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200 YEARS DIVERSIFYING THE ENERGY MIX? DIVERSIFICATION PATHS OF THE ENERGY BASKETS OF EUROPEAN EARLY COMERS VS. LATECOMERS

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200 years diversifying the energy mix? Diversification paths of the energy baskets of European early comers vs. latecomers

"*No matter how great the resources, nor how complete the knowledge, nor how sophisticated the decision making process, only fools put all their eggs in one basket*".

Old European proverb

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ABSTRACT

The changes in the composition of the energy basket in the long run lead to energy transitions. Primary energy substitution models allow addressing these phenomena. However, the diversification paths of the energy mix of different countries in a long term compared perspective have not been studied yet. This paper proposes an indicator, based on the Herfindahl-Hirschman Index, the Energy Mix Concentration Index (EMCI), to quantify the degree of diversification of the primary energy basket of eight European countries over the last two centuries. The results reveal that early comers, which are large energy consumers, required a huge concentration of their energy basket in the 19th century; however, the observed countries had converged to similar levels of diversification of their energy mixes from the second half of the 20th century, and more crucially after the oil crises. For some countries, today's degree of diversification is the largest in their energy histories, but it is not the case for all of them. Our results suggest that small energy consuming countries would be able to achieve higher diversification, and therefore to do a faster transition to a low carbon economy, than large energy consumers.

KEYWORDS: Energy mix, energy transitions, energy baskets, energy diversification, energy concentration index, Europe.

1 INTRODUCTION

The energy mix is crucial to determine important aspects of energy economics such as the energy efficiency, energy intensity or the carbon intensity of a country. The alterations in the composition of the energy basket in the long run define the concept of energy transition(s). Grübler (2004: 163) proposes a complex definition of energy transitions "in terms of three interdependent characteristics: quantities (growth in amounts of energy harnessed and used), structure (which types of energy forms are harnessed, processed, and delivered to the final consumers as well as where these activities take place), and quality (the energetic and environmental characteristics of the various energy forms used).

The shape and pace of future transitions have been investigated looking at past transitions (Fouquet, 2016; Rosenbloom and Meadowcroft, 2014; Steinmueler, 2013; Fouquet and Pearson, 2012; Rubio and Folchi, 2012; Bennet, 2012; Pearson and Foxon, 2012; Allen, 2012). The diversification of the energy baskets per se has not been studied in the long run. We ignore when (or whether) the energy baskets become more diversified, whether the levels of diversification of the energy mix have converged overtime, whether all countries followed similar paths, and whether diversification of the energy basket took place at the same time everywhere.

There exists a general intuition about the energy baskets becoming more diversified in recent times. This tends to ignore the different traditional forms of energy available in the past (draft power, wind, water, firewood), which allowed a variety of energy mixes with large diversification of sources in previous centuries. The interaction between energy mix and successive energy transitions also requires further investigation.

The energy ladder hypothesis, by which countries move to higher quality energy sources as their income increases, seems to imply a path towards increasing energy mix diversification as countries become richer. Yet it remains unclear whether the energy ladder is a theoretical myth or and empirical truth (van der Kroon et al., 2013). We find different countries' experiences depending, among other things, on their energy endowment (this entails the comparative advantages among the energy sources are different in every country), and the amount of energy consumed.

In addition to addressing these issues in this article, the approach of our research to the evolution of the diversification of energy mix over the long term may be also useful for shedding light into some other crucial questions such as whether it was easier to alter the energy mix in the past or in recent times. In other words, how quickly can an energy mix be altered? Last but not least, shall a country always prefer energy mix diversification to concentration?

A small body of evidence (Rubio and Folchi, 2012; Marcotullio and Schulz, 2007) suggests that countries consuming large amounts of energy behaved differently from small energy consumers in the process of altering their energy baskets –i.e. in their energy transitions. Rubio and Folchi, using Latin American data, showed that small energy consumers had earlier and faster transitions than larger energy consuming countries. Henriques and Sharp (2015) found a quick transition to coal in Denmark, a small consumer too. Following this reasoning, the article starts from the hypothesis that large and small energy consumer's baskets tend to change differently, which in turn will imply that the degree of concentration of the energy mix evolved with different patterns over time depending on the scale of energy consumption.

