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Domestic versus foreign energy use: an analysis for four European countries

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Abstract

In order to adequately assess energy policies and set clear objectives, a key preliminary step is to know the energy use patterns of the different countries. This paper estimates the evolution of the total energy use over the period 1995–2015 in four European Union (EU) countries, the Czech Republic, Hungary, Italy, and Spain, representative of two different energy patterns, the "Southern" one and the "Eastern" one. For doing so, we employ a Multi-Regional Input Output (MRIO) model. In difference with previous studies, in addition to differentiate between domestic and foreign use we distinguish whether this energy is produced domestically or abroad. The results obtained show a certain convergence in energy intensity across the four countries examined because of the radical transformations experienced by the Czech Republic and Hungary. Nonetheless, energy intensities are still substantially higher in Eastern than in Southern countries which confirms that the first group of countries have still a long road to go, especially regarding the incentives that their industries have to use energy efficiently. Taking our decomposition of total energy use, the reductions in total energy use were mainly caused by a high decrease in the importance of the domestic use of energy produced domestically. At the same time, a growing importance of the role played by the energy produced abroad was observed. These trends confirm the great importance of global value chains and the steady internalization of energy use. This methodology could be further applied to other countries.

Keywords Energy use · Direct use · Indirect use · Energy intensity · MRIO model

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1 Introduction

Energy use is responsible for a variety of economic, environmental, and social impacts (Miller et al., 2013) as it reflects the behavior and evolution of a society (Akizu-Gardoki et al., 2018). Although the global demand for energy has substantially increased over the last decades (IEA, 2019) at the same time the search for improvements in energy efficiency in order to achieve sustainable energy systems is growing (Dresselhaus & Thomas, 2001; Geels et al., 2018; Solomon & Krishna, 2011). This challenge is complex and it is affected by both internal and external factors. Thus, for one part, differences in starting conditions (geographical, economic, or technological) among countries can result into higher or lower levels of energy production and use (Suri & Chapman, 1998). For the other part, the globalization of production and trade that it is reflected in the development of global value chains (Gereffi et al., 2005) results into an increasing dependence on the supply of goods and services from foreign countries, especially of developed countries from developing ones (Lan et al., 2016). This phenomenon leads to substantial changes in trade relations and energy use (Chen et al., 2019a) and makes it necessary to adopt a global perspective when analyzing energy use.

As the energy transition process is a key element within the global environmental and sustainability challenges (Turnheim et al., 2015), most of the world's leading international organizations have established goals aimed at promoting energy sustainability. For instance, the seventh goal of the United Nations Sustainable Development Goals (SDGs) for the year 2030 is "to guarantee access to affordable, reliable, sustainable and modern energy for all" (United Nations General Assembly, 2015). In line with the 2015 Paris Agreement on climate change, the European Union (EU) (through the European Commission), includes within its Energy Strategy different commitments related to the consumption of renewable energies (RES), the improvement of energy efficiency and the reduction in greenhouse gas (GHG) emissions. Thus, the Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources sets a binding EU target of a share of at least 32% of the renewable energy consumed by 2030 (European Union, 2018a). The Directive (EU) 2018/2002 on energy efficiency (European Union, 2018b) sets an energy efficiency target expressed in primary and/or final energy consumption of at least 32.5% by 2030. Finally, concerning the governance of the Energy Union and Climate Action (European Union, 2018c), the Energy Union includes within its five dimensions decarbonization. In this regard, the EU endorsed the objective of a reduction of at least 40% in economy-wide GHG emissions by 2030 compared to 1990. From a long-term perspective the objective is more ambitious and by 2050 the GHG emissions in the energy sector are expected to reduce by over 80% compared to 1990, as this sector produces the lion´s share of man-made GHG emissions (European Commission, 2012).

In order to adequately assess energy policies and set clear objectives, a key preliminary step is used to know the actual energy use patterns of the different countries. In this line, the aim of this paper is to estimate the evolution of total energy use over the period 1995–2015 in four EU countries: the Czech Republic, Hungary, Italy, and Spain by using a multi-regional input output (MRIO) model. The contribution of the paper is twofold. First, we estimate total energy use distinguishing between domestic use and foreign use. In difference with previous studies, we identify whether the total energy used is produced domestically or abroad. Secondly, we focus on four countries representative of two different energy patterns that have been scarcely analyzed (Frolova et al., 2019). Thus, for one part, we take two Southern European countries, Italy and Spain, characterized by being net energy importers compared to their Northern European counterparts (Frolova et al., 2015; Gales et al., 2007), and, for the other part, we take two post-communist countries of the Eastern Europe, the Czech Republic and Hungary, characterized by being intensive energy users that had a great energy supply dependency from Russia (Bouzarovski, 2009; Bouzarovski & Tirado Herrero, 2017; Cornillie & Fankhauser, 2004).

The structure of the paper is as follows. First, we provide a brief review of the literature dealing with energy use and energy accounting. Next, we described the data and the methodology employed. Third, we comment on the results obtained. Finally, some conclusions are pointed out.

