Sustainability Indicators for the Assessment of the Energy System

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ABSTRACT

The discussion about sustainability in the construction and real estate sector was so far mainly focused on the contribution of individual buildings, quarters or cities to sustainable development. Several sustainability assessment systems have been developed and applied, which include technical, environmental, economic and social aspects.

Energy production and consumption has a major impact on sustainable development. Hence, the amount and impact of resource usage and environmental degradation associated with the construction sector and occurring within the life cycle of buildings are depending on the characteristics of the existing energy system. Private households shift to being consumers and producers of energy, thus becoming a more important part of the complex energy system. Furthermore, nature and amount of energy usage influence life cycle costs of buildings, affordability of housing, or external costs caused by the energy systems.

Due to the high relevance of sources and the efficiency of energy use for realising sustainable development, as well as increasing interdependencies between buildings and energy generation and usage, energy systems become accordingly relevant as a distinct object of sustainability assessment.

This article will concentrate on the question which criteria and indicators are appropriate to describe and assess the sustainability of energy systems. Two basic approaches will be outlined: firstly, the development and use of checklists or indicator sets, providing orientation for the collection and interpretation of data raised, and a basis for context-specific selections of indicators, by investigating each indicator separately. Secondly, the development and use of indicator systems, which provide a fundament for a finally aggregated assessment result. Methodological and conceptual questions associated with these two approaches that are discussed in this article can also be transferred to other subjects of assessment.

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Keywords: *energy measurement and verification, sustainability assessment, indicator sets and systems*

1. INTRODUCTION

The focus of sustainability-related debates in the construction sector is presently shifting from individual buildings to much more complex subjects of investigation, in particular urban residential districts and entire cities. The latter should no longer be considered being the mere sum of all buildings. Due to their close interconnections, they also have to be an assessment objective of a scientifically-based system analysis as spatial units. Sustainability assessment systems such as DGNB, LEED and BREEAM provide criteria especially for cities and urban quarters, which focus on an evaluation of the ecological, economic, socio-cultural, technical performance as well as the quality of the planning. They examine all relevant topics and issues of sustainability, including the supply of energy. Beyond the rather crude way of addressing energy issues in these existing tools, energy systems, as increasingly relevant subjects of sustainability assessment particularly in urban contexts, have to be analysed in a more comprehensive and integrated way. Main reasons for this are:

- The energy system, similarly to other basic supply systems, has to be understood as a socio-technical system, in which technical and social elements and realities interact in various ways.
- Options, opportunities and challenges of integrated solutions for the generation of renewable electricity and heat are becoming more diverse and complex, e. g. due to new actors. For instance, buildings are no longer only consumers in the energy market, but also producers ("prosumer"). Developing integrated solutions gains more and more importance for local energy supply and grid operation. The current trend in implementing such approaches promotes decentralization of the energy system towards a "smart" network based on many small regional and local units that provides innovative network and system implemented out in compliance with the principles of sustainable development.
- In order to protect ecosystems, a more environmentally sound energy generation and usage is required, in addition to a more efficient usage of materials based on the idea of a circular economy. Resource use and environmental degradation are strongly influenced by the direct use (e.g. heating and lighting in buildings) and indirect use of energy (e.g. included in building materials to newly construct, restore and maintain buildings). In principle, the energy supply sector can be regarded as an up streamed branch of the construction industry; therefore, it should be carefully analysed how a transformation of the energy supply towards more sustainability affects the sustainability of the construction industry.
- Official international and national objectives and target values, and according political decisions, such as the Agenda 2030 and the Sustainable Development Goals at the global scale or National Sustainability Strategies, clarify and reinforce the key role of energy for social and economic development in line with the objectives of environmental protection.

