Article

Monitoring Sustainable Development: Climate and Energy Policy Indicators

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ABSTRACT

Both the UN SDGs and the Paris Agreement imply ambitious long-term targets that can only be met through a fundamental restructuring of economic and social systems. We propose a set of energy and climate policy indicators that allow informed policymaking and go beyond the UN indicator set. The indicators cover the whole energy system as well as the three dimensions of sustainable development. Our approach combines an energy service centered perspective with research on energy and climate indicators, and it embeds the indicator framework in the broader socio-ecologic context. We compile a set of 109 high-level energy indicators for four key sectors of energy demand (households, transport, industry and manufacturing) that can be further disaggregated to 334 indicators. For electricity and heat supply we assemble a set of 21 indicators that can be disaggregated to 54 indicators, differentiating by energy source and plant type. Interactions, i.e., synergies and conflicts, between the different target dimensions and the corresponding indicators need to be carefully considered. The main aim of the comprehensive indicator set is to help policymakers define measurable goals and strategies in the field of energy and climate policy, as well as to provide a tool for policy monitoring, evaluation and revision. The challenge in using indicator systems for policy analysis is that they have to consider a multitude of aspects in order to reflect the complexity of the issues analyzed and at the same time have to deliver concise information on various trends.

KEYWORDS: sustainable development; indicator systems; energy policy; climate policy

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INTRODUCTION

2015 was marked by two important outcomes of international negotiations: the agreement on the UN Sustainable Development Goals (SDGs) and the Paris Climate Agreement. Both imply ambitious (long-term) targets that can only be met with a fundamental restructuring of economic and social systems. The greenhouse gas (GHG) emission reductions—required to limit climate change to well below 2 °C or even 1.5 °C above pre-industrial levels, as stated in the Paris Climate Agreement—call for a fundamental decarbonization. A substantial contribution needs to come from the energy system because energy-related emissions account for the largest share in total GHG emissions, e.g., 78% for the EU total [1].

For both the Paris Agreement and the SDGs, research is needed because the scope of the required changes calls for new measurement and monitoring approaches. This comprises work on governance structures, pathway analyses, as well as suitable indicator sets that comprehensively capture the socio-economic and environmental aspects and allow depicting synergies and trade-offs between the dimensions of sustainable development as well as between targets [2,3]. Therefore, indicator sets that provide more detailed information than the set of targets and indicators proposed by the UN are called for. In this paper, we propose a novel Climate and Energy Policy (ClEP) indicator system for the EU Member States that allows for informed policymaking. Compared to those approaches which mainly focus on progress based on the UN indicator set [4], our indicator system contains more disaggregated information with a focus on energy and climate policy. The proposed sustainable energy indicators cover the entire energy system as well as the three dimensions of sustainable development. The approach combines an energy service centered perspective with research on energy and climate indicators, and it embeds the indicator framework in a broader socio-ecologic context. The main aim of the comprehensive indicator set is to help policymakers define measurable goals and strategies in the field of energy and climate policy and to provide a tool for policy monitoring, evaluation and revision. For the EU Member States, relevant data so far are mainly available at the national level. Therefore, the relevant target group is national energy and climate policymakers, allowing them to conduct performance comparisons and to identify successful solutions. Moreover, some of the indicators could complement the existing energy and climate policy indicators at the EU level. One key advantage of our indicator system is its ability to facilitate public debate on trade-offs between different targets, thereby providing a basis for informed decision-making.

For a series of issues, in particular pertaining to the social dimension of sustainable energy development, at present no data are available and therefore have to be omitted from the analysis. The closing of the gap has to be spurred by policymakers (in providing the legal basis for data collection) and statistical offices in actual data collection and processing. This would help identify interlinkages and trade-offs between the dimensions of sustainable development as well as between different sectors.

The paper is structured as follows: The second section provides the broader context, embedding the climate and energy policy indicators into the socio-ecological framework defined by the UN Sustainable Development Goals. In the third section the conceptual approach of the ClEP indicator framework is presented. The fourth section discusses interactions between the target dimensions and indicators. The final section concludes.

CLIMATE AND ENERGY POLICY INDICATORS IN THE CONTEXT OF THE UN SDGS

The manifold interactions between the 17 SDGs and different sub-targets constitute a broad research area [2,5–10]. The assessment of interlinkages is of high relevance because ignoring synergies or trade-offs creates a risk of unintended outcomes. This applies to the entirety of the SGDs but also to the set of energy and climate policy indicators described below. Figure 1 illustrates which thematic areas of SDGs 7 and 13 we identified as being strongly or directly linked to eleven other goals and which interactions between these objectives must be considered to achieve the targets and design adequate monitoring approaches. For instance, policies aimed at reducing energy expenditures of poor households (thus contributing to improvements in the social dimension/SDG 10) might increase energy demand and in turn emissions (with negative effects on the environmental dimension/SDG 13), if not properly designed.

Figure 1. Interaction of the SDGs "Climate Action" and "Affordable and Clean Energy" with other SDGs; authors' own illustration.

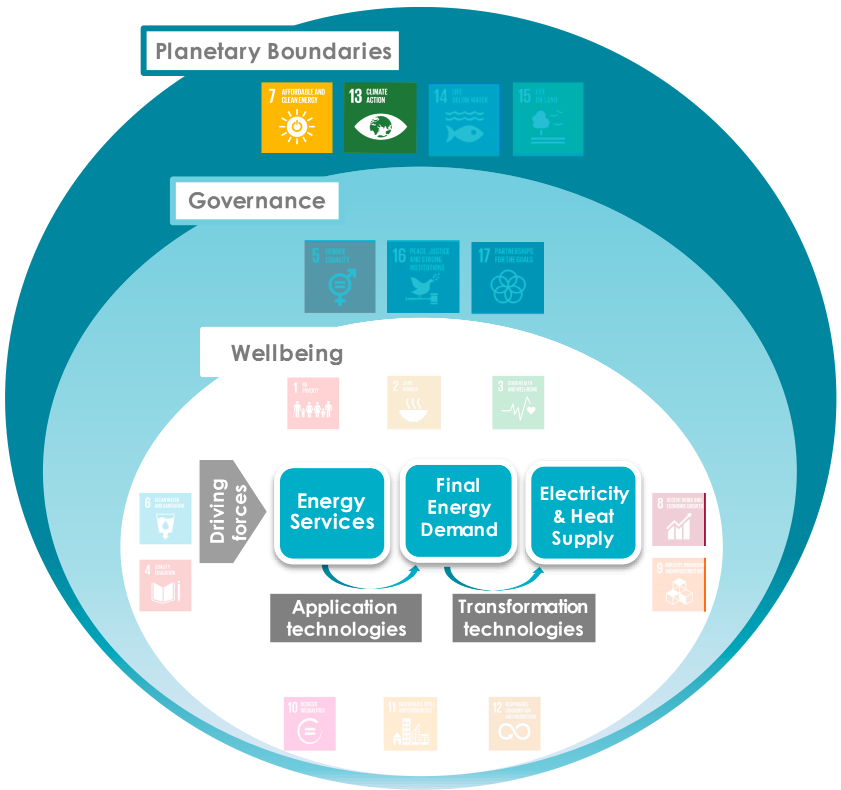
The indicator set is embedded in the broader socio-ecological framework defined by the UN SDGs but specifically focuses on two goals: "Affordable and clean energy" (SDG 7) and "Climate Action" (SDG 13). It consists of operational indicators putting energy services at the center because energy services generate welfare instead of energy flows [11–17]. The indicator set starts with energy services in four demand-side sectors—residential buildings, transport, manufacturing and services—which are complemented by consistent indicators for sustainable electricity and heat supply.

