are gaining in terms of value added and employment. This suggests updating the relevance of infrastructure investment costs also as a benefit to the economy in terms of value added. It implies highlighting the benefits and providing underlying analyses that account for the value added.

As for the private households, the analyses demonstrate that they gain considerably from the renewable energy transformation in terms of value added and also labour demand. Households are strongly involved in solar photovoltaics (PV) and wind projects, especially in the case of rooftop installations of solar PV, but also in the case of participative onshore wind projects. The strategy to "maximise the benefits from Energy Efficiency including zero emission buildings", proposed as one of the seven building blocks of "A Clean Planet for All", is therefore an important guideline to strengthen further collaborations with households. A key measure will be to enable households and real estate companies to invest in zero emission building technologies.

Third, **a portfolio approach for economic policies is recommended to help the transition**

to the renewable energy including three key components: a) tradable standards, b) scaling up investments, and c) innovation policies (technical analyses available in MEDEAS Tasks 7.2a-f).

a) Tradable standards can be applied to electricity supply, transportation fuels, personal vehicles, and industry. Examples are the renewable portfolio standard (RPS), implemented in 29 states in the U.S. and several provinces in Canada or the Renewable Obligation implemented in the U.K. The standard requires a minimum percentage of electricity (same value for each provider) to be generated from specified renewables each year. A provider can meet the minimum by itself, or can purchase credits from others who have exceeded the minimum if it is more cost-effective for the provider. MEDEAS project recommends the implementation of similar tradable standards in the EU.

Although economic analysis indicates that such market-oriented regulations have efficiency drawbacks relative to carbon pricing, empirical evidence suggests that they experience higher degrees of political acceptability. The surveys reported in Rabe (2018)[64] and Rhodes et al. (2014)[65] showed that carbon taxes received significantly stronger opposition in comparison with other market-oriented regulations in the U.S. and Canada. The surveys reported in Amdur et al. (2014)[66] and Rabe and Borick (2012)[67] showed that policy labelling such as avoiding the term tax and revenue recycling mechanisms can make important difference for improving the public acceptability of carbon taxes.

It is worth considering a combination of tradable standards and emissions reductions targets at the level of cities and municipalities. Such an instrument has the potential to redirect investment towards more sustainable infrastructure, promote the adoption of green technologies in cities, and encourage green behaviour of households and consumers which stimulate demand for green technologies.

b) Scaling Up Investments: the cost of capital (i.e., the weighted average cost of capital or WACC) is one of the most important elements for an investor to decide when and where investments take place. The cost of capital for low-CO_2 investments can be higher due to higher technology risks or uncertainty in relation to the market and regulatory environment, and this gap is dictated by external factors. With the mission to make it easier for the low-CO_2 solutions to better share risk and attract private investors, the European Fund for

64. Rabe, B. G. (2018) Can We Price Carbon? Cambridge MA: MIT Press. https://mitpress.mit.edu/books/can-we-price-carbon.
65. Rhodes, E., J. Axsen, and M. Jaccard (2014) Does effective climate policy require well-informed citizen support? Glob. Environ. Chang., 29, 92–104, https://doi.org/10.1016/J.GLOENVCHA.2014.09.001.
66. Amdur, D., B. G. Rabe, and C. P. Borick (2014) Public Views on a Carbon Tax Depend on the Proposed Use of Revenue. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2652403.
67. Rabe, B. G. and C. P. Borick (2012) Carbon Taxation and Policy Labeling: Experience from American States and Canadian Provinces. Rev. Policy Res., 29, 358–382, https://doi.org/10.1111/j.1541-1338.2012.00564.x.