In Germany, this led to a discussion about the sustainability of energy supply and the sustainability assessment of future options to design the national energy system. The national federal German energy concept from 2011 is based on the three classical energy policy goals energy supply security, affordability and environmental compatibility. One key statement of this article is that ensuring energy system sustainability requires considering additional assessment criteria beyond the three classical ones mentioned above, such as health compatibility, equitable distribution, low risk, or societal participation To check the degree to which these requirements and goals are met, suitable tools are needed to describe, assess, and steer the energy system. In addition to technical functionality, these tools have to focus on interrelationships between energy technologies and the natural environment, the economy and the society. Suitable assessment criteria and indicators and their flexible use in terms of a checklist will be discussed in the following.

2. ENERGY SYSTEMS AS OBJECTS OF ASSESSMENT

A system can be defined as a “set of elements with certain properties, of their interdependencies, and of their interactions with the environment”. Energy systems are commonly understood to be technical systems for the supply of energy. Active elements of these systems are technical facilities to produce primary energy carriers as well as systems to convert, store, transport, and use energy. Passive elements of the system are the energy carriers used. The attributes of these elements are of technical (e.g. capacities, efficiencies, availabilities, calorific values), economic (e.g. energy costs, plant and operation costs), and ecological character (e.g. emissions, consumption of resources). Implementation of the necessary transformation processes to meet goals, such as the German ‘Energiewende’, however, requires the energy system to be understood as a socio-technical system, in which technical and social elements and realities interact in various ways. The energy system is an open system interacting with overall economy, the environment, and the society, which represent corresponding systems. The state of this socio-technical system is characterized by certain attribute values at a certain time. System boundaries have to be chosen as a function of the object and perspective of assessment. When defining the system to be assessed, geographical conditions have to be specified. The existing technical system and the corresponding systems are determined by the geographic area in which they act and interact. Moreover, the time horizon has to be specified (hourly, annual or perennial assessment).

When deciding on detailed goals or action strategies, it is therefore important to not only consider the supply side, technologies, and infrastructures, but also the demand side and in particular the consumer and user behaviour of private and public actors involved as well as their interests, needs, and their rights of disposal. Moreover, the society’s acceptance of existing or new system elements, its participation in decision processes, and the handling of existing or expected conflicts have to be assessed.

3. ASSESSMENT CRITERIA AND INDICATORS – SET OR SYSTEM?

Assessment of sustainability is based on criteria and indicators. Indicators essentially serve to facilitate the representation of complex situations. They can be used as orientation aids in decision, control, and communication processes. Indicators initiate and support discussion, learning, and awareness building processes.

Indicators may be grouped in sets and systems. A set of indicators is a compilation of indicators used in a certain assessment context. This list can be complemented any time. A system of indicators essentially consists of a defined set of indicators and other components adapted to the assessment object. Local and spatially superordinate (national or international) indicator systems mainly differ in their basic understandings of contents, measurement variables used, reference values, and in the goals and addressees of indicator use. Use of internationally established indicator systems allows for a regular comparison of developments in different countries. Frequently, indicator systems serve to determine a fully aggregated index. This approach is associated with both advantages and drawbacks (easy communication of information versus information loss and problem of determining weighing factors). While the number of indicators in indicator systems is adapted at longer intervals only, a set of indicators can be adapted continuously.

Indicator systems are used in scientific and politico-institutional contexts on various spatial and political levels, e.g. on the supranational level of the European Union. Here, key indicators have been selected for ten areas. These key indicators are further detailed by so-called operative and describing indicators. As an example, the area of climate change and energy is outlined in Table 1. Every two years, the indicator system is used to assess changes as a function of time.

Area	Key Indicator	Operative Indicators	Describing Indicators
Climate change and **energy**	• Primary energy consumption	• Energy dependence; share of renewable energies in gross end energy consumption	• Domestic gross energy consumption of fuels • Electricity production from renewable energy sources • Share of renewable energy sources in fuel consumption of traffic • Co-generation systems

Table 1: Energy-related indicators of the EU Sustainable Development Strategy (EU SDS).