The importance of a varied energy mix and its evolution is that energy diversification is a driver of energy security. On the contrary, energy mix concentration has become a component of energy vulnerability (the higher the concentration, the greater the vulnerability)[1]. Energy diversity lies in "an evenly balanced reliance on a variety of mutually disparate options" (Stirling, 2010: 1622). The logic behind diversity is "it is better to be exposed to several risks with limited consequences than to one risk where the probability of failure is weak, but that failure has unbearable consequences for the economies" (Llerena and Llerena, 1993: 230). In any case, energy diversification –in its various facets– does not prevent from energy risks to occur, but reduces the social and economic impact in case of risk contingencies and provides alternatives to response in case there is any energy interruption (IEA, 1985: 90), or in the event of a sudden increase in prices (conditioned to fuel substitutability).

All this explains the recommendations to increase the countries' energy diversification (of primary energy sources, suppliers –producer regions– and supply routes[2]), among other strategies, in order to enhance their energy security (just some examples, from Churchill: "Safety and certainty in oil lie in variety and variety alone" (Yergin, 2006), to European institutions: European Commission (2001: 2; and many subsequent documents); European Parliament (2001: 17); and to international energy agencies: IEA (1993)). Energy security is the main benefit of energy diversity, nevertheless there are other potential gains of diversification in terms of competition, innovation (this is a key question when dealing with energy transitions)[3], adapting to different local conditions –cultural, ecological, geopolitical, geophysical…–, and of reconciling conflicting socioeconomic interests (Stirling, 2010). In international contexts of incertitude and ignorance, a systematic response to secure the energy supply should take into account the flexibility, resilience, robustness, stability, modularity and redundancy of the energy system; however, diversification is the most important amongst such approaches (Stirling, 1998: 20).

Nevertheless, diversification is not independent from the previously mentioned properties. In relation to the response capacity of the energy systems, diversity promotes flexibility, robustness, stability, redundancy and resilience since diversification is a way not only to reduce the vulnerability of the countries, but to adapt to and recover from potential shocks. On the other hand, diversity may involve costs and trade-offs such as performance penalty of marginal options, transaction costs, coherence, accountability, standardisation, economies of scale (Stirling, 2010), but also political, social and environmental costs.

In sum, when we deal with energy diversification we are dealing with vulnerability (exposure to energy risks) as well as many other features related to energy security. Diversification strategy might not be the best solution in a static economic analysis (i.e. in terms of costs and economic efficiency), but it is undoubtedly the best option in a dynamic environment. All this makes particularly insightful to analyse the diversification paths of the energy mix of different countries in the long term. In this paper, we show and compare the evolution of the primary energy baskets of eight European countries over the last two centuries, and quantitatively analyse the degree of concentration (versus diversification) of their energy mixes throughout the period.

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[1] For a detailed explanation about energy vulnerability and the difference between physic and economic vulnerability, see Escribano (2008).

[2] These are the most common aspects of energy diversity but, additionally, some other diversity parameters affect the energy security strategies, i.e., technologies, infrastructures, industrial interests, regulatory issues, manufacturers and workforces (Stirling, 2010).

3 Grubb et al. (2006) explore the relationship between the transition to a low carbon energy system (supported by the deployment of renewable technologies) and the diversity and security of the United Kingdom electricity system. For a more detailed explanation about transitions to sustainable energy and source diversity, see Stirling (2008) and Mitchell (2010, chapter 3).

The rest of the paper is organised as follows: the next section explains the data sources and the methodology used, based on concentration measures. The subsequent section focuses on the Energy Mix Concentration Index (EMCI) analysis and the results obtained. The article ends with some concluding remarks.

2 DATA AND METHODS

Some of the longest and more consistent series of primary energy consumption belong to eight European countries, and cover the period 1800-2010, i.e. two centuries. The historical database was developed over the last decade by a number of energy researchers – England and Wales (Warde, 2007), Italy (Malanima, 2006), Netherlands (Gales et al., 2007), Portugal (Henriques, 2011), Spain (Rubio, 2005) and Sweden (Kander, 2002). The results have now been synthesized and the list of countries expanded to include Germany and France in Kander et al. (2014). This makes the database internally coherent, using the same methodologies across countries and energy sources.

The energy data for these eight countries consider the full set of energies –traditional and modern– and refers to primary energy supply. The database includes food for men and working animals, firewood, traditional wind and water used in wheels and mills, and peat, recognised as traditional (also called 'organic') energy sources. Modern energy sources refer to the commercial resources developed after the industrial revolution: mineral coal, petroleum, natural gas and the primary forms of generating electricity –hydroelectricity, nuclear and renewable energies such as wind power, solar, geothermal, etc.