Strategic Investments (EFSI) introduced Industrial Investment Platforms for promoting low-CO_2 solutions in 2015-16, which is designed to crowd-in a wide range of public and private investors. The platform itself can provide loans and/or equity financing to the underlying projects which have a strong potential to be transformational in their target markets. As of June 2018, 41 investment platforms have been approved and they are expected to mobilise over €34.8 billion in investments. MEDEAS recommends similar investment platforms to be set up by sponsors or project promoters, such as public authorities or National Promotional Banks and Institutions, social sector players, and private stakeholders, at multiple administrative levels. The European Commission and the European Investment Bank could provide advice on the setting up of such investment platforms, in particular through the European Investment Advisory Hub. Such investment platforms would also be able to perform the function of a one-stop-shop for financing large industrial demonstration projects, in combination with grants or debt-based financing. As an extension, it is also worth considering broader and more ambitious instruments for the transformation to achieve net-zero greenhouse gas emissions by 2050. An example could be the establishment of a European Sovereign wealth fund for providing future-oriented ways of developing strategic sectors with a strong focus on innovation. As argued in EPSC (2019), such a publicly-owned or supported investment vehicle can serve as a strategic tool for European industries to achieve competitive advantages in the global competition and also to achieve the transition to a CO_2 neutral economy.

As acknowledged in the Public Procurement Strategy document of the European Commission, green and circular public procurement can serve as a driver of the transition towards a circular economy and sustainable development. It is recommended that existing policies and instruments should be used more frequently to ensure dissemination of best practices and to make innovative and green public procurement be widely adopted across all member states. The definition of «value-for-money» in tender specifications should be replaced by «value-for-money across the lifecycle of the asset», in a way as specified in Most Economically Advantageous Tender (MEAT) guidelines.

c) Innovation Policies: different stages of the technological innovation process require different policies and financing. In the R&D stage of low-CO_2 technologies, markets tend to undersupply private funds because of higher technology risks and market uncertainties. This creates a strong rationale for governments to fund public R&D and provide grants, subsidies and tax relief to private R&D investments. Demonstration is the next important stage of the innovation process. To help the innovating companies finance the innovative demonstration projects in the fields of energy system transformation, the InnovFin Energy Demonstration Projects of the European Investment Bank provide loans, loan guarantees or equity-type financing typically between EUR 7.5 million and EUR 75 million. At the country level, energy crowdfunding platforms, such as greenXmoney in Germany or

TRINE in Sweden, are being developed to address the financing gap for demonstration in green technologies. Despite the above financial help, most of demonstration projects have to leverage finance from diverse sources. Finding financial closure is typically time consuming and can delay the implementation of projects significantly. Therefore, it is recommended to develop one-stop-shops for project developers to get easier access to blended finance. At the adoption and diffusion stages, policy makers can use fiscal instruments such as withdrawing subsidies on fossil fuel-based technologies or taxing incumbent fossil-fuel based products (or fossil fuels themselves) to help low-emissions innovations compete against incumbent technologies, thus aiding their adoption and diffusion.

Targeted public procurement can serve as an economic instrument to promote innovations and stimulate “greener” production choices. Research based on firm-level data in the 28 EU Member States, Switzerland and the USA showed that innovative public procurement tends to increase the adoption of environmental innovations. Governments can also provide support to innovation and deployment of new technologies through subsidized loans or commercial “green banks”.

Chapter 13.

CLIMATE CHANGE ADAPTATION OF THE ENERGY SECTOR

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13.1 ISSUE DESCRIPTION

Having been scientific consensus for some time, climate change already delivers the expected impacts related to global temperature rise and will bring many more soon. This will challenge almost every level of human societies, as well as the natural environment. In 2013, the European Commission adopted an EU strategy on adaptation to climate change, being aware that "well planned, early adaptation action saves money and lives later." These adaptations could include: "using scarce water resources more efficiently; adapting building codes to future climate conditions and extreme weather events; building flood defences and raising the levels of dykes; developing drought-tolerant crops; choosing tree species and forestry practices less vulnerable to storms and fires; and setting aside land corridors to help species migrate."[68]

However, the model of life we have met so far is threatened not only because of climate change but also by changes in other areas, such as the growth of population, migration, resources overexploitation and depletion, destruction of biodiversity or unsustainable production and consumption of energy. Together these changes and problems create global ecological, energy, security, financial and even humanitarian crises which are unprecedented in the history of modern civilization. Not to mention that those countries which are the most affected by these changes are mostly not equally responsible for this situation. Therefore, the transition towards a climate-neutral as well as socially just economy is not only necessary but also urgent, as the latest IPCC report clearly says.