4. ADDITIONAL CRITERIA AND INDICATORS NEEDED FOR THE ASSESSMENT OF ENERGY SYSTEMS

Chapter 40 of Agenda 21 adopted by the United Nations Conference on Environment and Development (Rio de Janeiro, Brazil, 1992) already requested development and use of measurement parameters or criteria to assess national and international development processes. As in other sectors, the information obtained with the help of indicators in the energy sector mainly serves to analyze and evaluate the success or failure of measures taken (e.g. in the context of the 'Energiewende') and to determine trends. This information is the basis of consulting services and decision-making. Development and use of suitable indicators depend on normative or methodological goals as well as on the target group addressed (experts, politicians, public, energy consumers and so on).

Requirements to be met by indicators for the analysis of the energy system are listed in Table 2. They have to be considered when determining additional indicators.

Scientific Requirements	Representativeness and adequacy as regards ecological, economic, and social contexts; reproducibility of results; reproducibility of aggregation and of selection criteria; data quality; transparency of methods, assumptions made, or uncertainties of data
Functional Requirements	Sensitivity to changes in the course of time, suitability for determining trends, early warning, international compatibility, sensitivity to economic, ecological, and social interactions
Requirements from the User's Perspective	Goal orientation, addressee-adequate concentration of information, political controllability, understandability by politics and the public, consensus in society on the suitability of an indicator for presenting relationships and on the interpretation context
Practical Requirements	Data availability, possibility of regular updates, acceptable data supply expenditure

Table 2: Requirements to be met by energy-related indicators.

From the goals, such as the preservation of the ecosystem, saving of resources, maintenance of capital, securing health, comfort, and social solidarity, assessment criteria can be derived to support the development and specification of suitable indicators. Such criteria are listed in the left column of Table 3.

5. APPLICATION EXAMPLE: "ENERGY-TRANS" PROJECT

Within the framework of the ENERGY-TRANS Helmholtz Alliance, sustainability indicators were developed to assess the energy system in Germany with the participation of the authors of this article. The project was aimed at defining indicators to better study the energy system from the society's demand and user side and to better analyze the interfaces between technical and social factors that decisively affect the required system transformation process. The set of indicators proposed by the Alliance included generally accepted techno-economic and ecological indicators, such as energy consumption, energy efficiency, emission rates, or the share of renewable energy sources in energy production. Such indicators are also used in the monitoring report of the federal government. In addition, the Alliance proposed other indicators, such as areas needed for energy plants or the extent of internalizing external costs in the energy system, and indicators to better represent the socio-technical characteristics of the system. The latter describe the interaction and active participation of citizens in the transformation of the energy system or possibilities of participation in decision processes when planning infrastructure projects in the energy sector.

The left column of Table 3 lists criteria for a systematic assessment of the energy system on the national level as well as topics and indicators discussed in literature. This list does not claim to be complete and may be extended. It is to serve as a checklist or selection menu for a first assessment. The right column lists the indicators developed in the ENERGY-TRANS project, thus illustrating how the catalogue can be complemented.

criteria	indicators ENERGY-TRANS
overall economy („macro level")	• Use of Primary Energy, Final Energy Productivity of the German Economy, Final Energy Productivity of the German Industry, Final energy consumption of private households per capita, Final Energy Productivity of Trade, Commerce and Services; Specific Energy Consumption of Households for Heating (Temperature Adjusted), Final Energy Consumption in the Transport Sector, Modal Split in the Transport Sector
energy transformation sector	• Share of Renewable Energy on Gross Final Consumption of Energy, Installed Capacity of Renewable Energy Power Plants
emissions	• Energy-related Greenhouse Gas Emissions, Energy-related Emissions of Acid-forming Gases
health risks	• Energy-related Emissions of Particulate Matter, Energy-related Emissions of Cadmium, Energy-related Emissions of Mercury,
environmental risks	• Amount of High-Level Radioactive Waste which has not been transferred to a safe final disposal place, Energy-related Hazardous Solid Wastes,