2 Energy use and energy accounting: an overview

As was mentioned above, energy use plays a key role in the current process of decarbonization and energy transition. Energy accounting studies emerged in the 1970s when the oil crisis resulted into an energy crisis in which electricity, gasoline or natural gas experienced shortages (Binder, 1974). In this decade three scientists at University of Illinois at Urbana-Champaign, Bruce Hannon, Clark Bullard and Robert Herendeen developed energy input output matrices for the US and tried to combine ecology and economics in one single discipline (Hannon, 2010). Herendeen (1973) introduced the concept of indirect energy requirements starting from the fact that most of energy consumption was not direct personal consumption (more than two thirds of energy use in the US went to other uses) and that it was necessary to take into consideration the indirect energy demand derived from the demand for goods and services to account for total energy use. In his seminal paper (Herendeen, 1973), he converted the 1963 input output table for the US to energy terms. Subsequent works estimated total energy costs of goods and services (Bullard & Herendeen, 1975a, 1975b; Costanza, 1980; Herendeen, 1978). This energy input output analysis starts from the traditional Leontief model (Leontief, 1936) but it changes the balance equation to energy units by using energy intensities (Casler & Wilbur, 1984). As a complement to the analysis of energy flows in the economy, a framework for the analysis of energy in ecosystems was developed by Hannon (1973). In this model the production energy flow comprises energy inflows (like sun) and intrasystem energy flows (like the grass), the components of the system are the energy sources and the individuals, species or trophic levels and the respiration energy flows are those energy flows that have no consumer.

In the late 1970s and early 1980s, energy index decomposition analyses were introduced to assess energy efficiency at the industry level. As pointed out by Hoekstra and van der Bergh (2003), there are two main types of techniques for decomposing indicator changes at the sectoral level, namely, structural decomposition analysis (SDA) and index decomposition analysis (IDA). While SDA analysis uses input output data IDA does not employ any input output model. IDA can be linked to two main groups of methods: the first one is based on the Laspeyres index and the second one draws on the Divisia index (Ang, 2004). Among the first works in this line, we can cite the study of Jenne and Cattell (1983) that examined the evolution of the energy efficiency in the British industry or the paper by Marlay (1984) the focused on the US industry. SDA and IDA present both advantages and disadvantages. Thus, as it uses input output coefficients, SDA allows to capture indirect effects and differentiates between technological effects and final demand effects. In contrast, IDA carries out a more detailed analysis (Cellura et al., 2012).

The oil crisis of the 1990s brought about a renewed interest on energy accounting (Adelman, 1990) and drawing on energy accounting a strand of the literature dealing with energy footprint emerges in the last two decades. Three main methodological approaches can be differentiated: input output analysis (IO), life-cycle assessment (LCA) and Ecological Network Analysis (ENA). In their comparison of these three approaches Chen et al. (2020) highlight the main advantages and disadvantages of each technique. Thus, IO adopts a top-down perspective and it is carried out the macro-level. It allows the estimation of embodied energy and to trace total energy flows across sectors and regions thereby revealing the impact of globalization on energy use. Its main disadvantages are the time lag in the publication of input output tables and the hypotheses of input output models (Leontief, 1936, 1970), namely, the homogeneity, proportionality and import hypotheses. In contrast to IO, LCA is conducted at the micro-level and adopts a bottom-up perspective. LCA is particularly useful to assess the energy performance and efficiency of a particular product or system (Goldstein et al., 2013; Lee & Tzeng, 2008; Pehnt, 2006). One of its main drawbacks, however, is the uncertainty about input variability, model parameters and, especially, model form (Ziyadi & Al-Qadi, 2019). In order to avoid the disadvantages of LCA, hybrid input–output life cycle assessment models (IO-LCA) have been developed (Feng et al., 2014; Suh & Nakamura, 2007; Wiedmann et al., 2011). Finally, ENA focuses on the analysis of ecosystems and adopts a system-oriented perspective drawing on the pioneering work of Hannon (1973). Recent studies have employed this methodology to analyze urban systems (Zhang et al., 2010). Despite ENA allows the evaluation of complex structures and networks within the ecosystems, there is no widely accepted rule for defining the system boundaries. At the urban scale, energy flow analysis (EFA), which resembles the methodology of material flows analysis (Brunner & Rechberger, 2004), or structural path analysis (SPA) have been employed recently to study energy flows (Feng et al., 2019; Zhang et al., 2017).

Table 1 presents a brief review of recent works dealing with energy accounting. As described above, seven main types of methodological approaches can be differentiated: input output (IO) analysis, input output life cycle assessment (IO-LCA), structural decomposition analysis (SDA), index decomposition analysis (IDA), ecological network analysis (ENA), energy flow analysis (EFA) and structural path analysis (SPA).

As can be observed, most of studies are carried out at a national or international scale and employ IO analysis. Among those studies that estimate total energy flows (both direct and embodied) at the global level we can highlight the paper by Chen and Chen (2013) that incorporates simulations to IO analysis in order to forecast direct and indirect global energy flows. More recently, Chen and Wu (2017) estimate the source-sink relations among the 20 major world economies in energy supply chains. In the same vein, Chen et al. (2018) describe the structure of embodied energy flows at global level and regional level, differentiating four groups: the EU, the ASEAN, the NAFTA and AU. In the paper by Wu et al., (2019b) a global energy profile is constructed by estimating total global energy consumption. In a complementary way, Wu et al., (2019a) conducted a similar analysis but focused on household consumption.