Widening the scope beyond commercial energy sources has proven to make important differences interpreting long term trends on most aspects of the relationships between the economy, the environment and the energy consumption (Bertoni et al., 2009; Bartoletto and Rubio, 2008; Gales et al., 2007; Kander, 2005). That is why this article is restricted to these few countries for which traditional energy consumption has been estimated. Given the importance of traditional energy sources up to well into the 20th century, any attempt to measure the degree of concentration of the energy baskets in the long run without including them will be flawed.

These eight European countries can be grouped into two categories according to their economic and energy use histories. Four of these countries were *early comers*, both by energy standards –with coal as their dominant energy resource along the 19th century– and by their economic histories as advanced nations in the industrial processes: England and Wales, France, Germany and the Netherlands. The other four countries, situated at the European periphery, are often referred to as *latecomers*: both energetically –with firewood dominating their energy baskets until the 20th century– and economically: Italy, Portugal, Spain and Sweden.

In order to answer the questions posed in the introduction, some sort of quantitative index of concentration of the energy baskets is needed[4]. In this field, the simplest measure of concentration is the mix share, that is, the percentage of each energy source in the energy matrix. However, there are some other more sophisticated concentration indicators, so it is worth looking at other disciplines. Some of the deepest research activity on diversity/concentration has taken place in the area of ecology; nevertheless contributions come also from other disciplines in the field of natural and social sciences (such as financial management and energy economics).

[4] As we explained before, concentration is one dimension of energy vulnerability. For a quantitative analysis on other facets of vulnerability, see Marín and Escribano (2008), Gupta (2008), APERC(2007), Alhajji y Williams, (2003). A classification including this (and other) types of energy indicators is provided in Muñoz (2012) and García-Verdugo and Muñoz (2012).

According to the acknowledged research work of Stirling (1998: 39-40; 2010: 1625-26), diversity entails three properties, named *variety*, *balance* and *disparity*:

- *Variety* refers to the number of categories into which the variable in question can be fractioned. The greater the variety of options in a system, the greater the diversity of the system. For our purpose, i.e. the analysis of the energy mix, variety corresponds with the number of different options –energy sources– in a system.
- *Balance* refers to the pattern in the distribution of that variable across the relevant categories (this property is close to the concept of variance). The more equal the portions are, the more even the balance is, and therefore the greater is the system diversity. In our case, balance concerns the share (%) of each source in the energy mix.
- *Disparity* refers to the nature and degree of differentiation among the categories. This is a qualitative and context-dependent facet of diversity and, as such, it is subjective. The more disparate the options comprised in an energy system, the more diverse it is. In the energy mix, disparity is related to the different nature and characteristics of each energy source.

According to this author, the three properties are necessary and independently partial (Stirling, 1998) since they are all "holistic system-level properties" (Stirling, 2010: 1622). However, most of the analysis omits one or two of them. In general, the analyses of diversity of the energy mix tend to focus on balance and variety, since disparity is a qualitative feature of the energy basket. We stick with the dual-concept indicators that consider the balance and variety features. Two major reasons justify this methodological decision and some other considerations deserve a mention.

First, our aim is to study and compare energy transitions. In order to do so, we need to know the energy sources that prevail in a country along the time –number and shares–, not how much disparate they are between them.

In addition, we consider variety and balance are positively related to security of supply, but not always disparity contributes to enhance energy security due to substitutability reasons. Highly disparate energy sources are less likely to be able to be substituted with each other and to achieve economies of scale than similar ones as a result of their diverse origins and required processes. Following Stiling's example (2010: 1626): an electricity supply system equally divided among gas, nuclear, wind and biomass power is more disparate than one evenly distributed among coal, oil and gas. Considering mixed power stations can use different types of fuel (coal, fuel-oil, natural gas), the negative impact to the economy of an interruption in the gas supply would probably be less harmful and the resilience capacity higher in the second system (assuming mixed power stations are operating in that system).

On the other hand, disparity is a multifaceted qualitative characteristic of diversity, what adds more difficulties to the quantitative approach of diversity: first, to identify all different disparity attributes, then to assess their degree of differentiation and finally to weight the attributes according to their relative importance. Undoubtedly, this process requires certain value judgements. Stirling (2010) proposes to use datasets and indicators based on expert interviewees to generate disparity structures (vectors), and "disparity distances" to measure the differences between each pair of elements. Disparity distances arise from the economic and/or sustainability performance of individual energy options. Given the various performance aspects (i.e. financial, operational, environmental, health, social…), the more different performance between energy options (energy sources), the larger distances between them and, therefore, the more disparate options they are. However, depending on the performance data and criterion applied (including the aggregation method), each option will provide different performances and results of the disparity analysis.