To ensure Europe's sustainable economy, climate and environment, we need to create societal awareness and acceptance for the aforementioned challenges and adapt to the upcoming changes. MEDEAS analyses, in line with others, showed that changes and strategies which MEDEAS proposed should be implemented as soon as possible. This is the case especially in the energy-related sectors, which are major contributors to global and EU's greenhouse gas emissions. Therefore, energy systems are crucial areas of the urgently needed transition towards a renewable net-zero economy. According to the strategic vision report of the European Commission "A Clean Planet for All", this transformation "relies on a secure and sustainable energy supply". That is why strategies to minimise the impacts related to greenhouse gas emissions and temperature change presented in this chapter are based on research identifying how climate change will affect both the supply and demand of energy. In 2013 the EU adopted an adaptation strategy to make Europe more climate resilient and its response to impacts to climate change. The strategy has encouraged Member States to adopt adaptation strategies, introduced adaptation in the Covenant of Mayors and enabled the climate proofing of the Common

68. See https://ec.europa.eu/clima/policies/adaptation_en.

Agricultural Policy (CAP), the cohesion policy and the common fisheries policy. The adaptation strategy considers measures in number of EU Policy Sectors (Agriculture, Biodiversity, Coastal areas, Forestry, Water management, Marine and fisheries, Ecosystem-based Approaches, Disaster Risk Reduction, Buildings, Energy, Transport, Health, Urban) as well as measures concerning EU Regional Policy. A regulation on risk preparedness in the electricity sector is also part of the adaptation measures prepared by the Commission. In addition, the Commission together with the Member States promotes insurance and other financial products for resilient investment and business decisions.

MEDEAS' policy recommendations, as well as the underlying studies, consider the variety of conditions in the European countries and regions. The expected impacts of climate change on energy generation and consumption include the following: changes in solar radiation intensity; changes in wind characteristics; increased role of air-conditioning: need of heating and cooling; and impacts of these changes on social strata. Finally, MEDEAS considered limitations to renewable energy sources due to climate change impacts and thus, how these changes could affect the planned policies and strategies for the renewable transition.

13.2 WHY WE NEED TO TACKLE THE ISSUE

There are many possibilities and ways how to start, accelerate and to complete the transformation towards a low-carbon economy, as detailed in the 2050 long-term strategy by the European Commission. The EU has set itself targets for reducing its greenhouse gas emissions and this renewable transition should be adopted progressively up to 2050. However, climate change impacts, as well as issues related to the energy sector, are only partly predictable. That is why MEDEAS needed to consider several scenarios of climate change effects on energy supply and demand and take into account the respective consequences. By including these expected climate change impacts (changes in wind, solar radiation, cooling-heating and social impacts) we get a better understanding of the effectiveness of policies and strategies under different conditions of temperature increase and other associated costs.

We know that when a global transition to renewable energy sources is undertaken the temperature change slows down until 2050 and, on the contrary, emissions and temperature continue to grow if nothing happens in the way we produce and consume energy today. However, the degree of the slowdown depends on the strength of the transition and on the rate of penetration of renewable energy sources in the socio-economy. Similar results could be found also at the EU geographical level alone. Results from both the global and European scale are framed in the context of a growing population reaching more than 9 billion people by 2050 in the world and well over 540 million people by 2050 in the EU.

Another important issue related to climate change adaptation is whether the imports of energy will be affected, making the EU more dependent on external energy sources. According to Eurostat, the dependency rate on foreign energy imports increased from 40% to 55% between the years 2000 and 2017, and the results presented in this chapter indicate that both the energy transition and climate change impacts may even further increase such dependence, making the EU vulnerable to political instabilities and supply shortages in the producing countries. To put that into perspective, and also according to Eurostat, in 2018 almost two thirds of the extra-EU's crude oil imports came from Russia (27.3%), Norway (11.2%), Iraq (6.9%), Kazakhstan (7.8%), Nigeria (8.1%) and Saudi Arabia (6.6%). Similarly, more than three quarters of the EU's imports of natural gas came from Russia (40.2%), Norway (35%), Algeria (11.3%) and Qatar (5.8%), while almost three quarters of solid fuel (mostly coal) imports originated from Russia, Colombia and the United States. The most desirable situation is the one in which the rate of decisive implementation of renewable energy sources is the highest since it dramatically reduces the need for energy imports. The later we start investing in renewable energy to tackle climate change, the more dependent on imported fossil fuels the EU will be. In general, the wider the renewable energy sources penetration the less need for imports.