Figure 2A presents a conceptual illustration for a better understanding of the interlinkages between the SDGs. We use a "doughnut" representation similar to other research concerned with the SDGs [18], in which the socio-ecological framework is partitioned into three layers—wellbeing, governance and planetary boundaries [2], and to which the SDGs are assigned in the context of our research. This combination of the concept of wellbeing and the concept of planetary boundaries creates a space in which sustainable development can be achieved, i.e., social goals are met while at the same time the integrity of ecosystems is preserved so that they can provide the services on which our societies depend. In this visualization we attribute ten SDGs to the layer of wellbeing (inner layer). The second layer of governance structures constitutes the supporting framework for wellbeing and comprises three SDGs. The third layer comprises the planetary boundaries, i.e., the biophysical base and natural limits for all human activities.

As emphasized in TWI2050 [19], the starting point for any clustering of SDGs must be the definition of the research question for which it is of relevance. There is no "absolute" categorization of the SDGs because they do not comprise a specific model, but TWI2050 [19] concluded that "(i) the SDGs are universal, holistic and interdependent and thereby indivisible, and (ii) any clustering method is context specific, being dependent on the question being addressed, modelling approach, or regional context."

To develop this representation or clustering of SDGs we focused on human wellbeing and those goals that directly affect living conditions and quality of life. Our energy system approach [14] can then be integrated into this perspective (Figure 2(B)). This allows considering in more detail to what extent energy services, i.e., the use derived from "consuming" energy, are crucial for all aspects of economic and social development. A given level of energy services can be provided by different combinations of technologies (stocks) and energy flows. The range of available technologies and energy sources thus opens up a spectrum of options entailing different environmental impacts for any given energy service level. The energy efficiency of the capital stock (i.e., both of conversion technologies and application technologies/passive systems) is one key determinant of energy flows and the corresponding greenhouse gas emissions associated with a certain level of energy services [11,14,15]. In contrast to the welfare-inducing energy services, the physical aspects of energy (flows) and related greenhouse gas emissions are part of the "planetary boundaries".

(**A**) Embedding the SDGs into the broader socio-ecological context



(**B**) Embedding the ClEP indicator approach into the broader socio-ecological context

Figure 2. Socio-ecological context; authors' own illustration.

Thus, the detailed indicator set describes or quantifies the areas of energy and climate, on the one hand, but emphasizes the relevance of these areas for people's wellbeing, on the other. And while the interlinkages between energy and climate are at the center of our analysis, interlinkages with other SDGs, although highly relevant (see also Figure 1), are beyond the scope of this research.

THE CLEP INDICATOR FRAMEWORK

Literature Overview

The multidimensionality of sustainable development entails a high degree of complexity. Sets of indicators—such as those developed, for instance, by the EU and the UN [20–24]—are considered to be appropriate tools with which to reduce this complexity and to illustrate the interactions between society and ecosystems.

The adoption of the SDGs and the publication of the corresponding indicator framework have stimulated the latest wave of developing comprehensive indicator frameworks. The SDGs of the 2030 Agenda for Sustainable Development are the continuation of the Millennium Development Goals [23] and were adopted by 156 states in 2015 after an extensive planning and consultation process. In the SDGs, the overarching aims of ending all forms of poverty, protecting the planet and ensuring prosperity for everyone are broken down into 17 goals and 169 detailed targets. In contrast to the Millennium Development Goals, the SDGs refer not only to developing countries but to all signatories.

For the monitoring of the SDGs and the respective sub-targets, an indicator system comprising 244 indicators (or respectively 233 indicators, with some occurring more than once in the system) was developed, some of which are used to monitor more than one target [22]. In general, the goals/targets and the respective indicators are based on the three dimensions of sustainable development and can be divided into the five pillars of the Agenda 2030 (the five "Ps"—people, planet, prosperity, peace, partnership).

In the EU, the UN SDG framework has been implemented by Eurostat as well as at the Member State level, with national indicator frameworks differing from the Eurostat system. In the following, the indicators for SDGs 7 and 13 proposed by the UN are compared with the indicators put forward by Eurostat, and the indicators developed for Austria as an example of a national indicator framework. A different approach is applied by the Sustainable Development Solutions Network (SDSN) and the Bertelsmann Stiftung, who provide a composite SDG Index and dashboards describing countries' progress towards achieving the SDGs [25]. The 2018 SDG Index includes 88 global indicators and 111 indicators for the Dashboard for 156 OECD countries. Thirty-nine of these indicators match UN indicators exactly, 28 are closely aligned, and 44 are not included in the UN framework.

Eurostat has developed its own indicator set that puts emphasis on interlinkages between targets by defining so-called multi-purpose indicators (monitoring more than one target). The Eurostat framework consists of 100 indicators, with a maximum of 6 indicators being assigned to each SDG.

For Austria, the national statistical office, Statistics Austria, implemented an indicator framework closely related to the UN indicators [26]. For almost half of the proposed UN indicators, national data are currently available from Statistics Austria or from other data sources. Forty-five indicators that are not relevant to Austria (e.g., indicators related to marine life or targeted at developing countries) have been omitted. For another 19% of the proposed UN indicators no data for Austria are available. However, the national statistical office has added additional indicators that are of particular relevance from an Austrian perspective (headline indicators from the national wellbeing measurement initiative “Wie geht’s Österreich”).

Table 1 lists the indicators used for monitoring SDG 7 “Affordable and clean energy” and SDG 13 “Climate Action” developed by the UN, Statistics Austria and Eurostat, along with the sub-targets. The indicators by the UN and Statistics Austria largely correspond to the ten sub-targets. For SDG 7, these include providing access to affordable, reliable and modern energy services for all, substantially increasing the share of renewable energy and accelerating energy efficiency improvements, along with assistance for lower-income countries. While Statistics Austria has not adopted the indicators “7.1.1 Proportion of population with access to electricity” and “7.1.2 Proportion of population with primary reliance on clean fuels and technology” because these targets have already been achieved in Austria, final energy consumption has been included as an additional indicator. The six Eurostat indicators include information on energy poverty, final energy consumption, energy dependence, energy productivity and GHG emissions intensity of energy consumption as a multi-purpose indicator.

