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Decoupling energy use and economic growth: Counter evidence from structural effects and embodied energy in trade

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HIGHLIGHTS

- The effects of energy efficiency measures are largely offset by economic growth in Switzerland.
- Index decomposition analysis shows that structural effects are significant for in trade related activities.
- Energy intensity does not adequately reflect decoupling as embodied energy in trade is not accounted for.
- Indirect energy consumption in economic activities reached 81% of direct energy use.

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ABSTRACT

Decoupling economic growth from energy consumption is a wide spread attempt to decarbonize economic activities and increase energy security. Almost all members of the European Union have decoupled the two since 2005 as measured by a steady decline in energy intensity, the ratio of final energy consumption and gross domestic product. Economic growth, energy efficiency and structural changes have all contributed to changes in energy intensity of economic activities at the national level. In this article, the authors analyze to what extent decoupling can be attributed to each of these three factors and in particular structural effects, namely deindustrialization and tertiarization, which shifts energy consumption abroad and re-imports it as embodied energy in products.

We quantify the effects of structural changes, economic growth and energy efficiency measures as well as embodied energy in trade at the level of economic activities. The methodological approach combines decomposition and input-output analysis to address boundary cases where monetary trade surpluses meet energy trade deficits. Switzerland provides a case in point with the added hurdle of low data availability per economic activity over time.

The results show that the share of embodied energy in imports has reached 81% of final energy consumption in economic activities. A comparison of energy intensities with and without embodied energy in trade shows that decoupling is more virtual than actual. Shifting energy intensive activities abroad improves domestic performance but worsens both overall energy use and security by relying on more indirect energy consumption. Energy indicators should therefore be adjusted to avoid potentially conflicting policy objectives between energy intensity and security as well as trade.

1. Introduction

Economic development is directly proportional to the amount of useful energy involved, as shown by long term empirical evidence [1]. Given the impact of the energy system on climate change, essentially emissions from fossil fuel combustion, many countries have made efforts to decouple energy use from economic growth. Decoupling consists of increasing the energy productivity of economic activities such that more output can be produced per unit of energy used. According to the European Environment Agency (EEA) [2], almost all members of the European Union have decoupled since 2005 as measured by a steady decline in energy intensity, or the ratio of final energy consumption and gross domestic product (GDP). The greatest decline was observed in Eastern Europe thanks to changes in economic

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structure according to the EEA. To what extent structural changes influence energy intensity is precisely the first object of the research outlined in this article.

Several factors may explain a decreasing energy use per unit of GDP. Energy efficiency measures are expected to be the main factor in reducing energy intensity and an indicator of successful decoupling. In fact, energy policies in Europe and elsewhere that place high expectations on energy efficiency improvement to reduce primary and final energy consumption e.g. [3,4]. Voigt et al. [5] showed that improvements in technology contribute the most to lower energy intensity while the impact of structural changes remain small. However, important exceptions were identified, including the US and Japan, where structural changes play a significant role. Energy intensity as an indicator of economic performance has its limitations, in particular because economic output is correlated with energy input [6]. Nevertheless, the impact of energy efficiency measures can be quantified more so than structural effects, provided rebound effects remain low. This leads to the second question in this article, can structural changes such as deindustrialization and tertiarization, which indirectly reduce energy consumption domestically, be considered successful decoupling? Deindustrialization (outsourcing of energy intensive industries) on one hand, and tertiarization (growing contribution of the service sector in monetary terms) on the other, indeed tend to yield higher value added per unit of final energy consumption. At constant consumption levels, deindustrialization induces an increase in imports of semi-finished and finished products to compensate for the loss of domestic manufacturing of equivalent products. The energy used in manufactured products (goods and services) and innovations is then imported in the form of embodied energy. Services and innovations also require energy, which can be shifted abroad through outsourcing [7].