Assigning weights to the various dimensions of a composite indicator when aggregating those aspects is controversial, since it introduces an element of subjectivity into the analysis that will affect the outcome. This concern applies to dual concept indexes, such as the ones we will present subsequently (although they embrace implicit weights). But the previous-paragraphs considerations make even more difficult to determine the weights of the three properties in composite indicators of diversity, and of the different attributes in a combined indicator of disparity, in itself.

The second main reason for dismissing disparity in our analysis is that energy sources performances have been changing along the time as energy technologies and societies have been evolving. Distance between pair of options varies as those options performances change. Furthermore, in a very same moment, various countries –with their particular energy systems– will face different performances of their energy mix options depending on their technical, economic and social characteristics (level of technological innovation, resource quality and depletion, operational integration…).

As a result, we omit disparity in our analysis, nevertheless we agree it would be neglectful to omit disparity dimension when dealing with future energy strategies and planning. In that case, it is necessary to take into account all factors, dimensions, properties and agents involved.

In the field of energy economics, the most common concentration/diversity indicators are based on the Herfindahl-Hirschman Index (in ecology, the Simpson Index) and the Shannon-Wiener Index. They are also the "two more prominent 'dual concept' ecological diversity indices" (Stirling, 1998:51)[5].

The Herfindahl-Hirschman Index (HHI)[6] commonly applies to market concentration analysis. It is measured by the sum of the squares of the market shares of each energy source in any given period, which corresponds to the formula:

$$HHI_t = \sum_i^t p_i^2 \qquad [1]$$

where p_i is the energy share of energy source *i*. Smaller values of the HHI indicate greater diversification, with 0 being the minimum concentration and 1 being the maximum concentration (in case the shares are expressed as fractions, where the aggregation of all the portions sum one –i.e. 10% would be considered as 0.1–)[7].

[5] A review of "dual concept" (as well as "mono concept") indexes of non-parametric measures of ecological diversity can be found in Stirling (1998).

[6] The paternity of this index is shared by the economists Orris C. Herfindahl and Albert O. Hirschman. In 1945, Hirschman (in *National Power and the Structure of Foreign Trade*. University of California Press, Berkeley, Los Angeles, London) proposed an index of trade concentration consisting of the square root of the sum of the squares of the market share of each country in the market. For his part, in 1950, Herfindahl (in his doctoral dissertation, *Concentration in the steel industry*, Columbia University) proposed an index for measuring the firms' concentration in the steel industry, which was computed the same as the Hirschman index, but without the square root i.e. the sum of squares of firm sizes, all measured as percentages of total industry size. In Hirschman (1964) he claimed the authorship of the index.

7 Sometimes, the shares are expressed as percentages –i.e. 10% would be considered as 10–. In this case, the maximum concentration would be 10,000.

The Shannon-Wiener Index (SWI) or just Shannon Index[8] is also known as a measure of entropy. It was initially used in the field of information, choice and uncertainty, nevertheless it spread to other areas, such as energy economics. It is expressed as the market share multiplied by the natural logarithm (originally normal log –not Napierian–) of the market share for each fuel in the market summed together.

$$SWI_t = -\sum_i^t p_i \ \ln(p_i \ ) \qquad [2]$$

where ρi represents the proportion of the total mix supplied by fuel i. The minimum value the SWI can produce is zero, which occurs when only one fuel is consumed. This would be the case of maximum concentration in the energy mix. In other words, there would be no diversity of supply. High values imply high diversity, but SWI has no upper limit (since new options would increase the potential values of the SWI).

Although some researchers prefer the SWI as an indicator of energy diversity (van Vliet et al. (2012), Shrestha and Shakya (2012), Bollen (2008), BERR (2008), Costantini et al. (2007), APERC (2007), Jansen et al. (2004), Stirling (1994)), a majority of authors and institutions prefer the HHI, US FERC (2016, 2013, and previous orders and analysis, from 1992 Guidelines[9]), Genc (2016), Gupta (2016), Muñoz et al. (2015), Ben Ammar and Eling (2015), Chernenko (2015), Sällh et al. (2013), Brazilian National Petroleum, Natural Gas and Biofuels Agency (2012, in Quintino and David, 2013), US Department of Justice and FTC (2010), Le Coq and Paltseva (2009), Jun et al. (2009), Gupta (2008), Doane et al. (2008), Frondel and Schmidt (2008), IEA (2007), Chandarasupsang et al. (2006), Fischer (2005), Blyth and Lefevre (2004), Liston-Hayes and Pilkington (2004), Sen (2003), Weston et al. (1999), EIA (1999) and Neff (1997). Some others use both indicators, like van Hove (1993) –and then he chooses the HHI for presenting and analysing his results–, DTI (2005), DECC (2010, and previous reports), Kruyt et al. (2009) and Grubb et al. (2006).

