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ASSESSMENT OF MAJOR ELECTRICITY GENERATION TECHNOLOGIES BASED ON DIFFERENT ENERGY INDICATORS – THE EFFECT OF SYSTEM BOUNDARIES

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ABSTRACT

The aim of this paper is to improve the basis for the comparison of energy products. The paper is based on results for hydropower, wind power and electricity from biomass, gas and coal, and discusses how system boundaries affect the results of the various energy indicators.

The internal ranking of cases within one electricity generation technology is dependent on the choice of energy indicator. These variations do not, however, alter the general ranking of the major technologies studied.

Future assessments are suggested to focus on a smaller set of energy indicators. CED should be included as it is the most universal indicator.

INTRODUCTION

A wide range of indicators have been designed to impart information about the life-cycle energy performance of energy products. This paper aims to describe the most common energy indicators and define their purpose and system boundaries in order to propose methods to improve the consistency of results. Inconsistencies with regard to energy performance assessment methods have been documented by Davidsson et al. (2012) and Modahl et al. (2012), showing that there is a need for an increased effort in work on standardising energy performance calculations methods.

METHODS

Energy indicators can basically be divided into two categories according to their purpose and system boundaries: 1. Tracking all the energy required by an option. This process requires the inclusion of all upstream and embedded energy. 2. Assess the payback of energy options. A selection of activities is included, without including the embedded energy.

Figure 1 and table 1 present some of the energy indicators used, together with their calculation method and system boundaries.

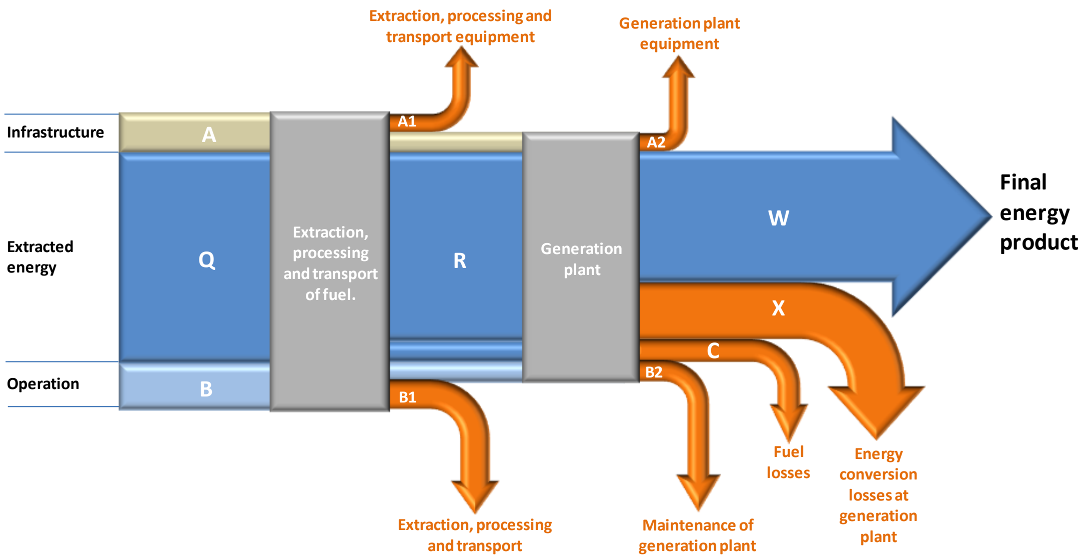

Figure 1 Life-cycle chain of energy products.

Table 1 Energy indicators.

System boundaries	Indicator/ calculation	Description
Embedded energy included.	CED = Cumulative Energy Demand = (A+B+Q)/W	All primary energy required to build, maintain and supply the system, divided by the final energy product generated during a system lifespan.
	NER = Net Energy Ratio = W/(A+B+Q)	Final energy product generated during a system lifespan, divided by the *fossil* energy required to build, maintain and supply the system.
Embedded energy not included as invested energy (the denominator). Based on W/(A+B).	EPR = Energy Payback Ratio = W/(A+B)	Final energy product generated during a system's lifespan, divided by the primary energy required to build, maintain and supply the system.
	Net Energy Payback	Identical to EPR.
	Energy budget	
	Energy ratio	
	EROEI = Energy Return on Energy Investment	
	External Energy Ratio = $W/(A+B)_{fossil}$	Electricity delivered to the grid divided by (fossil fuel energy consumed within the system, minus the energy contained in the fuel fed to the power plant).

