Pathways to Sustainable Energy

Accelerating Energy Transition in the UNECE Region

Energy underpins economic development and the 2030 Agenda for Sustainable Development and has a critical role to play in climate change mitigation. The recognition of the role that energy plays in modern society is highly significant, however, there remains an important disconnection between agreed energy and climate targets and the approaches in place today to achieve them. Only international cooperation and innovation can deliver the accelerated and more ambitious strategies. Policies will be needed to fill the persistent gaps to achieve the 2030 Agenda. If the gaps are not addressed urgently, progressively more drastic and expensive measures will be required to avoid extreme and potentially unrecoverable social impacts as countries try to cope with climate change.

This report uniquely focuses on sustainable energy in the UNECE region up to 2050 as regional economic cooperation is an important factor in achieving sustainable energy. Arriving at a state of attaining sustainable energy is a complex social, political, economic and technological challenge. The UNECE countries have not agreed on how collectively they will achieve energy for sustainable development. Given the role of the UNECE to promote economic cooperation it is important to explore the implications of different sustainable energy pathways and for countries to work together on developing and deploying policies and measures.

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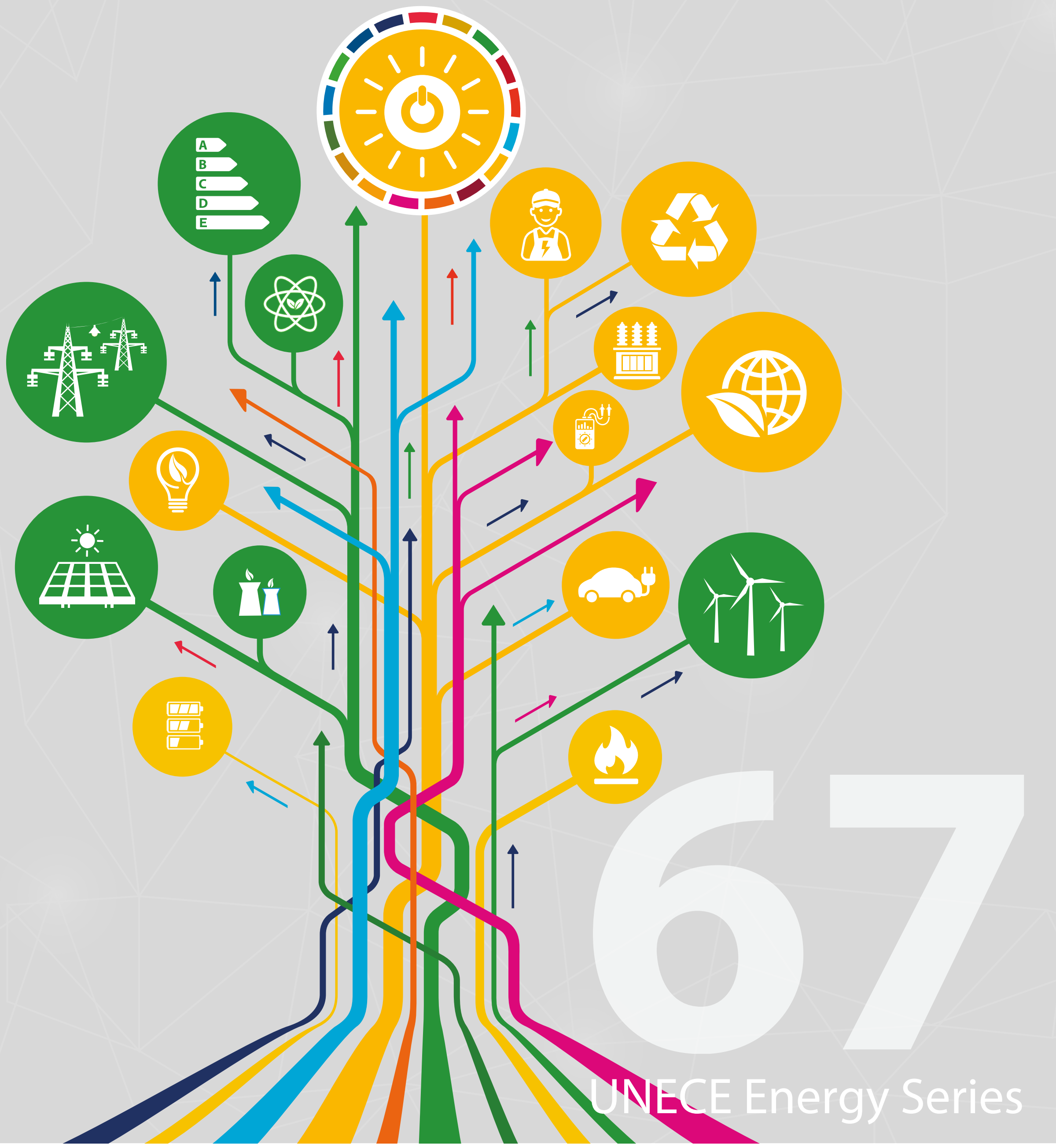

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Foreword

In September 2015 countries agreed to the 2030 Agenda for Sustainable Development that comprises seventeen Sustainable Development Goals (SDGs). Attainment of the goals depends directly or indirectly on the availability of sustainable energy. Member States of the UNECE have asked how the region can attain the sustainable energy objectives in the context of the 2030 Agenda, and there is an opportunity to consider alternative sustainable energy strategies for the UNECE region. The *Pathways to Sustainable Energy* project explores different sustainable energy pathways to provide a basis for policy dialogue and to assess and track attainment of sustainable development obligations.

There are various interpretations both of what sustainable energy is and of how to assess the efficacy of alternative pathways to the desired outcomes. Each country has its own endowment of natural resources and its own cultural heritage and legal and regulatory infrastructure. Its national energy strategy therefore will be tailored necessarily to its own priorities. The response for the region as a whole is therefore complex.

The UNECE Committee on Sustainable Energy has evaluated factors shaping future energy systems and has considered alternative views of how the future might evolve to support development of robust policy and market frameworks. This project was initiated to address uncertainty about a sustainable energy future and to initiate an informed policy dialogue among countries. The project has provided clarity for UNECE member States on how to attain sustainable energy outcomes. It also has initiated mechanisms to provide early warning if the region is not on track to achieve its objectives.

The goals of the 2030 Agenda for Sustainable Development can be achieved through proper stewardship of natural resources, sustainable production and consumption patterns, resilient infrastructure, and coordinated overall system development. Access to affordable, reliable and sustainable energy is key to sustainable development. Energy underpins social and economic welfare, ending poverty, ensuring healthy lives, and raising standards of living. Going forward this project can provide needed impetus for action, so that countries of the UNECE can pursue regional co-operation and work together to attain their collective and individual objectives.

Olga Algayerova
Executive Secretary
United Nations Economic Commission for Europe

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Glossary

Sustainable Energy
The notion of sustainable energy has many aspects and may imply different interpretations by different stakeholders. For the purposes of this project, we have defined "Sustainable Energy" in terms of three pillars: energy security, quality of life, and environmental sustainability, each of which contributes to achieving sustainable energy, but none of which individually or even jointly fully describes sustainable energy. The pillars are interdependent; there are trade-offs but also synergies. The pillars are intimately linked with the 2030 Agenda for Sustainable Development (2030 Agenda). Energy underpins achievement of most, if not all, Sustainable Development Goals (SDGs). In turn, the implementation of most non-energy related SDGs has bearings on the way sustainable energy can be defined. To account for energy-related interlinkages between SDGs, the "energy for sustainable development" framework shall be applied. Each of the three pillars has many attributes. A major contribution of this study is to assign specific metrics (quantifiable measures, see below) to describe the state of each of the three pillars and to track its evolution.

Long-Term Performance Goals
Long-term performance goals (LPGs) are sustainable energy targets with a clear constraint that can be measured and are inherently globally harmonious. The LPGs are desired state of the world at a specific point in time. They cannot be defined such that the goal of one region (or time period) would conflict with the goals of another. By setting a specific, measurable goal, success can be defined as achieving that goal. For the purposes of this project, the constraints will be defined as outcomes in the year 2050 (or 2100). An example of a target is the international agreement to limit global warming to 2ºC.

Metrics
Metrics are quantifiable indicators that are consistent with the attributes of the pillars of sustainable energy. They must be measurable in the real world (e.g., GDP or GDP per capita) and from models' outputs. Metrics are useful because they can help track progress toward goals. Exploring multiple metrics not only gives a more nuanced understanding of sustainable energy, it can also identify synergies and/or trade-offs between different aspects of sustainable energy. Metrics were linked back to energy-related SDGs according to the "energy for sustainable development" framework described under sustainable energy. Metrics either are consistent with indicators of SDGs, such as the share of renewable energy in total final energy consumption, or they can become an "proxy indicator" assigned to a specific SDG. Metrics hence help track progress towards achieving Agenda 2030 (and a view towards 2050).

Key Performance Indicators (KPIs)
Some metrics may be identified as uniquely important. These are called Key Performance Indicators (KPIs). In the context of this project, desirable ranges for selected metrics were used for most of the KPIs. More than one desirable range for a KPI may be defined, but modelling work may have to focus on each one individually, as desirable ranges are not necessarily harmonious (i.e., achieving one KPI may make achieving another easier or harder). As such KPIs are different from LPGs which define the overall sustainable energy target that is to be achieved by 2050. (See Annex 6.4. and 6.5.)

Scenarios
In the context of this project, the term "scenarios" means quantified descriptions or images of the future (often outlined by a storyline). While scenario quantification is synonymous with making assumptions about the future, storylines underpin scenarios by providing a qualitative but internally consistent vision of the future and/or its key developments and events. There are three major elements that were used to develop scenarios: Quantified Assumptions, Quantified Relationships, and Quantified Outcomes.

➢ *Quantified Assumptions*: These are the key drivers of a future sustainable energy system that we take as given for the purpose of scenario development and are inputs to the modelling process. These fall into five broad categories: i) Demographics—the number of people and their geographic, age, and gender distribution; ii) Economic—the evolving economic state of the world, e.g., labor productivity growth rates; iii) Resources—the availability and quality of natural resource assets such as fossil fuels, minerals, uranium, land, wind, solar insulation, water, or geothermal energy; iv) Technology—the set of knowledge and processes that can be used to extract and transform resources to meet energy service demands; v) Institutions and Policies—the formal and informal rules that govern and direct human decisions.

➢ *Quantified Relationships*: These are the rule-based interactions between the key energy system components, i.e. the equations of the model that link the scenario drivers (assumptions) and outcomes in a model. These relationships can be either simple or complex. In this exercise, the relationships are embodied in science-based methods and well-documented, peer reviewed computer codes.

➢ *Quantified Outcomes*: These are quantified measures of human and natural systems that are determined by the assumptions and result from the model relationships. Examples include metrics such as energy extraction, energy supply mixes and shares, demand, imports and exports, land use, food prices, oil prices, pollution, water and withdrawals in specific places and times. Outcomes are contingent on quantified assumptions. If the assumptions change, the outcomes change as well.

Reference Scenario

All analysis begins with a set of baseline assumptions based on historical trends and current policies. It is an evaluation of the world as it stands right now. A reference scenario enables analysis of whether the world is likely to achieve specific goals along its current trajectory. This is a vital part of all research. Analysis of specific metrics based on the outcomes of a reference scenario may show that a long-term performance goal (LPG), such as a 25% reduction in energy intensity by 2050, would likely be achieved with our current assumptions about the pace of economic development and the evolving relationships between energy and economic development. The outcomes of a reference scenario may also show that, under the current set of assumptions and relationships, a specific LPG is unlikely to be attained. The reference scenario for the Pathways project is the Shared-Socio-Economic Pathway 2 (SSP2) (see section 2.3.), a "Middle of the Road" Pathway.

Policy Scenarios

Policy scenarios can take two forms. In the first, a policy proposal is defined and the modelling and analysis shows what the outcomes are. In the second, a goal is set, and the models show what would need to be done to achieve this goal.

• *Analysis of specific policy proposals*: In the first, the implications of a specific policy proposal, such as a $0.50/kWh subsidy intended to increase deployment of solar, wind, and hydropower, can be analysed. Here, the proposed policy is included in the model on top of the baseline assumptions in the reference scenario. In this type of policy scenario, metrics – such as the cost of electricity, total subsidy cost to the government, renewable share of electricity by 2040, or total consumption of electricity and fossil fuels – can be analysed to improve the understanding of the broader implications and end result of a policy proposal.

• *Analysis of a Long-Term Performance Goal*: In the second type of policy scenario, a LPG is implemented as a constraint in the model, with the technology and development assumptions defined in the reference scenario. In this type of policy scenario, a goal is defined – such as achieving a 100% share of renewable electricity generation by 2050 – and the models determine what would need to change in order to achieve this goal. The same general set of metrics as above can also be analysed, with the difference being that the models determine what level of effort and types of changes need to occur to achieve this goal.

The difference between these types of policy scenarios is subtle, but important. In the first, the question is: If I change X in this way, how close to Y do I get? In the second, the question is: If I want to achieve Y, how does X need to change? It is essential to understand that the answers to the two types of questions may be incompatible with each other. The first type of policy analysis can inform as to whether a renewable subsidy of $0.50/kWh is sufficient to achieve the goal of 100% renewable electricity by 2050 or not. It will also inform policy makers on the unintended consequences of a policy action, such as increases in fossil fuel consumption in regions without such a policy. In the second type of analysis, a model will achieve the goal at the least total economic cost (within the context of the reference assumptions and relationships). In this case, who bears the burden and in what way (e.g., changes in food prices or export revenues) is an important part of the analysis. Ultimately, policy makers determine what the final goal is and what types of costs are acceptable in working toward that goal. The models can show whether a goal is achievable within these constraints, but not determine what the "right" level of a target or acceptable costs to society should be. The modelling of policy scenarios led to the formulation of policy pathways. See "pathways" for more information.

Pathways

Pathways are alternative possible trajectories within the overall context of a scenario. They assess the feasibility and implications of a strategy to reach an objective, say, sustainable energy (meeting a range of sustainability objectives simultaneously). They also envisage different means of dealing with incomplete knowledge, uncertainty, highlighting and responding to the different aspects of risk such as lock-in effects and stranded assets.

Abbreviations

BRIICS	Brazil, Russia, India, China and South Africa (plus Indonesia for the purposes of the OECD study)
CCS	Carbon Capture and Storage
CSP	Concentrated Solar Power
COP 21	Conference of Parties - United Nations Climate Change Conference in 2015 in Paris
EV	Electric Vehicles
HELE	High efficiency, low emission
GCAM	Global Change Assessment Model
GHG	Greenhouse Gas Emissions
Gt	Gigatonne
GW	Gigawatt
HPBI	High Performance Building Initiative
ICT	Information and Communication Technologies
IIASA	International Institute for Applied System Analysis
LNG	Liquefied natural gas
MESSAGE	Model for Energy Supply System Alternatives and General Environmental Impacts
NDC	National Determined Contribution
NPV	Net present value
OECD	Organisation for Economic Co-operation and Development
P2C	Paris to 2-degrees Scenario
PNNL	Pacific Northwest National Laboratory
R&D	Research & Development
REF	Reference Scenario (SSP2)
SDG	Sustainable Development Goals
SSP2	Shared Socio-economic Pathway 2
TPES	Total Primary Energy Supply
UNECE	United Nations Economic Commission for Europe
UNFC	United Nations Framework Classification

UNECE Subregions in the model:

BMU	Belarus, Moldova and Ukraine
CAS	Central Asia
EEU	Central and Eastern Europe
NAM	North America
RUS	Russian Federation
SCS	South Caucasus
WEU	Western Europe

Executive Summary

Energy is critical for assuring quality of life and underpins attainment of the 2030 Agenda for Sustainable Development (2030 Agenda). The role that energy plays in modern society is recognised, but there remains an important disconnect between countries' agreed energy and climate targets and what countries are doing in reality. UNECE member States therefore conceived a project to help countries develop, implement and track national sustainable energy policies to mitigate climate change and contribute to sustainable development called "Pathways to Sustainable Energy". The project was designed to inform decision-makers about effective policy and technology options to attain sustainable energy.

Pathways Project – A Tool to Facilitate Countries' Intentions to Attain Sustainable Energy

The project has developed a policy tool to help countries make informed decisions to attain sustainable energy. The approach combines modelling of energy scenarios with policy dialogue, technology research and the development of an early-warning system concept to monitor and forecast if achievement of sustainable energy objectives is on track.

Attaining Sustainable Energy in the UNECE Region - Mission (Im)Possible?

Attaining sustainable energy is a complex social, political, economic and technological challenge. UNECE countries have not agreed how collectively they will achieve sustainable energy. The dialogue alone constitutes an important step forward for countries by highlighting trade-offs and synergies between 2030 Agenda goals and targets, national energy security concerns, quality of life and social aspects, and environmental and economic objectives.

Based on the analysis, the current sustainable energy framework is out of balance, showing that sustainable energy in the UNECE region cannot be achieved unless there are some trade-offs. Countries will make their own decisions and there will be necessarily a mosaic of choices across the region, usually with a focus on energy security with the environmental and quality of life aspirations on the second place.

The region is overdependent on fossil fuels. Today, roughly 80% of the energy mix is fossil fuel-based. Many countries across the region benefit from fossil fuel energy, and coal, oil and gas remain vital for their energy security and economic well-being. The number of people whose livelihoods depend on fossil energy is vast and it cannot be expected that they easily sacrifice their quality of life ambitions in favour of a 2ºC target. In the same way it will be unjust to ignore the impact of climate change across the population of the world as the 2030 Agenda advances.

After many years of debating climate change, the world is still on a path to global average temperatures that are 4-6ºC above pre-industrial levels. Climate science indicates that the Northern Hemisphere will suffer twice that warming and so the impact on the UNECE region will be the most severe. As such levels are considered a catastrophic, existential threat, there is a critically urgent imperative to find a sustainable way forward given the competing interests of governments.

The related structural change of the energy sector needs to start now and for most has already begun. Because the energy transition will increase energy prices, many countries cannot accelerate their pace of change in the face of social upheaval.

The longer structural and policy reforms are delayed, the more expensive these reforms will become. Society will eventually pay the price. Today, we estimate that the countries of the UNECE region need to invest USD23.5 trillion in the energy system by 2050. Changing policies to meet a 2ºC target by 2050 results in additional investments of "only" USD200 billion per year higher for the entire region. Well planned and thought through national strategies can achieve sustainable energy with limited impact on energy prices.

Accelerated decarbonisation of the energy sector coupled with technology change and close subregional and regional cooperation will enable the countries of the UNECE region to attain sustainable energy. The investments need to be distributed across a broader range of technologies, including zero and negative emissions technology options, and across all subregions, to benefit from a deep, holistic transformation of the energy sector in the UNECE region. All the energy stakeholders in the region need to join forces to explore all possible solutions to stop rising GHG emissions, to protect mankind and to meet set objectives.

Solutions to Attain Sustainable Energy

⇨ Immediate Action – Stop Growing the Problem and Limit GHG Emissions

Challenge: The results from the modelling of energy scenarios indicate that there is no economically rational scenario that involves a substantial reduction in the use of fossil fuel before 2050. In addition, the current climate pledges are insufficient to meet the 2ºC target. Countries in the UNECE region need to cut or capture at least 90Gt of CO_2 emissions by 2050 to meet the 2ºC target. Since climate change has no boundaries and not all regions in the world have the same level of economic development, the UNECE region will need to be carbon negative if the global goal is a net zero carbon society. This concept is, however, different from the one investigated in this project and will require further thought.

Proposed solution: The future energy system must be designed with systemic efficiency as its core value. Capturing GHG emissions from the fossil fuels that remain in the energy system becomes an imperative to avoid the impacts of climate change. Significant investment in low and negative carbon technologies is crucial if fossil fuels endure in the energy mix in the mid-term. However, immediate investments in renewable energy can set a scene in the subregions where renewable energy infrastructure is very limited such as the Caucasus, Central Asia, East and South East Europe. Attaining carbon neutrality is the first milestone on the path to sustainable energy and to get there, all technologies have a role to play.