causally determined economic factors	• Energy Import Dependency, Volume of publicly financed loans for energy-related investments, Market Share of the Four Biggest Electricity Companies in Total Electricity Production • Share of Employees in the Renewable Energy Sector on Total Employees, Gender Pay Gap in the Highest Salary Group in the Energy Sector, Relation of technician salary to manager salary in the big energy suppliers, Not used renewable electricity due to management measures
affordability	• Monthly energy expenditures of households with a monthly net income less than 1,300 Euros
support to developing countries	• Share of Development Aid Expenses for Energy-related Projects on Total GDP
stock of energy resources (deposits, potential of renewable energies)	Not covered
avoided environmental damages	• Added Value Creation from Energy Efficiency Measures in Households,
external benefits	• Added Value Creation from the Renewable Energy Sector
external costs (damage costs)	Not covered
internalization of external costs	• Degree of Internalization of energy-related external costs
research and development	• Number of University Graduates in the Field of Energy Sciences, Federal Expenditures for Energy Research, Number of German Patents in the Field of Renewable Energy and Energy Efficiency, Number of Start-ups in the Renewable Energy and Energy Efficiency Sector, Relation between Costs saved for Imported Conventional Fuels and Investments in RE Technologies
competition for land	• Area under Cultivation of Energy Crops
acceptance by the general public/ society	• Acceptance of Grid Extension for Achieving 100% Renewable Energy Supply, Acceptance of Renewable Energies in the Neighborhood, Share of Population Satisfied with Opportunities to Participate in Decision Making for power transmission grids, Share of Tourists Who Perceive Energy Power Technologies as Being Disruptive in the Vacation Region Share of Population living in Regions with the Objective to shift to 100% Renewable Energy
tourism	Not covered
demographic factors	• Share of Households Buying Renewable Electricity
transport structure	• Number of Electric Vehicles
efficiency of energy use	• Share of Installed Smart Meters Mandatory for Large Electricity Consumers
grid infrastructure (e.g. investments in the energy transport infrastructure)	Not covered
spatial distribution of power plants (e.g. degree of centrality vs. de-centrality of energy generation plants)	Not covered
ownership situation	• Number of Energy Cooperatives Engaged in Renewable Energy Plants, Share of Households Producing Renewable Electricity
supply reliability and quality of voltage	• SAIDI (System Average Interruption Duration Index) of Electricity

power generation technologies (e.g. installed generation capacity, efficiency, conversion and distribution losses, level and pace of innovation, type of conversion technology)	Not covered
compliance	• Share of regulatory tools in the planning of power transmission grids which fulfil participation requirements

Table 3: „Checklist" for a systematization of the valuation object „energy system"

Based on this comprehensive list of indicators, indicator systems can be compiled for specific assessment tasks. This compilation may also include further information, methods, and algorithms for analysis and assessment of the indicators. In this way, the assessment method can be adapted flexibly to the respective contexts. Practical implementation is being discussed at the moment.

6. OUTLOOK

Apart from the selection of suitable indicators and their analysis and evaluation with appropriate methods, interactions among these indicators and the goals defined are important, but have hardly been considered systematically so far. Interaction analyses are required to identify and study existing or potential target conflicts and to determine indicators of higher or lower relevance (due to the number and intensity of interactions with other indicators). This will help more adequately develop problem solution strategies. The highly suited cross-impact analysis method has not yet been applied systematically in most of the indicator-based studies in the energy and other sectors. Here, there is a considerable need for analysis and research in the future.

