Project Number: 949125

Start Date of the Project: 01 January 2020

Duration: 42 months

Deliverable D3.1

Selected indicators to measure progress towards decarbonisation and competitiveness

DISSEMINATION LEVEL	Public
DUE DATE	31 December 2020/30 June 2021 (v. 2)
ACTUAL SUBMISSION DATE	22 December 2020/30 June 2021
WORK PACKAGE	WP3 - Impact assessment pursuant to the Clean Energy Transition policy framework
TASK	3.1 - Selecting indicators to analyse effect of policies
TYPE	Report
NUMBER OF PAGES	43
AUTHORS'NAME AND AFFILIATION	Witold-Roger Poganietz, Lei Xu, Maryegli Fuss, (all Karlsruhe Institute of Technology); Janina Hierl, Holger Ihssen, (all Helmholtz Association); Ingeborg Graabak, Sarah Schmidt (all SINTEF)
REVIEWER'S NAME AND AFFILIATION	
DESCRIPTION	The aim of this study is to present a comprehensive and applicable indicator framework to measure progress towards decarbonisation and competitiveness of the energy sector compared to the international landscape.

The SUPEERA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 949125.

Version	Date	Author	Description
V0.1	17.11.2020	Lei Xu	
V0.2	19.11.2020	WR Poganietz	update
V0.3	22.12.2020	WR Poganietz	finalization
V.1.1	19.05.2021	WR Poganietz	update
V.2.0	30.06.2021	WR Poganietz	finalization v. 2

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 949125.

The information contained in this document has been prepared solely for the purpose of providing information about the SUPEERA project. The document reflects only the SUPEERA beneficiary's and linked third parties' view and the European Commission is not responsible for any use that may be made of the information it contains.

Table of Contents

ABBREVIATION LIST

CFC-11	Trichlorofluoromethane
EEA	European Economic Area
EU	European Union
EU27	European Union as of February 1st, 2020
Fe	Iron
GDP	Gross Domestic Product
GENeSYS-MOD	Global Energy System Model
NECP	National Energy and Climate Plan
P	Phosphorous
R&D	Research and Development
R&I	Research and Innovation
RES	Renewable energy sources
SCI	Supplier Concentration Index
SET-Plan	Strategic Energy Technology Plan
UK	United Kingdom of Great Britain and Northern Ireland

VERSION 2

This version of the deliverable D3.1 is an update of the one, which was due on 31 December 2020. This update addresses different demands of the EU Commission:

- Final availability check of the available indicators, as presented in Section 3;
- Analysis whether the European Green Deal demands additional indicators (see Sections 2.1, 4 and 5);
- Analysis whether the latest report of the EU Commission to the European Parliament and Council on progress of clean energy competitiveness implies additional indicators (see Section 2.2, 4 and 5);
- Specification of the further steps, as they are addressed in Section 6.

I INTRODUCTION

A climate neutral society by 2050 comprises one of the highest political aims of the European Union (EU) (European Commission 2020a), while maintaining the opportunity for a decent life for all inhabitants in the EU. A pre-condition for the latter is to secure the competitiveness of the European economies on a global scale.

The objective of a climate neutral society is fixed in a set of policy initiatives under the EU Green Deal (European Commission 2019a) and is reaffirmed by the European Recovery Plan (European Commission 2020b). Although the objective targets entire economies, high efforts are set on the transformation of the energy sector (European Commission 2020a).

The Clean Energy Transition entails a sustainable and socially fair transformative process, encompassing technological, social, economic, and political dimensions, towards a cleaner and integrated energy system (European Commission 2019b). This requires the reconciliation of the technological, economic, societal, environmental, and political demands to become a reality. Setting the right policy framework priorities will be essential to accelerate the energy transition and maximize its impact.

The Strategic Energy Technology Plan (SET-Plan) is such an essential framework that sets the roadmap to foster the Clean Energy Transition in Europe. The plan is also crucial in setting the direction in the wider context of the Green Recovery and the new long-term EU climate policies pertaining to the Clean Energy Transition. The realization of the SET-Plan will boost Research and innovation (R&I) with its central role in speed up the transformation of the energy system, by designing, demonstrating, de-risking, and deploying innovative solutions (European Commission 2019c).

In this context, the SUPEERA project is proposed to strengthen European cooperation in research and innovation to realise the objectives of the SET-Plan in the broader perspective of the Clean Energy Transition. One of the tasks of the project is to address the impact of technologies pursuant to SET-Plan priorities on research and innovation as well as the European policy framework on Clean Energy Transition. This demands not only a specific perspective on technology, but also a systemic one. That means the assessment of specific technologies has to be embedded in a systemic analysis of the energy system. However, the project shall recognize also the impacts of different initiatives and policies on technical progress.

To assess the success of the different initiatives and policies, and thus, to reveal strengths and issues for competitiveness as well as to quantify realized or intended pathways to a climate neutral energy system appropriate indicators are required. These indicators have to be suitable and applicable. Considering the complexity of the system under review indicators addressing decarbonisation and competitiveness shall recognize this complexity, while considering the necessity of being communicable to the stakeholder.