For SDG 13, the UN indicators focus mostly on a policy/finance dimension and cover both climate change mitigation and adaptation. Most indicators have a global dimension, e.g., “13.3.2 Number of countries that have communicated the strengthening of institutional, systemic and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions”. Statistics Austria has omitted most of these global targets and adapted some of them to the national context. In addition, it included GHG emissions as an indicator. The Eurostat indicators, in contrast, focus on GHG emissions and the impacts of climate change. Moreover, Eurostat stresses the nexus between emissions and energy use by including final energy consumption and the share of renewables as multi-purpose indicators.

Table 1. Indicators used by statistical offices for Monitoring SDGs 7 and 13.

Goal/Target	Indicators		
	UN	**Statistics Austria**	**Eurostat**
SDG 7. Ensure access to affordable, reliable, sustainable and modern energy for all			
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.1 Proportion of population with access to electricity	- [a]	07.10 Percentage of people affected by fuel poverty (inability to keep home adequately warm) 07.20 Share of renewable energy in gross final energy consumption 07.30 Primary energy consumption; final energy consumption by sector 07.32 Final energy consumption in households per capita 07.33 Energy dependence 07.35 Energy productivity 13.14 Greenhouse gas emissions intensity of energy consumption [c]
	7.1.2 Proportion of population with primary reliance on clean fuels and technology	- [a]	
7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	7.2.1 Renewable energy share in the total final energy consumption	Renewable energy share in gross final energy consumption	
7.3 By 2030, double the global rate of improvement in energy efficiency	7.3.1 Energy intensity measured in terms of primary energy and GDP	Energy intensity: Final energy consumption per GDP	
	-	Final energy consumption	
7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology	7.a.1 International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems	International financial flows to developing countries in support of clean energy research and development and renewable energy production	
7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support	7.b.1 Investments in energy efficiency as a proportion of GDP and the amount of foreign direct investment in financial transfer for infrastructure and technology to sustainable development services	-	

Table 1. *Cont.*

Goal/Target	Indicators		
	UN	**Statistics Austria**	**Eurostat**
Goal 13. Take urgent action to combat climate change and its impacts			
13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Number of deaths attributed to disasters per 100,000 population	13.11 Greenhouse gas emissions (indexed totals and per capita) 13.14 Greenhouse gas emissions intensity of energy consumption 13.21 Global (and European) near surface average temperature 13.45 Economic losses caused by climate extremes (consider climatological, hydrological, meteorological) 13.51 Contribution to the 100bn international commitment on climate related expending (public finance) 13.63 Share of EU population covered by the new Covenant of Mayors for Climate and Energy (integrating mitigation, adaptation, and access to clean and affordable energy) 07.20 Share of renewable energy in gross final energy consumption [c] 07.30 Primary energy consumption; final energy consumption by sector [c] 12.51 Average CO_2 emissions per km from new passenger cars [c] 14.31 Ocean acidification [c]
	13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	National Crisis and Disaster Management	
	13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies		
13.2 Integrate climate change measures into national policies, strategies and planning	13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production	Austrian National Adaptation Strategy	
	-	Greenhouse gas emissions	

Table 1. *Cont.*

Goal/Target	Indicators		
	UN	Statistics Austria	Eurostat
Goal 13. Take urgent action to combat climate change and its impacts			
13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	13.3.1 Number of countries that have integrated mitigation, adaptation, impact reduction and early warning into primary, secondary and tertiary curricula	- [b]	
	13.3.2 Number of countries that have communicated the strengthening of institutional, systemic and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions	- [b]	
13.a Implement the commitment undertaken by developed country parties to the UNFCCC to a goal of mobilizing jointly $100 billion annually by 2020 from all sources	13.a.1 Mobilized amount of United States dollars per year between 2020 and 2025 accountable towards the $100 billion commitment	- [a]	
13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities	13.b.1 Number of least developed countries and small island developing States that are receiving specialized support, and amount of support, including finance, technology and capacity-building, for mechanisms for raising capacities for effective climate change-related planning and management, including focusing on women, youth and local and marginalized communities	- [b]	

[a] Not relevant for Austria/already achieved, [b] Indicator at UN level, [c] Multipurpose indicator.

The indicator systems described above cover the three pillars of sustainable development [27], also recognizing the central role of energy and climate change. Given that the scope of these indicator systems is very broad, they are not suitable for a detailed monitoring or steering of policy towards achieving the SDGs. Several indicator sets are available that focus on energy as a key element in sustainable development, most notably the Sustainable Energy Development (SED) Indicators [28] devised by the International Energy Agency (IEA) and the International Atomic Energy Agency (IEA), and the IAEA Energy Indicators for Sustainable Development [29]. These will be described in more detail below.

The SED indicators measure the progress towards "the provision of adequate energy services at affordable cost in a secure and environmentally benign manner, in conformity with social and economic development needs" [28]. IEA and IAEA propose 41 indicators for sustainable energy development that cover the whole energy system and its driving forces. This means the indicators cover primary energy supply, transformation technologies and final energy demand as well as energy intensities, the fuel mix and energy service demand. Economic and social factors (e.g., GDP, prices, population growth) affect the energy system and emissions resulting from energy consumption and energy supply.

The IEA/IAEA SED indicators have been applied to a number of countries (e.g., Lithuania [30], Cuba [31] and Mexico [32]). Depending on the challenges of energy policy and data availability, in most cases only a subset of indicators was used. Davidsdottir et al. [33] applied a set of SED indicators to Iceland, UK, USA, Sweden, Brazil and Mexico. In addition, Davidsdottir et al. [33] and Ibarrarán Viniegra et al. [34] show that the SED indicators can be communicated more easily when they are aggregated as a composite index, the so-called Sustainable Energy Index, which consists of one sub-index for each dimension of sustainable development.

Other indicator frameworks address energy security instead of sustainable energy consumption. If energy security is defined broadly, there is a strong overlap with sustainable energy development. The broad notion of energy security has economic, social and ecological aspects, albeit often with a stronger focus on economic aspects. Relevant works in this context include [16,17,35–39]. With respect to climate change, several indicator systems are also available. These indicators or indices, however, follow a less comprehensive approach, addressing mainly environmental aspects. Examples include the National Climate Indicators System Report [40], the Climate Change Performance Index [41], and the Climate Change Cooperation Index [42].