Finally, even when other countries and regions in the world will not tackle climate change, the difference between business as usual and a renewable transition in the EU continues to be very important. However, if the rest of the world does not undertake the transition this will have an effect on the EU of shifting to a more carbon-intensive situation. This is due to the increase in energy demand in Europe to tackle the impacts of climate changes generated on a global scale. Therefore, another potential gain of adoption of renewable energy sources is not only the reduction of greenhouse gas emissions but also diminishing the import of non-renewable sources into the EU.

13.1 POLICY RECOMMENDATIONS

In general, there are several policies or goals related to climate change adaptation in the EU which are already considered during decision making. The EU itself has a policy framework to facilitate the transition away from fossil fuels towards renewable energy and to deliver on the EU's Paris Agreement commitments for reducing greenhouse gas emissions. The Paris Agreement was adopted on December 12, 2015, at the COP21, and has been ratified by 166 countries. The goal of the agreement is to limit the increase in global temperatures to less than 2°C (ideally below 1.5°C), to increase the capacity of countries to adapt to climate change and to direct financial flows toward economic activities that produce very low greenhouse gas emissions.

However, there are also policies specifically related to adaptation of the energy sectors. Climate change and extreme weather events increasingly affect the EU energy system. The current policy agenda on climate and energy for the EU is driven by the 2030 climate and energy framework, adopted by the European Council on 24 October 2014, which includes EU-wide targets and policy objectives for the period between 2020 and 2030 to meet its long-term (2050) greenhouse gas reductions target, in line with the Paris Agreement. The figures for renewables and energy efficiency were subsequently increased in the context of the Clean Energy for all Europeans package. This package was approved on 30 November 2016 by the Commission and includes eight legislative proposals covering governance, electricity market design, energy efficiency, energy performance in buildings, renewable energy and rules for the Agency for the Cooperation of Energy Regulators, and marks a significant step towards the implementation of the energy union strategy. Among the four main targets, there is one concerning CO_2 emissions, which aims at reducing CO_2 emissions by 40% compared to 1990. For 2050, EU leaders have endorsed the objective of reducing Europe's greenhouse gas emissions between 80% and 100% (climate neutrality) compared to 1990 levels (European Commission, 2018). The European Commission has also published a roadmap for building the low-carbon European economy that this will require.

To meet the EU's new energy and climate targets for 2030, the Member States were required to establish 10-year National Energy and Climate Plans (NECP) for the period from 2021 to 2030 (and every subsequent ten-year period), setting out how to reach their national targets, including the binding national target for reducing greenhouse gas emissions that are not covered by the EU Emissions Trading System (EU-ETS). Adaptation goals are part of the NECPs.

The following policy recommendations rely on MEDEAS results and are also in line with many of the above-described EU policies, documents, strategies, visions and goals. Therefore, MEDEAS recommends these three policies related to climate change adaptation of the energy sector:

(1) First, the EU should consider climate change impacts when planning renewable energy sources deployment and electrification. The starting hypothesis in MEDEAS was that climate change may substantially affect the capacity factors of solar and wind technologies, through changes in solar radiation and wind patterns. Of course, there are also other impacts of climate change such as temperature increase, sea-level rise and changes in the water cycle (precipitation, desertification), loss of biodiversity, health problems, etc. In this context, adaptation must support and be supported by the protection of the EU's biodiversity (nature-based solutions).

