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How methodological issues affect the energy indicator results for different electricity generation technologies

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HIGHLIGHTS

- There is a need for stricter standardisation of energy performance assessments.
- System boundaries for renewable sources should be harmonised.
- One should focus on a smaller set of indicators. CED should be included.

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ABSTRACT

The aim of this paper is to improve the basis for the comparison of energy products. The paper will discuss important methodological issues with regard to various energy indicators and it will, by means of a few selected energy indicators, show examples of results for hydropower, wind power and electricity from biomass, gas and coal. Lastly it will suggest methods to achieve results which are more consistent when comparing electricity production technologies.

In general, methodological issues can affect the results of life cycle assessments. In this paper, the authors have focused on the effect of system boundaries for energy indicators and found that the internal ranking of cases within one electricity generation technology is dependent on the indicator used. These variations do not, however, alter the general ranking of the major technologies studied.

The authors suggest that future assessments should focus on a smaller set of indicators: the Cumulative Energy Demand (CED), which is the most "universal" indicator, Energy Payback Ratio (EPR) for assessment of upstream activities, and a suggested "Cumulative Fossil Energy Demand" (CFED) for resource depletion assessments. There is also a need for stricter standardisation and increased transparency in the assessment of energy products.

1. Introduction

The purpose of life-cycle assessments (LCAs) is to assess environmental impacts, during the complete life cycle of a product or a service. These assessments include an inventory of all relevant activities, from the extraction of raw materials to the final elimination or recycling of the product. Energy is an important factor in each of these activities, as many impacts relate to energy input. Most LCAs therefore calculate the energy indicator Cumulative Energy Demand (CED). CED is normally expressed as energy input per unit of final consumed product or per unit of weight (kg) for bulk products. CED can also be calculated for an energy product, such as one unit of electricity (kWh) or one unit of heat (MJ).

A wide range of indicators, however, have been designed to impart information about the life-cycle performance of energy products. This paper aims to describe the most common energy indicators for different energy products and define their purpose and system boundaries in order to propose methods and parameters to improve the consistency of results. Inconsistencies with regard to energy performance assessment methods have been documented by Davidsson et al. (2012), Arvidsson et al. (2012) and Modahl et al. (2012), among others, showing that there is a need for an increased effort in work on standardising energy performance calculations methods. This is crucial if energy performance of energy products is to play a role in policy guiding. Important questions to be answered in this paper are which indicators are normally used by researchers, when assessing energy products, such as electricity, fuel and heat? Are these indicators consistent

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and comparable? Are the terminology and definitions clear and easily understood?

On this basis, the article aims to:

- Describe the most common energy indicators for energy products and define their purpose and system boundaries.
- Discuss the methodological issues of energy indicators for energy products.
- Show results for certain energy indicators for examples of certain major electricity generation technologies.
- Discuss methodological issues that could affect the results of these comparisons.
- Propose methods and parameters to improve the consistency of results.

2. Life-cycle energy indicators: Their design, purpose and methodological issues

2.1. Schematic description of the life-cycle of energy options

The next section describes the contributions made by various authors or institutions in designing specific energy indicators. In order to clarify the calculation of these indicators and the different system boundaries used in literature, we have created a schematic description of the life-cycle of energy options (Fig. 1 and Table 1). The parameters shown in Fig. 1 will then be used to describe the various indicators.

2.2. Energy indicators

2.2.1. Energy indicators—An overview

Many indicators have been designed to impart information about the life-cycle performance of energy technologies. Tables 2 and 3 present some of these indicators, together with their calculation method and system boundaries. It can be seen that the indicators were designed for various purposes. These include showing the energy trends in agriculture or in oil extraction; the assessment of efficiency in bio-fuel production and testing whether upstream energy investments might not disqualify emerging sources of renewable energy.

As life-cycle assessments of energy technologies have become more widespread, however, the purpose of these indicators has become the more “universal one of” comparing the performance of numerous energy technologies. Taking into account the variations in calculation methods, the authors propose to identify the

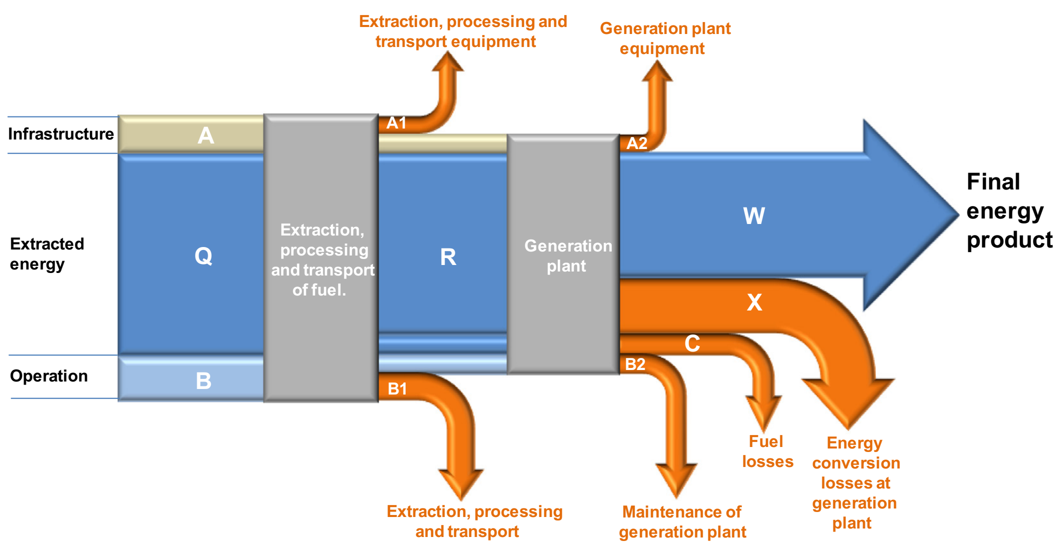

Fig. 1. Life-cycle chain of energy products.

Table 1
Description of Fig. 1 parameters.

Category	Letter in Figure A	Details
Energy use for production of energy infrastructures	A	Primary energy[a] required for building the infrastructure relating to extraction, processing and transportation ($A1$) and for building the generation infrastructure ($A2$)
Energy use for delivery of fuel source and internal energy use at the generation plant	B	Primary energy required for extraction, processing and transport of fuel ($B1$) and fuel consumption at the plant for internal purposes ($B2$)
Extracted energy	Q	Total amount of extracted primary energy necessary for the generation of a specific amount (e.g. 1 kW h) of the delivered final energy product. For some indicators, Q can be characterised as *embedded energy* in the extracted fuel
Fuel losses	C	Losses in all fuel steps, such as fugitive emissions in gas delivery or storage losses of biomass
Energy resource delivered at the generation plant	$R=Q-C$	Primary energy delivered, before conversion to final energy product. For some indicators, R is used to define life-cycle *embedded energy* in the fuel. The use of Q is, however, more accurate than the use of R
Final energy product	W	Delivered final energy product. This is directly dependant on the efficiency of the generation plant
Energy conversion losses at the generation plant	X	Energy losses in the final conversion process, principally wasted heat

[a] Primary energy is the energy embodied in natural resources prior to undergoing any human-made conversions or transformations. Examples of primary energy resources include coal, crude oil, sunlight, wind, running rivers, vegetation, and uranium. Kydes (2011). Definition from EIA (2000): Site energy is the energy directly consumed by end users, and primary energy is site energy plus the energy consumed in the production and delivery of energy products.