⇨ Mid-term Action - Implement New Policies and Champion Technology Winners

Challenge: Transition to a sustainable energy system implies far-reaching changes in the socio-economic system and may result in economic inequality and marginalisation leading to tension and conflict, if not tackled carefully. The UNECE region is heterogeneous with countries at different levels of economic development. Disproportionate wealth across the region could limit some subregions trying to modernise their infrastructure and accelerate their energy transition. This could be looked at in more detail in a future phase of the project.

Proposed solution: The shift to a sustainable energy system is a long-term undertaking and must embrace all pillars of sustainable development seeking to leave nobody behind and maintaining social cohesion. International financial institutions, United Nations and all governments in the region need to target investments towards low-income countries in order to accelerate energy transition in eastern subregions, e.g. the Caucasus, Central Asia, East and South East Europe. In many cases, the legacy infrastructure is suitable for the region to enhance the interplay between renewable energy and gas and, then further embrace the potential of decarbonised gases. In addition, as the energy transition accelerates, the social and economic impact of the transition needs to be addressed for all and will require rethinking of social values and quality of life aspirations.

⇨ Long-term Action – Embrace Sustainable Energy Based on Circular Economy and Nexus Approaches

Challenge: Energy revolution requires an exponential amount of resources driven by the growing demand for electric vehicles, batteries and storage. Meeting the needs of a sustainable energy future will have implications on countries’ resource base and availability, costs and prices of critical raw materials and rare earth minerals.

Solution: The region needs to embrace sustainable energy within a circular economy and nexus approach. Securing the raw materials for this approach will become a strategic issue. Sustainable resource management practices that embrace circular economy principles and that integrate the full spectrum of the 2030 Agenda should be on the forefront of countries' strategies.

Extensive consultation exercise across expert network resulted in the recommendations and policy imperatives below.

Policy Imperatives

⇨ STOP GROWING THE PROBLEM AND LIMIT GHG EMISSIONS

1. **Pursue energy efficiency as a basis for systemic efficiencies:** Energy conservation and energy efficiency should be the core elements of future energy systems. Energy efficiency and productivity improvements in the production, transmission, distribution and consumption of energy must be addressed as a priority. Such measures also protect the population from energy price increases resulting from decarbonisation.
    - **Develop progressive energy efficiency retrofit schemes for residential sector** and introduce stringent building standards.
    - **Initiate national programmes and encourage private sector** to prioritise improvements in energy productivity for industrial processes and building performance.
    - **Develop progressive mobility solutions to reduce the carbon intensity of transport**. Promote new technologies to reduce all types of travel, increase the use of shared commuter transport and bicycle schemes.

2. **Cut 90Gt of CO_2 Emissions by 2050**: The 2ºC target and net zero commitments can only be achieved with reduced and negative carbon emission technology to bridge the gap until innovative, next generation low-, zero-, or negative-carbon energy technologies are already available and can be deployed widely. Such action must be accelerated and implemented swiftly.
    - **Position carbon capture and storage (CCS) and high efficiency and low emissions (HELE) and negative carbon technologies** in policy parity with other carbon neutral electricity generation technologies (such as nuclear energy or renewable energy) and phase out production and consumption subsidies that are not promoting carbon efficiency.
    - **Identify and support lowest cost CCS opportunities** across sectors and implement them to build experience and capability.
    - **Develop and disseminate investment guidelines for low-carbon technologies HELE and CCS**.
    - **Prevent excessive fugitive emissions in the energy sector. Deploy and disseminate best practice guidance on methane management** (monitoring and remediation) in extractive industries and natural gas system.

⇨ IMPLEMENT NEW POLICIES AND CHAMPION TECHNOLOGY WINNERS

3. **Accelerate the transition to a sustainable energy system:** Modernising and optimising the existing fossil-based infrastructure and integrating renewable energy-based infrastructure is essential to achieve sustainable development. Any reductions in fossil fuel contribution must be managed with appropriate action to mitigate negative socio-economic implications.
    - **Address the social and economic impacts of energy transition starting now.** Mitigating the negative social dimension is key to a just energy transition. All

stakeholders need to be involved in developing new business models and creating job opportunities in order to not to leave anybody behind and avoid regional desertification.

- **Recognise the new cost paradigm of renewable energy and invest** in renewable energy at a rate which at least satisfies electricity demand growth, especially in the Caucasus, Central Asia, East and South East Europe.
- **Address the challenge of integrating intermittent renewable energy into power and heating grids.** Demand-side flexibility and storage can facilitate integration of variable renewable generation. Standards are required to optimise flexible power systems that rely on the interplay of fossil fuels and renewable energy.
- **Build cross border integration and resilience** of energy networks with quality energy access in mind.

4. **Allow new business models to emerge and private sector to take lead in accelerating deep transformation of the energy sector:** There is a need for an overview of countries' policy readiness for the energy transition. Improvements in the legal, regulatory, and market structure frameworks are needed to enable further transformation of the energy system. The improvements need to be transparent, embrace all technologies that can contribute to attainment of sustainable energy and support the emergence of new business models.

    - **Discourage the use of high carbon energy sources with environmental taxes or a price on carbon.** A measure that reflects the costs and consequences of climate change is vital for the economics of lower carbon energy solutions and to catalyze the energy transition.
    - **Promulgate policies to commercialise decarbonised gases** (such as hydrogen and biomethane) as essential elements for advancing decarbonisation through sector coupling and sectoral integration.
    - **Establish regulatory frameworks for big data, smart grids and an integrated systems approach** to support energy transition and create opportunities for new entrants.
    - **Accelerate deployment of Information & Communication Technologies (ICT)** (e.g., smart grids, internet of things, 5G technology for advanced and smart consumption metering etc.) to improve demand-side participation in energy markets, improve supply and demand side efficiencies, and enable greater penetration of intermittent renewable energy.
    - **Implement energy market designs that promote innovative, sustainable and flexible business models.**
    - **Create regulatory frameworks** that foster technological innovation and energy transition in the region.
    - **Set national targets and pursue sustainable energy action plans.** Regional and national early warning systems need to be developed to help forecast progress and indicate optimal pathways to achieve sustainable energy.

5. **Accept that the transition to sustainable energy as a shared challenge:** It requires continuous action and effective, accountable and inclusive institutions at all levels. The focus should be on promotion of mutually beneficial economic-interdependence to accelerate attainment of the 2030 Agenda through integrative, nexus solutions. Neutral platforms, such as United Nations committees, are best positioned to foster dialogue and exchange of best practices and lessons learnt.

    - **Advocate efficient integration of energy markets**, rather than energy independence, to ensure energy security.
    - **Facilitate technological and regional cross-border cooperation** to strengthen best practice exchanges. Introduce and scale up low-carbon technologies engagement in joint investments.

- **Increase investment in renewable energy in the Caucasus, Central Asia, Russian Federation, East and South East Europe**, given that renewable energy potential (power, heat, transport) in these subregions remains untapped and investments are decreasing.
- **Promote dynamic and integrative public private partnerships** and clarify the criteria for assessing sustainability of investments.
- **Accelerate the energy transition in low-income countries** through capacity building, direct investment and best practices exchange.

⇨ EMBRACE SUSTAINABLE ENERGY BASED ON CIRCULAR ECONOMY AND NEXUS APPROACHES

6. **Promote sustainable resource management:** Promotion of a low-carbon, circular economy is a Herculean task that requires significant international cooperation and should not be underestimated, including in modelling assumptions. Sustainable resource management practices that embrace circular economy principles and that integrate the full spectrum of the 2030 Agenda's goals and targets need to be implemented.

    - **Monitor developments of energy storage technologies that need to be promoted to support fluctuating renewable energy systems**. Heat storage in molten salts, phase change materials and other forms of thermal mass, power-to-energy as well as other forms of chemical energy storage also need to be investigated.
    - **Implement waste-to-energy technologies**, especially providing visibility for new, sustainable technologies as options for countries.
    - **Identify subregional opportunities for joint energy system planning** to strengthen national and regional grids, improve energy security and provide integrated planning of resources (such as water, energy and agriculture).
    - **Improve quality of life through better air quality in cities and polluted areas**. This benefit should be included in the cost benefit analysis of energy transition investments.
    - **Explore additional policy options to use concentrated sources and atmospheric CO_2 within a circular economy as a feedstock** for petrochemical and inorganic materials, since large-scale removal of CO_2 from the atmosphere will be required to meet the 2°C target.

Lessons Learnt from the Project and Going Forward

This project is the unique vehicle for understanding the baseline of sustainable energy in the region and can be used as a tool for a much needed, informed collaboration on sustainable energy within the UNECE region and beyond.

Attaining sustainable energy is complex. Each country will pursue its own path based on their economic circumstances and natural endowments. However, regardless of the approach, countries will need such a platform for a common, informed dialogue at regional and subregional level.

As regional trade and mutual energy independence are not straightforward, there is need for partnerships, inclusive dialogue and closer cooperation on both subregional and regional level. We should look at the history of energy transitions and learn the lessons on how to minimise social disruption.

1. Introduction

Affordable, reliable and sustainable energy is key to sustainable development. It is instrumental to the transition to a modern society. Energy remains crucial for social and economic welfare, ending poverty, ensuring healthy lives, and raising standards of living. The energy system of the future must be achieved through sustainable management of natural resources, ensuring innovative production and consumption patterns, and sustainable industrialisation that further fosters building resilient energy infrastructure, as well as proper and coordinated planning of the overall system development.

2015 was an important year in framing international energy and climate objectives for the future. Agenda 2030 provides a framework and the Sustainable Development Goals (SDGs) were agreed. While SDG 7 defines the targets for "clean and affordable energy for all", it is not the only energy-related SDG. The Paris Climate Agreement was drafted and further shaped national energy policies through a global climate change mitigation agenda.

In this context, UNECE countries have been asking how to define sustainable energy in order to move towards it. However, there is no consensus definition of what this is nor how to set objectives for it. Countries do not have a common understanding of sustainable energy and what sustainable energy pathways could look like. Currently, national energy strategies tend to reflect differing national priorities such as, economic growth, environmental and climate concerns, energy access, energy security, and resource efficiency, among others.

The UNECE region, therefore with its highly diverse membership, is an excellent test case for understanding sustainable energy and how to achieve sustainable energy for all. The region is diverse, comprises high and low income countries, countries that are energy rich and energy poor, and countries that are in the midst of an economic transition. Fossil fuels comprise 80% of primary fuel, making the UNECE region one of the largest emitters of greenhouse gases, accounting for about half of global emissions. The region produces 40% of the world's energy while consuming 45%. It is home to important energy industries, generates nearly 50% of global economic output and is dominant in the world's financial structure.

It is, therefore an ideal region to explore the implications of different sustainable energy strategies. The project supports this process by combining the modelling of sustainable energy pathways with a policy dialogue, and the development of a mechanism to track implementation of climate and sustainable development obligations.

This is why the UNECE Committee on Sustainable Energy (the Committee) began the so called "Pathways Project" with the objective to support UNECE countries to develop and implement national sustainable energy policies. The energy system in the region is complex and a subject of many possible policy and external challenges, not least of which is the rapid development of technology options.

Each country has its own starting point in terms of resources, infrastructure, legislative and regulatory framework, and its cultural and natural heritage. Consequently, each country has a distinct set of options for how to proceed. It is essential for countries to explore their options and then to consider individually and collectively how the objectives of energy for sustainable development might be achieved. The approach in this project recognises that sustainable energy policies cannot be developed by anyone in isolation. They need to align with physical energy flows, international agreements, and cross-border energy transmission systems. The tracking of any policy objectives should be in a common format that all UNECE countries can use and it should lead towards Agenda 2030.

2. Pathways Project Design

Project Structure

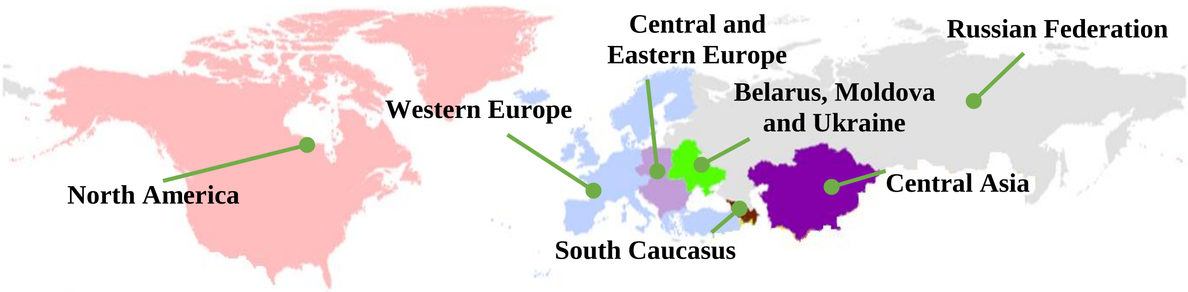
The project was structured in three overlapping phases:

Phase I "Futurise": Repeated discussion with experts and stakeholders and the identification of 13 critical factors shaping the energy future (see Annex 6.1.). The resulting 13 proposals were grouped into three categories, namely i) global politics and economic situation; ii) technology and iii) energy policy and market development. Among the critical factors, the experts chose "degree of cooperation on Sustainable Development Goals" and "advanced technology and business models" as the two most important, uncorrelated factors shaping the scenario space for the project.

Phase II "Modelling": Construction of a robust integrated energy and climate analytical architecture based on complex modelling with three leading institutions. This included a Technology Map to inform countries of the status of several energy technologies and projected the likely costs. It also included a dialogue on how indicators for sustainable energy could be incorporated into the modelling for tracking purposes in an "early warning system". Such an early warning system would aim to monitor if achievement of sustainable energy objectives conforms to a plan and allows to propose course corrections to get back on track (see Annex 6.2.).

Phase III "Informed Dialogue": Repeated stakeholder consultations at the regional and subregional level focused the on assessment of modelling results and preparation of policy recommendations. Results were prepared for the aggregated UNECE level and seven subregions[1]: i) Belarus, Moldova and Ukraine; ii) Central Asia; iii) Central and Eastern Europe; iv) North America; v) Russian Federation; vi) South Caucasus; vii) Western Europe.

Figure 1
Pathways to Sustainable Energy Subregions[2]



Governance Structure

The Committee, an intergovernmental body in the United Nations Development System, and its six subsidiary bodies[3] provided the guidance and the expert network for the consultation process. The project was assisted by an independent Project Advisory Board comprised of high-level international panel of experts (see Acknowledgments).

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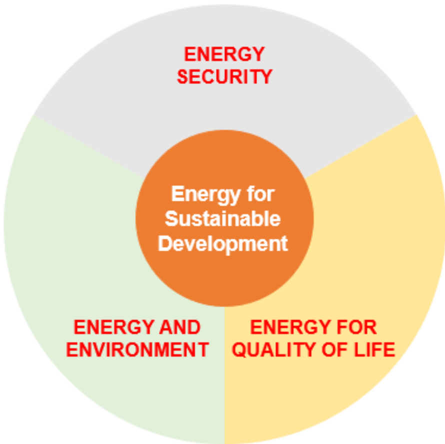
[1] This report shows results mainly on the regional level with some key insights from subregions. This report will be accompanied by a series of brochures on subregions that will be made available electronically on the project website: https://www.unece.org/energy/pathwaystose.html
[2] For the purposes of this study Israel as a member State of the UNECE was included in Western Europe subregion. Complete list of all countries included in each region can be found here: https://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/MESSAGE-model-regions.en.html
[3] i) Group of Experts on Renewable Energy (GERE), ii) Group of Experts on Energy Efficiency (GEEE), iii) Group of Experts on Gas (GEG), iv) Group of Experts on Coal Mine Methane (CMM), v) Group of Experts on Cleaner Electricity Systems (CES), and vi) Expert Group on Resource Management (EGRM).

2.1. Defining Sustainable Energy

Three pillars of energy for sustainable development

There are many different interpretations of what is "Sustainable Energy" and the one adopted for this project recognises the key role that energy plays in economic and social development as well as its environmental impact. For the purposes of this project, "Sustainable Energy" was defined through the three pillars that embrace the most relevant SDGs: i) Energy Security, ii) Energy and Quality of Life, and iii) Energy and Environment (see Figure 2). Relevant SDGs align with these three pillars (as shown in Annex 6.3.). This visualisation highlights the interconnection among the different facets of sustainable energy and trade-offs that countries will face when moving towards one area.

Figure 2
Energy for Sustainable Development



Energy Security: 'Securing the energy needed for economic development'

The Energy Security pillar deals with economic aspects of energy security from a national perspective. It includes accessibility to energy supplies including import, export, and transit considerations. There are considerable social, economic, environmental and technological factors which come into play in this area. Some countries define energy security as energy independence, whereas others see energy security in a regional context, with a focus on interconnectivity and trade. A new perspective on energy security is to ensure that energy makes optimal contribution to a country's social, economic, and environmental development. It requires countries to embrace greater creativity in developing policy, to ensure that they are alert to changes and adaptive in the response and to build resilience into their policies to cope with inevitable surprises. The constraints and opportunities facing countries are not static. New energy options, such as renewable technologies and interconnected grids are increasingly attractive and the threats to energy security are multiplying from climate change policies to geopolitics and terrorism.

Energy for Quality of Life: 'Provision of affordable energy that is available to all at all times'

The Energy for Quality of Life pillar recognises the aim to improve living conditions of citizens by providing access to clean, reliable and affordable energy for all. This objective includes not only physical access to electricity networks, but also the quality and affordability of access to the broader concept of energy services. Costs for energy services including electricity, heating, cooling, and transport are important measures. In relation to bio-energy and its nexus-related considerations, such as competition for resources for food production, food prices can give an indicator to the sustainability of energy as well as food systems. An issue is that, apart from affordability, the benefits of clean energy on Quality of Life are not currently quantified in a mathematical modelling and optimisation approaches, and it is difficult to equate the benefits of clean energy whether they are social or economic, to the energy options chosen.

Energy and Environment: 'Limit the impact of energy system on climate, ecosystems and health'

The third pillar of Energy and Environment represents the trade-offs between meeting the increasing demand for energy, providing a healthy environment with clean air, and protecting mankind from climate change. Energy emissions contribute 60% of total greenhouse gas emissions, so the energy sector needs to reduce its carbon footprint across the energy supply chain to support climate change mitigation efforts. Beyond climate change and air pollution measures, the Energy and Environment pillar also includes further nexus topics such as the competition for use of water in the energy sector, transport emissions, and air pollution caused by energy generation and consumption. In all scenarios, CO_2 emissions are the dominant environmental constraint in this project.

2.2. Measurement of "Sustainable Energy" that can be Incorporated in Integrated Climate and Energy Assessment Models

GCAM and **MESSAGE** – two integrated assessment models based on different methodologies

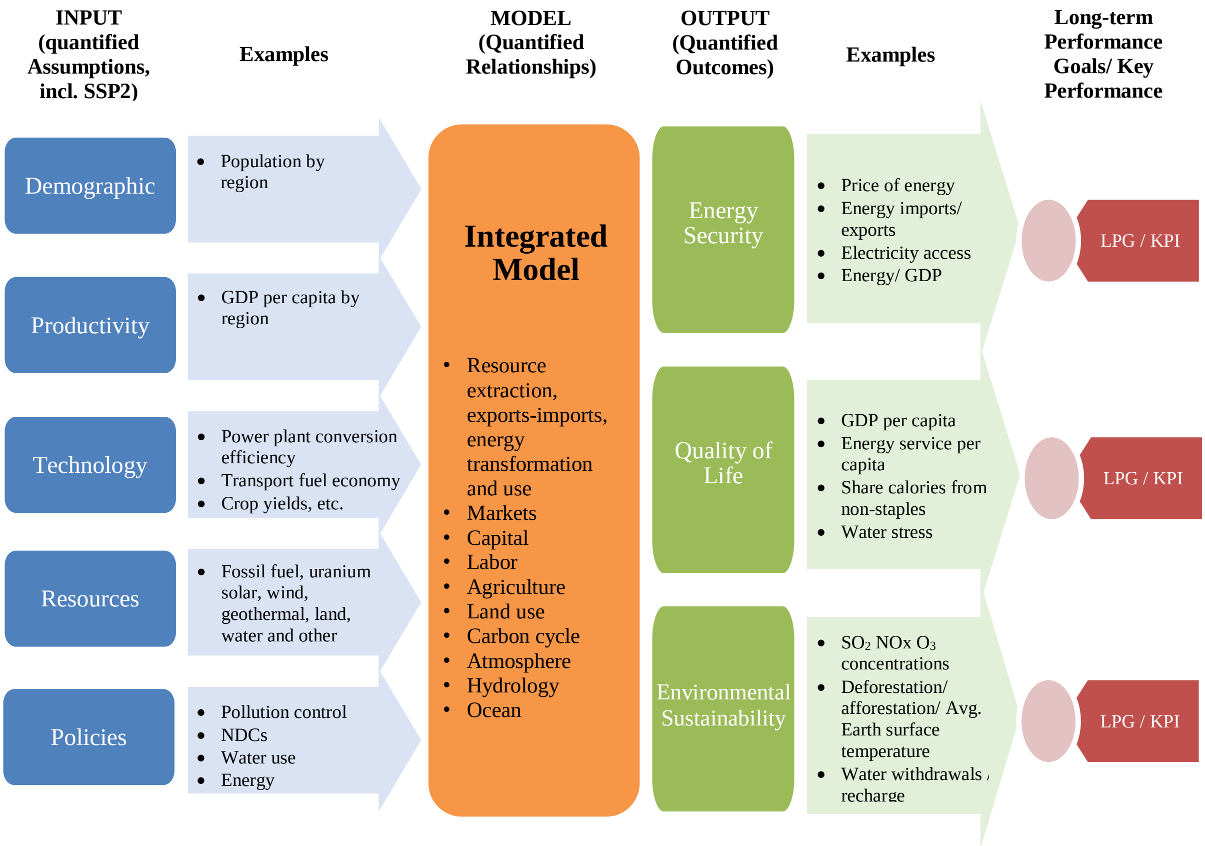
A milestone for the UNECE in the project is the agreement on measures to represent the impact of various climate, technology and policy scenarios. This required the identification of useful parameters that could be part of the models and were developed with stakeholders and the three modelling institutions – the International Institute for Applied System Analysis (IIASA), the Pacific North West National Laboratory (PNNL) and the Fraunhofer Institute.