To define most appropriate future policies an assessment of actual policies will not be supportive. The same is true for evaluating innovative technologies. It is necessary to describe the most promising frame conditions under which specific technologies will prosper, always considering the systemic embeddedness of technologies.

Thus, the aim of this study is to present a comprehensive and applicable indicator framework to measure progress towards decarbonisation and competitiveness of the energy sector compared to the international landscape. Emphasis is placed on depicting the reported development situation in each EU Member State as well as in Norway, Switzerland, and UK on a comparable basis. This requires a uniform set of indicators.

To secure a scenario-based analysis of future decarbonisation and competitiveness grounded on the indicators the selected one are connected to energy system models or to energy-related models. The indicators are implemented as variables of the selected models, or the connection is only indirect, i.e. additional calculations are needed. The study will make use of the H2020 project openENTRANCE. OpenENTRANCE "aims at developing, using and disseminating an open, transparent, and integrated modelling platform for assessing low-carbon transition pathways in Europe" (www.openentrance.eu; accessed 21.12.2020).

The study is organized as follows. Section 2 provides a delimitation of the terms decarbonisation and competitiveness. Section 3 describes the used approach, whereas Section 4 presents the list of indicators. Section 5 shows additional indicators, which will be considered in a later stage of the project. The last Section 6 gives an outlook on further planned activities within the project related to the indicators.

II SHORT REMARKS ON DECARBONISATION AND COMPETITIVENESS

2.1 Decarbonisation

The core of the Clean Energy Transition is the decarbonisation of the energy generation and thus, of energy use (European Commission 2019b). Decarbonisation describes the process of dissolving the use of fossil-carbon related energy carriers for energy purposes (European Commission 2018).

Although decarbonisation is in the focus of energy policy of the EU, according to the European Commission the required transformation shall not be realized at the expense of energy security and energy affordability, framing possible policy options (European Commission 2019b).

Energy security consist of two facets: Secure provision of

- use energy to satisfy the demands of companies and households; and of
- primary energy carriers and energy technologies to the European energy sector as a pre-condition for a secure provision of use energy.

Realising a secure provision of use energy in an energy system characterized by a high share of fluctuating renewable energy sources (RES) demands a more flexible setting of the energy system. Increased security regarding energy carriers and energy technologies implies policies addressing available energy carriers, energy exporting countries outside the European Economic Area (EEA), but also availability of critical resources as well as the competitiveness of energy technologies constructed in the EU. To deal with both facets digitisation of the energy generation, transport, and use is needed.

The demanded high flexibility of the energy system is mainly a consequence of the increasing share of fluctuating renewable energies in the energy conversion, but may be due to the fact of increasing flexible energy demand. The European Commission sees as main options to enhance system integration and cross-border trade, energy storage as well as sector coupling.

The EU translates a more secure supply of primary energy carriers in less dependency on single energy carriers and energy exporting countries. Thus, the Member States are obliged to increase the diversification of energy supply regarding energy carriers and trade partner (Regulation 2018/1999/EU). Regarding energy technologies, the EU sees the focus in increasing the competitiveness and in securing the import of critical metals.

With a growing share of fluctuating renewables the challenges to control the energy system increases. Renewable power plants are injected on different voltage levels, requiring for example bi-directional transport of electricity, in contrast to fossil power plants. In addition, for efficient demand side management, precise information about demand requirements and electricity availability are needed, leading to the need to digitisation of energy generation, transport, and use. An efficient use of energy due to digitisation would also decrease the dependency from imported energy carriers and energy technologies.

Nevertheless, despite different measures to achieve a better energy security the 'energy efficiency first' principle must be part of policy actions (Directive 2018/2002/EU). That means efficient use of available energy resources will reduce the relevance of the challenges.

Considering the comprehensive understanding of decarbonisation, the indicators measuring it should not only focus directly on greenhouse gas emissions. The indicators should also tackle energy security, energy dependency, and digitisation, i.e. taking into account factors influencing the fulfilment of climate policy targets.

With the launch of the European Green Deal (European Commission 2019a) the understanding of the challenges in respect to the energy transformation broadened by stressing the relevance of a just transformation. Although traditionally, solidarity is an important pillar of the Commission's policy, in respect to energy transformation until now a precise understanding and indicators to measure just transformation are still lacking.

2.2 Competitiveness

While there is a rather common understanding what describes decarbonisation of energy systems, this holds not in case of competitiveness.

Competitiveness of a nation is the ability of an economy to provide its population with high and rising standards of living and high rates of employment on a sustainable basis (European Commission 2001). Translating this understanding into the context of energy, competitiveness is defined as the capacity to produce and use affordable, reliable, and accessible clean energy through clean energy technologies, and compete in energy technology markets, with the overall aim of bringing benefits to the EU economy and people (European Commission 2020c). That means competitiveness of the energy sector addresses two aspects:

- The generation of clean energy, and
- the provision of competitive innovative energy technologies.

An appropriate set of indicators considers both aspects.

Said that, competitiveness is a multi-dimensional concept, monitored through a number of indicators. They are best interpreted by reference and comparison to other indicators, but also to other countries.

Discussing appropriate indicators to measure competitiveness two facets have to be considered:

- Disclosing of today's competitiveness of the energy sector. The indicators would address the current situation on the markets for energy and for energy technologies as well as the situation of the involved companies;
- Indicating the future prospective of competitiveness. The indicators would take into account research and investment relevant activities regarding energy technologies.