At the national level, Tang et al. (2013) examine UK´s energy imports embodied in trade. Owen et al. (2017) also estimate total energy flows in the UK but using two different energy vectors. Focusing on the Chinese case, Zhang et al. (2016) estimate embodied energy transfers via China´s domestic trade and Wu and Chen (2017) examine the cross-scale effect with the rest of the work by estimating the embodied energy intensity of Chinese foreign imports. Zhang et al. (2013) adopts a regional approach and estimate energy requirements in the Chinese regions.

Table 1 Empirical studies on energy accounting

Author	Period	Territorial scale	Sector	Methodology
Chen and Chen (2011)	2004	Global	General	IO
Chen and Chen (2013)	2007	Global	General	IO
Chen and Wu (2017)	2010	Global	General	IO
Chen et al. (2018)	2012	Global	General	IO
Wu et al. (2019b)	2012	Global	General	IO
Wu et al. (2019a)	2012	Global	Households	IO
Tang et al. (2013)	1997–2011	National	General	IO
Owen et al. (2017)	1997–2013	National	General	IO
Zhang et al. (2016)	2002–2007	National	Domestic	IO
Wu and Chen (2017)	2012	National	General	IO
Zhang et al. (2013)	2007	Regional	Domestic	IO
Zhang et al. (2015)	2007	Local	Domestic	IO
Li et al. (2016)	2010	Local	General	IO
Li et al. (2020)	2002- 2012	Urban	General	IO
Chen and Chen (2015)	2007	Urban	General	IO; EFA; ENA
Chen et al. (2019b)	1985–2012	Urban	General	IO; SDA; ENA
Tian et al. (2019)	1995–2009	National	Sectoral	IO
Chang et al. (2010)	2002	National	Construction	IO-LCA
Feng et al. (2014)	2000–2010	National	General	IO-LCA
Wiedmann et al. (2011)	2004	National	General	IO-LCA
Owen et al. (2014)	2007	Global	General	SDA
Lan et al. (2016)	1990–2010	Global	General	SDA
He et al. (2019)	2004–2015	National	General	SDA
Wachsmann et al. (2009)	1970–1996	National	General	SDA
Su and Ang (2017)	2007–2012	National	General	SDA
Zhang and Lahr (2014)	1987–2007	National	General	SDA
Jacobsen (2000)	1966–1992	National	General	SDA
Weber (2009)	1997–2002	National	General	SDA; IDA
Wang et al. (2017)	1991–2015	National	Textiles	IDA
Zhang et al. (2017)	2012	National	Sectoral	SPA

Finally, from a local and urban perspective we can mention the study of the four Chinese municipalities of Beijing, Tianjin, Shanghai and Chongqing conducted by Zhang et al. (2015) or the in-depth analysis of Beijing carried out by Li et al. (2016) that it is replicated at the level of headquarters in the paper by Li et al. (2020). Chen and Chen (2015) and Chen et al., (2019b) also focus on Beijing to compare the results of IO analyses with other approaches like SDA, EFA and ENA.

As pointed out above, the estimation of total energy flows can be a very useful preliminary step to examine energy footprints. Thus, Chen and Chen (2011) estimate embodied CO_2 emissions induced by fossil fuel combustion for three supra-national coalitions (the G7, the BRICs and rest of the world). Tian et al. (2019) estimate China´s energy footprint at the sectoral level. IO-LCA is employed to examine the case of the construction sector in the paper by Chang et al. (2010) and to analyze eight electricity generation technologies in China (Feng et al., 2014). Wiedmann et al. (2011) employ this methodology to examine wind power in the UK.

Among those works using SDA, we can highlight the paper by Owen et al. (2014) that compares the impact of using different IO databases on the estimation of emissions or Lan et al. (2016) that quantifies changes in global energy footprints. Analyses for individual countries like Australia (He et al., 2019), Brazil (Wachsmann et al., 2009), China (Su & Ang, 2017; Zhang & Lahr, 2014), Denmark (Jacobsen, 2000) or the US (Weber, 2009) have been carried out too. As for the rest of methodologies, IDA is employed for the analysis of the energy footprint of the textile sector in China (Wang et al., 2017) and SPA is used to identify primary energy requirements in China (Zhang et al., 2017).

As a complement to energy accounting, some recent approaches highlight the need for decoupling growth and energy consumption (Akizu-Gardoki et al., 2018, 2021). Regardless of the methodological approach, there is a clear recognition of the need for adequately estimating total energy use and for differentiating between domestic and foreign factors. The next section describes the data and the methodology employed.

3 Data and methodology

Within IO analysis, the MRIO models, that is, that IO analyses that employ MRIO tables, are commonly used for the evaluation of environmental impacts generated by economic activities. In this paper we focus on total energy use and extend the traditional MRIO model by differentiating between the domestic and foreign origin of the energy used.

3.1 Data

A number of MRIO databases are available with different regional and sectoral coverage, such as the EORA database (Lenzen et al., 2012, 2013), the World Input−Output Database (WIOD) (Timmer et al., 2015, 2016), the database of the Global Trade Analysis Project (GTAP) (Aguiar et al., 2019), the EXIOBASE (Stadler et al., 2018), which was a product of the EXIOPOL project (Tukker et al., 2013), and the OECD inter-country input–output tables (OECD, 2018) which is based on the United Nations International Standard Industrial Classification of all economic activities (ISIC). Table 2 summarizes the characteristics of the main MRIO databases.