The unique interplay of two integrated assessment models[4] – the Global Change Assessment Model (GCAM) and the Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE) - provide a unique approach and strengthen the robustness of the results.

[4] Global Change Assessment Model (GCAM) is an equilibrium model that clears markets through iterative price adjustments and feedback loops. Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE) is an optimisation model that is based on the premise that supply must meet predetermined demand at minimum system costs.

This integrated method allowed to deliver a three-pillar sustainable energy framework (see Section 2.1.). To run this framework in a computer model, numerical input parameters and assumptions were needed based on various socio-economic, technological, and climate-related indicators (see Annex 6.4.).[5]

Figure 3
Modelling Approach



[5] Glossary: SSP2 - Socio-Economic Pathways; KPI – Key Performance Indicators; LPG - Long-Term Performance Goals
For more information see the glossary that can be downloaded online: https://www.unece.org/energywelcome/areas-ofwork/pathways-to-sustainable-energy/resources.html

2.3. Policy Scenarios for the Modelling Exercise

This project's results are based on exploring three distinctive scenarios:

Reference Scenario based on the Shared Socio-economic Pathway (SSP2).

The reference scenario is based on shared socio-economic pathway (SSP2), a "Middle of the Road" or Business-as-Usual Pathway, as point of departure. Its socio-economic, market and technology assumptions represent middle-of-the-road developments. SSPs[6] do not include climate mitigations policies or measures other than those existing in 2010. SSP2 provides an appropriate 'base case' for the exploration of multiple (alternative) pathways and is also basis for the Intergovernmental Panel on Climate Change (IPCC) work.

NDC Scenario based on country-level NDCs as pledged by countries.

The NDC scenario assumes the implementation of the Nationally Determined Contributions (NDCs) under the Paris Agreement up to 2030 and then maintains them effectively forever.

P2C Scenario assumes attainment of the 2°C target of the Paris Agreement by 2100.

The P2C scenario is a techno-economic scenario, where regional CO_2 constraints consistent with NDC through 2030 are assumed to continue reduction beyond 2030 and thus allows to stay below 2°C by 2100.

Within each of the scenarios, the sensitivity of the model to the choice of technology is based on a view of technology costs and timescale for implementation. It was decided to explore variations in technology cost assumptions for renewable energy (onshore and offshore wind, solar photovoltaic, concentrated solar power, geothermal energy), CCS, and nuclear power. The costs used in the model are investment and operating costs excluding research and development, government investment and technology learning costs as well as economic incentives for accelerated technology uptake.

The sensitivity of the model to a technology was examined in each scenario to understand the impacts of alternative technology options on policies.

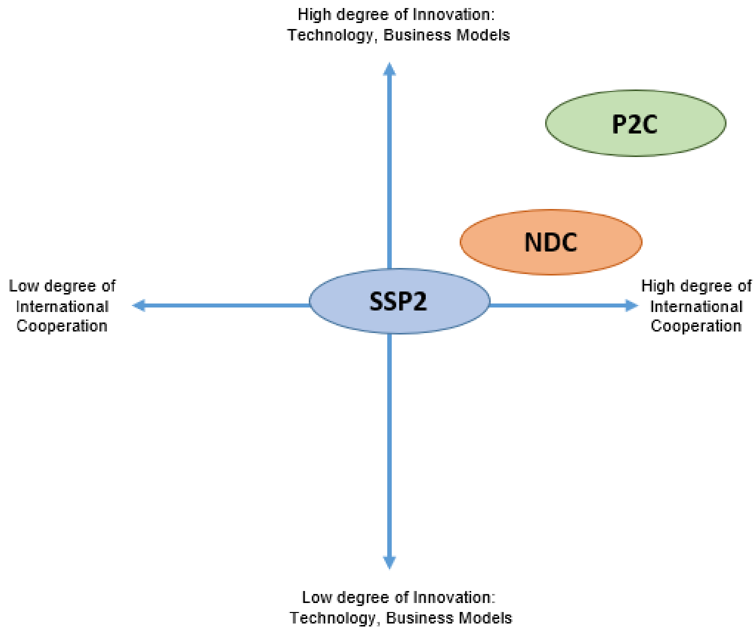
The three scenarios and variations within the technology costs were clustered within the two axes for the scenario space[7] (see Figure 4). Innovation was interpreted as all types of innovation including technology and business models. International cooperation focuses on the willingness of counties in the region to

[6]See page Glossary for more information and detailed description of SSPs in Riahi K. et al (2017): The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. In: Global Environmental Change 42 (2017) 153–168.
[7] These two axes were identified during stakeholder workshops in 2016 and define the most important and uncertain variables influencing the future of sustainable energy. (See Annex 6.1.)

cooperate in order to achieve shared targets under the 2030 Agenda and the Paris Climate Agreement.

Figure 4
From Storylines to Policy Pathways

High degree of international cooperation and high degree of innovation are preconditions for attaining sustainable energy in the region.



3. Modelling Results for Sustainable Energy Scenarios in the UNECE

The following sections of the report compare the primary energy, final energy and electricity generation mix in the UNECE region today with a possible future energy mix based on the three policy scenarios – Reference, NDC and P2C as detailed in sections 3.1 to 3.5. This analysis shows possible technology options to meet the 2°C target in the region.

3.1. Sustainable Energy in the UNECE Region Today

Before examining the model results, it is worth summarising the current situation in the UNECE region. Today, roughly 80% of UNECE energy mix is fossil fuel-based. Even though fossil fuels underpin the quality of life across the whole region, this high dependence implies that accelerated decarbonisation of the entire energy system coupled with technology change is crucial for the UNECE to play its part towards meeting 2°C.

In the UNECE region, about **80% of today's energy mix is fossil-based.** There is a critically **urgent imperative to** reduce carbon emissions to contribute to the achievement of the global 2°C target.

The challenge is significant. In 2015, the region's 56 countries accounted for 39% of the world's primary energy consumption to produce 41% of world GDP. The region produced 40% of the world's primary energy resources and emitted 39% of global CO_2 from fossil fuel combustion. When averaged across the entire region, the share of fossil fuels in total primary energy supply is 80% (similar to the global ratio of 81%). When evaluated across the subregions, the least share is in Western Europe at 71%, and the greatest is in Central Asia at 94%.

In the UNECE, the number of countries and the number of people whose national incomes and livelihoods depend on fossil fuel energy is large. It is important to rethink how the existing fossil fuel infrastructure can be adapted through new business models and innovation in order to allow everybody to meet their quality of life ambitions, create new jobs and not to leave anybody behind.

The world is on a path to global average temperatures that are 4-6ºC above pre-industrial levels, levels that are considered a catastrophic, existential threat. Climate science indicates that parts of the North Hemisphere are likely to experience twice this level of warming. It is critically urgent, even more so for the UNECE region, to find a sustainable balance among competing interests.

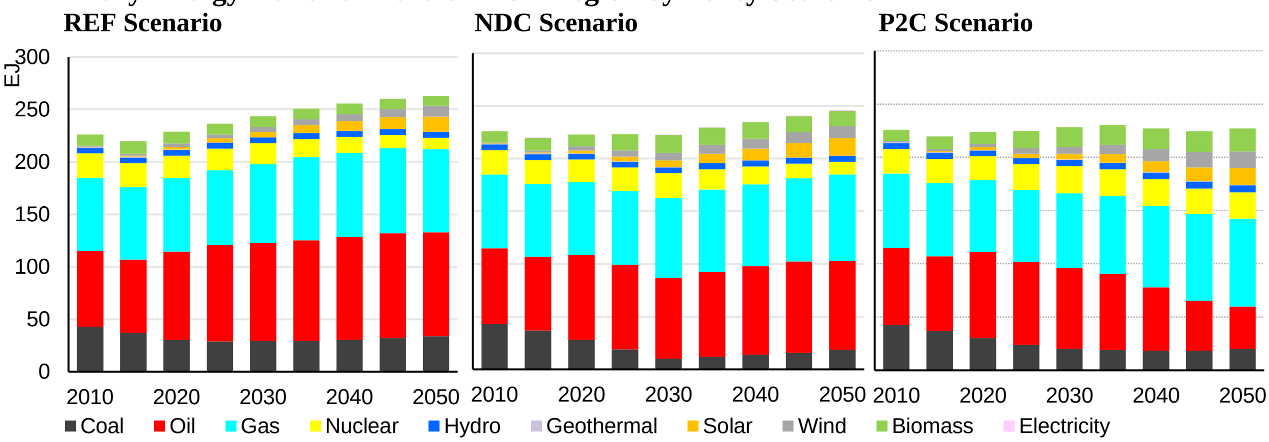
3.2. Energy Demand: Projections for the UNECE Region up to 2050

The integrated energy and climate models assume an economic growth and apply trends in energy consumption to determine the overall energy demand. The models satisfy this demand by selecting the lowest cost energy mix including the time required to install any new capacity consistent with meeting any cap on GHG emissions set by a policy scenario.

There is **no economically rational scenario involving a substantial fall in fossil** energy. **Carbon emissions must be captured** and prevented from entering the atmosphere in any scenario that reduces climate change if the 2ºC target is to be achieved by the end of the century.

Under an economically rational scenario that meets the 2ºC target while delivering on the other dimensions of the 2030 Agenda, fossil fuels (coal, oil and gas) will still account for 56% of the regional energy mix by 2050 (see Figure 5). This implies that alternative energy technologies are either more expensive or cannot be deployed within the timeframe of the model. For example, although renewable energy may be suited for electricity generation, deploying renewable energy in transport sector remains a challenge until costs of batteries further decline and infrastructure adapts to support wider public utilisation of electric vehicles.

Figure 5
Primary Energy Demand in the UNECE Region by Policy Scenario



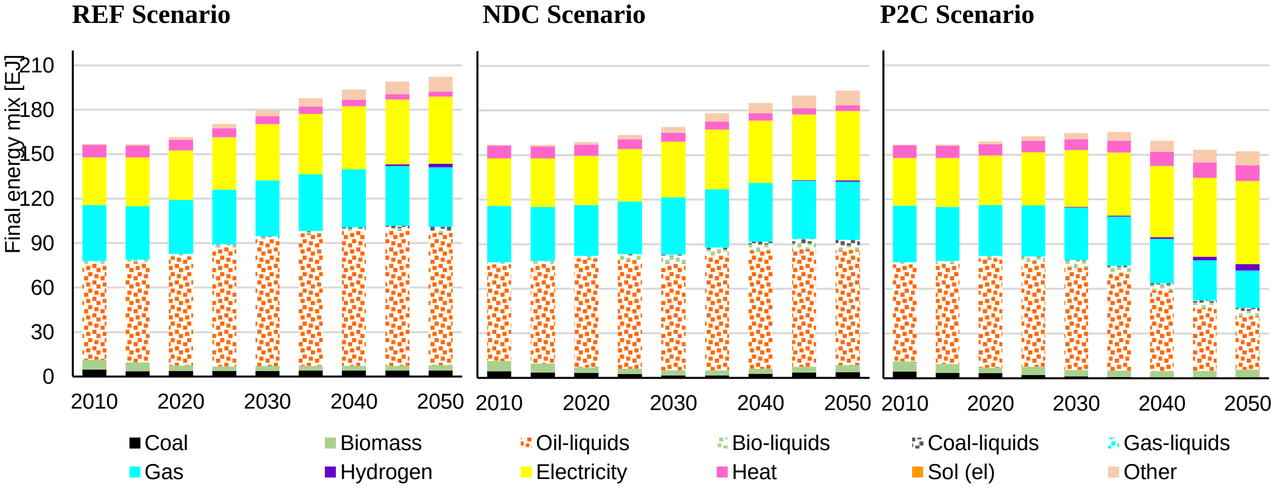
Regional overdependence on fossil fuels makes **decarbonisation urgent**. **Technological change** is crucial to **accelerate energy transition and achieve sustainable energy**.

Similarly to the primary energy mix, the final energy mix in the region is fossil fuel-based (see Figure 6). In the REF scenario, the total final energy demand grows after 2020 by 0.7% annually reflecting demographic change. It is based on oil-liquids followed by natural gas and electricity. Driven by the transportation sector and non-energy uses, demand for liquids is expected to increase through to 2050.

In the NDC scenario, final energy demand is not expected to significantly decline. Minor reduction in demand of about 6% is expected by 2050. This will be influenced by energy efficiency gains, fuel shifting and infrastructure adaptation. Between 2020 and 2050, final energy demand increased for all fuels (albeit at a lower pace than REF) except for district heating and natural gas. Liquids and electricity (gradually generated from renewable energy) are anticipated to substitute gas in the final energy mix.

After initial modest growth, in the P2C scenario, final energy demand declines steadily reflecting climate mitigation induced energy system transformation. In comparison to the REF scenario, final energy demand is expected to contract by about 25%, mainly driven by efficiency and intensity improvements, technology and structural and lifestyle changes, while oil-liquids and natural gas contract, nuclear energy stays strong over time period, consistent with its low-carbon aspect.

Figure 6
Final Energy Demand in the UNECE Region by Policy Scenario



3.3. Energy Demand: Projections for UNECE Subregions up to 2050

The UNECE region is complex with a diverse nature of its membership. It includes some of the world's richest countries, as well as countries with a relatively low level of development (see Figure 1). Providing an analysis solely on an aggregate regional level does not provide enough granularity for countries to explore policy options to attain sustainable energy. This is why this section analyses energy demand by scenarios on subregional level (see Figure 7).

Structural changes in the final energy mix will occur only from 2030 even if more ambitions climate mitigation policies are adopted.

In general, in both REF and P2C scenario little change in the final energy mix is expected by 2030. This implies that even under most ambitions climate mitigation policy scenario that meets the 2ºC target structural changes of the energy system across all subregions are expected to occur only post-2030. The degree of the structural change in some regions is expected to be more radical than in others.

Electrification of the transportation will first emerge in NAM and WEU displacing liquids.

While natural gas is expected to retain its role in the final energy mix, liquids will contract across all subregions through to 2050. This is mainly reflecting shifts in the transportation sector and accelerated penetration of electric vehicles (EVs) where liquids will be gradually replaced by electricity[8]. This trend is expected to firstly emerge in Western Europe (WEU) and North America (NAM) given the level of economic development.

To meet the 2ºC target, SCS primarily needs **electrify its domestic heating system**.

In the Caucasus (SCS), gas exports from this subregion are expected to increase while domestic gas consumption decline in mid- to long-term. In the REF scenario, gas will be replaced with liquids, whilst in the P2C scenario it is expected to be replaced with electricity. This will be predominantly led by the residential sector where electricity is expected to replace district heating.

Natural gas will retain the role in RUS, CAS and BMU for **fueling subregional district heating**.

While the SCS will decline its domestic reliance on natural gas, in the Russian Federation (RUS), Central Asia (CAS) and Belarus, Moldova and Ukraine (BMU) natural gas will continue to play an important role in the final energy mix in all scenarios in mid- to long-term primarily driven by the demand for district heating. From 2040 in the P2C scenario, district gas-fueled heating will gradually be replaced by electricity.

Coal will retain its role in the medium-term but will be replaced by lower and zero emission fuels in the P2C scenario unless coal with CCS commercialised.

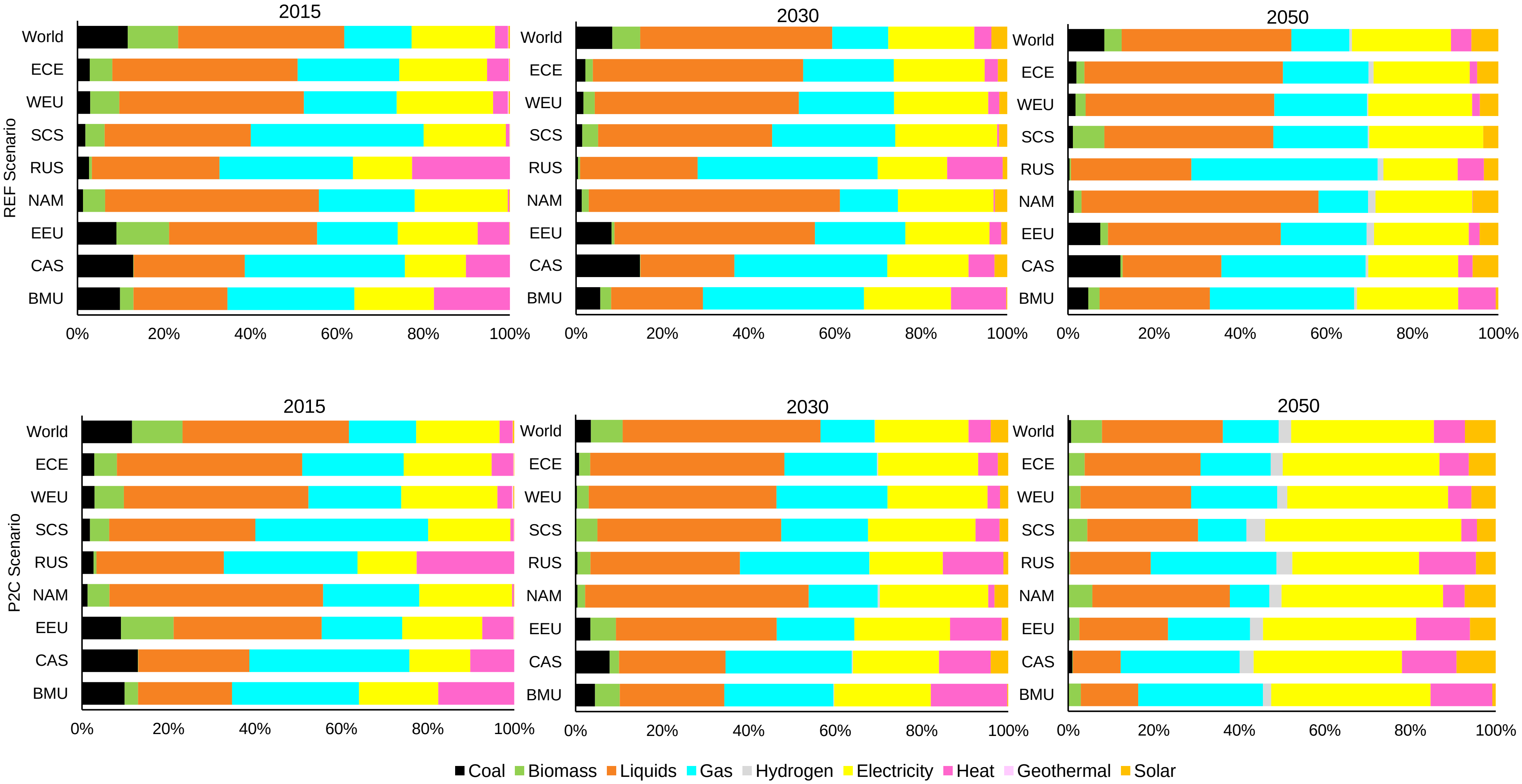
Coal, although marginal in the final energy mix, still retains its role in the mid-term. In the long-term, in the P2C scenario it will be replaced with lower CO_2 emissions sources, such as natural gas and electricity, unless coal with CCS implemented. This trend is expected in Belarus, Ukraine, Central and Eastern Europe (EEU) driven by Poland and in Central Asia (CAS) led by Kazakhstan. As many communities in these countries heavily depend on coal sector, any accelerated phase out needs to be supported by policies that address socio-economic concerns and facilitate structural and *just transition* (see section 4.4.).