The European Commission uses in its report to the European Parliament and Council (European Commission 2020c) a set of indicators to characterize the progress to clean competitive technologies (s. **Error! Reference source not found.**).

Table 1: Indicators to monitor progress in competitiveness (European Commission 2020c)

Technology analysis current situation and outlook	**Value chain of the energy technology sector**	**Global market analysis**
Capacity installed, generation (today and in 2050)	Turnover	Trade (imports/exports)
Costs or Levelized cost of generation (LCoE) (today and in 2050)	Gross value added growth (annual % change)	Global market leaders vs. EU market leaders (market share)
Public R&I funding	Number of companies in the supply chain, incl. EU market leaders	Resource efficiency and dependence
Private R&I funding	Employment	Real unit energy costs
Patenting trends	Energy intensity / labour productivity	
Level of scientific publications	Community production (annual production values)	

These indicators address the above mentioned claims for assessing competitiveness. The indicators were scrutinized before the background of the H2020 project openENTRANCE. The results of the analysis can be found in the Sections 4 and 5.

III APPROACH

The process of selecting the indicators is a multi-step procedure, which will be presented in the following (c. Figure 1).

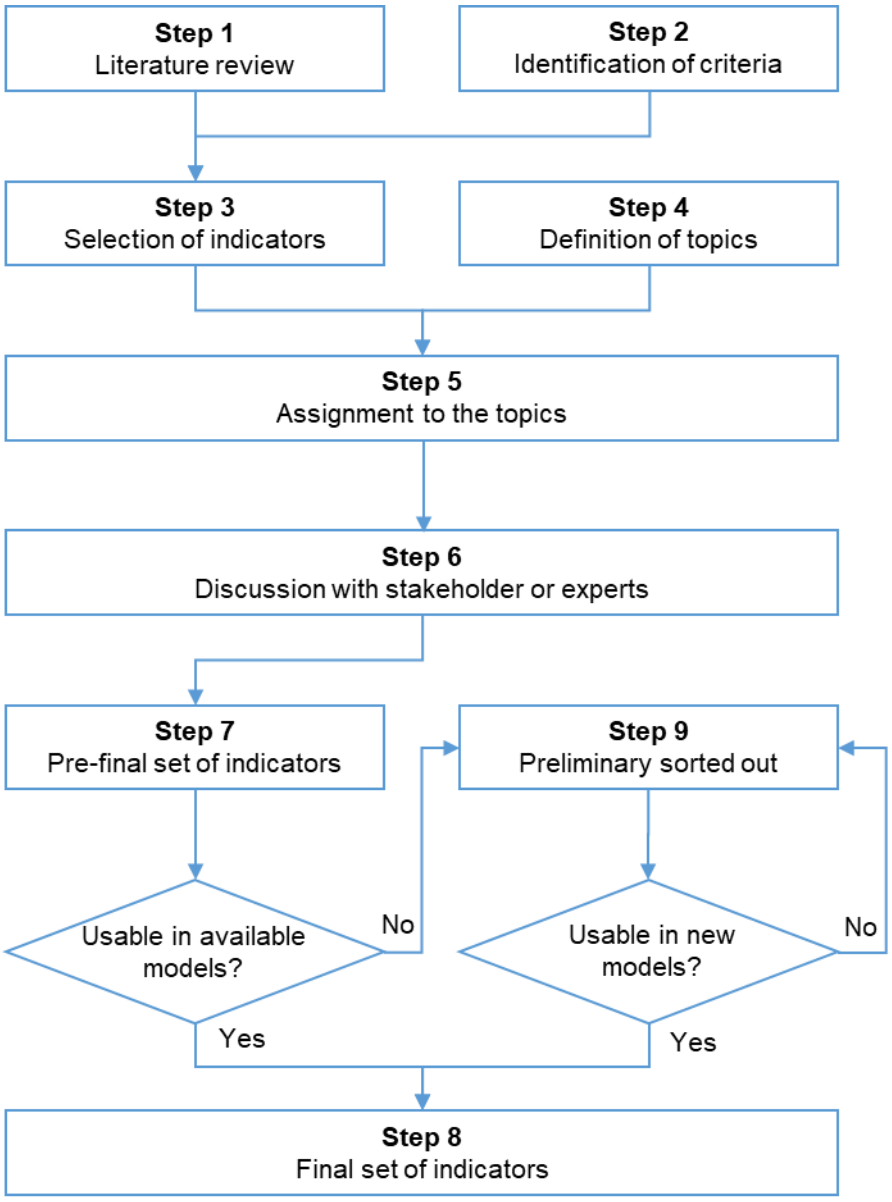

Figure 1: A systematic indicator selection approach

The first step consists of a comprehensive review of available literature dealing with decarbonisation and competitiveness of the energy sector.

Although a wide spread literature review was carried out, the focus was on the following studies: European Commission (2017), CoGEn Project (2019) and the Global Competitiveness Report 2018 (Schwab 2019). These studies provide a background in which

the most up-to-date indicators are listed. The additional references were used to fill possible gaps in the main studies.