In this paper we employ the EORA database as it has the wider country coverage. In particular, we use the EORA26 (version 199.82) with a harmonized classification of 26 sectors

Table 2 Main MRIO databases

Database	Period	Countries or regions	Sectors	Environmental extension (EE)	Last year of EE
EORA	1990–2015	189 countries and RoW	26	Included	2015
EXIOBASE	1995–2011	43 countries, 5 RoW regions	164	Included	2011
GTAP	2004/2007/2011	140 countries	57	Included	2011
OECD—ICIO	2005–2015	64 countries	36	Not included	–
WIOD	2000–2014	43 countries and RoW	56	Included	2009

RoW Resto of the world

and that covers 189 countries and the rest of the world over the period 1990–2015 (Eora, 2019). Inflows and outflows of energy uses were expressed in Terajoules (TJ) by using an energy vector based on data from the International Energy Agency (IEA, 2020).

3.2 Methodology

The demand-driven IO model for a single country was introduced by Leontief in the 1930s (Leontief, 1936) and environmentally extended in the 1970s (Leontief, 1970). In this model the total output required by country r to satisfy a certain final demand can be expressed as follows:

$$x^r = A^r x^r + y^r \tag{1}$$

where x^r is a vector of sectoral outputs in country r; A^r is a matrix of intermediate consumptions representing the industry requirements to produce one unit of output; and y^r is the final demand vector in country r.

Since imports are usually required to produce exports, direct energy use does not reflect the total energy use of a given economy. In order to obtain a clear picture of energy intensity we need to take into account the energy used to produce exports directed to other countries by employing MRIO databases. In particular, energy use has to be integrated within the economic system to illustrate the energy use profiles associated with economic flows. As an extension of the economic MRIO table, an energy use MRIO table was built starting from the monetary flows and the energy resources of each country aggregated into n countries and k sectors. Table 3 shows the structure of the energy use MRIO table.

If we consider country s and country r, each element z_{ij}^{sr} shows the intermediate deliveries from industry i in country s to industry j in country r. Each element y_i^{sr} shows the final deliveries from industry i in country s to satisfy the final demand in country r. Each element v_j^s shows the value added generated in industry j in country s. Each element x_j^s shows the output of industry j in country s.

An intermediate consumption matrix A^{sr} can be computed by dividing the intermediate delivery matrix Z^{sr} by a diagonalised output vector $\hat{x}^r$ as follows:

$$A^{sr} = Z^{sr}(\hat{x}^r)^{-1} \tag{2}$$

Each element a_{ij}^{sr} of the matrix A^{sr} shows the intermediate inputs from industry i in country s necessary to produce one unit of output in industry j in country r.

Starting from Eq. (1), the standard IO model can be written as follows:

$$x^s = \sum_{r=1}^{n} A^{sr} x^r + \sum_{r=1}^{n} y^{sr}, \tag{3}$$

where x^s is a vector of sectoral outputs in economy s; A^{sr} is a matrix of intermediate consumptions; and y^{sr} is the final demand vector from economy s to r.

Rearranging Eq. (3), we obtain the following expression:

$$x^s = \sum_{t=1}^{n} B^{st} y^{tr}, \tag{4}$$

Table 3 Structure of the energy use MRIO table

Input			Output										
			Intermediate use							Final demand			Output
			Country 1			…	Country n			Country 1	…	Country n	
			Industry 1	…	Industry K	…	Industry 1	…	Industry K	H	…	H	
Intermediate inputs	Country 1	Industry 1	z_{11}^{11}	…	z_{1k}^{11}	…	z_{11}^{1n}	…	z_{1k}^{1n}	y_1^{11}	…	y_1^{1n}	x_1^1
		…	…	…	…	…	…	…	…	…	…	…	…
		Industry k	z_{k1}^{11}	…	z_{kk}^{11}	…	z_{k1}^{1n}	…	z_{kk}^{1n}	y_k^{11}	…	y_k^{1n}	x_k^1
		…	…	…	…	z_{ij}^{sr}	…	…	…	…	y_i^{sr}	…	x_i^s
	Country n	Industry 1	z_{11}^{n1}	…	z_{1k}^{n1}	…	z_{11}^{nn}	…	z_{1k}^{nn}	y_1^{n1}	…	y_1^{nn}	x_1^n
		…	…	…	…	…	…	…	…	…	…	…	…
		Industry k	z_{k1}^{n1}	…	z_{kk}^{n1}	…	z_{k1}^{nn}	…	z_{kk}^{nn}	y_k^{n1}	…	y_k^{nn}	x_k^n
Value added			v_1^1	…	v_k^1	v_j^s	v_1^n	…	v_k^n				
Output			x_1^1	…	x_k^1	x_j^s	x_1^n	…	x_k^n				
Energy use			e_1^1	…	e_k^1	e_j^s	e_1^n	…	e_k^n				

where $B \equiv (\mathrm{I} - A)^{-1}$ is the Leontief inverse matrix. Matrix B^{st} shows the amount of output in a producing country s required for a one-unit increase in the final demand in destination country r.