Hydrogen plays a role in decarbonising final energy mix **from 2040 in the P2C scenario**.

Finally, innovative decarbonisation technologies such as, hydrogen develop over the longer term incentivised by more ambitious climate mitigation policies. Hydrogen as an energy vector emerges as a solution in all subregions from 2035 thanks to existing gas infrastructure. Hydrogen is well-placed to decarbonise sectors where reducing emissions has proven to be the hardest, such as heavy industry and long-haul transport. This requires investments into new business models and revision of current standards for hydrogen that would allow this energy vector to emerge in all subregions.

[8] For more information on electricity generation in the UNECE region and across its subregions see sections 3.4. and 3.5.

Figure 7
Final Energy Demand in UNECE Subregions by Policy Scenario[9]



[9] BMU – Belarus, Moldova and Ukraine; CAS – Central Asia; EEU – Central and Eastern Europe; NAM – North America; RUS – Russian Federation; SCS – South Caucasus; WEU – Western Europe

3.4. Energy Supply: Projections for the UNECE Region up to 2050

The **future power generation system** incorporates more **decentralised and smart systems and requires CCS in order to mitigate CO_2 emissions**.

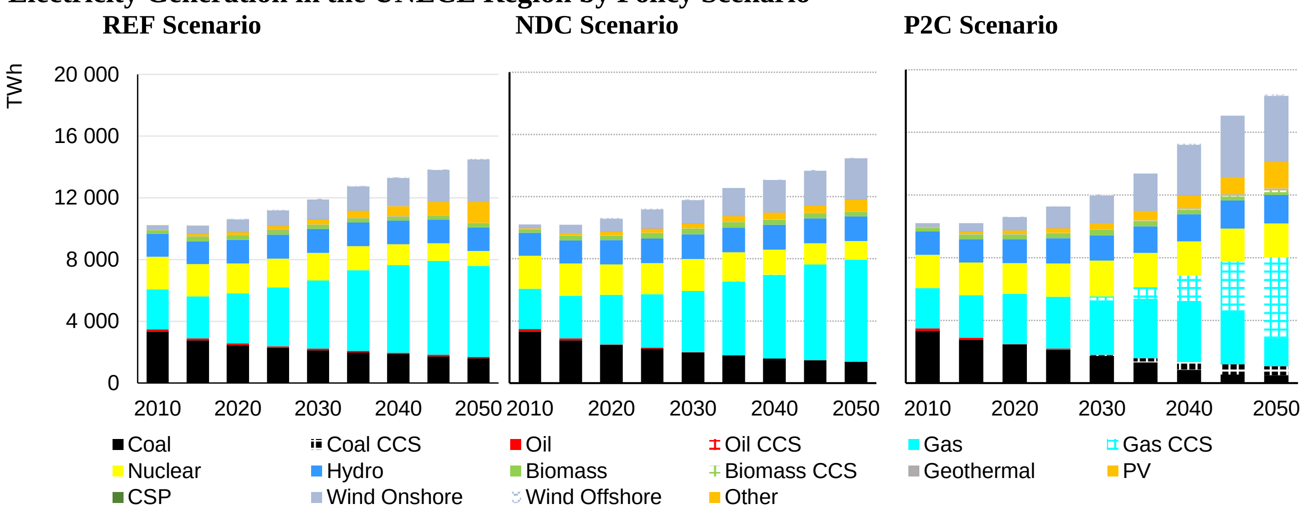
Since access to electricity and reliance on clean fuels and technology are the key indicators to measure achievement of SDG 7, for the purposes of this study energy supply in UNECE primarily focuses on role of various technologies in electricity generation.

The electricity generation mix in the UNECE region today is predominantly fossil fuel-based (coal and natural gas), followed by nuclear energy and hydro. The traditional electricity supply system is defined by large scale plants that generate single-directional, predominantly fossil-fuel based, power and heat to end-users.

Similarly to the final energy mix, the electricity generation mix is expected to experience significant structural changes only under the P2C scenario after 2030. In the NDC scenario, the slight increase in the electricity output is anticipated compared to the REF scenario, primarily driven by the uptake of electric mobility.

The P2C scenario, implies a higher degree of diversification with fast up-take of low-carbon emitting technologies. On the back of the expected widespread electrification of the energy system, 30% higher electricity demand is expected by 2050. Firstly, renewable energy experiences rapid expansion from 2025 primarily driven by wind and solar PV. This is under the assumption that required investments will be targeted towards regions where renewable energy infrastructure is still underdeveloped, such as the Caucasus, Central Asia, East and South East Europe (see section 3.2. and section 4.5.). Secondly, retrofitted coal and gas with CCS will slowly be introduced from 2030 and will increasingly gain traction through to 2050. Whilst conventional coal is expected to slowly phase out, some coal-fired power generation with CCS is expected to retain the role of coal in the power generation mix. Gas and coal with CCS have great potential in the region and if accelerated can serve as an immediate solution to limit CO_2 emissions from the energy sector.

Figure 8
Electricity Generation in the UNECE Region by Policy Scenario



The range of future UNECE electricity generation capacity portfolios necessarily mirrors the scenario-specific generation mixes shown in Figure 9 and can be subject to notable structural change by 2050 depending on how trade-offs between energy security, environmental protection and financing weigh on investment and policy decisions.

Natural gas will continue to play increasingly important role in power generation mix in the UNECE region.

In the REF scenario, the key factors determining the evolution of the capacity mix are electricity demand, fuel market prices, socio-political preferences (excluding climate mitigation) and economic risk perception. Natural gas-based generating capacities become the technology of choice both for replacing capacity retirements and demand growth. This is mainly driven by competitive prices, flexibility characteristics and lower investment costs compared to other thermal generating technologies. Consequently, natural gas experiences steady market penetration serving all segments from peak to baseload supplies. Although serving peak demand has been a traditional market for natural gas, the steadily growing contribution of intermittent renewable generation (growth of wind and solar generation is second only to gas) gives gas a crucial balancing role. In many regions, gas progressively substitutes retired coal, oil and nuclear capacities in the baseload market.

Notable structural changes. For each GW of fossil capacity almost 6 GW of low carbon capacity is expected to be built - of which 75% are intermittent renewable energy[10].

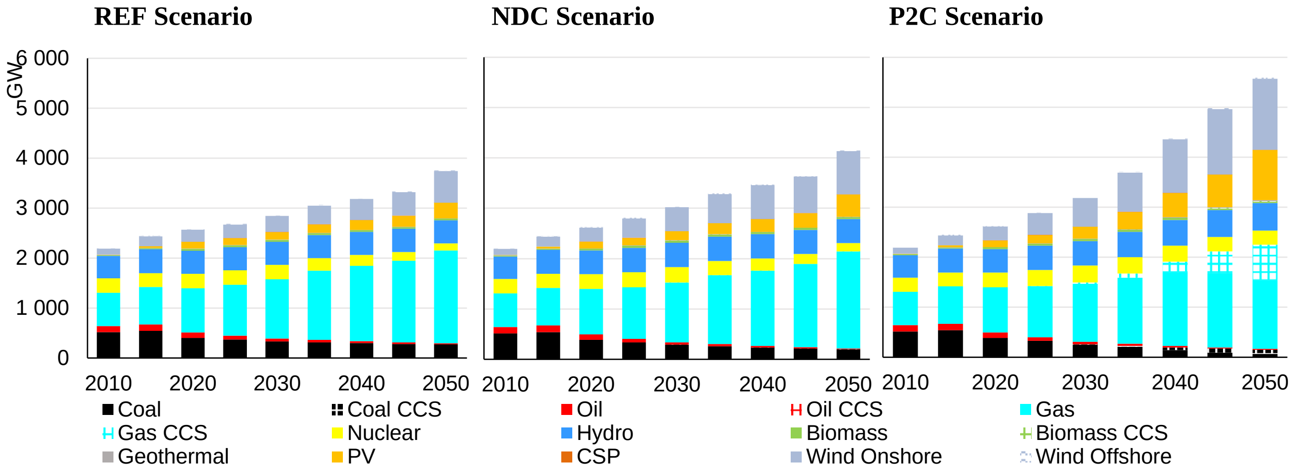
In the NDC scenario, the generating capacity structure differs only marginally from the REF scenario. Until 2030 coal and oil are expected to suffer from regional GHG emission limits and are gradually substituted by a varied portfolio of low carbon capacities ranging from natural gas, nuclear, hydro, solar PV and wind. From 2030 the continuation of NDC emission reductions leads to further substitutions of coal, oil but also natural gas (2030 to 2040) by additional non-fossil fuel capacities. Intermittent generation is expected to provide 25% of total generation by 2050 causing ‘rebound’ of gas capacities after 2040 for load balancing purposes. By 2050 coal generating capacities are 27% lower than in the REF scenario. This, however, does not imply the end of coal – 200 GW of relatively new coal-fired power plants are still operational in 2050. Moreover, limited coal plants equipped with CCS emerge in the market after 2040 - including gas and biomass CCS capacities.

This trend is even more pronounced in the P2C scenario. Total capacity requirements in P2C are 1,840 GW or 49% higher than in the REF scenario.

In the P2C scenario by 2050, renewable energy is expected to account for 55% (3,050 GW) of electricity generation. This translates into a replacement ratio of 18:1 of fossil fuels capacities by 2050 driven almost exclusively by the policy imposed global GHG emission budgets and associated readjustments of final energy mix (higher shares of electricity and, to a minor extent, hydrogen – see Figures 6 and 7). While coal capacities continue to be part of the mix (152 GW by 2050), they are dominated by plants equipped with CCS (86 GW). Essentially all new gas fired capacities built after 2030 are expected to be plants with CCS. Existing infrastructure is expected to be progressively retrofitted. Nuclear and hydro capacities supplement dispatchable baseload from coal and gas (all with CCS) – nuclear power capacities double compared with the REF scenario, i.e. range slightly above current levels (286 GW).

[9]For subregional insights see section 3.5. Such a structural change is not expected in all the subregions at the same level of intensity. Western Europe will lead such a structural change of the energy sector on the back of strong policy push for renewable energy.

Figure 9
Electricity Generation Capacity in the UNECE Region by Policy Scenario



3.5. Energy Supply: Projections for UNECE Subregions up to 2050

Natural gas and coal continue to play important role in power generation across all subregions. **Structural changes occur only from 2030 supported by more stringent climate mitigation policies**.

Similarly, to the trends in energy demand, power generation infrastructure varies across subregions. In the REF scenario, across all subregions power generation mix will continue to rely on fossil fuels (coal and natural gas). More stringent climate mitigation policies will incentivise diversification of the electricity generation mix (see the P2C scenario) However, while some subregions will deploy zero carbon technologies more quickly (fossil fuels with CCS, nuclear and renewable energy), other subregions such as, the Caucasus, Central Asia and Eastern Europe will be lagging. This is mainly due to imbalanced distribution of wealth and investments across the region which will continue to pose a severe challenge for energy transition going forward.

WEU champions renewable technologies in power generation.

WEU continues to champion deployment of renewable energy in the power generation thanks to strong policy incentives. CAS and SCS are catching up in the P2C scenario primary supported by solar and wind.

Coal continues to play important **role** in **EEU, CAS and BMU.**

Under current policies in EEU, CAS and BMU coal remains to be the basis of the electricity generation through to 2050. This implies significant socio-economic reliance on coal sector in some countries of these subregions, mainly Poland, Kazakhstan and Ukraine. In the P2C scenario, natural gas and renewable energy technologies substitute coal in BMU, EEU and CAS in the mid-term and a combination of coal and gas with CCS, nuclear and renewable energy in the long-term.

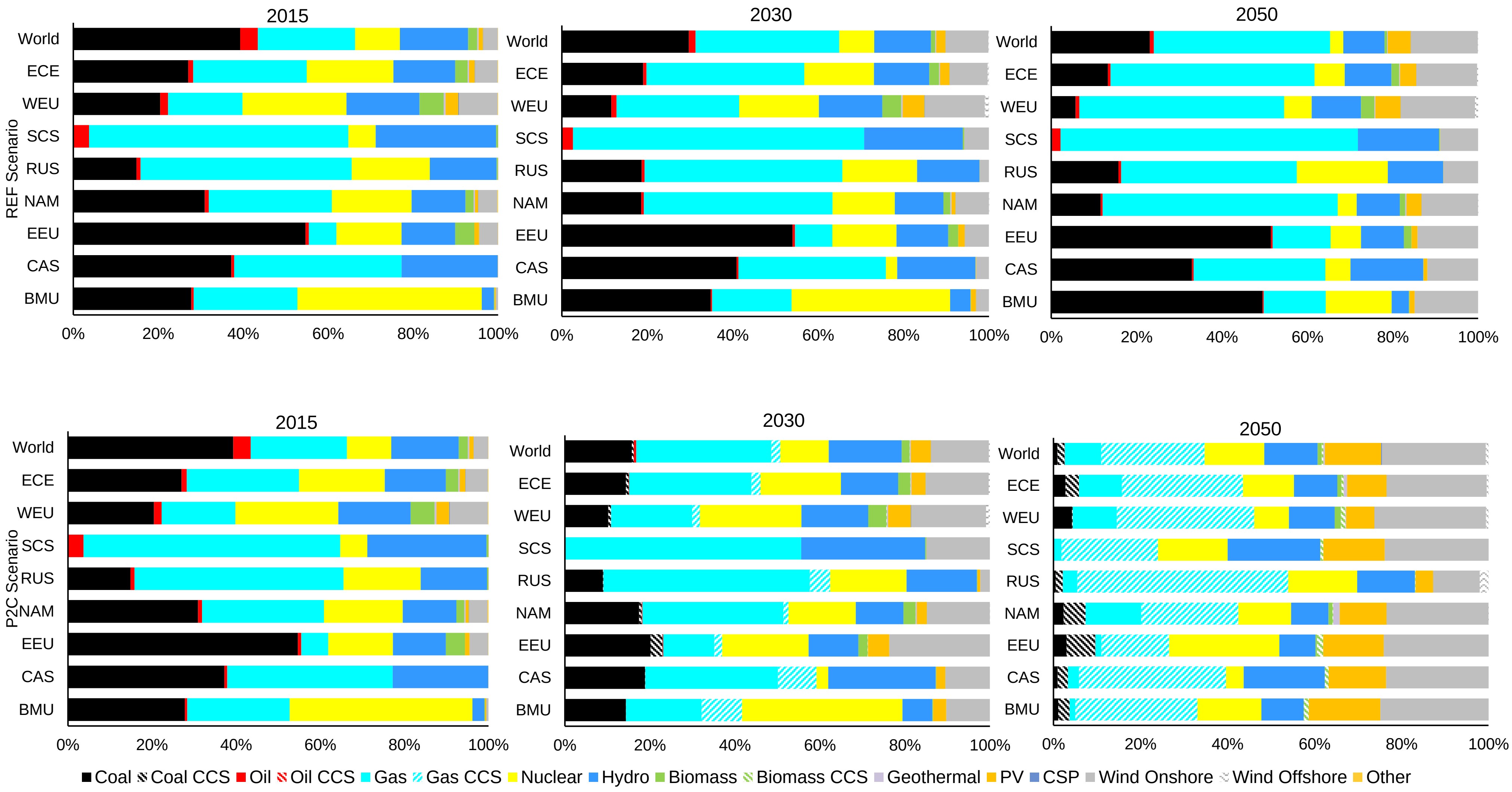
SCS shifts from full reliance on gas to full suite of zero carbon technologies.

In SCS, natural gas continues to be the backbone of the power generation mix. The structural change only occurs under the P2C scenario from 2040, when gas with CCS, nuclear energy and full suite of renewable energy technologies are deployed.

In **NAM and RUS gas and coal** continue to play an **important** role. **Renewable energy technologies are deployed faster in NAM than in RUS**.

Similar trend is expected in RUS and NAM. Power generation in both subregions continues to rely on gas with some coal even in the P2C scenario. More radical change occurs from 2035 when CCS technologies gradually commercialise and coal and gas with CCS are retrofitted. While NAM diversifies its mix and steadily introduces more renewable technologies, RUS continues to rely on gas, now with CCS, and explores renewable technology options yet only gradually from 2040.

Figure 10
Electricity Generation in UNECE Subregions by Policy Scenario[11]



[11] BMU – Belarus, Moldova and Ukraine; CAS – Central Asia; EEU – Central and Eastern Europe; NAM – North America; RUS – Russian Federation; SCS – South Caucasus; WEU – Western Europe

3.6. Projections for Investment Requirements in the UNECE Region up to 2050

Postponing structural change of the energy system **will increase the overall cost of the energy transition**.

Previous sections have analysed the energy supply and demand in the region over both mid- and long-term and explored various technology pathways for countries to meet the 2ºC target.

The required structural change in the region's energy system needs to accelerate immediately to limit global warming to 2ºC as there are significant time lags between investments and beneficial operation.

This section analyses investment requirements in the energy sector in the region in the timeframe from 2020 – 2050. The methodology estimates the capital investment costs associated with each scenario up to 2050 and chose the lowest cost energy mix. In all models, the main driver for the choice of energy mix is the GHG emission limit derived from NDC or overall emissions in the P2C scenario.

The investment cost is reported as the net present value of the investments. This simplifies a comparison of the scenarios. Such a simple comparison is useful but has limitations. The costs are 'typical' and do not allow for country specific details. Discounts rates used to calculate the net present value may vary between countries. The timing of expenditures is not obvious, with investments in the long-term future having less significance in the final net present value (NVP).

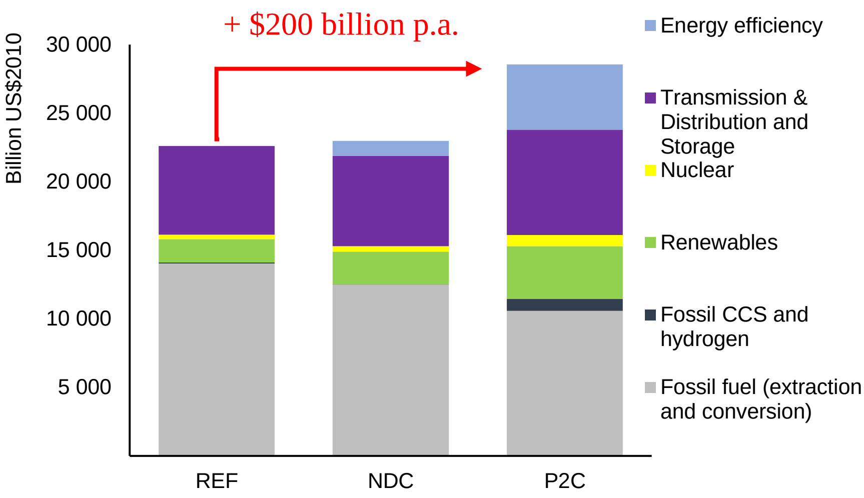
Factors such as the cost of natural resources and access to raw materials to support the emergence of some technologies[12] are not considered. Finally, these investments are also 'unconstrained' in the sense that they assume that the materials, land, natural resources, political and engineering resources are readily available when required. In the second phase of the project, such resource access constraints could further be investigated. An absolute comparison would require very detailed costings beyond the scope of this project.

Overall, in any scenario the models estimate investment costs that are large but still represent a small percentage of GDP. In comparison to the likely impacts on GDP of climate change, they are also not onerous (see Box 1).