In parallel to Step 1, criteria are developed (Step 2), to carry out a first quality check of the available indicators. All indicators has to fulfil the following criteria:

- Relevance or coherence: Selected indicators should be relevant to measure decarbonisation and competitiveness of the energy sector in each considered country;
- Consistence: Indicators should be described and calculated consistently for all countries to ensure that the indicators between different countries can be compared with each other;
- Suitable communication: Indicators should be easy to understand and suitable to communicate and implement, especially by non-experts;
- Transparency: Indicators should be transparent to the academia, the industry as well as the public;
- Traceability: Indicators should be traceable in order to assess the development by comparing historical conditions.

All these criteria affect the availability of data necessary to calculate the indicators. The required data should be widely available to the public. Furthermore, they should also fulfil the above-mentioned criteria. This can be expected, when existing Eurostat data or other official data sources are used. However, since the focus of the project is to evaluate future developments, the use of statistical data or other data will be limited to describe current situation (s. below).

Based on the criteria defined above, in Step 3 indicators not fulfilling the requirements were excluded. This step intends to identify commonly and applicably used indicators based on the literature review. The exclusion process depends on internal expert judgement.

To structure the in Step 3 identified indicators it is recommended to define topics, which characterize the system under review. The topics shall help to detect gaps not addressed by the selected indicators.

In case of this study, five topics were identified:

1. Decarbonisation of the economy
2. Energy security, solidarity and trust
3. Energy efficiency and moderation of demand
4. Integrated internal energy market
5. Research, innovation and competitiveness

The five topics refer to the facets of decarbonisation and competitiveness discussed in Section 2. They also link to the dimensions of the Energy Union. The dimensions are energy security, energy efficiency, internal energy market/market integration, decarbonisation and innovation & competition (Regulation 2018/1999/EU).

Additionally, to minimize the risk of overlooking important aspects areas of relevance were defined. In these areas, the indicators were combined and categorised.

In Step 5, those indicators that do not fit to the topics were excluded.

The ordering of the first four steps is arbitrary. A changed ordering would lead to the same outcome of Step 5.

The identified list of indicators should be presented to experts and stakeholders to discuss whether the pre-selected indicators are applicable or extensive enough. This process allows amendments and supplements of the selected indicators to evolve into a more applicable set. Another reason for the involvement of experts and stakeholder is to verify the relevance of the selected indicators.

As experts, the Coordinators of the Joint Programs of EERA were contacted. Due to the Corona crisis, a survey substituted the original planned workshop. The survey included all in Step 5 defined indicators. These were categorised along the topics. Each coordinator had the opportunity to assess each indicator, differing between highly relevant, relevant, less relevant and not relevant in respect to decarbonisation and competitiveness. Furthermore, “no answer” was also possible. The coordinator had also the possibility to amend indicators.

Of the 20 coordinators, only five reacted, of which only four answers were usable for any serious analysis. Considering the low number of participants, the project team refrained to make use of the findings. Instead, project-internal experts were consulted to reach a further quality check, i.e. to get additional assessments whether the list is plausible and complete, considering the current state of research. Despite a general approval, they also pointed to on-going research. This research will be considered in an updated version of the set of indicators in a later stage of the project.

Step 7 sees a pre-final set of indicators, after the discussion with stakeholders and experts. The pre-final set of indicators comprises all indicators, which are presented in this study, i.e. in the Sections 4 and 5.

Since the indicators will be used to assess innovative technologies as well as future policies, a further requirement for selecting indicators is whether they could be linked to energy system models or energy-related models. Due to this, scenario-based analysis and assessment of innovative technologies and policies are possible.

Only models considered in the H2020 project openENTRANCE have been taken into account in the analysis. Therefore, two interviews with the project coordinator of openENTRANCE were conducted, resulting in a final set of indicators. Due to the current state of the project openENTRANCE only the energy system model GENeSYS-MOD was included in the selection process.

GENeSYS-MOD or Global Energy System Model is an open-access multi-regional energy system model. Amongst others the EU27 Member States, Norway, Switzerland, and UK are included. The model considers electricity, transport, and heating/cooling. It is a linear programming optimizing model with total system cost minimizing as the objective function (https://openenergy-platform.org/factsheets/frameworks/73/; accessed 20.12.2020).

Finally, those indicators, which are connected to GENeSYS-MOD were selected. Section 4 shows the final set of indicators. In addition, Section 5 reveals those indicators identified in Step 7, but are not linked to GENeSYS-MOD. As the project openENTRANCE evolves, further models will be scrutinized to identify additional connections to indicators.

IV SELECTED INDICATORS

In the following those indicators are presented, which can be linked to GENeSYS-MOD. The indicators are assigned to five topics:

1. Decarbonisation of the economy
2. Energy security, solidarity and trust
3. Energy efficiency and moderation of demand
4. Integrated internal energy market
5. Research, innovation and competitiveness

The five topics refer to the facets of decarbonisation and competitiveness discussed in Section 2. They also link to the dimensions of the Energy Union. The dimensions are energy security, energy efficiency, internal energy market/market integration, decarbonisation and innovation & competition (Regulation 2018/1999/EU).