The ClEP Approach

The IEA system of Sustainable Energy Development (SED) indicators [28] provides a broad range of indicators for all levels of the energy system. This indicator set is the starting point for choosing relevant indicators in the demand-side sectors (residential buildings, mobility, manufacturing, services) as well as electricity and heat supply that could be applied to monitor progress in energy and climate policy at the EU or Member State levels. With respect to final energy demand, the focus is on indicators that relate to energy services because these determine welfare and economic development. The conceptual development of indicators was based on our extensive screening of available databases (e.g., Odyssee database, IEA database or Eurostat) regarding the availability of relevant indicators. Restrictions on data availability (many indicators are not available for all countries and years) co-determined the final set of indicators, i.e., we only included indicators for which at least some data for the EU Member States were available.

Data availability was acceptable for the economic and ecological dimensions but is particularly limited for the social dimension. Thus, additional information would be required to comprehensively track changes in energy use patterns and related social impacts. Gaps exist in the available data sets especially but not exclusively for the new EU Member States, where it is not possible to compile a longer time series. Moreover, for our analysis, more refined data on the use categories of final energy demand would be useful as well as more detailed information on the efficiencies of appliances (e.g., disentangling the effect of usage time from technical efficiency), non-motorised transport, investment costs, levelized costs of generation, life cycle emissions and other environmental effects such as land use and water use. Comprehensive and comparable data on energy poverty and mobility behaviour, as well as on the quality of employment at sectoral level, would also significantly improve the assessment of sustainable energy development.

In identifying indicators for sustainable energy demand, all levels of the energy system must be considered, from energy services via final energy demand to primary energy supply. Given that data on energy services are not available, proxy indicators must be specified to capture energy service demand. These proxies include transport performance, i.e., passenger and tonne kilometres for mobility as a proxy for the energy service "access to people, goods and services at different distances", the floor area of residential buildings as a proxy for "living space at a comfortable room temperature" or "lighting", population for "information, communication and other services related to consumer electronics" or "cooking" and gross value added as a proxy for energy services in the sectors manufacturing and services.

Table 2 shows the structure of the ClEP indicator framework (in Table A1 in the **APPENDICES** the disaggregated list of indicators is provided). For each sector, the indicators are arranged in five modules comprising context indicators, energy service indicators and energy system indicators covering the three dimensions of sustainable development.

Context indicators include e.g., average household size, energy prices or heating degree days. For the demand-side sectors, indicators for the economic dimension include the efficiency of energy service provision (i.e., the energy service proxy divided by final energy consumption), energy costs, and patents related to energy efficiency. Economic indicators for electricity and heat supply capture transformation and distribution efficiencies, energy technology patents, and public energy R&D expenditures. The environmental dimension covers the share of renewable energy as well as CO_2, NO_x and SO_2 emissions and intensities for all sectors. For the social dimension, we developed indicators for the following sectors: residential buildings, passenger transport, and electricity and heat supply. These indicators cover i.a. the affordability of energy-related appliances and comfortable room temperature, household equipment rates with certain appliances, differences in the shares of energy costs in household expenditure by income quintiles, or the share of electric and alternative vehicles in new registrations.

In contrast to the demand-side sectors, electricity and heat supply is only indirectly related to energy services. Final energy demand and energy supply technologies determine the energy input required to supply power and heat. Thus, emissions are a result of the transformation technologies used (plant types), the fuel mix and the level of final demand. The structure of energy indicators for this sector hence deviates from the demand-side sectors. The social indicators for energy supply include the gender pay and employment gap, wage issues, and work health aspects.

For the four demand-side sectors, a set of 109 aggregate energy indicators has been assembled. These indicators have been further disaggregated to 334 indicators (e.g., the energy efficiency of electricity and heat supply can be disaggregated by plant type, and household energy efficiency can be differentiated by use category). For electricity and heat supply, we compiled a set of 21 energy indicators providing an aggregate view of the sector. These indicators were further disaggregated to about 54 indicators, differentiated by energy source and plant type.

Table 2. List of indicators.

Dimension [of sustainable development]	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
Drivers/Context	Housing stock	**Stock of vehicles**	Stock of trucks and light vehicles			**Power plant capacity**
	FA per capita	**Modal split** Share of road pkm Share of rail pkm	**Modal split** Share of road tkm Share of rail tkm Share of inland waterways tkm	Share of GVA in GDP	Share of GVA in GDP	
	Number of HH	Road km Rail km		**Share of energy intensive industry [1] in FEC**		
	HH size	Road km/rail km				
	HH income	Share of e-vehicles				
	Heating Degree Days	Specific CO_2 emissions of car stock				
		Specific CO_2 emissions of newly registered cars				
	Energy price	**Energy prices**		**Energy prices**	**Energy prices**	**Energy prices**
				Carbon price		Carbon price

Table 2. *Cont.*

Dimension [of sustainable development]	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
Energy Service Proxies	Well-tempered living space: FA Illumination: HH Warm water: CAP Cooking: HH Communication/Entertainment: HH Other: HH	**Mobility: pkm**	**Transport of goods: tkm**	**GVA**	**GVA**	
Economic	**Efficiency of residential sector (HH/FEC)**	**Efficiency of passenger transport (pkm/FEC)**	**Efficiency of freight transport (tkm/FEC)**	**Efficiency of manufacturing**	**Efficiency of service sector**	**Distribution efficiency** **Transformation efficiency**
	FEC	**FEC**	**FEC**	**FEC**	**FEC**	**Transformation input (TI)** **Transformation output (TO)**
	Share of energy expenditure in household expenditure	Share of transport expenditure in household expenditure		**Share of costs**	**Share of costs**	
	Public R&D expenditures energy efficiency buildings	**Public R&D expenditures transport**		Public R&D expenditures energy efficiency industry		**Public energy R&D expenditures**
	Applied patents energy efficiency buildings	Applied patents energy efficiency transport		Applied patents mitigation industry		**Applied energy technology patents**

Table 2. *Cont.*

Dimension [of sustainable development]	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
Ecological	**Share of RES**	Share of RES	Share of RES	**Share of RES**	Share of RES	Share of RES in TI
	CO_2 emissions	CO_2 emissions	CO_2 emissions	CO_2 emissions	CO_2 emissions	CO_2 emissions
	NO_x emissions	NO_x emissions	NO_x emissions	NO_x emissions	NO_x emissions	NO_x emissions
	SO_2 emissions	SO_2 emissions	SO_2 emissions	SO_2 emissions	SO_2 emissions	SO_2 emissions
	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of TI
	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of TI
	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of TI
Social	Persons who cannot afford a telephone	New registrations of passenger cars				Low-wage earners
	Persons who cannot afford a colour TV	New registrations of electric passenger cars				Median hourly earnings
	Persons who cannot afford a computer	New registrations of passenger cars w alternative drives				Temporary contracts
	Persons who cannot afford a washing machine	Level of difficulty to access public transport				Incidence rate of fatal accidents at work
	Persons who cannot afford internet connection for personal use at home	Persons who cannot afford a car				Flexibility of the work schedule
	Population unable to keep home adequately warm by poverty status					Gender pay gap

Table 2. *Cont.*

Dimension [of sustainable development]	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
	Share of Heating costs in HH income					Gender employment gap
	Equipment rate-fridge					
	Equipment rate-freezer					
	Equipment rate-washing machine					
	Equipment rate-dishwasher					
	Equipment rate-TV					

CAP—persons; E&H—electricity and heat; FA—floor area; FEC—final energy consumption, GDP—gross domestic product; GVA—gross value added; HH—households, pkm—person kilometres; RES—renewable energy sources; R&D—Research and Development; TI—transformation input; TO—transformation output; tkm—tonne kilometres. Indicators in bold can be broken down into sub-indicators.