[12] There are opportunities to look more into detail cost of natural resources and access to raw materials which are required for new technologies to emerge and become commercialised. UNECE developed United Nations Framework Classification for Resources (UNFC) that provides countries, companies, financial institutions and other stakeholders a tool for sustainable development of energy and mineral resource endowments. UNFC applies to energy resources including oil and gas; renewable energy; nuclear fuel resources; mineral resources; injection projects for the geological storage of CO_2; and the anthropogenic resources such as secondary resources recycled from residues and wastes. For more information see: www.unece.org/energywelcome/areas-of-work/unfc-and-resource-management/about-unfc-and-sustainable-resource-management.html

Today we are ready to invest an estimated USD 23.5 trillion in energy system by 2050. Incremental **investments to attain sustainable energy** while meeting the 2ºC target by 2050 are **only USD 200 billion per year higher** for the entire region.

Figure 11
Comparing Investment Requirements in the UNECE Region by Policy Scenario, 2020 - 2050



In the REF scenario, in the period from 2020-2050 cumulative investments of USD23.5 trillion would be required, of which 50% of the total for the extraction of fossil fuels. Electricity generation investments are expected to be dominated by lowest carbon emitting hydro power and wind plants followed by nuclear power and solar.

In the NDC scenario, during the same period, anticipated investments are slightly higher (by USD800 billion) than the REF scenario, caused by a different investment portfolio. Energy efficiency and intensity reduction measures are steadily introduced. Investments in wind and solar are expected to dominate power generation.

In the P2C scenario, investments are expected to rise by 24% to USD29.2 trillion compared to the REF scenario. Whilst the upstream fossil fuels investments are anticipated to absorb 28% of investments, investments in energy efficiency will account for 25% of the total. Generation commands almost twice as much capital investment as in the REF scenario.

The difference between the P2C and REF scenario is about USD 6 trillion, or USD200 billion annually, which, spread over all economies of the UNECE countries and the timeframe represents a manageable sum compared to savings in costs of climate change (see Box 1).

Box 1
This project's economic modelling exercise solely includes estimates of investment costs in the energy sector (see Figure 10). Other studies exist which look into broader economic implications of climate change, such as impact of sea-level rises, human health effects, heat effect on labour productivity, agricultural productivity, tourism and energy demand (Moody's Analysis 2019). If we do not act now, by 2050 the world will be poorer due to impacts of climate change. Wealthier subregions are better placed to minimise the economic impact of climate change. Whilst in the North America and Western Europe the average real GDP loss is expected to be 1.1% and 1.7% respectively, in Eastern Europe is expected to be 3% (EIU 2019). In the UNECE region, poorer countries in the Caucasus, Central Asia, East and South East Europe are expected to suffer the most. The reductions in GDP from climate change are far greater than the investment costs in the energy sector estimated as part of the scope of this project. There is a need for policies that will embrace holistic economic benefit. To put it into context, according to an OECD study, in 2015 premature deaths caused by air pollution imposed a cost of USD1.8 trillion on OECD and BRIICS countries. This implies that additional investments required to meet the 2ºC target are negligible compared to health care and social cost of air pollution and stresses once more the nexus context of the project. (source: Roy, R. and N. Braathen, 2017)

Developing countries will be **more severely affected by the cost of climate change** than the developed world.

Economies in transition (which represent a large share of the UNECE membership) will be more severely hit by the cost of climate change. Whilst in North America and Western Europe the average real GDP loss is expected to be 1.1% and 1.7% respectively, in Eastern Europe it is expected to be 3% (EIU 2019).

The future of the energy industry in the region looks very different under the various scenarios and there will be winners and losers in all levels of society. The fossil fuels industries will be most negatively impacted but, at the same time, are essential for economic wellbeing during the transition which will last at least until the end of this century. Hence the pace of the energy transition depends on the agility of the utilities and fossil fuels sector towards new business models and innovation.

Investments need to be distributed to **support all zero emissions technologies** – fossil fuels with CCS, nuclear, hydrogen, renewable energy – **across all subregions**.

In 2050, half of the region's energy will still be fossil fuels-based under any economically rational scenario. In all subregions, power generation, district heating system as well as transport sector continues to rely on fossil fuels (see Figures 8, 9 & 10). Investments thus need to be distributed across the broader range of zero emission technology options and across all subregions to enable a swift energy transition towards sustainable energy.

A predictable environment with forward looking policies is a precondition for investments in energy innovation. **Poor governance and instability reduce investor confidence** in some countries in CAS, SCS, BMU and EEU.

The renewable energy sector in the Caucasus, Central Asia, East and South East Europe is still in its infancy. The opportunities in renewable energy remain untapped. There is a need for institutional investments and transaction frameworks. Poor governance, lack of long-term goals coupled with lack of technical local capacity and data on potential of renewable energy technologies have been regularly identified as the main barriers impeding the deployment of renewable energy in these subregions (see section 4.5.).

If achieving 2ºC target has priority above the other pillars of the sustainable energy framework – precisely energy security and quality of life – then many of the current economic priorities will shift towards a swifter energy transition which is not in balance with affordability and economic rational. A gradual change is highly unlikely to meet the target set in the P2C scenario.

The next sections of the report analyse the relationship between the three pillars of sustainable energy in the region and potential trade-offs.

3.7. Pillar I: Modelling Implications for Energy Security and Regional Interdependence

Energy security is a priority for countries.

For the region, ensuring energy security as part of the ongoing deep transformation creates an imperative to mobilise the necessary investment in the energy system of the future that is rational and pragmatic socially, environmentally, and economically.

For the UNECE region, **promoting mutually beneficial economic-interdependence** would accelerate attainment of the sustainable energy and 2030 Agenda.

Energy security is needed to ensure that energy supply, transformation, transport and demand make significant contributions to countries' social, economic, and environmental development. Countries that consider that energy supply can be assured through energy independence are prepared to pay a premium for it. Other countries consider that energy security can be achieved through diversification of technology choices, suppliers, transit routes, and consumers. Countries tend to focus on national level actions even when it would appear that global and regional solutions would be more effective if there were a culture of interdependence and reliability in energy transactions.

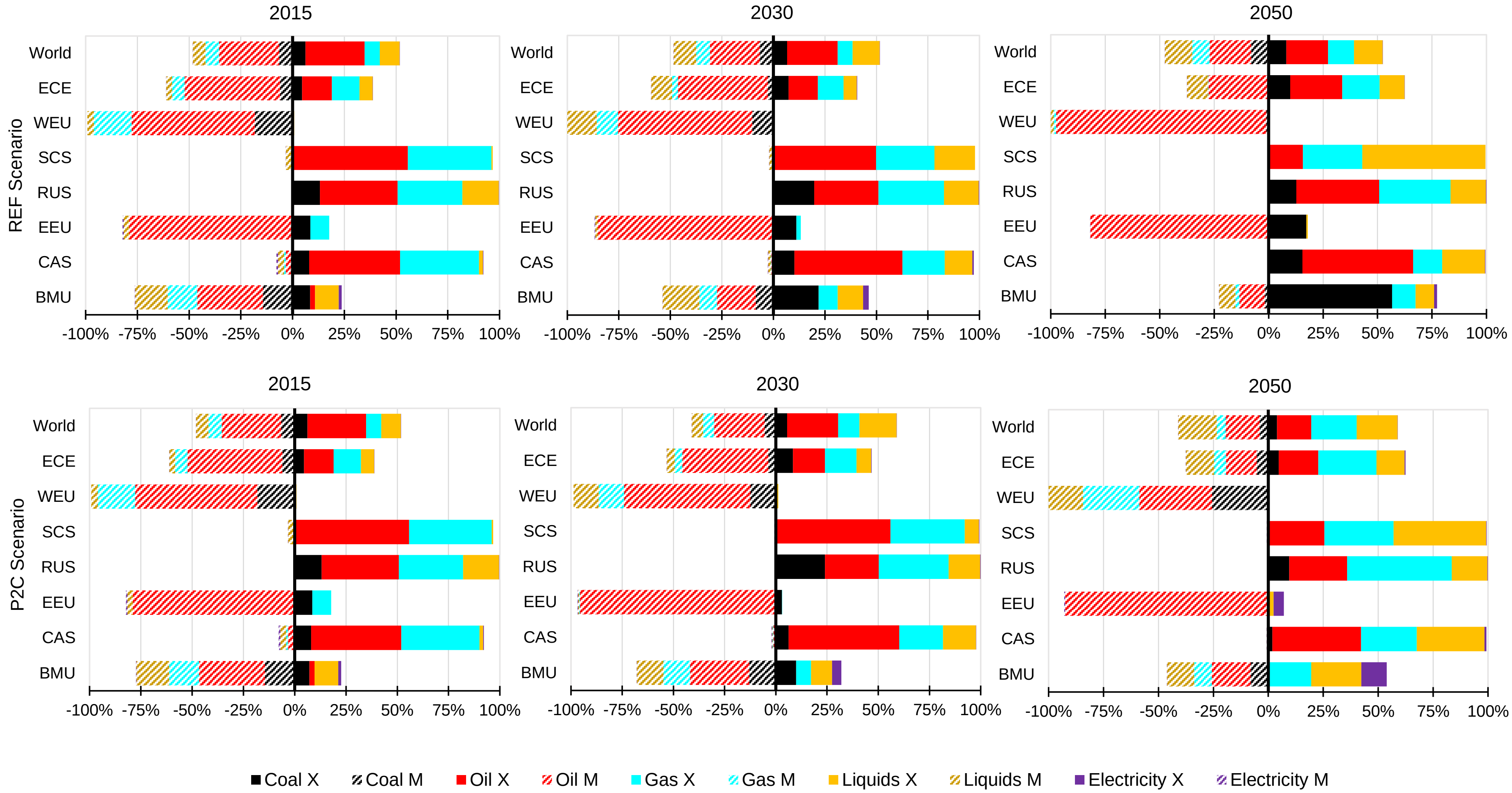
Trust and interdependence strengthen resilience of energy infrastructure and address potential risks.

Concepts of energy security have evolved over time from security of supply seen by importing countries to broader views of energy security that embrace supply, demand and transit. With increasing penetration of digital technology throughout the energy system and with intensification of climatic events, the energy system is exposed to new risks of either human (e.g. hacking or terrorist attacks) or natural origins (events like forest fires, hurricanes, or flooding from rising oceans). These additional security risks create an added imperative to address the challenge of resilience in terms of both planning and recovery. Trust and interdependence can help strengthen resilience of the system and protect regional energy security.

Most countries depend on either fuel imports or exports for their economic wellbeing. Others need transit fees to supplement government budgets. The diversity of trade flows is depicted in Figure 12[13]. Some subregions remain importers across all scenarios and time periods, e.g. WEU. Others, e.g. CAS, RUS and SCS are predominantly exporters with marginal or no energy imports. A general trend in the REF scenario is a shift towards trade of higher value-added refined products (e.g. liquids in the cases of SCS or CAS). This increase is driven by a switch from carbon-intensive fuels to low- or no-carbon fuels in scenarios with GHG emission constraints (NDC and P2C scenarios).

[13] Note: Solid bars indicate exports (right side in the panels) and hashed bars imports (left side). The bars show actually traded volumes in EJ as shares of total trades of a region, i.e. relative significance of different traded fuel commodities in the regional energy systems. The bars across exports and imports add up to 100%.

Figure 12
Energy Trade Balances in UNECE Subregions by Policy Scenario[14]



[14] BMU – Belarus, Moldova and Ukraine; CAS – Central Asia; EEU – Central and Eastern Europe; NAM – North America; RUS – Russian Federation; SCS – South Caucasus; WEU – Western Europe

3.8. Pilar II: Modelling Implications for Energy and Environmental Sustainability

There is an **urgent need to accelerate the transformation** to avoid tipping the climate into a dangerous state.

The region's ongoing dependence on fossil fuels is economically rational but has major implications for CCS if it is to meet sustainable energy objectives. Current NDC mitigation commitments are insufficient to achieve the 2ºC target. More determined action is needed before 2030.

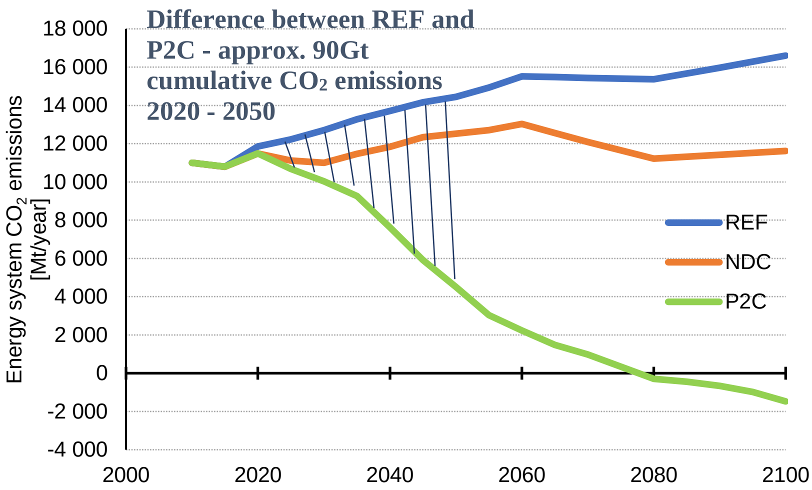
In the REF scenario, a temperature increase of 4.2°C is expected by 2100. Cumulative regional emissions are expected to amount to 1,250 Gt CO_2 (2020 – 2100). Under this scenario the impacts of climate change are expected to be severe and will probably trigger unrecoverable changes in the climate system, which the world probably does not have the resources to control.

In the NDC scenario, a temperature increase of 3.0°C is anticipated by 2100. Cumulative regional emissions are expected to be 18% (225 Gt CO_2) lower compared to the REF scenario (2020 - 2100). Under this scenario, the impacts of climate change are expected to be severe and may trigger unrecoverable changes in the climate system with serious consequences for the economy and society as a whole.

In the P2C scenario, a temperature increase of 2.1°C is expected by 2100. Under this scenario, emissions peak by 2020. To meet the target, negative emissions are mandatory post 2070. Under this scenario, climate change would be limited to, for example, more extreme weather patterns, major damage to coral reefs and marine systems, and major movements in agriculture.

Figure 13

CO_2 Emissions in the UNECE Region by Policy Scenario



Any economically rational scenario still implies that 50% of the region is based on fossil fuels in 2050. The difference between the REF and P2C scenario in cumulative CO_2 emissions from energy system from 2020 to 2050 account for approx. 90Gt of CO_2. This implies urgency for the widespread commercialisation of the CCS projects or other negative carbon technologies.

The **UNECE region needs to be carbon negative** by the middle of the century to offset other regions for which attaining the 2°C target is even more challenging given their level of economic development.

CCS is crucial, unless new technology becomes available, for keeping the region on track to meet 2°C target and attain sustainable energy. By 2050, the region must have the installed capacity to sequestrate 5Gt/yr of carbon dioxide. It is important to note that capacity available today is about tens of millions of tonnes (Global CCS Institute 2017). Since the region produces 39% of the global CO_2 emissions and includes countries with the highest level of economic development in the world, one can argue that this region must be carbon negative in order to compensate for the countries for which attaining carbon neutrality[15] is more challenging given their level of economic development .

3.9. Pillar III: The Importance of Energy Affordability

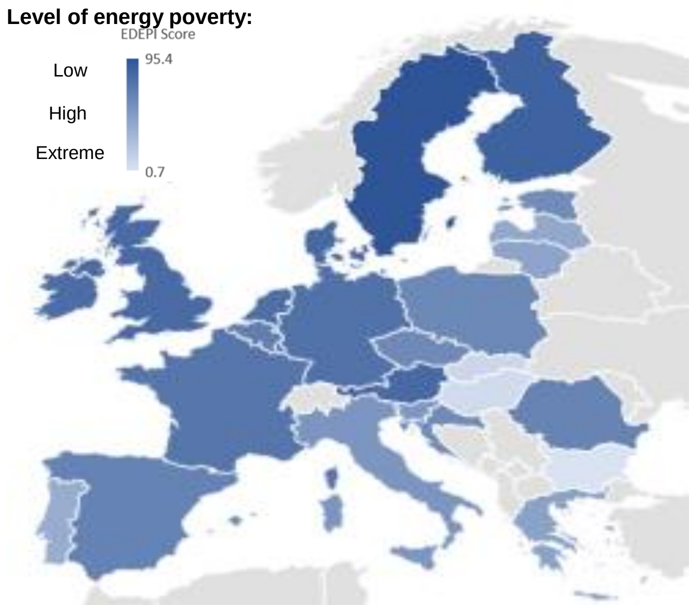
Energy poverty is a severe problem in the whole region.

In many countries across the region, energy poverty still needs to be tackled. Even in the European Union (EU), majority of EU countries have ‘moderately high’ to ‘extreme’ levels of energy poverty among low-income households (see Figure 14). Energy poverty is especially prevalent in south and east of the EU.

Energy poverty needs to be tackled across the whole region **including energy efficiency to insulate populations from the costs of decarbonisation.**

Figure 14

Energy Poverty in EU, EU Domestic Energy Poverty Index[16] in 2019



Source: OpenExp 2019

[15] Carbon neutrality or net zero carbon footprint, refers to achieving net zero CO_2 emissions by balancing carbon emissions with carbon negative technologies, such as afforestation or reforestation, bioenergy with carbon capture and storage, direct air capture, soil carbon etc. or simply eliminating carbon emissions altogether.

[16] The EDEPI index is based on four key indicators: damp and leaky homes, high energy costs for households, inability to keep homes warm in winter, and inability to keep homes cool in summer.

In Central and Eastern Europe, over 50 million of EU citizens cannot afford enough energy to support their health and well-being. The elderly population is the most vulnerable as energy bills sometimes equal 30% of their monthly pensions. This situation is more severe in countries with lower level of economic development in the Caucasus, Central Asia, East and South East Europe.

Poor insulation of buildings is one of the key opportunities for action across these subregions. Socio-economic factors play the main role in high energy poverty levels. Countries with better buildings regulations and higher GDP per capita show lower levels of energy poverty. There is need for policy action to address poorly maintained infrastructure, and buildings are an easy target.

A decarbonisation of the economy will have both positive and negative impacts on energy affordability. Investing into retrofitting of homes to cut emissions and energy bills is the first step towards fighting energy poverty and climate change in the region. Until this condition is not addressed costly energy transition will only create more financial burden to the most vulnerable citizens.

As energy transition comes with its cost (see Figure 11), it will create new energy affordability challenges across the whole region. This transition needs to embrace and lift people on all levels of the society not leaving anybody behind.

3.10. Trade-offs and Synergies between the Three Pillars of Sustainable Energy

Attaining sustainable energy is extremely challenging. The project has shown just how impossible it seems to be to fully satisfy all three preconditions of the sustainable energy – energy security, quality of life and climate change – simultaneously. There are trade-offs as three pillars are in constant competition and thus one could speak of a tension between at least two of the objectives or pillars.

Trade-off between **energy security and climate change.**

Since energy security is a priority for countries, countries that have access to fossil fuels are likely to continue to burn them as long as their economies continue to rely on them. There is a need for policy measures that will price carbon and create new business models needed to allow zero carbon energy solutions to emerge. Such countries need special attention by the international community to finance forward looking low-carbon energy infrastructure.

Trade-off between **affordability and climate change.**

Energy poverty is already a major problem in the region. Any additional increase of cost of energy may result in social unrest, which governments in power will avoid. Long-term plans need to be developed to mitigate rising electricity prices (that come along with investments in new energy infrastructure) and creating burden on already high cost of living for some levels of society. Prompt policy action is likely to lower any negative consequences and amplify the benefits. What does this mean for the region?

Across scenarios, energy and environmental indicators in the region improve until 2050 while energy expenditures per GDP are consistently higher compared to 2020 (see Figure 15).

Energy security indicators improve as the region shifts **from net energy importer to net energy exporter**.

Energy security indicators in the region improve driven by generally lower final demand growth after 2030 and the region's shift from an overall net energy importer to a net exporter which is supported by the 'energy import dependence' indicator shown at zero by 2050.

This trend is driven by doubling of oil exports while reducing oil imports by some 20%. The switch from a net energy importing to a net exporting region also improves the indicator 'total energy cost of energy sector per GDP' as export revenues reduce total costs and boost GDP.