Each indicator is depicted in a table containing the following information:

- Area of relevance
- Description
- Unit
- Motivation
- Supporting indicators
- Geographical coverage
- Model
- Additional remarks
- Reference

4.1

4.1 Topic 1: Decarbonisation of the economy

4.1.1 Indicator: Greenhouse gas emission reduction

Item	Explanation
Area of relevance	Renewable energy
Description	Total greenhouse gas emissions of a country in a specific year compared to 1990. The indicator includes indirect CO_2 emissions and emissions from international aviation.
Unit	Index number, base year 1990 = 100
Motivation	The indicator monitors the progress towards the EU's decarbonisation targets.
Supporting indicators	• Greenhouse gas emission reduction – Industry • Greenhouse gas emission reduction – Transport • Greenhouse gas emission reduction – Services • Greenhouse gas emission reduction – Households
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	GENeSYS-MOD is lacking emissions from agriculture, land use, land use change.
Reference	European Commission (2017)

4.1.2 Indicator: Gap between greenhouse gas emissions and NECP target in Effort-Sharing sectors

Item	Explanation
Area of relevance	Renewable energy
Description	Greenhouse gas emissions of Effort-Sharing sectors compared to NECP target
Unit	%
Motivation	The indicator is used to monitor the progress in the sectors not covered by the EU emissions trading system. The Effort-Sharing Decision sets national binding targets to be met through mitigation action in the Effort-Sharing sectors (transport, buildings, small businesses and services, agriculture and waste).
Supporting indicator	--
Geographical coverage	EU27 Member States, UK
Model	GENeSYS-MOD
Additional remarks	NECP targets are not included in GENeSYS-MOD. They need to be taken from the respective homepage https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en. Only Member States are obliged to deliver NECPs. UK submitted their NECP shortly before the end of 2020 (European Commission 2020d).
Reference	European Commission (2017)

4.1.3 Indicator: Greenhouse gas intensity

Item	Explanation
Area of relevance	Renewable energy
Description	Greenhouse gas emissions of a country in respect to national Gross Domestic Product (GDP)
Unit	Mg/EUR
Motivation	The indicator is relevant from the decarbonisation perspective and is used as a global sustainability indicator.
Supporting indicators	• Greenhouse gas intensity per capita [Unit: Mg/inhabitant] • Greenhouse gas intensity of power & heat generation [Unit: Mg/MWh]
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	Population and GDP developments have to be taken from Eurostat.
Reference	European Commission (2017)

4.1.4 Indicator: Renewable energy share

Item	Explanation
Area of relevance	Renewable energy
Description	Energy generation by renewable energy sources in respect to gross final energy consumption
Unit	%
Motivation	The progress on renewable energy penetration gives an important indication of the extent of decarbonisation of the energy system.
Supporting indicators	• Renewable energy share – Electricity • Renewable energy share – Heating & cooling • Renewable energy share – Transport Additionally, following indicators are taken into account: • Fossil fuels avoidance by RES • Greenhouse gas emissions avoided due to RES
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	The supporting indicators “Fossil fuels avoidance by RES” and “Greenhouse gas emissions avoided due to RES” need additional calculations.
Reference	European Commission (2017)

4.1.5 Indicator: Relative costs to implement decarbonized systems

Item	Explanation
Area of relevance	Business regulation of the EU Member States
Description	Costs to implement decarbonized energy system in respect to per-capita income
Unit	%
Motivation	This indicator can provide an indication of the business dynamism of the decarbonized system.
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	GENeSYS-MOD calculates costs for establishing new capacities. To calculate the indicator data in respect to income per capita is required.
Reference	Schwab (2019)

4.2 Topic 2: Energy security, solidarity and trust

4.2.1 Indicator: Net import dependence

Item	Explanation
Area of relevance	Self-sufficient market-size
Description	Total net imports of energy carriers in respect to total gross inland energy consumption. The indicator includes energy consumption of maritime bunkers.
Unit	MJ/MJ
Motivation	Net import dependence is the basic indicator to reflect the self-sufficient market-size.
Supporting indicators	• Net import dependence – Natural gas • Net import dependence – Crude oil • Net import dependence – Hard coal • Net import dependence – Nuclear fuels • Net import dependence – Electricity • Net import dependence – Biomass • Net import dependence – Hydrogen
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	Bunkers might have to be omitted.
Reference	European Commission (2017)

4.3 Topic 3: Energy efficiency and moderation of demand

4.3.1 Indicator: Primary energy consumption

Item	Explanation
Area of relevance	Overarching
Description	Total energy demand of a country. The indicator covers the consumption of the energy sector itself, losses during transformation and distribution of energy, and the final consumption by end users, but excludes energy carriers used for non-energy purposes.
Unit	TWh
Motivation	The indicator monitors the changes in primary energy consumption. The Energy Efficiency Directive translates the energy efficiency targets into maximum levels of primary energy consumption by 2020 and 2030.
Supporting indicators	• Primary energy consumption – Natural gas • Primary energy consumption – Crude oil • Primary energy consumption – Hard coal • Primary energy consumption – Nuclear • Primary energy consumption – Wind • Primary energy consumption – Photovoltaic / Solar • Primary energy consumption – Biomass
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	--
Reference	European Commission (2017)