What the results of MEDEAS analyses show is that the pace and capacity of renewable energy sources to deploy over time and the progressive electrification must take into account potential future climate change impacts so that the future supply infrastructure can meet the potential extra demand. Indeed, with the transition scenario which includes the potential effects of climate change on renewable energy sources and energy supply, climate change reduces the supply of electricity produced from renewable energy sources, which combined with the growing electricity demand following the fast electrification, results in an increased demand for fossil fuels to produce electricity. This phenomenon also causes an increase in overall energy consumption, since the transformation process involves some energy losses. In addition, the extra CO_2 emissions resulting from the increased burning of fossil fuels increase even further the energy demand to mitigate and adapt to the impacts of climate change, hence reducing the net energy available to society.

Regarding energy demand, electrification must progress at a similar pace as the renewable energy sources capacity to produce electricity to prevent having to burn fossil fuels to produce the extra required electricity to fulfil the demand. Moreover, this adaptation strategy provides several synergies, as "the competitive deployment of renewable electricity also provides a major opportunity for the decarbonisation of other sectors such as heating, transport and industry, either through direct use of electricity or indirectly through the production of e-fuels through electrolysis (e.g. e-hydrogen), when direct use of electricity or sustainable bio-energy is not possible" (European Commission, 2018).

(2) Second, MEDEAS argues that leading the energy transition at the international level and helping other regions to accomplish it will be beneficial also at the European level.

All levels of administration need to consider adaptation strategies, including local and regional levels. However, a temperature change of the atmosphere is a global phenomenon and does not depend exclusively on EU emissions. The European Commission is aware of the importance of efforts to cooperate at a global international level. As stressed in the EC's document "A Clean Planet for All": "The EU's long-term strategy cannot be pursued in isolation. The EU must, therefore, promote worldwide uptake of policies and actions to reverse the currently unsustainable emissions trajectory and to manage an orderly transition to a worldwide low carbon future. The EU should continue leading by example as well as foster multilateral rule-based cooperation" (European Commission, 2018). Enhancing complementarity with other key climate documents and strategies remains important.

MEDEAS supports this effort, as the calculations proved that if the world and the EU cover by 2050 at least 90% of the energy demand with renewable energy, the temperature change by 2050 is 1.71ºC, which is above the ideal 1.5ºC expected by 2100. However, the slope of the curve is already flat before 2050, which may indicate that unless greenhouse gases are emitted that are unaccounted for (e.g. release of methane stored in the Arctic permafrost, etc.), the global temperature increase could remain below the 2ºC limit defined in the Paris agreement. On the contrary, if the world would stick to predominantly non-renewable energy sources or starts with the renewable transition too late, the temperatures would increase by 1.83ºC or 2.05ºC, respectively. Therefore, we consider it important to support **innovation and worldwide technology transfer for climate change adaptation to reduce vulnerability and increase resilience**.

(3) Third, effective responses to climate change require innovations not only in technology, but the EU needs to rethink also social, institutional, and most importantly, economic behaviour and related models.

Implementation of carbon capture and storage technologies is not the only effective way to contribute to negative emissions. Climate change itself, as well as many other secondary environmental damages and impacts (e.g. plastic pollution), are the result of an economic model based on frequent purchases and growth. This fact, combined with the urgency of fundamentally transforming our societies, highlights the potential counter-productiveness of imposing very restrictive short-term energy consumption targets and carbon budgets. Indeed, setting too strict carbon budgets in the short term may inadvertently penalize some of those countries pioneering the energy transition. Indeed, as MEDEAS findings suggest, embarking on the energy transition results in rising energy consumption and greenhouse gas emissions at first, until enough renewable capacity is available.

Chapter 14.

CONCLUSIONS

The European Union faces a number of challenges that must be addressed to achieve a successful transition towards a low-carbon, climate resilient society. The H2020 MEDEAS project undertook a scenario analysis across a number of highly relevant issues for EU climate policy. On the basis of this analysis, MEDEAS derived recommendations for long-term policy, which are pertinent for the achievement of EU energy and climate targets and the implementation of the Clean Planet for All Strategy. Starting point for the scenario design was the available global carbon budget in order to limit global warming to 2°C, a target agreed by participating countries at the 21st Conference of Partners in Paris (COP21, United Nations, Paris Agreement, 2015).