Environmental indicators generally improve as the share of renewable energy in the energy mix expands. In addition, energy efficiency improvements lead to lower final 'energy intensities' resulting in reductions in CO_2 emission per GDP as well as per unit of electricity generated.

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While the decarbonisation of electricity generation and of the overall economy progresses moderately, this is not the case for the entire UNECE energy system. The carbon intensity of 'total primary energy supply' (TPES) remains almost unchanged at 2020 value. The indicators confirm that electricity generation represents 'low-hanging fruit' for decarbonisation. In the absence of environmental drivers, it can be expected that regional GHG emissions will increase at the growth rate of TPES. This means that decarbonisation targets after 2050 will become increasingly harder to meet with the technology options included in the model and new options may well be needed.

Environmental indicators improve on the back of **deployment of renewable energy and improvements in energy intensity.**

Given the modest differences in the energy mixes between the NDC and REF scenarios, one would expect few differences in their respective indicators. Clearly, the overall configurations of the radar chart entries seem to bear a close resemblance to each other, but important differences exist. Firstly, all carbon intensities are consistently lower in the NDC scenario compared to the REF scenario including the carbon intensity of TPES. Secondly, the share of renewable energy is slightly higher in the NDC scenario than in the REF scenario. In the NDC scenario, the increase in expenditures is the driven by the effective NDC constraints and exhibits the beginnings of energy system transformation in the region beyond the business-as-usual rate of change.

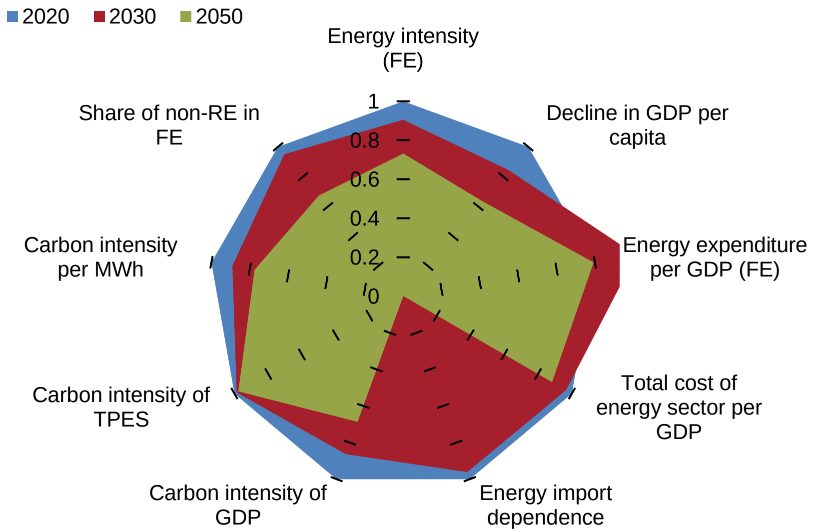
The P2C scenario indicates a considerable impact on the affordability of **energy associated with the underlaying energy system transformation**.

Across the region, the P2C scenario shows the improvement towards the sustainable energy goal most dramatically. All GHG related indicators improve significantly - carbon intensity of TPES, electricity and GDP are between 60% (TPES) and 85% (electricity generation) lower by 2050 than in the REF scenario. The improvement of these environmental indicators is driven by increased investments in energy efficiency measures resulting in 30% lower energy intensities and an 80% share of near-zero carbon supply of energy provided by renewable energy, nuclear and fossil fuels-based electricity generation with CCS. Until 2030, the indicators 'Energy expenditures per GDP' and 'Total energy sector cost per GDP' are largely comparable to NDC (only slightly higher). The main impacts occur between 2030 and 2050.

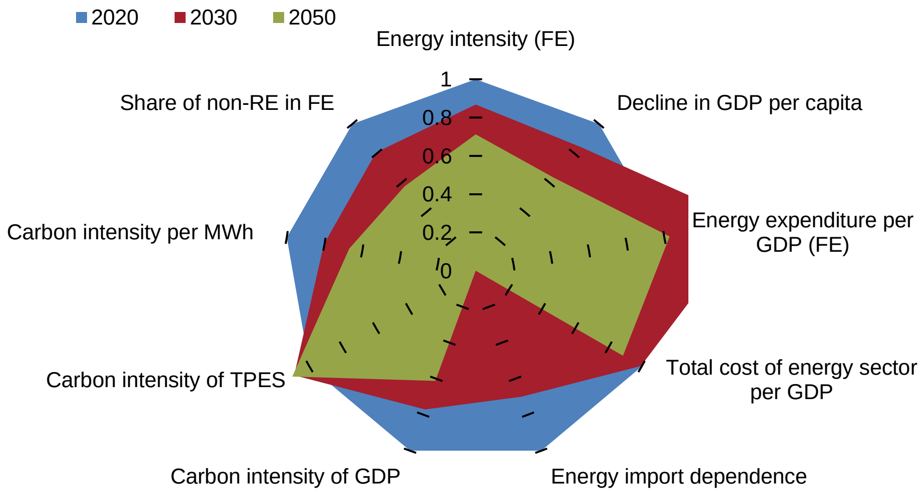
Figure 15

Trade-offs and Synergies based on Energy and Environment Indicators in the UNECE Region by Policy Scenario

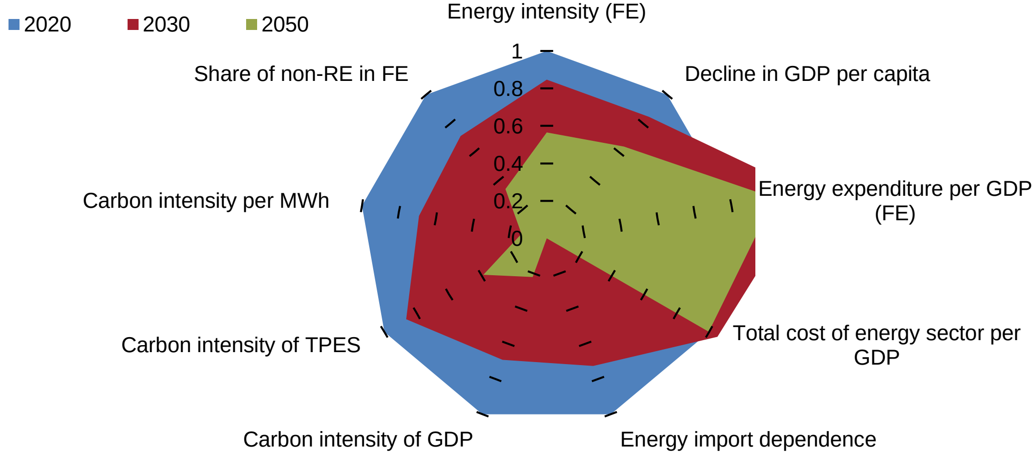
REF Scenario



NDC Scenario



P2C Scenario

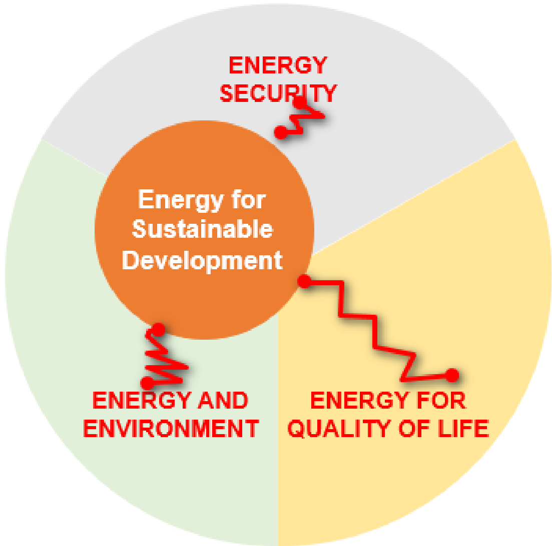


Note:

- Indicators are scaled relative to 2020, and any *__improvement in an indicator will result in values lower than 1__*
- If the shape of polygon becomes smaller compared to 2020, it shows improvement in the indicators

This analysis proves that sustainable energy in the UNECE region cannot be achieved unless policies are balanced and there are some trade-offs. Based on the above results, the sustainable energy framework is out of balance. The region has focused on energy security with the environmental[17] and quality of life issues taking second place (see Figure 16).

Figure 16
Energy for Sustainable Development in the UNECE Region



This situation in the region will severely affect some subregions where energy poverty already poses a problem. Whilst the situation in the Caucasus, Central Asia, East and South East Europe is alerting, neither North America nor Western Europe are immune to such phenomena[18].

Sustainable energy is not limited by geographic boundaries hence it cannot be addressed locally and unilaterally. All the energy stakeholders in the region need to join forces to explore all possible solutions to stop rising GHG emissions, save the planet and attain sustainable energy.

The next sections of the report explore what role different technologies can play in meeting the project's objectives.

[17] The main constraint in the model for the P2C scenario is the 2ºC target which is an input. It is qualified as global carbon budget of 1000 Gt of CO_2 equivalent for a time period 2020 to 2100 and serves as a policy driver.
[18] Energy affordability is a challenge that needs to be addressed holistically across all UNECE subregions. More investigations will be needed in future phases of the project.

4. Solutions to Attain Sustainable Energy in the UNECE Region

Above we have argued that the region will remain far too dependent on fossil fuels through to 2050 even under the most ambitious climate mitigation scenario (see Figures 5, 6 & 8) and this is reflected in the underlying tensions between three pillars of the sustainable energy.

From the discussions with stakeholders, the following opportunities have emerged as priorities for the region. These actions have been classified into three areas of urgency (immediate to long-term), as there are some options that can be pursued irrespective of the economic development of the country and state of the energy systems. These also make sense from a financial and economic perspective and relate to systemic efficiency. Other options are more long-term. These are solutions where the planning and infrastructure development should start now, but they can be implemented fully only in a future period, and still require more research and development, for example the infrastructure for the hydrogen economy.

Short-term Action: Stop growing the problem and limit GHG emissions

The future energy system must be designed with efficiency as its core value (see section 4.1.). Capturing GHG emissions from the fuels that are needed becomes an imperative to avoid the costs of climate change. Significant investments in low and negative carbon technologies are crucial if energy from fossil fuels is maintained in the energy mix in the mid-term (see section 4.2.). UNECE's Expert Groups concluded that attaining carbon neutrality must be the first milestone on the path to sustainable energy and that all technologies must play a role on this pathway.

Mid-term Action: Implement new policies and champion technology winners

Given its legacy infrastructure and abundant resources, the opportunities to enhance the interplay between renewable energy and gas are vast. This legacy infrastructure should be suitable for the region to develop flexible systems that would enhance the potential of decarbonised gases as well. In addition, as the energy transition accelerates, the social and economic impact of the transition needs to be addressed. The shift to a sustainable energy system is a long-term undertaking and must embrace all pillars of sustainable development seeking to leave nobody behind and maintain social cohesion. The international community needs to target investments towards low-income countries to accelerate the energy transition in all UNECE subregions.

Long-term Action: Embrace sustainable energy based on circular economy and nexus approaches

The region needs to embrace sustainable energy based on circular economy and nexus approaches. As the UNECE renewable energy system already vastly depends on hydropower and further deployment of renewable energy solutions will have an effect on agrarian land, a holistic water-energy-food nexus approach based on sustainable resources management needs to be embraced. Sustainable resource management practices that embrace circular economy principles and that integrate the full spectrum of the 2030 Agenda should be on the forefront of countries' strategies. Partnerships across the region need to be strengthened to increase investments in carbon neutral solutions and accelerate transition in low-income countries.

4.1. Pursue Energy Efficiency as the Basis for Systemic Efficiencies

The future energy system must be designed with efficiency as its core value.

The Group of Experts on Energy Efficiency leads UNECE's work on energy efficiency. This Group's work to date proves that energy efficiency improvements are the best way to reduce carbon emissions in the region. This reality applies across the entire economy, notably in buildings, industry and transportation sector.

Energy efficiency in **buildings**

Buildings are central to meeting the sustainability challenge. In the developed world, buildings consume over 70% of the electric power generated, 40% of primary energy and are responsible for 40% of CO_2 emissions. The High Performance Buildings Initiative (HPBI) is deploying UNECE's "Framework Guidelines for Energy Efficiency Standards in Buildings" and is working with partners to disseminate them worldwide. HPBI is aimed at radical reduction of the global carbon footprint of buildings and dramatic improvement in the health and quality of life provided by buildings. A network of International Centres of Excellence on High Performance Buildings[19] provides on-the-ground implementation assistance for building owners and developers, architects, engineers, contractors and planning officials.

Energy efficiency in **industry**

Saving energy brings financial benefits to companies, not only through the value of the energy saved, but also through increased productivity from process optimisation. The main challenge for improving industrial energy efficiency is addressing the issue of highly energy intensive processes in industries such as cement, steel, chemicals. Innovation and targeted research and development could help industry with efficiency improvements. Collaboration with the private sector is primordial in this respect and the UNECE provides industry with a view of energy efficiency initiatives to help companies decide which are most suited to help them pursue energy efficiency on their own accord for business reasons[20].

Energy efficiency in **transport**

Compulsory fuel economy standards play a pivotal role in boosting the efficiency of road vehicles. Carbon taxes have only a limited impact on the cost of mobility. Change in customer preferences coupled with the speed of innovation and commercialisation of new technologies, such as electric vehicles, biofuels and hydrogen, are expected to drive decarbonisation of the transport sector. The modernization of urban mobility can be addressed with proper planning of city infrastructure and transport efficiency. Long distance freight transport remains a challenge due to the volume and complexity of the transportation system.

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[19]For more information on the UNECE activities on energy efficiency in building see http://www.unece.org/energywelcome/areas-of-work/energy-efficiency/activities/energy-efficiency-in-buildings.html

[20] For more information on the UNECE Industrial Energy activities and Task Force see http://www.unece.org/energywelcome/areas-of-work/energy-efficiency/activities/energy-efficiency-in-industry-sector.html

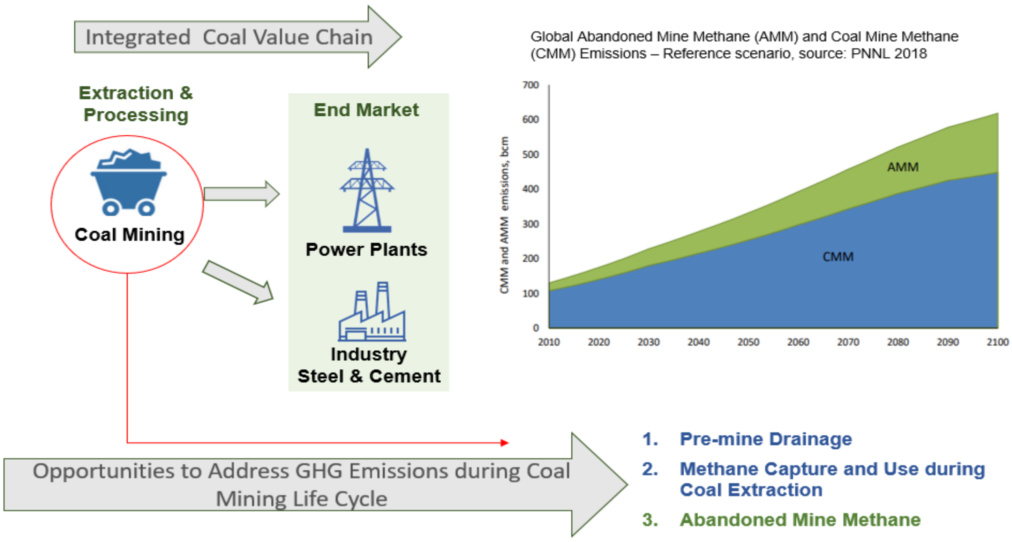
4.2. Address GHG Emissions from the Fossil Fuels

GHG emissions associated with coal mining need to be managed carefully. Methane has a severe impact on the environment and climate change that must be addressed.

The Group of Experts on Cleaner Electricity Systems and the Group of Experts on Coal Mine Methane have discussed how to reduce the environmental footprint of energy sector. The two groups have concluded that action needs to be taken throughout the whole value chain (see Figure 17).

Managing methane emissions throughout the whole coal mining value chain – from quantification of methane resources during coal exploration though capture and use during the mining lifecycle – is essential to converting fugitive emissions into an asset. Coal mines that are no longer active also emit significant amounts of methane. Annual emissions from one large underground coal mine in the United States amount to at least 2 million tCO_2e per year, or more. Mitigation projects at similar size mines rivals CCS projects at power plants.

Figure 17
Integrated Coal Value Chain



Box 2
Methane is a potent GHG with a high global warming potential (GWP). The GWP index presents the global warming of a greenhouse gas relative to CO2 (which by definition has a GWP value of 1). On an instantaneous basis, the GWP of methane is 120 times that of CO_2. Based on a 20-year timeframe, the GWP of methane is 80 times larger than CO_2 and over a 100-year timeframe the figure falls to 36 (IGU 2017, GECF 2019). Managing methane emissions from well to burner tip is essential given the global warming potential of methane.

Box 3
Where carbon-storage sites are available, CCS is a decarbonisation option at current commodity prices. In the UNECE, this technology is mainly expected to be implemented in Western Europe, North America and the Russian Federation. A Pilot CCS project in Canada has demonstrated to reduce 100% of the power station's SOx, 90% of CO_2, and 56% of NOx emissions. It captures 1mt of CO_2 annually, while producing 115 MW of power, which is enough to power approximately 100,000 homes (Source: World Coal Association, 2015; IEA Clean Coal Centre 2019). Work has been conducted to understand the global capacity for CCS in geological formations, but the overall potential in the region needs to be investigated.

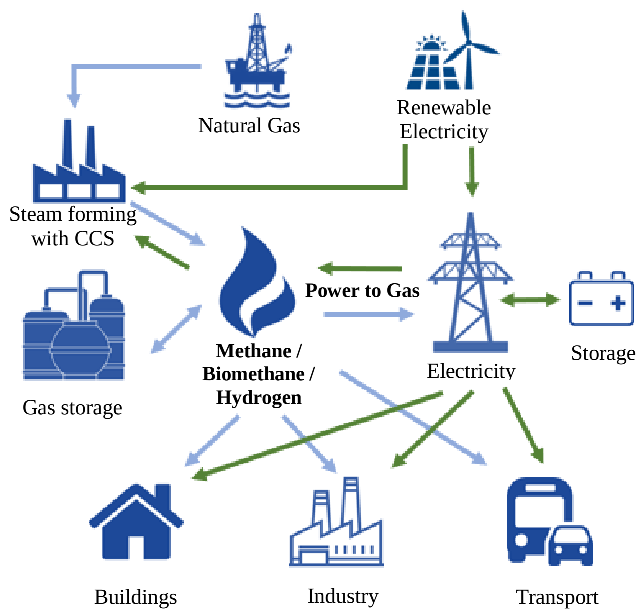
Through investments in cleaner technologies (e.g. CCS and HELE) coal can be maintained in the energy mix in the medium-term if countries decide so.

Further, investments in low and negative carbon technologies, such as CCS and HELE, are crucial to achieve sustainable energy and especially address climate change. This imperative applies to all fossil fuels sources (oil, gas and cleaner coal) as the region will remain dependent on them during this century (see Figures 5, 6 & 8).

4.3. Accelerate the Interplay between Renewable Energy and Renewable / Decarbonised and Low Carbon Gases

Gas will remain to have a large share of the energy mix in the UNECE region (see Figure 6 & 7) and can play a role in addressing climate change. In general, the interplay between renewable energy and natural gas can be used to accelerate the deployment of renewable energy in the UNECE region. The Group of Experts on Gas and the Group of Experts on Renewable Energy are exploring the synergies between the traditional and emerging energy sectors to develop solutions to limit GHG emissions of the energy sector and to enable zero carbon technologies to emerge.

Figure 18
Interplay between Renewable Energy and Natural Gas



UNECE member States seek to **develop flexible systems** that would allow **decarbonisation of power generation**.

Flexibility and low capital and operating costs make natural gas a competitive source of back-up power to support introducing renewable energy into the grid sustainably. The gas supply chain can respond quickly to changes in power supply and demand because of the rapid response time of gas generators and the availability of gas supply in gas storage facilities, liquified natural gas (LNG) and operational flexibility of gas pipelines. The existing gas infrastructure can enable the transition to a low emission economy as it can deliver high storage and transmission capacity in an efficient and cost-effective way.