REFERENCES

[1] Drosdowski, T., 2015. Theorie der Haushaltsenergieproduktion und die Transformation des Energiesystems, Osnabrück.
[2] Bundesregierung, 2011. Der Weg zur Energie der Zukunft: sicher, bezahlbar und umweltfreundlich, Berlin.
[3] Bundesministerium für Wirtschaft und Energie (BMWi), 2015. Ein gutes Stück Arbeit - Die Energie der Zukunft: Vierter Monitoring-Bericht zur Energiewende, Berlin.
[4] AGECC - UN Secretary General´s Advisory Group on Energy and Climate change. Energy for a Sustainable Future: Report and Recommendations, New York.
[5] German Advisory Council on Global Change (WBGU), 2003. World in Transition: Towards Sustainable Energy Systems, Berlin [u.a.].
[6] Expertenkommission zum Monitoring-Prozess „Energie der Zukunft", 2015. Stellungnahme zum vierten Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2014, Berlin, Münster, Stuttgart.
[7] Chr. Rösch (2017). Ethics of Sustainability—An Analytical Approach. In: The Ethics of Technology (Ed. Sven Ove Hansson), Rowman & Littlefield International, Ltd., London, pp 17-35.
[8] Rebhan, E., 2013. Energiehandbuch: Gewinnung, Wandlung und Nutzung von Energie, Berlin [u.a.].
[9] Ropohl, G., 2009. Allgemeine Technologie: Eine Systemtheorie der Technik, Karlsruhe.
[10] Grunwald, A., Poganietz, R.-W., 2010. Auf dem Weg zu einer nachhaltigen Energieversorgung: Beiträge von TA und Energiesystemanalyse, in: Institut für Technikfolgenabschätzung und Systemanalyse (ITAS) (Ed.), Technikfolgenabschätzung, Theorie und Praxis. Auf dem Weg zu einer nachhaltigen Energieversorgung - Beiträge von TA und Energiesystemanalyse, 4–11.
[11] Grunwald, A., Kopfmüller, J., 2012. Nachhaltigkeit: eine Einführung, 2. aktualisierte Auflage, Frankfurt, New York.
[12] Opschoor, H., Reijnders, L., 1991. Towards sustainable development indicators, in: Onno Kuik, H.V. (Ed.), In Search of Indicators of Sustainable Development, 7–27.
[13] Heiland, S., Tischer, M., Döring, T., Pahl, T., Jessel, B., 2003. Indikatoren zur Zielkonkretisierung und Erfolgskontrolle im Rahmen der Lokalen Agenda 21, Berlin.
[14] eurostat. Climate change and energy – Eurostat [online]. Retrieved from: http://ec.europa.eu/eurostat/web/sdi/indicators/climate-change-and-energy [Retrieved on January 2017].

[15] Vereinte Nationen (UN), 1992. AGENDA 21 Konferenz der Vereinten Nationen für Umwelt und Entwicklung, Rio de Janeiro.
[16] Hofer, P., AG, P., Scheelhaase, J., Wolff, H., 1998. Nachhaltige Entwicklung im Energiesektor?: Erste deutsche Branchenanalyse zum Leitbild von Rio, Heidelberg.
[17] Deutsches Institut für Wirtschaftsforschung (DIW), Fraunhofer Institut für Systemtechnik und Innovationsforschung (ISI), 1997. Energie-Effizienz-Indikatoren: Statistische Grundlagen, theoretische Fundierung und Orientierungsbasis für die politische Praxis, Berlin.
[18] Coenen, R., 2000. Konzeptionelle Aspekte von Nachhaltigkeitsindikatorensystemen, Karlsruhe.
[19] Rösch, K.-B. Bräutigam, J. Kopfmüller, V. Stelzer, P. Lichtner (2017): Indicator System for the Sustainability Assessment of the German Energy System and its Transition. Journal: Energy, Sustainability and Society DOI: 10.1186/s13705-016-0103-y.
[20] Diekmann, J., Eichhammer, W., Neubert, A., Rieke, H., Schlomann, B., Ziesing, H.-J., 1999. Energie-Effizienz-Indikatoren: Statistische Grundlagen, theoretische Fundierung und Orientierungsbasis für die politische Praxis, Heidelberg.
[21] Friedrich, R., Krewitt, W., 1997. Umwelt- und Gesundheitsschäden durch die Stromerzeugung: Externe Kosten von Stromerzeugungssystemen. Berlin, Heidelberg.
[22] Weimer-Jehle, W., 2006. Cross-impact balances: A system-theoretical approach to cross-impact analysis. Technological Forecasting and Social Change 73 (4), 334–361.