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Accounting for hidden energy dependency: The impact of energy embodied in traded goods on cross-country energy security assessments

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A R T I C L E I N F O

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A B S T R A C T

Energy security ranks high on the policy agenda of many countries. Accordingly, to provide policy guidance, a large and growing body of literature has proposed metrics to measure security of (primary) energy supply which are then applied in cross-country energy security assessments. In general, the data used in these assessments are based on production-oriented energy accounting frameworks. In doing this, these studies neglect additional indirect foreign energy consumption – i.e. consumption of energy embodied in traded goods. This paper highlights this issue. It provides and applies a methodology that allows including indirect foreign energy consumption into commonly used energy security indicators. In particular, it shows that the inclusion of foreign primary energy embodied in traded goods does not only change values of energy security indicators but also alters perceptions on regional energy security performance over time as well as relative to other regions' performance.

1. Introduction

Energy security ranks high on the policy agenda of many countries. Governments use the notion of energy security as a rationale for justifying massive intervention into energy markets. As a prime example, the European Union perceives its EU Energy Security and Solidarity Action Plan as an important step to increase energy security for its member states [1].

Accordingly, to provide policy guidance, a large and growing body of literature proposes metrics to measure security of (primary) energy supply. They measure either dependency levels on primary energy imports, primary energy carriers and suppliers or levels of vulnerability, i.e. how much the economy is exposed to events of supply disruptions essentially from an economic perspective [2]. These metrics are then frequently applied to track the evolution of energy security performance over time for single countries or to compare energy security performance across countries at certain points in time as well as over time. In general, these assessments are based on data coming from production-oriented accounting frameworks for regional primary energy consumption – i.e. direct energy consumption based on the territory principle – which are provided by various statistical institutions, e.g. the IEA (International Energy Agency), the U.S. EIA (Energy Information Agency), or Eurostat. Recently published studies providing such assessments for European countries include, among others, Frondel and Schmidt [3], Sovacool and Brown [4], Löschel et al. [5], and Le Coq and Paltseva [6].

However, energy is not only used directly in any given production and final demand sector but also indirectly – i.e. in the production of imported goods and services purchased for use in that sector [7]. Since in a highly globalized world countries are heavily and increasingly involved in international trade, trade in non-energy goods and services can substitute for trade and consumption of primary energy which in the end masks energy security issues [8]. To put it more pointedly: If trading partners providing imports of non-energy goods and services cannot secure their energy supply, how can energy security be provided without disconnecting from global trade of energy and non-energy goods [9].

Since energy security assessments usually only focus on direct energy use, they neglect this issue. This is of particular relevance for Europe. Because Europe is one of the dominant trading centers in terms of embodied energy [10], commonly applied energy security assessments are based on only an incomplete picture of the European energy situation. This implies that single-country as well as cross-country energy security assessments for European countries

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might be inaccurate. Acknowledging indirect energy consumption would require a switchover from production-oriented energy accounting to more consumption-oriented approaches for energy accounting. This switchover in energy accounting would provide a novel perspective on the European energy security problem. In the end, this would allow a better-informed energy security debate.

To the best of my knowledge, so far only some rare studies address the implications of indirect energy consumption for security of European primary energy supply. Bordigoni et al. [11] examine the role of these additional energy flows with a special focus on the European manufacturing industry. They apply a global MRIO (multi-region input–output) model and find that in 2005 energy embodied in imported manufactured products used in European production and final consumption comes close to energy consumed directly by the European industry and, therefore, has to be considered as a significant aspect of the European energy situation. In a similar way, Tang et al. [9] apply a SRIO (single-region input–output) model to quantify energy embodied in international trade of the UK. They find that UK is a net-importer of embodied fossil energy for every year within the time period 1997 to 2011. Accordingly, since the gap between fossil energy consumption and domestic fossil energy production is larger than commonly believed, they argue that if net-imports are taken into consideration, the energy security problem is greater than generally accepted. Therefore, they conclude that energy embodied in traded goods is another variable which should be considered in the complex equation of energy security. However, what has not yet done is a more in-depth investigation of this issue – i.e. whether the consideration of embodied energy substantially changes energy security perceptions of individual European countries and, if this is the case, whether they are for good or for worse.