Methane emissions associated with natural gas must be managed.

The lifecycle GHG emissions of gas-fired power generation are 40% lower than those of oil-fired power generation and 50% lower than those of coal-fired power generation. Switching from coal to natural gas in electricity generation can reduce the carbon intensity of fossil fuels energy and improve air quality. Methane emissions associated with the growing role of natural gas need to be managed carefully. Conducting methane emissions mapping exercises in terms of detection, quantification and mitigation of methane emissions along the gas value chain is necessary to better plan emissions management (see Box 2). Reducing methane emissions provides an opportunity to secure a sustainable energy future in which natural gas can continue to play a role for a foreseeable future in the region (see figure 7).

There is **strong** medium-to-long-term **future for natural gas if** the industry embraces energy transition and **partners with renewable energy to produce carbon free products (e.g. hydrogen) while embracing CCS.**

In the interplay between the gas and renewable energy, the most important contribution that gas can make will be in the form of ‘green’ or ‘blue’ gas[21] that has been largely or totally decarbonised. The Group of Experts believe that a modern energy system can rely on a combination of electrons (electricity) and molecules (gas) as more integrated and interlinked gas and electricity models will accelerate and deepen energy transition.

The UNECE region increasingly seeks to **develop flexible systems that would enhance the potential of decarbonised gases**.

Decarbonisation projects such as power-to-gas, energy storage and renewable, decarbonised and low-carbon gases (e.g. green/blue hydrogen and biomethane) can reduce the environmental footprint of the energy sector. Power-to-X technologies that can be used for production of hydrogen and subsequent conversion of hydrogen into hydrocarbons such as synthetic methane and methanol, can play important role in deep decarbonisation of the energy system. Renewable/decarbonised gases, such as hydrogen produced through renewable energy and biomethane/biogas, could be used for power generation to phase out natural gas and can play a critical role in decarbonisation of sectors where electrification is difficult - such as aircraft, ships, lorries (see Figure 18).

Despite the potential of the hydrogen economy to take-off and innovation across the decarbonised gases’ value chain, this emerging industry is still facing legislative and structural challenges. The value chain for decarbonised gases is still at its infancy with the focus on trial projects. There is still no common standard concerning the transmission of hydrogen through the natural gas pipelines. For instance, while the Netherlands allows a natural gas pipeline to carry up 12% of hydrogen

[21] ‘Blue’ hydrogen is obtained from natural gas or industrial residual gases through steam methane reformation splitting them into hydrogen (H_2) and carbon dioxide (CO_2). CO_2 is then captured through CCS technology. ‘Green’ hydrogen is produced through the electrolysis of H_2O. Using an electric current produced from renewable energy resources water, H_2O, is divided into its component elements of hydrogen (H_2) and oxygen (O_2)

There is **need for legislative frameworks** that **allow disruptive technologies to emerge.**

and Germany allows up to 10%, Belgium only allows up to 0.1%. Advocates of hydrogen economy consider it is safe for natural gas pipelines to carry as much as 18-20% of hydrogen in the gas mix (UNECE 2019). In addition, public acceptance and perceived safety impose barriers for implementation and further commercialisation. It should be noted that UNECE is working on developing a separate assessment of the prospective role of decarbonised gases in attaining sustainable energy.

4.4. Address the Social and Economic Impact of the Energy Transition

Any reductions in fossil fuels energy's contribution **must** be managed with appropriate action to **mitigate negative socio-economic implications**.

Modernising and optimising the existing fossil fuels-based infrastructure is essential to achieve sustainable development but it cannot be done fast if social disruption is to be avoided. Many communities and sectors will still be dependent on fossil fuels and any phase out must be managed carefully. The use of land for renewable and social changes aimed at reducing GHG emissions will also impact almost everyone and is another factor to be considered.

The Group of Experts on Coal Mine Methane looked into the concept of *just transition* and its implications in the UNECE. They noted that there are environmental, economic and social concerns associated with phasing out obsolete and aging fossil fuels-based infrastructure that need to be taken into consideration when planning energy transition in the UNECE region (see Figure 19).

Figure 19
Environmental, Economic and Social Concerns

Environmental Concerns

- Promote carbon neutral technologies, especially in the case of most carbon intensive uses.
- Introducing water and air management in existing assets.

Economic Realities

- Manage the speed of energy transition as local and national economies need to adjust to new circumstances.
- Potential for new business opportunities, however, structural change needs to be carefully managed.
- The problem of vested interests. The expected resistance of current system beneficiaries and important stakeholders needs to be managed.

Social Concerns

- Fossil-industry dependent communities face challenges, such as job losses, economic decline, disruptive cultural changes.
- A concept of "just transition" can facilitate in structural planning.
- Benefits of transition include job creation in low-carbon sectors.

The social dimension of communities dependent on fossil fuel activity and the regional socio-economic infrastructure must be carefully managed through sustained long-term governmental policies. In the UNECE region, there are localities, such as Upper Silesia in Poland, Lausitz in Germany or Karaganda in Kazakhstan, that still depend on the coal sector. Coal mines, power generating plants, metallurgical processing plants, manufacturing and shipping facilities are integrated into dense, interrelated business over decades. Any accelerated coal phase out thus needs to be supported by proactive processes to facilitate structural transition of the coal sector and involve both affiliated and ancillary sectors. The approach taken needs to harmonise often conflicting policy realms and will take long-term planning to avoid regional desertification and social unrest.

Box 4

Currently ca. 18,500 persons are employed in lignite-fired power plants and mining in Germany. An additional 4,000 – 8,000 employees work in coal-fired power plants. Germany is devoted to the retirement of its coal power plants. It is estimated that in the REF scenario (without additional climate policies) by 2030 number of employees will decrease to approx. 14,500 employees. In accelerated climate mitigation scenarios, reductions could fall to approx. 8,000 employees. By 2038, the regions that are currently still involved in lignite mining will have received funds amounting to €26 billion to ensure they undergo a profound structural change. Economic development that will follow energy transition process is expected to create new jobs that will offset employment cuts resulted by coal phase out. In recent years approx. 100,000 new jobs have been created in renewable energy. Coal phase out can incentivise needed investments in renewable energy, storage technologies, energy demand management and energy efficiency measures. This forward-looking, innovation-based approach will create new opportunities for next generations and allow them to stay in the region and build their lives (source: German Institute for Economic Research, Wuppertal Institute, Ecologic Institute, 2019).

4.5. Increase Investments in Renewable Energy in Subregions and Accelerate Energy Transition in Low-Income Countries

The **competitiveness of renewable energy** has been substantially **increasing**, yet **in many subregions in the UNECE the potential of renewable energy still remains untapped.**

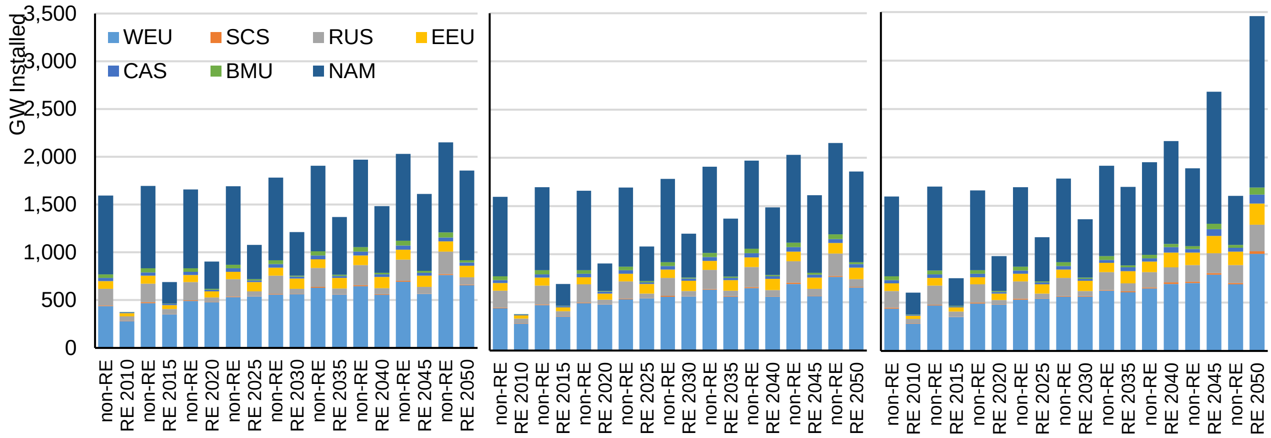
Renewable energy is a key element of energy system transformation. The competitiveness of renewable energy has been substantially increasing. However, despite an overall increase of renewable energy capacity in the region, in many subregions the potential of renewable energy remains untapped. The UNECE Group of Experts on Renewable Energy explored how to accelerate the deployment of renewable energy in the Caucasus, Central Asia, East and South East Europe, since these subregions have been identified as challenging for the development of renewable energy markets (UNECE & REN21 2017).

In 2015, the installed electricity capacity of renewable energy sources in the UNECE region amounted to about 869 GW (388 GW from large hydro power plants), accounting for almost half (49%) of the renewable electricity capacity installed worldwide.

It must be noted that the role of renewable energy in the energy mix across the region is highly variable. Whilst Europe and North America account for 23% and 16% of the total renewable generation capacity, the Caucasus, Central Asia and the Russian Federation collectively account for only 4% (see Figure 20).

Hydropower continues to generate large share of electricity in the eastern subregions especially in the Russian Federation, Georgia, Kyrgyzstan and Turkmenistan. Solar PV grows across all subregions mainly driven by installations imported from China. Kazakhstan started investing in local manufacturing of solar PV modules. Vast wind potential is present in the region, with the largest sources in the Russian Federation, Belarus, Ukraine and Serbia (UNECE & REN21 2017).

Figure 20
Non-renewable vs. Renewable Electricity Generating Capacity by Subregion and Scenario



Despite the vast natural potential to deploy renewable technologies across the region, renewable energy infrastructure in the eastern subregions is limited due to lack of investment. In 2015, the Caucasus, Central Asia, the Russian Federation, and East and South East Europe represented a fraction (0.2%) of global investments in renewable energy in 2015. This is an decrease from 0.5% in 2014 (UNECE & REN21 2017). International donors and development banks are an important source of debt financing and grants for renewable energy projects, but the scale of activity is modest.

New business models based on renewable energy applications, increasing energy efficiency and more control by customers are emerging and creating **bottom up approach** in accelerating energy transition.

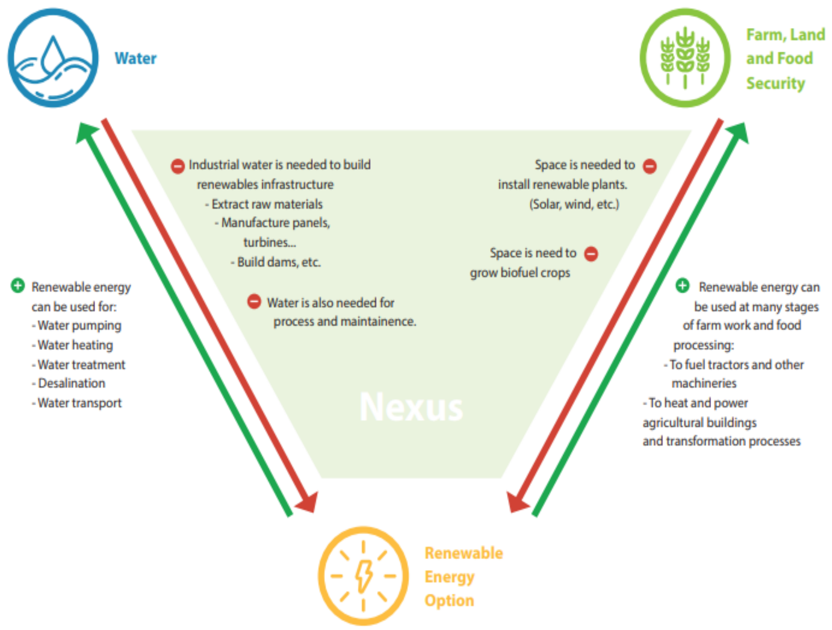
There is a need for new business models that would allow bottom-up approaches and accelerate an energy transition across the region. Ongoing innovation and digitalisation of the energy system is creating a new generation of consumers. Consumers are increasingly interested in solar panels, and other sources of residential and community scale renewable power generating units are being deployed. Modern customers value control – these so-called "prosumers" value producing as well as consuming energy. As the cost curves for renewable energy are declining and more reliable storage solutions such as batteries are being developed, consumers are moving to occupy a central position. The UNECE is planning to embark to further explore the opportunities that innovation and digitalisation offer for the deep energy transition in the region. This activity will be run under the auspices of the Group of Experts on Energy Efficiency, Cleaner Electricity Systems and Renewable Energy.

4.6. Embrace Water-Energy-Food Nexus Approach Across the Whole Region

Renewable energy in the UNECE region is largely comprised of hydropower. Adding renewable energy capacity across the region in the form of wind and solar (see Figure 8 & 9) will affect land use. Increasing demand for land could have negative effects on agriculture sector and food supply with consequences for food prices. In order to avoid such a scenario a holistic water-energy-food nexus approach based on sustainable resources management needs to be embraced. The objective would be to promote, coordinate and integrate planning and sustainable management of interlinked resources across sectors.

Renewable energy technologies could **address trade-offs between water, energy and food production**, with substantial benefits in all three sectors.

Figure 21
Water-Food-Energy Ecosystem Nexus



Source: UNECE 2017a

Integrated management of natural resources such as energy, raw material and water resources would improve efficiencies, reduce environmental footprints and eliminate waste. The distributed nature of many renewable energy technologies allows them to offer integrated solutions that enhance security across the three sectors. With an integrated approach renewable energy technology can provide energy services using resources sustainably. For example, in the transboundary river basins in South East Europe, the Caucasus and Central Asia, the riparian countries have not only active hydropower development, but also the potential to exploit solar, wind and geothermal energy. The energy-water-food nexus approach aims to support more sustainable renewable energy deployment by building synergies, increasing efficiency, reducing trade-offs and improving governance among the sectors.

Box 5
The UNECE promotes transboundary cooperation in both energy sector development and water management. Increasing the share of renewable energy in the region can help reduce water requirements in the power generation, boost water security by improving accessibility, affordability and safety, and contribute to food security objectives. Lack of intersectoral coordination is a major challenge in leveraging all the existing opportunities for renewable energy deployment in the riparian countries. This gap exists on both national and subregional level in energy, land management, and water resources planning (UNECE 2017).

The Food-Water- Energy nexus integrating the security, accessibility and affordability of essential resources underpins the sustainable management of resources with the 2030 Agenda framework. The United Nations Framework Classification of Resources (UNFC) is a tool that breaks "silos" and links policy objectives seamlessly to project implementation. Energy and water resources are integrally related and strongly interdependent. Facilitating integrated management and monitoring offers an important foundation for sustainable development. The United Nations Framework Classification of Resources (UNFC) can support this process by enabling harmonised data and information on energy and water resources.

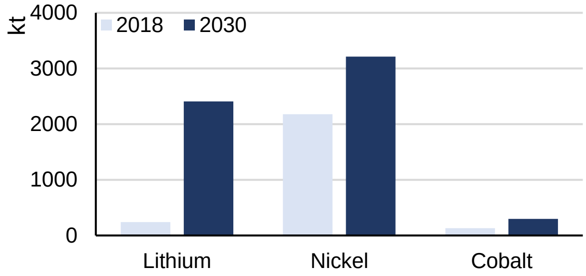
Box 6
The UNECE project "Integrated energy and water resource management in support of sustainable development in South East Europe and Central Asia" started in 2018, with the participation of Bosnia and Herzegovina, Kazakhstan, Kyrgyzstan and Serbia. UNFC has built-in guidance for the management of social and environmental aspects throughout the cycle of natural resource development. Best practices promoted by UNFC delve into approaches that can help transform challenges into opportunities.

4.7. Sustainable Resource Management for Energy Storage Solutions

Sustainable resource management practices that embrace circular economy principles and that integrate the full spectrum of the 2030 Agenda should be on the forefront of countries' strategies.

Meeting the needs of a sustainable energy future will have implications on countries' resource base and availability, costs and prices of critical raw materials and rare earth minerals. Over 80 elements in the periodic table are required for energy production today e.g. for batteries and renewable energy technologies, such as lithium, cobalt and nickel (see Figure 22). Sourcing these essential materials and minerals for production purposes will be a challenge. Geopolitical relationships are already shifting as these materials are located in a limited number of countries.

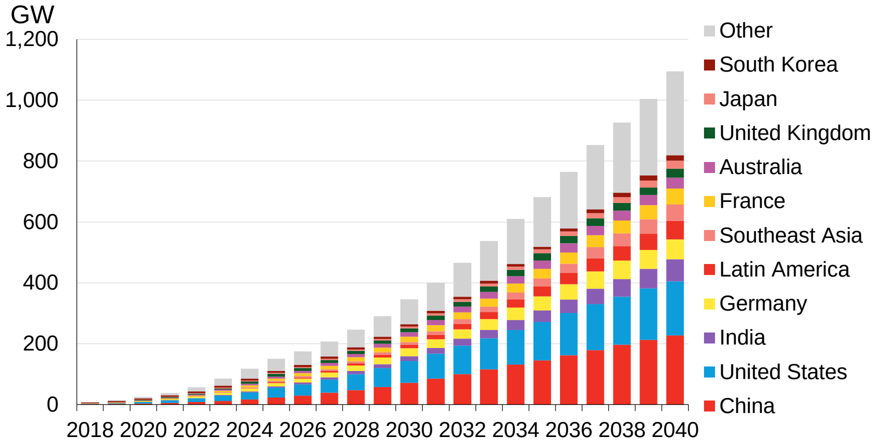
Figure 22
Global Demand for Metals



Source: WEF, Global Battery Alliance 2019

As batteries become more efficient and cost competitive, the demand for these technologies is expected to grow exponentially (see Figure 23). According to Bloomberg NEF, the price of an average battery fell by 85% from 2010 – 2018 reaching USD 176/kWh. It is expected that the price will go further down over the next decade reaching USD 94/kWh by 2024 and USD 62/kWh by 2030 (Bloomberg NEF 2019a). If such an exponential trend is realistic is hard to tell. Nevertheless, the electrification of the energy system is ongoing and battery development is a key component for the electric future. Currently our model does not take it into account extensively and further development will be needed in the next phases of the project.

Figure 23
Battery Energy Storage for Selected Countries



Source: BloombergNEF 2019b

"If the 20th century was the age of the internal combustion engine, the 21st belongs to the battery."

Batteries have limited life cycles and over time their energy storage capacities reduce. It is important to find solutions to prolong their life by repurposing. For example, giving batteries from EV a "second life" in the power sector, especially as the multitude of designs makes them hard to dismantle for recycling. When the energy storage capacities are eventually completely exhausted, there is a need for solutions to limit their environmental footprint. Alternative technologies, innovation, acceptable international standards and adoption of circular economy practices can reduce material demand and costs as well as increase resource security. This is an area that would need to be further analysed as the region is moving towards widespread electrification. The Expert Group on Resource Management and the Group of Experts on Cleaner Electricity Systems are best placed to look into this challenge at the UNECE.

5. Conclusions

Attaining sustainable energy is a complex social, political, economic and technological challenge. Although UNECE countries have not agreed on how collectively they will achieve energy for sustainable development, it is clear from the modelling that each country should pursue its own path based on their economic circumstances and natural endowments. This can be made far more effective through international cooperation and innovation which can deliver accelerated and more ambitious strategies.

The dialogue that follows policy formation and modelling alone constituted an important step forward for countries. It highlighted trade-offs and unforeseen consequences between 2030 Agenda goals and targets, national concerns of energy, quality of life and social aspects in combination with environmental and economic strategies. Moreover, it showed the importance of the UNECE as a regional commission to bring stakeholders together.

The modelling shows that the current NDCs are projected to result in an uncomfortably high level of global warming. In order to limit global warming to 2°C, the UNECE region needs to reduce its dependence on fossil fuels from over 80% to around 50%, and cut or capture at least 90Gt of CO_2 emissions by 2050. Given the technologies incorporated in the model and timelags involved, this transition needs to start immediately.