RESULTS

Because CED and EPR are the most general indicators in each category, these two were chosen to represent the two different purposes for using energy indicators. These indicators have been compared for all the 44 investigated studies, representing five different electricity production technologies; hydropower, wind power and electricity from biomass, gas and coal (Askham 2007; Vold et al. 1998; Kyläkorpi and Setterwall 2011; Bureau Veritas Certification 2010 and 2011; Ecoinvent Centre 2010; Raadal and Vold 2012; Lenzen and Munksgaard 2002; Burger and Bauer 2007; Schleisner 2000; Voorspools et al. 2000, Crawford 2009; Bauer et al. 2008 and Vold et al. 2012). The study shows that hydropower achieves the best performance, wind power comes second, and the thermal power generation technologies (biomass, natural gas and coal) have the lowest performance. These results are achieved both by CED and EPR.

When looking more closely at the figures, however, the internal ranking between specific cases within one technology is dependent on the choice of indicator.

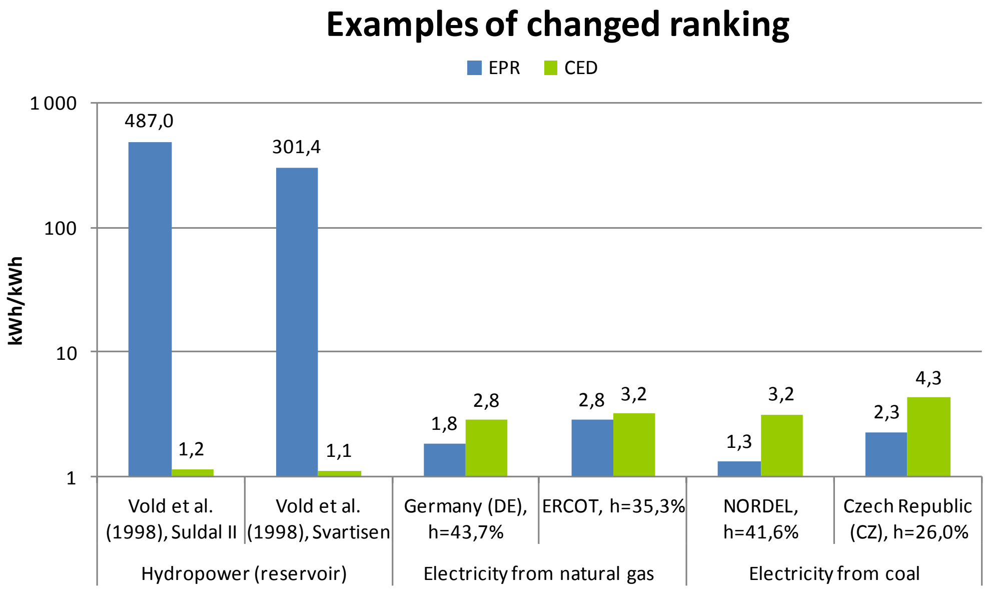

Figure 2 Examples of changed ranking. h = plant efficiency. The higher the EPR, and the lower the CED, the more efficient the performance.

DISCUSSION

As EPR ranks technologies based on “supporting energy”, thus excluding the electricity conversion loss in the invested energy, small differences in supporting energy (compared to the total delivered electricity amount) creates large differences in EPR. In contrast, the CED includes embedded energy as invested energy, showing the energy efficiency throughout the total value chain.

This fundamental difference in system boundaries can lead to the result that a number-one thermal plant according to EPR could be ranked as average, or even the worst case, according to CED, and vice versa.

CONCLUSIONS

It is unlikely that methodological issues would change the overall ranking. However, the internal ranking within each technology is dependent on the choice of indicator, due to the differences in system boundaries of the energy indicators.

Considering the many different energy indicators, it is suggested that future assessments focus on a smaller set of indicators. CED should be included as it is the most universal indicator. In addition, it can be split into the different energy sources and life cycle stages, hence CED can give added information compared to most other indicators.

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