[1] Energy intensive industry here includes chemical sector, primary metals production, non-metallic minerals production, paper production, and wood production.

AVAILABLE DATA SOURCES FOR THE CLEP INDICATORS

In order to compile the indicators for the EU Member States, several databases need to be deployed. Data are available from the following databases:

- *Odyssee database* [43]: data on energy service proxies (floor area of dwellings, number of households, passenger and freight transport performance, gross value added of the manufacturing and service sectors), and the related efficiency data, information on the different capital stocks and equipment rates, sectoral shares of renewable energy sources and final energy consumption by energy source;
- *The European Environment Agency's database* [44]: CO_2 emissions of newly registered vehicles;
- *IEA database* [45–47]: transformation input and output by energy source, plant capacities, energy prices and sectoral public energy expenditure;
- *UNFCCC National Inventories* [1]: GHG emission data;
- *Eurostat database* [48–52]: household income and expenditures, social indicators (except for equipment rates);
- *OECD database* [53]: patent data;
- *EEX* [54]: data on carbon prices.

We aimed at identifying official data sources for the indicators that are available for all (or at least for the majority of) the EU Member States (like the Eurostat database, the OECD database, the EEA database or the UNFCCC National Inventories). Especially with respect to energy services and stocks, relevant data was not available from official statistical sources, so we relied on the Odyssee database in this regard. The latter provides information on final energy consumption by end-use category, the underlying drivers of energy demand, disaggregated energy efficiencies and CO_2 related indicators; data are provided by national institutions (e.g., energy agencies or statistical organizations) from all EU countries as well as Norway, Switzerland and Serbia. Moreover, we suggest using information on energy prices and sectoral public energy expenditure from the IEA database due to better data availability as compared to the Eurostat database. The detailed list of data sources for the individual indicators can be found in Table A2 and Table A3 in the **APPENDICES**.

A GLANCE AT INTERACTIONS BETWEEN DIMENSIONS AND INDICATORS

Given the importance of accounting for interactions between SDGs and sub-targets, we highlighted the relationship between the energy service focused ClEP indicators and the broader context of the SDGs. For example, when integrating the social dimension into the climate and energy policy indicator set, the focus is on the quality of employment on the energy supply side, whereas the focus is on daily conduct of life practices in private households on the energy demand side [55]. We identified cross-cutting issues that are relevant for all areas and at the same time highlight the relation to some other SDGs: gender equality [56,57] and gender equity [58]—both for energy supply and energy demand [59], improving the quality of employment (on the energy supply side) and respectively quality of life (on the energy demand side), as well as participation on the energy supply side or inclusion on the energy demand side. Reflecting the outcomes makes the multidimensionality and the ambivalences of the different dimensions visible, in particular as a consequence of the inclusion of the social dimension. For example, an increase in physical assets such as household appliances and vehicles may mean a reduction of social inequality and/ or an increase in mobility, but at the same time can have negative impacts on the environment—depending on the choice of technologies and/or fuels. This example reveals the multiple uncertainties associated with attempts to predict how particular future trends affect everyday life, consumption and mobility behaviors.

Table 3 exemplifies interactions between different indicators and goals. Trade-offs between different SDGs become visible. Depending on the underlying assumptions, different development paths are conceivable, with varying impacts on the environment as well as economic and social development.

Table 3. Interdependence table of social indicators and their impact on the SDGs.

		Social							
		Population able to keep home adequately warm				New registrations of passenger cars with electric or alternative drives			
		7 Affordable and clean energy	5 Gender equality	13 Climate action	GHG emission reduction	7 Affordable and clean energy	5 Gender equality	13 Climate action	GHG emission reduction
Social	Reduced number of low-wage earners	2	2	−1	−2	1	1	−1	−1
	Reduced gender employment gap	1	1	1/−1	−1	1	2	1/−1	1

The evaluation of interactions follows Nilsson et al. [5] and ranges from -3 to +3: −3 denotes cancelling targets while +3 denotes indivisible targets.

Table 3 shows that an increase in the number of low-wage earners implies a considerable change in material and immaterial deprivation. This may entail, for instance, an increase in the proportion of the population unable to sufficiently heat their home or a lower number of newly registered electric cars and cars with alternative drive systems. This would negatively impact the achievement of SDG 7 “Ensure access to affordable, reliable, sustainable and modern energy for all”. At the same time, this raises the question of whether the purchase of a more energy-efficient car would replace an existing conventional vehicle or if it would add an additional car to the household’s stock. The latter may possibly mean an increase in mobility, in particular of women and young adults in the household, since they are often the users of the additional car, which in turn would have a negative effect from an environmental perspective and respectively SDG 13 “Take urgent action to combat climate change and its impacts”. By contrast, if increased mobility implies that women drive more, it would positively affect SDG 5 “Achieve gender equality and empower all women and girls” by increasing mobility options and the opportunities for participation in the labour force or other social activities. These different lines of argumentation illustrate that, depending on the assumptions made or the focus chosen, the effects would need to be judged differently.

These observations point to the comprehensive political and social challenges, both regionally and globally, of finding and deploying holistic and coherent measures that address the complex interactions between the SDGs in unison. It should be noted that all SDGs are “integrated and indivisible” and therefore should be considered equal [24]. Focusing on individual goals and ignoring others creates the risk of overlooking relevant side effects and failing to recognise and make use of potential synergies [2].

Added to this is the problem of data availability mentioned before. The lack of data can distort the picture, if indicators for relevant impacts and policy areas are missing.

CONCLUSIONS

The UN SDGs and the Paris Climate Agreement both imply ambitious (long-term) targets that can only be met with a fundamental restructuring of economic and social systems. In this context, monitoring of progress towards achievement of goals is essential and requires thorough measurement systems.