The policies required for a sustainable energy pathways cover immediate action to improve energy efficiency, limit the GHG by reducing the use of fossil fuels at the same time as implementing carbon capture technologies, and invest in renewable and low carbon energy in the subregions where renewable energy infrastructure is especially limited such as the Caucasus, Central Asia, East and South East Europe.

Up to 2050, the scale of the transition is significant and will have a cost if the world is to avoid significant climate impacts. These costs are not overwhelming and are likely to be far less than the impact of climate change on GDP according to published studies. As energy transition comes with its cost, it will create new energy affordability challenges across the whole region. This transition needs to embrace and lift people on all levels of the society not leaving anybody behind.

After 2050 new zero and negative carbon energy technologies will be needed and these should be researched. As the modelling showed, there is no economically rational scenario which gets the UNECE fossil fuel dependence under 50% by 2050. This is because, unlike the electricity sector, fuels for transportation and heavy industry are very hard to replace with renewable energy given current technologies.

Regardless of the approach countries will need a mechanism for a common, informed dialogue at regional and subregional level. There is need for partnership, inclusive dialogue and closer cooperation on both subregional and regional level. This project is a good vehicle for a much-needed informed collaboration on sustainable energy which requires a trusted source of shared up-to-date knowledge, common set of information and projections, interpreted by a wide range of stakeholders and experts.

6. Annex

6.1. Scenario Building Process

Table 1
Scenario Descriptions and Variations

Group	Descriptors No	Title	Variables (options)
Global Political and Economic Situation	1	Degree of cooperation on SDGs	Low
			High
	2	Key country leadership (US, China, EU, other)	Leadership by several or all
			Lack of Leadership
	3	Cost/availability of energy	High cost with low availability
			Low cost with high availability
	4	Food, water, energy and land Nexus	Abundance for all
			Scarcity across some or all
Technological Developments	5	Advanced technology and business models	Low technology improvements with conventional business model
			Advanced technology with services based business model
	6	Information and communication technology (ICT) impact and grid development	Smart grid build out
			Dumb and constrained grids
	7	Storage	Low cost and broadly applicable
			High cost and region specific
	8	Carbon Capture and Storage (CCS) available at competitive prices	Competitive with carbon price
			Uncompetitive
	9	Broad range of competitive low carbon technologies	Few technologies available
			Many technologies (RE, Nuclear, CCS) available
Energy Policy Developments	10	Impactful Price of Carbon	$6/tonne
			>$300/ tonne
	11	Taxes/subsidies	Support for conventional energy
			Support for low-carbon energy
	12	Awareness of multiple benefits of energy efficiency	Disjointed energy efficiency and energy policy
			Integrated energy efficiency and energy policy
	13	Free or Managed Markets	Free markets
			Highly regulated markets

6.2. Early Warning System Concept

Early Warning System Concept[22] highlights the important aspect of the early warning and planning system including those specific to adaptive policy pathways for sustainable energy. This requires an iterative process (see Figure 24).

Sustainable energy policies affect the global economy and environment, not just the UNECE region. These global changes can be tracked and incorporated in the model making the regional monitoring process more realistic and relevant. Any deviations can lead to a revision of the initial targets and the adjustment of sustainable energy aims. The sustainable energy targets and updated input assumptions can then be used to model adaptive pathways towards these targets. Insights from the modelling activity can then be used to aid the policy design with the latest information.

Given a suitable organisation, this process can become iterative. It is estimated that this process would have to be repeated every couple of years to allow enough time for the policy to produce notable results and changes in the global system to be incorporated.

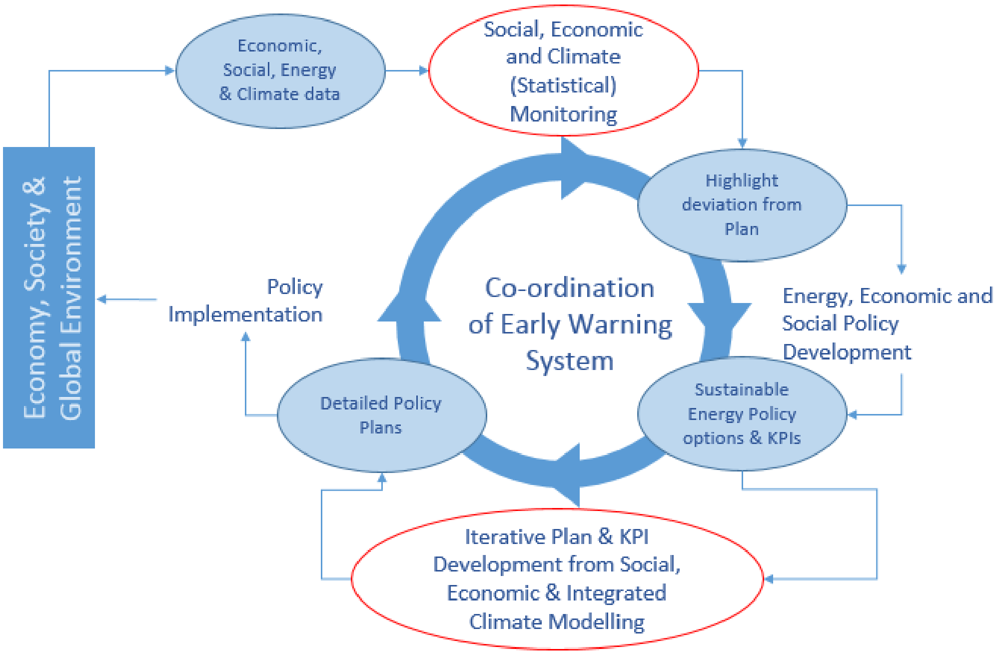
[22] A complete paper "Early Warning System Concept" can be found on the project Pathways to Sustainable Energy webpage: https://www.unece.org/energy/pathwaystose.html

The overall concept facilitates the use of scenarios to show how and by which methods and indicators unforeseen and undesirable developments can be identified early and reliably.

In addition, the approach allows the development of an understanding of the likely origins of the undesirable developments, allowing rapid intervention in the sectors concerned.

Figure 24

Elements of an Early Warning and Planning System Highlighting the Role of Indicators and Modelling

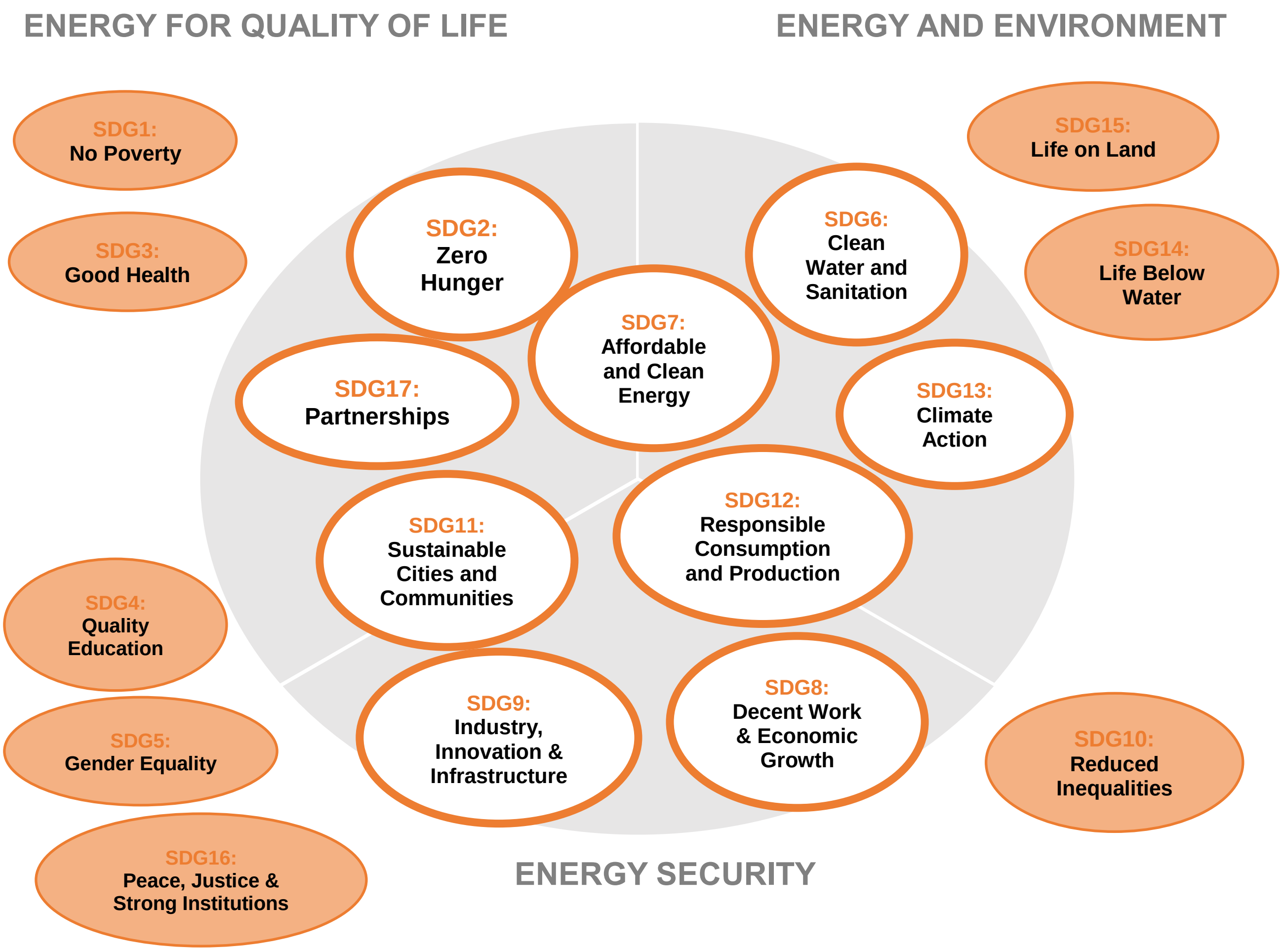


6.3. Linking the Sustainable Energy Pillars to the 2030 Agenda

Recent international agreements for a sustainable future, notably the energy-related SDGs and subsequent pledges made during the COP 21 in December 2015, provide an important context for the project. The 2030 Agenda requires countries to pursue concerted and accelerated action on sustainable energy in their national programmes in order to reconcile the world's growing need for energy services while mitigating the impacts of energy resource development and use. Any definition of "Sustainable Energy" should relate to these overriding international agreements if it is to be of relevance to policy makers.

Figure 25 shows how the SDGs can help define the concept of "Energy for Sustainable Development". It summarises the energy-related links of all the SDGs. More direct links are clustered in the core of the diagram. Indirect links are clustered on the perimeter. Figure 25 also shows how the SDGs align according to the three Sustainable Energy Pillars developed above.

Figure 25
Links to SDGs in Defining the Framework of Energy for Sustainable Development



Within the pillar **"Energy and Environment"**, in addition to SDG 7, three additional SDGs are most prominent: SDG 6 on "Clean Water and Sanitation", SDG 12 on "Responsible Consumption and Production" and SDG 13 on "Climate Action".

- **SDG 6** links with energy because the energy sector consumes a substantial amount of water, for example, through hydropower generation or by using water for cooling in thermal energy generation. The competition for water resources results in a nexus which requires an integrated water and energy approach which in some cases spans national borders.
- **SDG 7** is *the* energy goal among the 17 SDGs. It aims to "ensure access to affordable, reliable, sustainable and modern energy for all". It has defined targets to substantially increase the share of renewable energy, to double the global rate of improvement in energy efficiency, to advance cleaner fossil fuel technologies, and to ensure universal access to affordable, reliable and modern energy services. In addition, it calls for international cooperation and investment in sustainable energy research, technology, and infrastructure.
- **SDG 12** aims to increase the importance of the "Circular Economy". The energy sector plays a critical role in achieving resource efficiency targets. The sustainable use of energy is an important aspect of SDG 12 as well as SDG 7. SDG 12 further includes the phase out of fossil fuel subsidies which distorts the energy market. This will adversely impact the economics of fossil fuels-based energy generation and hence reduce the impact on the environment through the release of greenhouse gas emissions. An additional linkage is related to the awareness and application of energy saving and energy efficiency measures.

- **SDG 13** provides the link to national climate mitigation pledges to be achieved until 2030 - the so called Nationally Determined Contributions (NDCs). The NDCs are the core of the Paris Agreement which is a joint effort in keeping global warming well below 2ºC. The energy sector contributes about two thirds of all greenhouse gas emissions, so it is a crucial sector to be included in any climate change mitigation and adaptation actions.

Within the "**Energy Security**" pillar, the most significant energy-relevant SDGs are SDG 8 on "Decent Work and Economic Growth", SDG 9 on "Industry, Innovation and Infrastructure", SDG 11 on "Sustainable Cities and Communities", and SDG 12 on "Responsible Consumption and Production".

- **SDG 8 & 12** links with energy security as energy is a crucial input factor for economic growth and SDG 12 requires a move towards a more sustainable economic growth model based on improvements in the energy sector. Economic growth needs to decouple from both energy demand and environmental degradation. Key target areas include the reduction of the environmental footprint of the energy sector, an increase in resource and consumption efficiency along the energy value chain, and improved energy intensity across all economic sectors.
- **SDG 9** includes the energy industry, energy-intensive industries, energy innovation and the overall energy infrastructure. Achieving SDG 9 needs an energy transition that moves towards a resilient and sustainable energy infrastructure and resource use, as well as the development, dissemination and local adaptation of energy technology.
- **SDG 11** relates to the transition and development of a sustainable and resilient urban energy infrastructure, the sustainable energy supply for cities**,** urban and rural communities, and the electrification of transport and development of sustainable transport fuels. Other important aspects include energy efficient buildings.

Within the "**Energy for Quality of Life**" pillar, the most significant energy-relevant SDGs are SDG 2 on "Zero Hunger", SDG 7 on "Affordable and Clean Energy", SDG 11 on "Sustainable Cities and Communities", and SDG 17 on "Partnerships".

- **SDG 2** links to the energy sector through the Food-Energy-Water Nexus because of the competition for resources with the food sector. The agriculture sector is both water and energy intensive. Bio-energy may compete with food production as is in the case of maize.
- **SDG 7, 11** and **12** links are similar to those in the other two pillars.

6.4. Measuring "Sustainable Energy" in Integrated Assessment Models

One key component of the project is the numerical modelling of climate, technology and policy scenarios. A combination of bottom-up and top-down modelling was applied. The models need numerical input parameters and assumptions for various socio-economic, technological, and climate-related indicators. Also, numerical constraints[23] were integrated into the models to set specific targets on sustainable energy for 2050.

The development of numerical inputs relevant to policy development around sustainable energy is not trivial. The models used have large amounts of input and output parameters which can be selected. It is also not simple to introduce new parameters not already included in the datasets.

The objective of the project was to identify a set of the most important indicators that best represent the definition of sustainable energy described above. These could be used as Key Performance Indicators (KPIs) within the project. After a broad stakeholder consultation, a list of KPIs was developed.

6.5. Summary of the Pathways Project KPIs for Sustainable Energy

The table below summarises the KPIs that can be modelled and that will be used for the presentation and analysis of the scenarios to be modelled.

Table 2
Indicators for Measuring Energy Security Criteria

Name	Title	Measurement in the model	Interpretation and Analysis / Relationship to SDGs
ES-M1	**Energy self-sufficiency: net imports**	Net imports in each sub-region and overall UNECE region	Relates to SDGs 8 & 9. Interpreted in the context of regional cooperation and interconnectivity.
ES-M2	**Energy efficiency**	Energy intensity: units of energy per unit of GDP (J/US$ PPP) Rate of improvement in energy intensity (% CAGR) Conversion efficiency	Relates to SDG 7.3 target to double the rate of improvement in energy efficiency by 2030. Energy intensity is the SDG7.3 indicator. Interpreted in the context of both thermodynamic conversion efficiency as well as the energy efficiency of the economy.
ES-M3	**Investment requirements to achieve sustainable energy**	Energy investment of GDP (% GDP)	Relates to SDG 7.A , SDG 13.A Interpreted in the context of impacts and ability to finance the investments.
ES-M4	**Diversity of supply: fuel mix in energy and electricity**	Share of different fuels in Total Final Energy Consumption (TFC) and Total Primary Energy Supply (TPES), and in electricity (%)	Relates to SDG 7.2 target 'substantially increase the share of RE in TFC'. Interpreted in the context of diversification of supply, share of low-carbon / fossil fuel energy supply, etc.

[23] See glossary for explanation on terminology

Table 3
Indicators for Measuring Energy for Quality of Life Criteria

Name	Title	Measurement in the model	Interpretation and Analysis / Relationship to SDGs
QL-M1	**Access to energy services**	Energy / electricity services per capita (efficiency adjusted energy consumption) (J/capita/year)	Relates to SDG 7.1 target: Universal access by 2030, and SDG1.
QL-M2	**Energy affordability**	Total energy expenditures per GDP per capita	Relates to SDG1 and SDG 7. Interpreted in the context of energy poverty and household income spent on energy expenditures.
QL-M3	**Food security**	Share of calories from non-staple food (%) *(GCAM model only)*	Relates to SDG 2.4 (sustainable agriculture), 2.3 (reduce food loss), 13.1 (impact of climate change). Will be interpreted with a focus on the linkages between sustainable bioenergy (solid biomass) generation of food production.

Table 3
Indicators for Measuring Energy and Environment Criteria

Name	Title	Measurement in the model	Interpretation and Analysis / Relationship to SDGs
EE-M1	**GHG emissions from the energy sector**	Total global GHG emissions of the energy sector in MtCO2eq	Relates to SDG13.
EE-M2	**Air polluting energy emissions**	Emissions from energy sector: Sulphur Dioxide (SO2), Nitrogen Oxides (NOx), Particulate Matter (PM2.5) (ppm or µg/m3)	Relates to SDG 3.9.1.
EE-M3	**Water use efficiency and water stress caused by the energy sector**	Cooling water use in electricity generation (l/kWh) Water use associated with energy resource extraction (GJ liters absolute and/or L/GJ)	Relates to SDG 6.4.1 ‘substantially increase water use efficiency’ and 6.4.2 ‘substantially reduce water scarcity’. Interpreted in the context of water use of the energy sector: power generation and water consumption from energy extractive industries.

These KPIs were monitored as output parameters to determine the impact of a policy within a scenario. In addition, some of them were used as target values (model constraints) in which case the model used them as a target from which it was assessed how the other output parameters perform.
Assigning target values can be performed for the following KPIs:

Green House Gas Emissions from the energy sector

Given the COP 21 Paris Agreement, policy scenarios under the project aimed to limit global warming to maximum 2ºC. The 'target' value or constraint for the model limits cumulative total global greenhouse gas emissions of the energy sector over the remainder of the 21st Century to stay below the 2ºC maximum temperature limit. In addition to this "Paris to 2ºC" scenario, other scenarios include the "Reference Scenario" based on SSP2[24] and "NDC Scenario" that highlight results without the 2ºC constraint in place. These scenarios help assess the gap between the current policies in place and the Sustainable Energy objectives agreed within the project.

Air polluting energy emissions

Emissions from energy and transport sector including Sulphur Dioxide (SO_2), Nitrogen Oxides (NOx), and Particulate Matter (PM2.5), among others. These were integrated in the model as constraints

Energy affordability

In line with SDG 7 target 7.1, universal access to energy is to be achieved by 2030. The UNECE region has officially achieved 100% access to electricity and so the indicator to be used measures affordability of energy services. A desired target of maximum 10% of disposable income spent on energy expenditures has been set. This indicator is not a constraint that can be used to converge the model to a solution, so it can only be calculated along with the other modelling outputs.

[24] The baseline input assumptions are based on the Socio-Economic Pathways (SSPs). The advantage of using the SSPs is that they have been developed through various iterations by an international research community, including IIASA and PNNL, with the objective to provide five narratives describing alternative socio-economic developments and plausible major global developments. SSPs are used to analyse the feedbacks between climate change and socio-economic factors and to develop scenarios for use by the research community. The SSPs include qualitative narratives and quantitative elements. To develop the project scenarios, basic socio-economic assumptions from SSP2 and respective datasets will be used. SSP2 will function as the base case scenario ("No Policy Scenario") in the Pathways project. It describes a "middle of the road" scenario. See detailed description of SSPs: Riahi K. et al (2017): The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. In: Global Environmental Change 42 (2017) 153–168.

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