To obtain the total (direct plus indirect) energy use, we need to compute the direct energy use vectors e^s in the same way as we compute the intermediate consumptions matrix, as follows:

$$(e^s)' = (\varepsilon^s)'(\widehat{x})^{-1}. \tag{5}$$

where ε^s is a vector of direct energy use in country s. Each element e^s_j of vector e^s shows the direct energy use per unit of output in industry j of country s.

The total energy use (E^{sr}) of country s from country r can be obtained by pre-multiplying Eq. (4) by the direct energy consumption vector as follows:

$$E^{sr} = \sum_{t=1}^{n} (e^s)' B^{st} y^{tr}. \tag{6}$$

The Leontief inverse matrix B can be decomposed into two matrices: B^d, which represents the domestic sectoral relationships; and B^w which accounts for the sectoral relationships with the rest of the world.

$$B = B^d + B^w. \tag{7}$$

The final demand Y can also be decomposed into two matrices: Y^d, which represents the domestic final demand; and Y^w which represents the final demand from the rest of the world.

$$Y = Y^d + Y^w \tag{8}$$

Using these two decompositions, we can rewrite Eq. (6) as follows:

$$E^{sr}_{0j} = e^{0s}_{0j} \times B^{sr}_{ij} \times Y^{sr}_{i0}. \tag{9}$$

If we use the decomposition of energy use associated to final demand, we obtain the following expression:

$$E^d_i = E^{dd}_{i0} + E^{dw}_{i0} + E^{wd}_{i0} + E^{ww}_{i0} \tag{10}$$

The first term E^{dd}_{i0} represents the domestic use of energy produced domestically. The second term E^{dw}_{i0} captures the domestic use of energy produced abroad. The third term E^{wd}_{i0} represents the foreign use of energy produced domestically. Finally, the fourth term E^{ww}_{i0} comprises the foreign use of energy produced abroad. Each of the four terms of Eq. (11) can be obtained as follows:

Firstly, the total energy used and produced domestically:

$$E^{dd} = \sum_{j=1}^{n} (e_j \times B^d_{ij} \times Y^d_i) \tag{11}$$

Secondly, the total energy used domestically but produced abroad:

$$E^{dw} = \sum_{j=1}^{n} (e_j \times B_{ij}^{w} \times Y_i^{d}) \tag{12}$$

Thirdly, the total energy used abroad but produced domestically:

$$E^{wd} = \sum_{j=1}^{n} \left(e_j \times B_{ij}^{d} \times Y_i^{w} \right) \tag{13}$$

Finally, the total energy used and produced abroad:

$$E^{ww} = \sum_{j=1}^{n} (e_j \times B_{ij}^{w} \times Y_i^{w}) \tag{14}$$

4 Results and discussion

4.1 Direct use, indirect use and total energy intensity

Before entering into the analysis of the four components of the energy use of our model, we examine the evolution of total energy use over the period 1995–2015 by taking into account both direct and indirect use. Figure 1 shows a comparison of the evolution of total direct and indirect energy use measured both in TJ and in intensity terms (that is, as a share of final demand).

It can be observed that most of the total energy used is indirect. Again, the country that shows the highest growth in total energy use over the period 1995–2015 was Spain: total energy use grew by 28%, the pace of growth being faster for indirect energy use than for direct energy use. The growth rates experienced by total energy use in the Czech Republic and Hungary were similar (around 4–5%) while in Italy there was a slight decline of -1.5%.

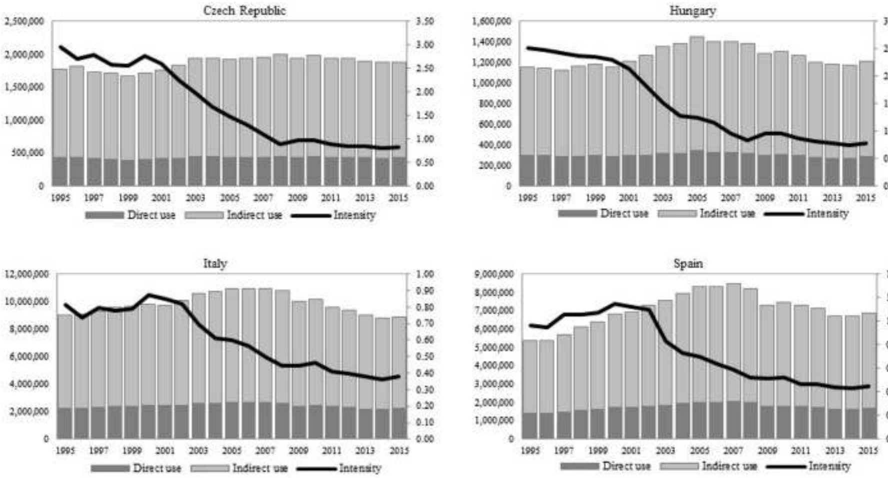

Fig. 1 Direct and indirect energy use and total energy intensity in the Czech Republic, Hungary, Italy and Spain, 1995–2015