The MEDEAS analysis shows that the transition to a low carbon economy leads to a counterintuitive increase of GHG emissions at the beginning of the transition, which appears essential to power the renewable energy deployment. Another important finding is the increasing amount of raw materials that is required for an economy based on renewable energy sources. Furthermore, our outcomes stress the fact that a substantial increase of current renewable energy implementation rates are required to fulfil the EU objectives by 2050. Based on these and further findings, This White Book proposes strategies and policies to achieve the transition with a minimum impact on society's wellbeing. in the following sectors: power sector and grid upgrade, transport, the role of natural gas, energy efficiency, energy costs, financing cross-border energy infrastructure, price regulation, raw materials and re-cycling, environmental impacts, social and behavioural adaptations, economic development and climate change adaptation.

The MEDEAS analysis shows that an important driver for a decarbonised energy system is the growing role of electricity, both in final energy demand and in the supply of alternative fuels. Higher investment levels in renewables and infrastructure are required to reach full decarbonisation while meeting electricity demand resulting from increased electrification of the society. Grid upgrade both at transmission and distribution level as well as sufficient interconnections will have to be prioritized in order to secure the increasing variable renewable energy and distributed production. In addition, it highlights the important role of storage in achieving a secure and flexible energy system. Storage is necessary at different time scales and capacity ranges and different technologies from grid battery storage to pumped storage power plants have different levels of scalability, reaction times and maturity levels. Storage capacity can be utilized for grid stability purposes. With the increase of RES flows in the grid, the importance of markets for balancing services is likely to continue growing in the future.

The analysis also showed that progress towards low-emission mobility requires simultaneously addressing priority actions on low-emission means of transport, efficient organization of the mobility system, infrastructure, i.e. completion of the Trans-European main network (TEN-T) by 2030 and of the comprehensive network by 2050 and speeding up the deployment of low-emission alternative energy for transport, such as sustainable biofuels, electricity, hydrogen and renewable synthetic fuels and removing obstacles to the electrification of transport.

Despite the significant progress made in developing the e-mobility sector in Europe, there are still a number of measures that the European Union could undertake to further support the transition. Steps should be taken to properly design the market to support technological solutions (i.e. smart charging, plug standards) coupled with innovative financing schemes. Until now, the focus has been mainly on implementing policies for passenger vehicles. In the future, the European Commission should actively try to develop policies to target long haul and heavy duty travel in order to integrate e-mobility solutions into this sector. Other sectors that could offer significant potential is the electrification of the maritime and aviation sectors as well as the cargo transport sector.

The design, selection and combination of policies for the decarbonisation of the energy sector must entail a careful consideration of all interdependencies of the economy, not disregarding the economic situation, priorities and individualities of each Member State and overcoming several economic, institutional, political, legislative, social and environmental barriers. Pricing tools to promote decarbonization must in general be part of a well-balanced mix of policies. Furthermore, it has to be stressed that during the policies setting process, it should be ensured that multiple scopes are served. This means that support schemes of RES technologies should not only aim at deployment of the respective technologies, but also, to safeguard final consumers burden in the energy bills, enable their role as prosumers and facilitate grid integration.

MEDEAS also shows the critical importance of energy efficiency and of following consequently the principle “energy efficiency first” in European energy policy. Energy efficiency is the key to a sustainable management of renewable energy resources and materials and should be combined with renewable energy to make the most use of available resources. Without energy efficiency a transition towards a climate proof future is not possible at all.

An additional essential aspect of the transition towards a sustainable energy system and the common internal market are cross-border infrastructures. The promotion of cross-border infrastructure projects and leveraging of the appropriate funding for their realization is a complicated process. It spans from political will and regional cooperation among the interested Member States to European-wide implementation of tools to support and eliminate financial barriers for projects deemed critical for meeting EU goals on climate and energy. Considering the above challenges, it is important to set up an appropriate regulatory environment for cross-border infrastructure projects which should provide transparency, stability, long-term predictability and attractiveness to investors through improved returns on investment, shorter payback periods and lower risks. What is of major importance, since at least two Member States are involved in cross-border projects, is to harmonize national rules and policies, possibly starting at EU level. This harmonization should first consider the benefits and costs and the interests of all relevant actors and Member States during the interconnection in order to enhance the integration of the energy market. The regulatory environment should also foresee and be accompanied by improved cooperation among all relevant actors, from national authorities and EU to system operators and investors, in order to reduce the complexity in the project implementation and increase transparency. While developing such projects, planners should ensure that cross-border infrastructures do not negatively affect low-income groups of citizens or inadvertently create isolated communities. Systematic approaches are needed to develop infrastructure projects that are strongly backed by the public.