4.3.2 Indicator: Final energy consumption

Item	Explanation
Area of relevance	Overarching
Description	Total energy consumed by end users, excluding self-consumption by the energy sector.
Unit	TWh
Motivation	The indicator monitors the changes in final energy consumption. The Energy Efficiency Directive translates the energy efficiency targets into maximum levels of final energy consumption by 2020 and 2030.
Supporting indicators	• Final energy consumption – Industry • Final energy consumption – Transport • Final energy consumption – Services • Final energy consumption – Households
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	Self-consumption needs to be calculated additionally.
Reference	European Commission (2017)

4.3.3 Indicator: Final energy intensity – industry

Item	Explanation
Area of relevance	Energy intensity/efficiency – industry
Description	Energy consumption in respect to value added of industry and construction sector
Unit	MWh/EUR
Motivation	Monitoring sectoral energy-intensity developments can provide an indication of progress in terms of energy efficiency by revealing the extent to which energy consumption is decoupled from economic growth, or the specific energy used in producing a unit of GDP or value added.
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	GENeSYS-MOD calculates energy use of the industry. To calculate the indicator information in respect to value added is required, which is not provided by the model. The indicator may be refined by also measuring final energy consumption in respect to amount of physical output. The unit would be MWh/Mg or MWh/m³. To calculate the refined indicator information in respect to physical output is required, which is not provided by the model.
Reference	European Commission (2017)

4.3.4 Indicator: Final energy consumption – transport: traffic

Item	Explanation
Area of relevance	Energy intensity/efficiency – transport
Description	Energy used in respect to passenger-kilometre travelled
Unit	MWh/Pkm
Motivation	The indicator can compile an accurate picture of transport activities and related energy consumption and enable in-depth analysis of energy-efficiency developments in transport.
Supporting indicators	• Share of collective transport in all passengers' transport • Final consumption in transport vs. passengers and freight activities
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	--
Reference	European Commission (2017)

4.3.5 Indicator: Final energy consumption – transport: freight

Item	Explanation
Area of relevance	Energy intensity/efficiency – transport
Description	Energy used in respect to tonne-kilometres travelled
Unit	MWh/tkm
Motivation	The indicator can compile an accurate picture of transport activities and related energy consumption and enable in-depth analysis of energy-efficiency developments in transport.
Supporting indicator	Final consumption in transport vs. passengers and freight activity
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	--
Reference	European Commission (2017)

4.4 Topic 4: Integrated internal energy market

4.4.1 Indicator: Electricity interconnection capacity

Item	Explanation
Area of relevance	Electricity and gas interconnections
Description	Electricity interconnection capacity of a country in respect to its total generation capacity
Unit	%
Motivation	The 2030 climate & energy framework (European Commission 2020e) referred to the need to monitor the deployment of smart grids and interconnections between Member States against the agreed 2020 objective of electricity interconnections of at least 10% of national installed production capacity, moving towards 15% by 2030.
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	--
Reference	European Commission (2017)

4.4.2 Indicator: Gas interconnection capacity

Item	Explanation
Area of relevance	Electricity and gas interconnections
Description	Gas interconnection capacity of a country in respect to its total generation capacity
Unit	%
Motivation	Apart from electricity, gas is another important type of energy in the energy market
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	--
Reference	European Commission (2017)

4.4.3 Indicator: Installed capacity of energy storage resources

Item	Explanation
Area of relevance	Electricity and gas interconnections
Description	Installed capacity of energy storage resources connected to the electricity grid
Unit	MW
Motivation	Energy storage resources as a flexibility option are getting more and more important in the electricity system with high shares of renewable energy sources.
Supporting indicator	Electricity delivered to the market [Unit: MWh]
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	Following technologies are considered: • Batteries with interoperable capabilities, • Pumped-hydro, • Flywheels, • Compressed Air Energy Storage (CAES), • Hydrogen.
Reference	CoGEn Project (2019)

4.4.4 Indicator: Installed capacity of electrolysers for Power-to-Gas applications

Item	Explanation
Area of relevance	Electricity and gas interconnections
Description	Total installed capacity of electrolysers for Power-to-Gas applications
Unit	MW
Motivation	Power-to-Gas is seen as a promising technology to store excess energy from RES.
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	--
Reference	CoGEn Project (2019)

4.4.5 Indicator: Wholesale electricity prices

Item	Explanation
Area of relevance	Energy market coupling
Description	Electricity prices at wholesale market
Unit	EUR/kWh
Motivation	The 2030 climate & energy framework (European Commission 2020e) referred to the need to monitor competition and market concentration on wholesale and retail energy markets at both national and (for regions with functioning coupling) regional level.
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	In GENeSYS-MOD, marginal production costs are calculated; fees, taxes etc. are lacking.
Reference	European Commission (2017)

4.4.6 Indicator: Share of electricity at total energy use in non-energy sectors

Item	Explanation
Area of relevance	Energy market coupling
Description	Electricity use compared to total energy use in non-energy sectors
Unit	%
Motivation	The indicator could assess the degree of electricity used in non-energy sectors, giving an indication for sector coupling.
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	--
Reference	European Commission (2017)