If we want to compare energy intensities across the four countries, it is necessary to take into consideration the growth experienced by total final demand. Thus, if we divide total energy use by total final demand, we can obtain a proxy of the energy intensity of the production system of each country. As shown in Fig. 1, all countries reduced their energy intensity during the years examined. The reductions were particularly remarkable in the Czech Republic and Hungary. In these two countries the diminution in the total energy use per unit of total final demand was of 72% and 68%, respectively. In annual terms, the reduction in energy intensities experienced an annual average rate of 6% and 5%, respectively. Concerning Italy and Spain the reductions in total energy use per unit of final demand were lower. Both countries registered a fall of 53% in the total energy use per unit of final demand, or, put in annual terms, an average annual reduction rate close to 4%. Nonetheless, if we compare the energy intensities across the four countries we can note how, despite its positive evolution, there is still a long way to go in the improvement of energy intensity in the Czech Republic and Hungary. Thus, the production systems of these two countries registered an energy intensity of 0.83 and 0.79 TJ per unit of final demand, respectively, in 2015.In contrast, the total energy use per unit of final demand was substantially lower in Italy and Spain, with figures of 0.38 TJ and 0.48 TJ, respectively, in 2015.

4.2 Direct energy use and its domestic and foreign components

Once examined the evolution of total energy use, we focus on the domestic and foreign origin of the domestic use of energy. Put in a simple way, direct energy use reflects the direct use of energy as intermediate input in the productions processes without taking into consideration intersectoral relationships, that is, the energy embodied in those goods and services that are used as intermediate inputs in the production processes. As noted in the previous section, direct energy use can be decomposed into four terms: energy used and produced domestically (DU-PD), energy used domestically but produced abroad (DU-PA), energy used by foreigners but produced domestically (FU-PD) and energy used by foreigners and produced abroad (FU-PA). Figure 2 reports the evolution of the direct energy use

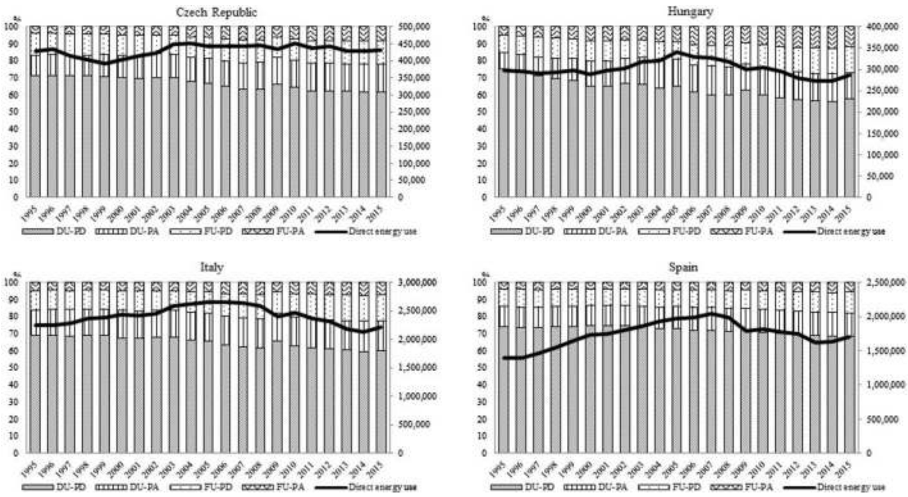

Fig. 2 Direct energy use in the Czech Republic, Hungary, Italy and Spain, 1995–2015

in the four countries under study. It also shows the share of each of the four types of direct energy use described above.

As was expected, direct energy use is closely linked to the economic cycle. The highest growth in direct energy use over the period 1995–2015 was reported by Spain: it registered a growth rate of 22% (from 1,398,168 TJ in 1995 to 1,705,081 TJ in 2015). In contrast, in the rest of countries direct energy use in 2015 was very similar to that registered in 1995. Thus, in the Czech Republic, the direct energy use in 1995 was 430,127 TJ and 431,919 TJ in 2015, in Hungary it was 298,524 TJ in 1995 and 287,475 TJ in 2015 and in Italy it was 2.246.614 TJ in 1995 and 2.215.319 TJ in 2015.

We have to highlight that while the trends in direct energy use are very similar to those shown in Fig. 1 for the total energy use in Spain and Italy, the evolution in the Czech Republic and Hungary are quite different for direct use and for total use. Thus, in the Czech Republic there was an increase higher than 5% in total energy use, while the growth experienced by direct energy use was lower than 0.5%. In the case of Hungary, the differences are more striking: while total energy use increased by 4.6%, direct energy use decreased by 3.7%. These differences are mainly explained by the evolution explained by indirect energy use that experienced a growth rate superior to 7% in both countries.

Concerning the structure of direct energy use, despite the direct energy used and produced domestically accounts for the highest share in direct energy use, it diminishes in all countries over the period 1995–2015. The highest drop is reported by Hungary, where the share of direct energy used and produced domestically fell from 75% in 1995 to 58% in 2015. The Czech Republic and Italy registered the same drop (9 percentage points each) while in Spain the diminution was much more modest, 5 percentage points, being the country with highest share of direct energy used and produced domestically in 2015 (69%).