In this article, we use the HHI for several reasons. As we may note, in the field of energy security and energy economics the HHI is more common. Indeed, the IEA (2007: 54) states "HHI is a well-established measure of market concentration commonly used by governments". Therefore, we can update and extend previous works (such as van Hove's cross-country analysis) and/or make comparisons with them.

The main difference between both indicators is the HHI puts relatively more weight on the influence of larger source/partner supplies, while the SWI places more emphasis on smaller source/partner supplies[10]. Since we deal with energy transitions, we focus on the major energy sources in the energy systems. Consequently, we find more appropriate the

[8] The mathematician and electrical engineer Claude Elwood Shannon, known as "the father of information theory", proposed this index in 1948, in his article "*A mathematical theory of communication*" (Bell System Technical Journal*)*. Dr. Shannon gave credit to Norbert Wiener for contributing to the development of basic philosophy and theory of communication theory (Shannon, 1948, 626-627). However, Professor Wiener later remarked that Shannon's initial works on the field of switching and mathematical logic preceded his own interest in this domain, and considered that Shannon deserved "credit for independent development of such fundamental aspects of the theory as the introduction of entropic ideas" (Weaver in Shannon and Weaver, 1964: 3).
Besides this double form of naming the index, many times it is also named as the Shannon-Weaver Index. Professor Warren Weaver joined Shannon's research in late forties and together they published "*The mathematical theory of communication*" (University of Illinois Press). This publication consists of two separate papers, "Recent contributions to the mathematical theory of communication" and "The mathematical theory of communication", by Weaver and Shannon, respectively. The authorship of the full publication is Shannon and Weaver, so we presume when some researchers quote Shannon's index they refer to both authors because both of them deal with this measure, despite the indicator originally comes from Shannon.

[9] Merger Policy Statement, FERC Stats. & Regs. 31,044 at 30,119-20, 30, 128-37.

[10] For a detailed comparison and discussion of advantages and disadvantages of both indicators, see Stirling (1998) page 50 and following.

HHI. In any case, when simultaneously both indicators applied to the same variables, results of both measures are consistent and present similarities (Kruyt, 2009; Grubb et al. 2006; van Hove, 1993).

However, the final reason why we decided to use the HHI is that the potential range of the SWI values increases with the number of market sources/participants, which "undermines the usefulness of the index for comparison across markets/countries" (Le Coq and Paltseva, 2009: 4475). As the UK Department of Trade and Industry (DTI, 2005: 6) and the Department for Business Enterprise and Regulatory Reform (BERR, 2008: 30) remark, the SWI "can be used to see how diversity of a particular market is changing over time. It should not be used to compare different markets with each other". This is an important technical consideration for a cross-country study like the one we perform.

Accordingly, for this paper the concentration of the energy mix in a given year has been calculated using the HHI. For each country, we built a matrix containing the share of each energy source in the total energy consumption of every year from 1800 to 2010 –from mid-19th century in the case of Italy, Portugal and Spain.

3 RESULTS AND DISCUSSION

Applying the Herfindahl-Hirschman Index to the composition of the energy mix we obtain the yearly Energy Mix Concentration Index (EMCI hereafter) over the last two hundred years for these eight European countries. The respective EMCI are plotted in Fig. 1 for England and Wales, France, Germany and the Netherlands and in Fig. 2 for Italy, Portugal, Spain and Sweden. The smaller (larger) the EMCI is, the more diversified (concentrated) the energy mix turns out to be. The vertical lines in each country graph mark the year in which the previous prevalent primary energy source gives way to the next dominant source, which we identify too. The figures also include an intuitive classification between low, medium and high concentration according to the theoretical distribution of the EMCI, with the lower third of the index been classified as low concentration of the energy mix (i.e. high diversification) and the values falling on the upper third corresponding to high concentration of the energy mix (i.e. low diversification).