The principal objective of this paper is to acquire some first insights into this relatively unexplored perspective on energy security. First, it provides a methodology that enables the quantification of indirect energy consumption. Second, the scope of three conventionally used energy security indicators – energy intensity, net-import dependency, and primary energy carrier dependency – is extended such that they also include indirect energy consumption.[1] Third, to quantify the impact of the switchover in the energy accounting framework on indicator values and perceptions on country-specific energy security performance, the production-oriented and consumption-oriented indicators are applied for 25 European countries for the years 1995 to 2009.[2] Rather general implications for European countries are analyzed by means of descriptive statistical analysis while for some specific countries more in-depth analysis is provided which connects indicator changes and changing perceptions on energy security performance to embodied energy trade flows.

Since indicator values sometimes change quite substantially, the application shows that in many cases the incorporation of primary energy embodied in traded goods has an impact on perceptions about energy security performance of European countries. Especially as it comes to tracking the countries' performance with respect to single indicators over time, turning from production-oriented to consumption-oriented energy accounting results in a trend reversal for some countries. This is particularly the case for net-import dependency and primary energy carrier dependency. Furthermore, as it comes to cross-country energy security assessments, perceptions about the countries' relative performance to other countries are also sensitive to choices on the energy accounting framework. Therefore, the question as to whether indirect energy consumption should be taken into consideration is of particular relevance for comparing security of primary energy supply across countries.

The remainder of the paper is organized as follows. Section 2 presents the input–output model used to quantify primary energy embodied in traded goods (Section 2.1), three energy security indicators which are commonly used in energy security assessment (Section 2.2), the production-oriented as well as the consumption-oriented versions of these indicators (Section 2.3), and the data used in the application (Section 2.4). Section 3 presents and discusses the results of the application. Section 4 summarizes and concludes.

2. Methods

2.1. Multi-regional input–output model

Quantifying regional amounts of direct and indirect primary energy consumption requires analyzing intra-regional and inter-regional economic relationships among sectors of regional economies. For this, MRIO (multi-regional input–output) models, that include the complete global production chain of goods and services, are well established analytical frameworks.

The calculation of primary energy embodied in imports and exports other than primary energy is based on a MRIO (multi-regional input–output) model extended by sector- and carrier-specific primary energy consumption. The model includes $r, s \in R$ regions, $i \in I$ production sectors whereas each of them is producing a single homogenous commodity, and $g \in G$ activities consisting of all production sectors plus final demand activities.[3] Y_{gr} denotes the activity level in sector g in region r. X_{isr} are exports of commodity i from region s to region r, while M_{ir} are imports of commodity i in region r. Z^D_{igr} (Z^M_{igr}) denote domestic (imported) intermediate inputs of commodity i in activity g in region r.

The model includes six different primary energy carriers $pe \in PE$ which are the following: crude oil, coal, natural gas, nuclear energy hydropower, and renewables. The carrier-specific primary energy content of a good is composed of primary energy used in the production of the good itself as well as of primary energy that is used to produce required intermediate inputs. To calculate the full carrier-specific primary energy content (per USD of output) input–output accounting identities are used and the associated linear system of equations is solved for the primary energy content of production activities ($pec^Y_{pe,gr}$) and the primary energy content of imports ($pec^M_{pe,ir}$).

Total carrier-specific primary energy embodied in output of activity g in region r is equal to the sum of direct carrier-specific use of domestic and imported primary energy ($evd_{pe,gr}$ and $evi_{pe,gr}$), carrier-specific embodied primary energy in domestic intermediates, and carrier-specific embodied primary energy in imported intermediates (see Eq. (1)). Total carrier-specific primary energy embodied in imports of commodity i in region r is equal to

[1] This study does not consider supplier dependency. This is principally due to a lack of appropriate data. In particular, the WIOD data set, which is the only appropriate data set for this analysis, does not include all of Europe's principal primary energy suppliers, e.g. Norway, Algeria, or the OPEC member countries.

[2] Clearly, to provide guidance to current policies, it would be more valuable to include more recent years into the analysis. Unfortunately, this is not possible to date due to a lack of appropriate data enabling the calculation of primary energy embodied in traded goods (see also Section 2.4). However, the general implication on the design of policies addressing energy security (see Section 4) remains valid.

[3] Table A.1 and A.2 in Appendix A provide an overview over regions ($r \in R$) and sectors ($g \in G$ and $i \in I$) included in the model. They are chosen in accordance to the WIOD data base (cf. Section 2.4). Furthermore, since each production sector produces only one commodity, production sectors and commodities are equivalent.