The complexity calls for indicator systems instead of single indicators. Although the list of indicators proposed to monitor the 17 SDGs and the corresponding 169 targets is already very comprehensive, more detailed indicator sets for individual SDGs are required for the monitoring and steering of policy. Moreover, the General Assembly of the UN proposed complementing the UN indicator set with operational indicators at the national and regional levels to be developed by the countries and which would reflect their particular circumstances [24]. Against this background, we propose a set of indicators that allow monitoring of progress towards energy and climate policy targets at the EU and Member State levels.

We combine the energy service perspective with research on sustainable energy development indicators and apply this approach in the broader context of the SDGs. Furthermore, we put particular emphasis on the consideration of the social dimension and the development of respective indicators. The proposed sustainable energy indicators cover the three dimensions of sustainable development. As for the SDGs, interactions (i.e., synergies and conflicts) between the different target dimensions and the corresponding indicators need to be carefully considered.

As shown in Kettner et al. [60], a composite index can be used to complement comprehensive indicator systems such as the one at hand. Composite indices are a common method used to condense multifaceted information and to improve the communicability of results. In Kettner et al. [60], this approach was applied to assess the sustainable energy development in nine EU countries using a subset of indicators. One group of composite indices focussed on the dimension of sustainable development and the other on the sectoral disaggregation, providing concise information on trends in each country. Recently, composite indices that summarise global progress while considering possible conflicts and trade-offs between individual targets and indicators have been developed based on a Goal Programming Model [61,62] or a Multidimensional Synthesis of Indicators approach [63]. Applying these methods to our indicator set would presumably deliver valuable insights but would require better data availability.

Given the complexity of the issue and the gaps in data availability/adequate indicators, it is challenging to interpret certain observable trends. For instance, an increase in electric cars can have both beneficial and detrimental effects on the environment, depending on whether these cars are substitutes for fossil-fuel-powered cars or additional vehicles. By contrast, an increasing number of vehicles can enhance mobility and thereby be interpreted as an improvement in the social dimension of sustainable development. However, the net effect on mobility is again impossible to assess because no data on non-motorised transport are available and particularly due to the complex underlying interactions. This needs to be kept in mind when using the indicator system for policy analysis. The analysis highlights the importance of taking into account the multitude of interactions between different sustainable development targets. The comprehensive assessment helps prevent perverse outcomes and contributes to fully utilising the potential for achieving synergistic outcomes for other targets. Applying advanced statistical methods such as principal component analysis would shed light on correlations between the individual indicators. This would require, however, further advances in data and indicator availability for a larger number of EU Member States because many indicators currently are available only for a small number of countries and individual years.

AUTHOR CONTRIBUTIONS

All authors jointly designed the study and developed the indicator framework. All authors contributed to writing the paper.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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APPENDICES

Table A1. Detailed list of indicators.

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
Drivers/Context	Housing stock	**Stock of vehicles** • Vehicles • Diesel-driven cars • Gasoline-driven cars • Gas-driven cars • Electric-driven cars • Motor cycles • Busses	Stock of trucks and light vehicles			**Power plant capacity** • Capacity power plants • Capacity nuclear plants • Capacity hydro plants • Capacity geothermal plants • Capacity solar PV plants • Capacity solar thermal plants • Capacity combustible plants • Capacity other sources plants
	FA per capita	**Modal split** • Share of road pkm • Share of rail pkm	**Modal split** • Share of road tkm • Share of rail tkm • Share of inland waterways tkm	Share of GVA in GDP	Share of GVA in GDP	

Table A1. *Cont.*

Dimension (of sustainable development)	**Sector**					
	Demand Side					**Electricity & Heat Supply**
	Residential	**Passenger Transport**	**Freight Transport**	**Manufacturing**	**Services**	
	Number of HH	Road km Rail km		**Share of energy intensive industry [1] in FEC** • Share of energy intensive industry in FEC • Share of energy intensive industry in FEC coal • Share of energy intensive industry in FEC gas • Share of energy intensive industry in FEC oil • Share of energy intensive industry in FEC biomass • Share of energy intensive industry in FEC electricity • Share of energy intensive industry in FEC heat		
	HH size	Road km/rail km				
	HH income • Quintile 1 • Quintile 2 • Quintile 3 • Quintile 4 • Quintile 5	Share of e-vehicles				
	Heating Degree Days	Specific CO_2 emissions of car stock				
		Specific CO_2 emissions of newly registered cars				
	Energy prices • Gas price households • Oil price households • Electricity price households	**Energy prices** • Gasoline price • Diesel price		**Energy prices** • Gas price industry • Heavy fuel oil price industry • Light fuel oil price industry • Coal price industry • Electricity price industry	**Energy prices** • Gas price • Oil price • Electricity price	**Energy prices** • Gas price energy plants • Oil price energy plants • Coal price energy plants
				Carbon price		Carbon price

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
Energy Service Proxies	Well-tempered living space: FA Illumination: HH Warm water: CAP Cooking: HH Communication/Entertainment: HH Other: HH	**Mobility** • Pkm total • Pkm road • Pkm rail	**Transport of goods** • Tkm total • Tkm road • Tkm rail • Tkm inland waterways	**GVA** • GVA industry • GVA chemical sector • GVA primary metals production • GVA non-metallic minerals production • GVA wood sector • GVA paper sector	GVA	
Economic	**Efficiency of residential sector (HH/FEC)** • Household/FEC • Household/FEC coal • Household/FEC gas • Household/FEC oil • Household/FEC biomass • Household/FEC electricity Household/FEC heat	**Efficiency of passenger transport (pkm/FEC)** • Pkm/FEC • Pkm/FEC gasoline • Pkm/FEC diesel • Pkm/FEC gas • Pkm/FEC jet fuel • Pkm/FEC electricity • Pkm/FEC biofuels	**Efficiency of freight transport (tkm/FEC)** • Tkm/FEC • Tkm/FEC diesel • Tkm/FEC electricity • Tkm/FEC biofuels	**Efficiency of manufacturing** • GVA/FEC • GVA/FEC coal • GVA/FEC gas • GVA/FEC oil • GVA/FEC biomass • GVA/FEC electricity • GVA/FEC heat	**Efficiency of service sector** • GVA/FEC • GVA/FEC coal • GVA/FEC gas • GVA/FEC oil • GVA/FEC biomass • GVA/FEC electricity • GVA/FEC heat	**Distribution efficiency** • Distribution efficiency • Distribution efficiency electricity • Distribution efficiency heat