Natural gas could also play an intermediate role towards a renewable and energy efficiency based future but investments in gas infrastructure will depend on the development of renewable electricity and fuels, and flexibility needs to ensure the adequacy and operational reliability of the overall energy system. Gas investments should take into account the risk of becoming potential stranded assets in the long term if they are not implemented taking into account synergies with renewables or if technologies such as synthetic or renewable gas fail to achieve the progress expected. It is of utmost importance that in the long term the EU moves towards a system that guarantees not only sustainability but also security of energy supply and substantially reduces dependence on politically volatile fuels. In this context, the gas industry needs to carefully examine both its assumptions and investments in relation to the carbon footprint of natural gas and explore how it can change to be in line with a fully decarbonised energy system. Investments in gas infrastructure assets should properly take into account the specific risks related to the changing gas demand and supply patterns. It is essential that the legislation creates a common playing ground where different solutions are fairly assessed.

Materials extraction and use also plays a very important role in the transition towards a climate benign economy. Securing the supply of raw materials is essential in order to meet the growth in demand that the energy transition will bring but the energy mix should be planned and designed taking into account the expected demand for raw materials, their respective resources and reserves, their economic importance, the international context in which they are being produced, their embedded energy, their recyclability and the environmental impacts along their life-cycle. Developing more resource efficient and durable RES technologies and finding replacement materials for the most critical ones as well as implementing end of life management strategies for RES technologies is essential for a sustainable approach. This includes setting of targets for recyclability, reusability and repurposing of materials and waste. The EU should be accountable for all impacts generated for the extraction of raw materials and the manufacturing of the end use products consumed within its borders.

MEDEAS also looked into the environmental aspects of the climate and energy transition. Among others, the MEDEAS project acknowledges and emphasises the importance of granting financial support to bioenergy production from forest biomass conditional to compliance with sustainability criteria laid down in the Renewable Energy Directive. The utilization of forest biomass for heat or electricity production should only be possible under the condition of a sustainable forest management, where the specific sets of criteria should be implemented on the national level. Moreover, forests in the national parks and nature reserves should be managed according to special plans and left to natural development in selected zones without exceptions. In addition, natural rejuvenation is widely recommended in Natura 2000 areas. Regarding wind energy, a landscape capacity assessment, spatial planning and appropriate site location are the key preventive instruments of negative impacts

Furthermore, MEDEAS recommends upscaling the experiences from coordinated market economies which have vocational training structures with close collaboration between industries, education and research. Although uniform approaches to renewable energy policies exist, this coherence is currently lacking for vocational training and labour skills development more broadly. MEDEAS analyses have revealed that such education policies that take into account coordination between industries and education, as in vocational education and training (VET), may be especially fruitful to enable renewable energy adoption while simultaneously improving energy intensity across industries.

In order to assess adaptation policies, MEDEAS considered several scenarios of climate change effects on energy supply and demand taking into account the respective consequences. By including these expected climate change impacts (changes in wind, solar radiation, cooling-heating and social impacts) MEDEAS was able to shed light into the understanding of the effectiveness of policies and strategies under different conditions of temperature increase and other associated costs. On this basis, MEDEAS makes policy recommendations which are in line with many EU strategies, visions and goals, in particular the Clean Planet For All Strategy. The EU must consider climate change impacts when planning renewable energy sources deployment and electrification. The EU must also lead the energy transition at the international level and provide support in form of technical assistance to other regions of the world regarding the implementation of adaptation strategies. The European Commission is aware of the importance of efforts to cooperate at a global international level. The EU should continue leading by example as well as foster multilateral rule-based cooperation. Effective responses to climate change require innovations not only in technology, but the EU needs to rethink social, institutional, and most importantly, economic behaviour and related models.