4.5 Topic 5: Research, innovation and competitiveness

4.5.1 Indicator: Capacity installed

Item	Explanation
Area of relevance	Innovation deployment
Description	Installed capacity per technology.
Unit	MW
Motivation	The indicator shall give an indication of the situation in respect to the energy mix / technology mix.
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	The indicator shall differ between technologies.
Reference	European Commission (2020c)

4.5.2 Indicator: Trade openness

Item	Explanation
Area of relevance	Innovation deployment
Description	Imported and exported energy
Unit	Depends on the energy carrier
Motivation	The indicator shall give an indication of the global market situation
Supporting indicator	--
Geographical coverage	EU27 Member States, Norway, Switzerland and UK
Model	GENeSYS-MOD
Additional remarks	The indicator shall differ between technologies.
Reference	European Commission (2020c)

V ADDITIONAL INDICATORS

The analysis of literature and the discussion with experts revealed a larger number of relevant indicators compared to the one listed in Section 4. In the following, those indicators are shown, which are seen promising to help measuring the progress of decarbonisation and competitiveness, but currently are not connected to GENeSYS-MOD. The main sources are the same mentioned in Section 4 as well as experts from KIT ITAS.

Contrasting the presentation of the indicators in Section 4, only the indicator definition plus the proposed unit is revealed. The indicators are assigned to the five topics and areas of relevance. Nevertheless, all indicators shall cover the EU27 Member States, Norway, Switzerland and UK.

5.1 Topic 1: Decarbonisation of the economy

Indicator	Unit
Area of relevance: Macroeconomic stability	
Sectoral added value growth rate	%
Area of relevance: Health life expectation	
Disability-Adjusted Life Year (DALY)	Years
Particulate matter emissions	Mg
Area of relevance: Unintended environmental impacts	
Eutrophication	kg P-Equivalents
Metal depletion	kg Fe-Equivalents
Ozone depletion	kg CFC-11
Change of land occupation in respect to energy systems transformation	Hectare
Area of relevance: Social costs	
Average income of employees compared to total income average	%
Area of relevance: Financial system	
Capital availability for renewable energy sources	EUR
Capital availability for new jobs	EUR
Credit to the energy sector	EUR
Area of relevance: Business regulation	
Insolvency recovery rate in the energy sector	%
Growth rate of innovative companies in the renewable energy sector	%

5.2 Topic 2: Energy security, solidarity and trust

Indicator	Unit
Area of relevance: Self-sufficient market size	
Net import dependency of energy technologies, e.g. wind turbines	Value of net imports per domestic investments of the technology
Area of relevance: Electricity supply (market)	
Aggregate supplier concentration index	Index number
System Average Interruption Duration Index (SAIDI)	Time
Area of relevance: Smart grid infrastructure	
Grid length	km
System Average Interruption Frequency Index (SAIFI)	Average number of interruptions per customer
Roll-out plan for smart meters[1]	Share of households
Area of relevance: Electricity supply quality	
Electric power losses	%
Area of relevance: Digitization	
Investment costs	EUR/MW
Operating costs	EUR/MWh
Energy cost savings	EUR per avoided MWh
Area of solidarity and justice	
Energy affordability	Share of energy expenditure at final consumption expenditure for the lowest quintile
Energy consumption support	Amount of financial support regarding energy costs for the lowest quintile
Energy investment support	Support for private households to invest in renewable energy technologies
Remaining carbon budget that is consistent with the Paris Agreement goal of limiting global warming to 1.5°C	Gt $CO_{2eqiv.}$
Proportion of households whose share of energy expenditure at income is more than twice the national median share of energy expenditure	%
Proportion of households whose absolute energy expenditure is below half the national median	%
Share of socialized energy system costs (direct and indirect subsidies for renewables and fossils) covered by 20% of lowest-income households vs. 20% highest-income households	%
Direct and indirect subsidies for fossil fuels	EUR
Direct and indirect subsidies for renewable energy	EUR
Gender pay gap in the energy industry	EUR or %

Public opinion on the extent to which the transformation is perceived as fair and inclusive	--

Note: [1] affects also Topic 3: Energy efficiency and moderation of demand

5.3 Topic 3: Energy efficiency and moderation of demand

Indicator	Unit
Area of relevance: Energy intensity/efficiency – residential	
Energy consumption of households per m^2 of floor area in residential buildings, climate corrected	kWh/m²
Area of relevance: Energy intensity/efficiency – services	
Final energy intensity in services sector	MWh/EUR

5.4 Topic 4: Integrated internal energy market

Indicator	Unit
Area of relevance: Energy market coupling	
Gas price at wholesale market	EUR/GWh
Area of relevance: Market concentration	
Market concentration index – electricity	Herfindahl-Hirschman-Index
Market concentration index – gas	Herfindahl-Hirschman-Index
Area of relevance: Switching rates	
Annual switching rates – electricity (household customers)	Share of switching households
Annual switching rates – gas (household customers)	Share of switching households