Table A1. *Cont.*

<table>
<tr><th rowspan="3">Dimension (of sustainable development)</th><th colspan="6">Sector</th></tr>
<tr><th colspan="5">Demand Side</th><th rowspan="2">Electricity & Heat Supply</th></tr>
<tr><th>Residential</th><th>Passenger Transport</th><th>Freight Transport</th><th>Manufacturing</th><th>Services</th></tr>
<tr><td></td><td>Efficiency of space heating (FA/FEC)
• FA/FEC space heating
• FA/FEC coal space heating
• FA/FEC gas space heating
• FA/FEC oil space heating
• FA/FEC biomass space heating
• FA/FEC electricity space heating
• FA/FEC heat space heating</td><td></td><td></td><td>Efficiency of chemical sector (GVA/FEC)
• GVA/FEC chemical sector
• GVA/FEC coal chemical sector
• GVA/FEC gas chemical sector
• GVA/FEC oil chemical sector
• GVA/FEC biomass chemical sector
• GVA/FEC electricity chemical sector
• GVA/FEC heat chemical sector</td><td></td><td>Transformation efficiency (TO/TI)
• Transformation efficiency
• Transformation efficiency coal plants
• Transformation efficiency gas plants
• Transformation efficiency oil plants
• Transformation efficiency waste plants
• Transformation efficiency renewables plants</td></tr>
</table>

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
	Efficiency of warm water (CAP/FEC) • CAP/FEC warm water • CAP/FEC coal warm water • CAP/FEC oil warm water • AP/FEC gas warm water • CAP/FEC biomass warm water • CAP/FEC electricity warm water • CAP/FEC heat warm water			*Efficiency of primary metals sector (GVA/FEC)* • GVA/FEC primary metals sector • GVA/FEC coal primary metals sector • GVA/FEC gas primary metals sector • GVA/FEC oil primary metals sector • GVA/FEC biomass primary metals sector • GVA/FEC electricity primary metals sector • GVA/FEC heat primary metals sector		

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
	Efficiency of cooking (CAP/FEC) • CAP/FEC cooking • CAP/FEC coal cooking • CAP/FEC gas cooking • CAP/FEC biomass cooking • CAP/FEC electricity cooking			*Efficiency of non- metallic minerals production (GVA/FEC)* • GVA/FEC non-metallic minerals production • GVA/FEC coal non-metallic minerals production • GVA/FEC gas non-metallic minerals production • GVA/FEC oil non-metallic minerals production • GVA/FEC biomass non-metallic minerals production • GVA/FEC electricity non-metallic minerals production • GVA/FEC heat non-metallic minerals production		

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
	Efficiency of electrical appliances (HH/FEC)			*Efficiency of paper production (GVA/FEC)* • GVA/FEC paper production • GVA/FEC coal paper production • GVA/FEC gas paper production • GVA/FEC oil paper production • GVA/FEC biomass paper production • GVA/FEC electricity paper production • GVA/FEC heat paper production		
				Efficiency of wood production (GVA/FEC) • GVA/FEC wood production • GVA/FEC coal wood production • GVA/FEC oil wood production • GVA/FEC gas wood production • GVA/FEC biomass wood production • GVA/FEC electricity wood production • GVA/FEC heat wood production		

Table A1. *Cont.*

Dimension (of sustainable development)	**Sector**					
	Demand Side					**Electricity & Heat Supply**
	Residential	**Passenger Transport**	**Freight Transport**	**Manufacturing**	**Services**	
	FEC • FEC • FEC coal • FEC gas • FEC oil • FEC biomass • FEC electricity • FEC heat	**FEC** • FEC • FEC gasoline • FEC diesel • FEC gas • FEC jet fuel • FEC electricity • FEC biofuels	**FEC** • FEC • FEC diesel • FEC electricity • FEC biofuels	**FEC** • FEC • FEC coal • FEC gas • FEC oil • FEC biomass • FEC electricity • FEC heat	**FEC** • FEC • FEC coal • FEC gas • FEC oil • FEC biomass • FEC electricity • FEC heat	**Transformation input** • TI • TI coal • TI gas • TI oil • TI waste • TI renewables
	FEC space heating • FEC space heating • FEC coal space heating • FEC gas space heating • FEC oil space heating • FEC biomass space heating • FEC electricity space heating • FEC heat space heating			*FEC chemical sector* • FEC chemical sector • FEC coal chemical sector • FEC gas chemical sector • FEC oil chemical sector • FEC biomass chemical sector • FEC electricity chemical sector • FEC heat chemical sector		**Transformation output** TO • TO coal plants • TO gas plants • TO oil plants • TO waste plants • TO renewable plants

Table A1. *Cont.*

<table>
<tr><th rowspan="3">Dimension (of sustainable development)</th><th colspan="6">Sector</th></tr>
<tr><th colspan="5">Demand Side</th><th rowspan="2">Electricity & Heat Supply</th></tr>
<tr><th>Residential</th><th>Passenger Transport</th><th>Freight Transport</th><th>Manufacturing</th><th>Services</th></tr>
<tr><td></td><td>FEC warm water
• FEC warm water
• FEC coal warm water
• FEC gas warm water
• FEC oil warm water
• FEC biomass warm water
• FEC electricity warm water
• FEC heat warm water</td><td></td><td></td><td>FEC primary metals production
• FEC primary metals production
• FEC coal primary metals production
• FEC gas primary metals production
• FEC oil primary metals production
• FEC biomass primary metals production
• FEC electricity primary metals production
• FEC heat primary metals production</td><td></td><td></td></tr>
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Table A1. *Cont.*

<table>
<tr><th rowspan="3">Dimension (of sustainable development)</th><th colspan="6">Sector</th></tr>
<tr><th colspan="5">Demand Side</th><th rowspan="2">Electricity & Heat Supply</th></tr>
<tr><th>Residential</th><th>Passenger Transport</th><th>Freight Transport</th><th>Manufacturing</th><th>Services</th></tr>
<tr><td rowspan="2"></td><td>FEC cooking
• FEC cooking
• FEC coal cooking
• FEC gas cooking
• FEC biomass cooking
• FEC electricity cooking</td><td rowspan="2"></td><td rowspan="2"></td><td>FEC non-metallic minerals production
• FEC non-metallic minerals production
• FEC coal non-metallic minerals production
• FEC gas non-metallic minerals production
• FEC oil non-metallic minerals production
• FEC biomass non-metallic minerals production
• FEC electricity non-metallic minerals production
• FEC heat non-metallic minerals production</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>FEC electrical appliances</td><td>FEC paper production
• FEC paper production
• FEC coal paper production
• FEC gas paper production
• FEC oil paper production
• FEC biomass paper production
• FEC electricity paper production
• FEC heat paper production</td></tr>
</table>

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
				FEC wood production • FEC wood production • FEC coal wood production • FEC gas wood production • FEC oil wood production • FEC biomass wood production • FEC electricity wood production • FEC heat wood production		
	Share of energy expenditure in household expenditure	Share of transport expenditure in household expenditure		**Share of costs** • Share of energy costs industry • Share of energy costs gas • Share of energy costs heavy oil • Share of energy costs coal • Share of energy costs electricity	**Share of costs** • Share of energy costs service • Share of energy costs gas • Share of energy costs oil • Share of energy costs coal • Share of energy costs electricity	