This fall in the role played by the direct energy used and produced domestically translates into a growth of the role played by foreign production, especially in the case of the Czech Republic and Hungary. Thus, in the Czech Republic the share of direct energy used domestically but produced abroad rose from 12% in 1995 to 16% in 2015. The increase was similar in Hungary, where it rose from 10% in 1995 to 15% in 2015. In Italy and Spain, the increases were lower (2 percentage points in both cases).

Regarding the energy used by foreigners, we can note the existence of differences across the four countries under study. The country with a highest share of direct energy used abroad in 2015 was Hungary, with a share of 27%. The Czech Republic and Italy show the same share, 22%. In contrast, the country with the lowest participation of energy used abroad was Spain, with a share of 18% in 2015. Overall, most of the energy used abroad was produced domestically.

In brief, the analysis of the evolution of the direct energy use reveals the growing importance acquired by foreign production and use.

4.3 Total energy use and its domestic and foreign components

To adequately analyze the evolution of total energy use is necessary to incorporate the indirect energy use, so after examining the evolution of the four components of direct energy use, we turn to decomposition of total energy use. Figure 3 shows the evolution of total energy use distinguishing between the total energy used domestically and the total energy used by foreigners and whether the energy used was produced domestically or abroad.

As was pointed out before, indirect energy use plays a key role in total energy use so some changes can be observed with respect to the conclusions reached when we focus

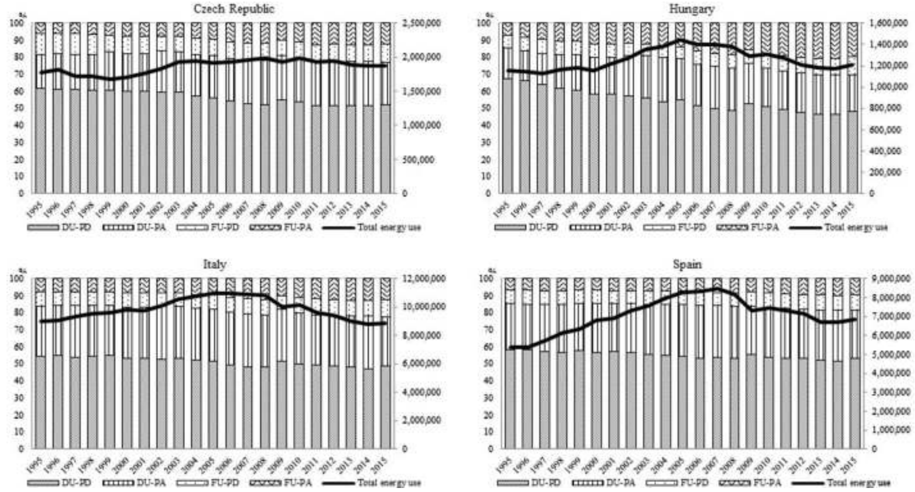

Fig. 3 Total energy use in the Czech Republic, Hungary, Italy and Spain, 1995–2015

on direct energy use. For instance, in the case of the Czech Republic the evolution experienced by the total energy used by foreigners but produced domestically registered a drop over the period 1995–2015, from 212.492 TJ in 1995 to 195.279 TJ in 2015. In terms of participation, this translated into a fall in its share in total energy use from 12 to 10%. In contrast, there was a substantial increase in the domestic use of energy produced abroad, that accounted for 25% of total energy use in the Czech Republic in 2015. In Hungary the main difference is found in the total energy used by foreigners and produced abroad that increased from 82.002 TJ in 1995 to 234.147 TJ in 2015, being the country with the highest participation of this component in its total energy use. While in Spain the evolution of the four components of total energy use was very similar to that shown by these four components in direct energy use, in Italy the major difference is found in the evolution registered by the total energy used domestically but produced abroad, that declined steadily since the 2008 crisis.

In sum, the examination of the evolution of total energy use confirms the existence of different patterns across the four countries examined. While the Czech Republic and Hungary reported modest increases in their total energy use over the period 1995–2015, Spain registered a high growth in total energy use and in Italy there was a slight reduction. However, if we take into consideration the evolution of final demand, we can observe that all countries reduce their energy intensities, especially the Czech Republic and Hungary, although their total energy use per unit of final demand almost doubled the figures for Italy or Spain in 2015. Entering into the distinction between the total energy used domestically and used by foreigners, we can note that, despite most of total energy used is used domestically (82% in Spain, 78% in Italy, 77% in the Czech Republic and 70% in Hungary), a growing share of this energy used domestically is produced abroad. Concerning the total energy used by foreigners, with the sole exception of Spain, most of this energy is produced abroad. These two facts confirm the key role assumed by global value chains.

Table 4 summarizes the main changes in total energy use by country. Changes were classified as “high” when increases in growth rates were superior to 10 percentage point,

Table 4 Main changes in total energy use in the Czech Republic, Hungary, Italy, and Spain, 1995–2015

Country	Reduction in energy intensity	Domestic use		Foreign use	
		Produced domestically	Produced abroad	Produced domestically	Produced abroad
Czech Republic	High	High reduction	Moderate increase	Low reduction	High increase
Hungary	High	High reduction	Moderate increase	Moderate increase	High increase
Italy	Moderate	Moderate reduction	Stagnation	Low increase	Moderate increase
Spain	Moderate	Moderate reduction	Stagnation	Low increase	Low increase

as “moderate” if they were higher than 4 percentage points but lower than 10 percentage points and as “low” if they were lower than 4 percentage points.