5.5 Topic 5: Research, innovation and competitiveness

Indicator	Unit
Area of relevance: Technology analysis	
Energy costs in respect to value added in manufacturing, excluding refinery sector	EUR/EUR
Area of relevance: Value chain analysis	
Levelized costs of energy (LCOE)	EUR/kWh
Turnover per technology groups	EUR/TWh
Employment in the energy sector	Number
Labour productivity	Value added / output per employment
Energy generation per legal entity	Annual production values / outputs per legal entity
Area of relevance: Global market analysis	
Resource efficiency of energy generation	Non-energy resources / metal resources / strategic metals per output
Resource dependency	Share of imported non-energy resources / metal resources / strategic metals at domestic investments in respect to energy technologies
Area of relevance: Research and Innovation funding (R&I)	
Public R&I funding	EUR
Private R&I funding	EUR
Area of relevance: Public Research and Development (R&D)	
Public investments on Energy Union related Research & Innovation	% of GDP
Patents related to Energy Union R&I priorities	Annual patents per inhabitant
Area of relevance: R&D	
Patent application regarding energy technologies	Annual number of patents
Scientific publications regarding energy	Annual number of scientific publications
Area of relevance: Collaboration	
Co-inventions with partner outside the EEA in respect to energy technologies	Number of co-inventions per inhabitant
Multi-stakeholder collaboration	Annual number of collaborations
Area of relevance: Technology market	
Number of companies in the supply chain incl. EU market leaders	Number
Market share of EU companies at global market	%
Financial efforts (taxes and subsidies) to support the energy sector[1]	EUR

Area of relevance: Skills	
Capacity building for energy research and innovation	EUR
Average years of schooling	Years
Further education and training measures in the energy sector	Days per year

Note: [1] The indicator will differ between electricity and gas

VI OUTLOOK

The presented study is the first deliverable of SUPEERA focussing on indicators, which could help to measure the progress of decarbonisation and competitiveness in a model-based environment. At the current step, only indicators were selected, which are linked to GENeSYS-MOD, an open-access energy system model. In the second half of the project, following activities are planned:

1) Updating of the indicator list (until 09/22): Continuous scanning of literature and discussions with experts on the necessity to include other indicators; but also to substitute the presented one, if new indicators emerged and to streamline them, if possible or necessary.
2) Updating of the indicator list in respect to model-based data availability (4/22-9/22). As the project openENTRANCE is evolving indicators as they are listed in Section 5 will be once again reviewed, at aiming to up-date the list of indicators of Section 4.
3) Evaluating a small set of selected policy scenarios using the indicators to illustrate the appropriateness (06/21-12/22). The work will built on the H2020 project openENTRANCE and the scenarios developed in that project.

REFERENCES

BMWi – Federal Ministry for Economic Affairs and Energy (2020): Grids and infrastructure. https://www.bmwi.de/Redaktion/EN/Artikel/Energy/electricity-grids-of-the-future-01.html, accessed 17.12.2020.

CoGEnN Project (2019). Addressing demand-side flexibility and system efficiency in the National Energy & Climate Plans. https://www.cogeneurope.eu/images/Addressing_demand-side_flexibility_and_system_efficiency_in_the_NECPs.pdf

Directive 2018/2002/EU: Revised Energy Efficiency Directive.

Emissions-EUETS.com (2020): System Average Interruption Duration Index (SAIDI). https://www.emissions-euets.com/internal-electricity-market-glossary/2069-system-average-interruption-duration-index-saidi, accessed 17.12.2020.

European Commission (2001): European competitiveness report 2001. Luxembourg: Publications Office of the European Union.

European Commission (2017). Second Report on the State of the Energy Union. COMMISSION STAFF WORKING DOCUMENT Monitoring progress towards the Energy Union objectives – key indicators. https://ec.europa.eu/commission/sites/beta-political/files/swd-energy-union-key-indicators_en.pdf.

European Commission (2018): Final Report of the High-Level Panel of the European Decarbonisation Pathways Initiative. Luxembourg: Publications Office of the European Union.

European Commission (2019a): The European Green Deal. COM(2019) 640 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN, accessed 21.12.2020

European Commission (2019b): Clean energy for all Europeans. Luxembourg: Publications Office of the European Union.

European Commission (2019c): The strategic energy technology (SET) plan. Luxembourg: Publications Office of the European Union.

European Commission (2020a): Committing to climate-neutrality by 2050: Commission proposes European Climate Law and consults on the European Climate Pact. Press release 04.03.2020, https://ec.europa.eu/commission/presscorner/detail/en/ip_20_335, accessed 21.12.2020.

European Commission (2020b): Recovery plan for Europe. https://ec.europa.eu/info/strategy/recovery-plan-europe_en, accessed 21.12.2020.

European Commission (2020c): On progress of clean energy competitiveness. COM(2020) 953 final. https://ec.europa.eu/energy/sites/ener/files/report_on_clean_energy_competitiveness_com_2020_953.pdf, accessed 30.06.2021.

European Commission (2020d): National energy and climate plans (NECPs). https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en, accessed 19.12.2020.

European Commission (2020e): 2030 climate & energy framework. https://ec.europa.eu/clima/policies/strategies/2030_en#tab-0-0, accessed 17.12.2020.

Regulation 2018/1999/EU on the Governance of the Energy Union and Climate Action.

Schwab, K. (2019). The Global Competitiveness Report. Insight report. World Economic Forum. Geneva. http://www3.weforum.org/docs/GCR2018/05FullReport/TheGlobalCompetitivenessReport2018.pdf