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
	Public R&D expenditures energy efficiency buildings	**Public R&D expenditures** • Public R&D expenditures for energy efficiency transport • Public R&D expenditures for e-mobility		Public R&D expenditures energy efficiency industry		**Public energy R&D expenditures** • Public R&D expenditures for renewable energy sources • Public R&D expenditures for carbon capture storage
	Applied patents energy efficiency buildings	Applied patents energy efficiency transport		Applied patents mitigation industry		**Applied energy technology patents** • Applied patents mitigation • Applied patents carbon capture storage
Ecological	**Share of RES** • Share of RES in HH FEC • Share of RES space heating • Share of RES warm water • Share of RES cooking	Share of RES	Share of RES	**Share of RES** • Share of RES industry • Share of RES chemical sector • Share of RES primary metals production • Share of RES non-metallic minerals production • Share of RES paper production • Share of RES wood production	Share of RES	Share of RES in TI
	CO_2 emissions	CO_2 emissions	CO_2 emissions	CO_2 emissions	CO_2 emissions	CO_2 emissions
	NO_x emissions	NO_x emissions	NO_x emissions	NO_x emissions	NO_x emissions	NO_x emissions
	SO_2 emissions	SO_2 emissions	SO_2 emissions	SO_2 emissions	SO_2 emissions	SO_2 emissions
	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of FEC	CO_2 efficiency of TI

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of FEC	NO_x efficiency of TI
	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of FEC	SO_2 efficiency of TI
Social	Persons who cannot afford a telephone	New registrations of passenger cars				Low-wage earners
	Persons who cannot afford a colour TV	New registrations of electric passenger cars				Median hourly earnings
	Persons who cannot afford a computer	New registrations of passenger cars w alternative drives				Temporary contracts
	Persons who cannot afford a washing machine	Level of difficulty to access public transport				Incidence rate of fatal accidents at work
	Persons who cannot afford internet connection for personal use at home	Persons who cannot afford a car				Flexibility of the work schedule
	Population unable to keep home adequately warm by poverty status					Gender pay gap

Table A1. *Cont.*

Dimension (of sustainable development)	Sector					
	Demand Side					Electricity & Heat Supply
	Residential	Passenger Transport	Freight Transport	Manufacturing	Services	
	Share of Heating costs in HH income • Quintile 1 • Quintile 2 • Quintile 3 • Quintile 4 • Quintile 5					Gender employment gap
	Equipment rate-fridge					
	Equipment rate-freezer					
	Equipment rate-washing machine					
	Equipment rate–dishwasher					
	Equipment rate-TV					

CAP—persons; E&H—electricity and heat; FA—floor area; FEC—final energy consumption, GDP—gross domestic product; GVA—gross value added; HH—households, pkm—person kilometres; RES—renewable energy sources; R&D—Research and Development; TI—transformation input; TO—transformation output; tkm—tonne kilometres.

[1] Energy intensive industry here includes chemical sector, primary metals production, non-metallic minerals production, paper production, and wood production.

Table A2. Demand-side indicators: Data sources.

Dimension	Sector	Indicator	Source
Context	Residential	Household data	Odyssee database
		HH income (qu.)	EU-SILC
	Transport	Car stock data	Odyssee database
		Modal split	Odyssee database
		Road/rail km	Odyssee database
		Share of e-vehicles	EEA, CO_2 emissions from passenger cars
		Share of alternative drives	EEA, CO_2 emissions from passenger cars
		Specific CO_2 emissions of newly registered cars	EEA, CO_2 emissions from passenger cars
		Specific CO_2 emissions of car stock	Odyssee database
	Industry/Service	GVA	Odyssee database
	All sectors	Energy prices	IEA Energy Price Taxes
Energy Service	Residential	Well-tempered living space proxy: Floor area	Odyssee database
		Illumination Proxy: Floor area	Odyssee database
		Warm water Proxy: Population	Odyssee database
		Cooking Proxy: Households	Odyssee database
		Communication/Entertainment Proxy: Households	Odyssee database
	Passenger Transport	Mobility Proxy: pkm	Odyssee database
	Freight Transport	Transport of goods proxy: tkm	Odyssee database
	Service	Proxy: GVA	Odyssee database
	Industry	Proxy: GVA	Odyssee database
Economic	All sectors	Energy efficiency data	Odyssee database
		R&D data	IEA, Energy R&D Expenditures
		Patent data	OECD, EPO database
	Residential/Transport	Share of energy expenditure	Eurostat, COICOP
	Industry/Service	Share of energy costs	IEA, Odyssee
Ecologic	All sectors	Share of renewables in sectors	Odyssee database
		Emission data	UNFCCC, National Inventory Reports
Social	Residential/Transport	Affordability data	Eurostat, EU-Silc
	Residential	Equipment rates	Odyssee database
		Share of heating costs (qu.)	Eurostat, Household budget survey
	Transport	New registration of cars	EEA, CO_2 emissions from passenger cars
		Accessibility of public transport	Eurostat, EU-Silc

Table A3. Supply-side indicators: Data sources.

Dimension	Indicator	Source
Context	Energy Prices	IEA Energy Price Taxes
	Carbon prices	EEX
	Capacity power plants	IEA Electricity information
Economic	Transformation efficiency electricity plants	IEA Energy Balances
	Transformation efficiency CHP	IEA Energy Balances
	Transformation efficiency heat plants	IEA Energy Balances
	Distribution efficiency electricity	IEA Energy Balances
	Distribution efficiency heat	IEA Energy Balances
	Transformation input	IEA Energy Balances
	Public energy R&D expenditures	IEA, Energy R&D Expenditures
	Applied energy technology patents	OECD; EPO database
Ecological	% of RES in Electricity and Heat supply	IEA Energy Balances
	CO_2 emissions	UNFCCC, National Inventory Reports
	NO_x emissions	UNFCCC, National Inventory Reports
	SO_2 emissions	UNFCCC, National Inventory Reports
	CO_2 efficiency of Electricity and Heat supply	UNFCCC, National Inventory Reports
	NO_x efficiency of Electricity and Heat supply	UNFCCC, National Inventory Reports
	SO_2 efficiency of Electricity and Heat supply	UNFCCC, National Inventory Reports
Social	Low-wage earners	Eurostat, Structure of Earning Survey
	Median hourly earnings	Eurostat, Structure of Earning Survey
	Collective pay agreement	Eurostat, Structure of Earning Survey
	Temporary contracts	Eurostat, Structure of Earning Survey
	Incidence rate of fatal accidents at work	Eurostat - European Statistics on accidents at work (ESAW)
	Flexibility of the work schedule	Eurostat: Labour Force Survey (LFS)
	Gender pay gap	Eurostat: Labour Force Survey (LFS)
	Gender employment gap	Eurostat - Structure of Earnings Survey (SES)

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