Hence the authors estimate the respective contributions of energy efficiency measures, structural changes in the economy and trade to the observed decline in energy intensity. Much work has been done to evaluate patterns of energy consumption in deindustrializing nations such as Germany, the Netherlands and Belgium, illustrating the impact of structural effects on energy intensity and the need to account for them in policy making e.g. [8,9]. Similarly, energy and in particular emissions, embodied in trade have been quantified for large importing and exporting countries, highlighting the difference between production and consumption based accounting of energy and emissions e.g. [10–13]. These results build on advances in input-output analysis and the availability of data for estimating embodied energy and emissions in trade. A shift towards indirect energy consumption in the form of imports can be observed for countries with high GDP per capita [14]. Yet, much less research exists on countries for which the energy and monetary terms of trade are highly unequal. For example, countries such as Germany and Switzerland run large trade surpluses yet their trade balance in energy terms is negative. Consumption based accounting of energy embodied in the manufacturing of imports and exports is highly relevant for both importers and exporters in moving along the value chain through deindustrialization and/or tertiarization [15]. This allows us to distinguish between virtual decoupling, that is, a lower energy intensity as a result of structural changes and relative (or absolute) decoupling due to the implementation of energy efficiency measures or productivity gains. One of the first attempts to quantify the energy embodied in products was based on an extended version of input output tables for the US in 1967 [16]. Input output analysis has increasingly been used to estimate trade related emissions thanks to the availability of environmentally extended input output tables (EE IOTs) e.g. [17,10]. Since Wiedemann et al. [18] conducted a thorough review of input output analysis to estimate the environmental terms of trade, multi-regional input output tables (MR IOTs) also became available [19–22]. Yet, little exists on linking embodied energy in trade and structural effects of deindustrialization and tertiarization from top down and bottom up approaches respectively. Moreover, boundary cases with growing trade surpluses and energy deficits provide perfect ground to test if decoupling is more virtual than relative before applying the methodological approach to other cases. This is the very purpose of this article in which the authors assess the impact of structural changes on energy intensity and energy consumption through a combination of index decomposition and input output analysis. This approach has the dual purpose of validating the results and examining the extent to which input output analysis captures the evolution of national economies with highly unequal monetary and energy terms of trade. The methodological approach applied to a boundary case therefore brings new insight to explain both the underlying changes behind decoupling and the lack thereof.

The effects underlying energy consumption are decomposed into 3 factors: economic growth, energy efficiency and structural changes in economic activities. Much research has already been conducted on decomposing these drivers behind energy consumption, using both index and structural decomposition e.g. [23,14]. Yet few look at the respective contribution of these drivers towards decoupling. At the EU level, a study over the 2001 to 2008 period re-emphasized that energy efficiency measures largely compensate for growth in economic activities [24]. Whether these measures actually contribute to the achievement of energy efficiency targets is the subject of more recent work which highlighted changes in the electricity generation sector [25]. Understanding the respective roles of economic growth, energy efficiency and structural changes has far reaching consequences for policy making, e.g. for energy security and industrial and trade policies. Moreover, examples of such methodological approaches focus more on carbon emissions than energy consumption [26,27].

Switzerland provides a case in point as it holds a sizable and growing trade deficit in physical terms (see Fig. 2), yet runs trade surpluses, including with China, the world's largest net exporter. The other example is Germany for which the reported share of embodied energy in imports has increased by 18% from 2000 to 2007 as shown by specific EE IOTs [28]. In addition, a common pattern of deindustrialization can be observed across Europe, with countries increasingly relying on imports as domestic manufacturing declines and income rises [29]. Thus, understanding the reasons behind the evolution of energy intensity is of prime value for policy making, particularly energy security and energy efficiency.

Section 2 below provides some background on methods and data and Section 3 discusses the results. The authors conclude on the interlinkages between energy and trade policies, as well as on the need to improve indicators of energy intensity to measure actual rather than virtual decoupling.

2. Materials and methods

2.1. Background

Fig. 1 shows the decline in energy intensity in Switzerland at a relatively constant rate of 4% per year since 2001. If GDP is a conventional measure of economic output, different metrics are used for energy consumption, from total primary energy input to final energy consumption or useful work [30]. In this article, final energy consumption corresponds to the energy used by economic activities to supply final demand and includes the energy sector (e.g. transformation losses in nuclear power plants, refineries and pumped hydro storage) but excludes non-energy use of fossil fuels (e.g. lubricants and bitumen) which makes a significant difference for the chemical and construction sectors. In short, energy use and energy consumption are used interchangeably to mean the same quality as final energy consumption.

From 2000 to 2013, the trade surplus in monetary terms increased 14-fold (+22,000 million CHF) while the trade deficit in physical terms increased by 14% (+4.4 Gigatons), a sign that the economy continues to import more semi-finished and finished products [32]. As shown in Fig. 2, the economic downturn of 2008 unexpectedly affected the monetary and physical trade balances of Switzerland, leading to a