There is no doubt that the evolution and changes in energy use in these countries have been affected by certain similarities, that can be associated to the fact that energy use is sensitive to economic cycle and that they belong to the same economic block (the EU), but there were also differences. Overall, changes were greater in Eastern countries than in Southern countries.

5 Conclusions

This paper analyzes the evolution of total energy use in the Czech Republic, Hungary, Italy and Spain over the period 1995–2015 distinguishing between the total energy used domestically and the total energy used by foreigners. In difference with previous studies, we also identify whether the energy used was produced domestically or abroad.

In line with previous works, the results obtained show a certain convergence in energy intensity across the four countries explained, at least partially, by the more radical transformations experienced by the economies of the Czech Republic and Hungary (for instance, over the 2000s the gas sector was privatized in the Czech Republic and Hungary deregulated its electricity market (Markandya et al., 2006; Mussini, 2020)). As a result, despite the four countries reduced their total energy intensity during the years 1995–2015, the pace of reduction was considerably faster in the Eastern countries than in the Southern ones. Taking our decomposition of total energy use, these reductions were mainly caused by a high decrease in the importance of the domestic use of energy produced domestically. Nonetheless, energy intensities are still substantially higher in Eastern than in Southern countries which confirm that Eastern countries have still a long road to go, especially regarding the incentives that their industries have to use energy efficiently.

At the same time, we also observed a growing importance of the role played by the energy produced abroad. In spite of the fact that the domestic use of energy produced abroad grew faster in Eastern countries than in Southern countries. If we compare the share of the total energy used domestically but produced abroad in 2015, we can confirm that Italy and Spain are much more dependent on energy produced abroad than the Czech Republic and Hungary. In addition, in all cases, the foreign total use of energy increased, which confirms the growing importance of global value chains and the steady internalization of energy use.

As mentioned before, this study has limitations. From a methodological point of view, energy conversion efficiencies could be incorporated to the model to deal with secondary energy production. In addition, sectoral disaggregation is very reduced and does not allow to capture the heterogeneity of products within sectoral categories. The use of commodity-by-industries energy models could be useful in this sense (Miller & Blair, 2009). We also have to note that IO matrices in the model do not include personal energy use.

To conclude, we have to highlight that understanding the evolution of total (both direct and indirect) energy use is essential for the formulation of adequate energy policies aimed at achieving the transition to environmentally sustainable energy systems. As the production systems of the different countries are ever more closely intertwined, it could be interesting to apply this methodology to other countries in order to capture the main changes in the total energy use of the production systems. Furthermore, the identification of the most energy intensive user industries across the different countries could help to draw a more accurate picture of sectoral and cross-country interdependencies in energy terms. The results of this methodology could also serve as a starting point for the analysis of energy-related GHG emissions.

Our study offers some policy implications to meet the EU´s energy targets for 2030 and more concretely regarding the objectives and measures included within the integrated national energy and climate plans (NECPs) for the period 2021–2030 that all EU countries are required to elaborate. Among other aspects, NECPs outline how the EU countries intend to address energy efficiency. In the case of the Czech Republic and Hungary, their objectives regarding the reduction in final energy consumption included in their NECPs can be classified as "modest" or "low" and the energy efficiency principle is not explicitly included in neither of the two countries (Ministry of Industry and Trade of the Czech Republic & Ministry of the Environment of the Czech Republic, 2019; Ministry of Innovation & Technology of Hungary, 2019). In contrast, in Italy and Spain energy efficiency targets are ambitious and governments are going to conduct important funding efforts on research into clean energy, doubling public funds (Ministry for Ecological Transition & Demographic Challenge of Spain, 2020; Ministry of Economic Development of Italy et al., 2019). As we pointed out above, energy intensities are notably higher in Eastern countries compared to Southern ones so their governments should take into account this fact and make greater efforts in research and investment in order to achieve energy efficiency levels similar to the rest of EU countries in 2030. Concerning energy security, import dependency is a key variable to take into consideration. In our study we found a rising share of the energy produced abroad as well as a higher dependency from foreign energy in Southern countries. The measures included within the different NECPs reflect only partially this fact. Whereas the Czech Republic plans to reduce its level of dependency at 65% in 2030 and Hungary only partially specifies the measures supporting the reduction of energy dependency, in Italy and Spain the objectives set are very different. Thus, Italy plans to reduce its energy dependency from the current 77.7% to 75.4% in 2030. In contrast, Spain, with a quite similar starting level (74%) plans to reduce its energy dependency to 61% in 2030 (Ministry for Ecological Transition & Demographic Challenge of Spain, 2020; Ministry of Economic Development of Italy et al., 2019; Ministry of Industry and Trade of the Czech Republic & Ministry of the Environment of the Czech Republic, 2019; Ministry of Innovation & Technology of Hungary, 2019). In brief, a balanced commitment of all governments in achieving the EU energy targets by 2030 is essential. For instance, Eastern European countries that are less dependent on foreign energy should raise their efforts regarding energy efficiency and in Southern countries, more dependent on foreign supply, diversification should be a priority.

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