The countries in Fig. 1 exhibit some common features for the early comers, which turn out to be some of the largest energy consumers in Europe. They made an early transition from firewood to mineral coal, linked to their economic transformation from an agricultural economy to an industrial one. In fact, according to these data England and Wales entered the 19th century with coal already as prevalent energy source. France, Germany and the Netherlands entered the coal era by mid-19th century. For all of them, the transition from firewood to coal implied an increasingly concentrated energy mix, as coal took larger shares of their energy basket in order to feed their growing energy requirements. This is particularly marked in England and Wales and Germany, the leading countries in the continent during the First and Second Industrial Revolutions, respectively. These four early comers remained under coal dominance for over a century.

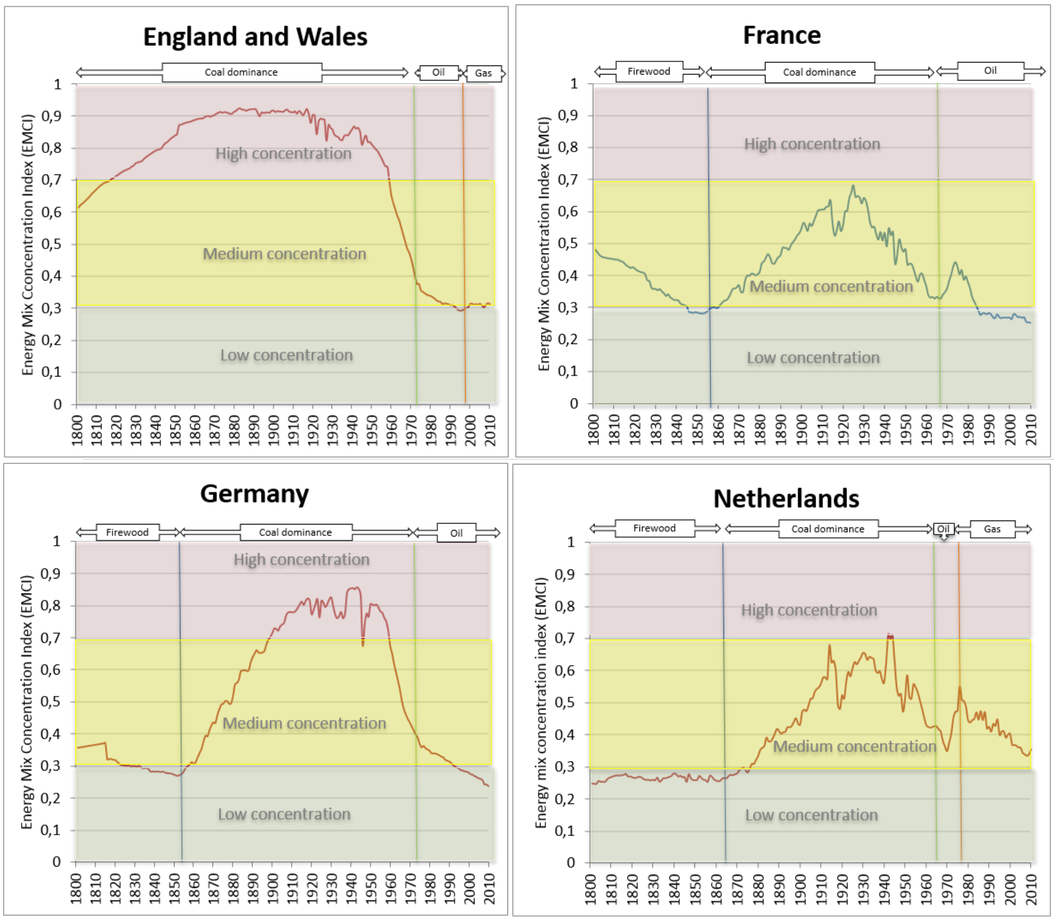

Fig. 1: Energy Mix Concentration Index (EMCI), dominant fuel, and year of transition for 4 European early comers from year 1800 through 2010.

Sources and notes: energy data from Kander et al. (2014), includes pre-modern and modern energy sources (i.e. food for men and working animals, firewood, traditional wind and water used in wheels and mills, peat, mineral coal, petroleum, natural gas and the primary forms of generating electricity–hydroelectricity, nuclear and renewable energies such as wind power, solar, geothermal, etc.). Energy Mix Concentration Index (EMCI) measured by a Herfindahl-Hirschman Index (HHI). The smaller (larger), the more diversified (concentrated) the energy mix. The vertical lines mark the year in which the previous prevalent energy source gives way to the next dominant source.

They also share the dates and effects on diversification of the transition from coal to oil. Petroleum became the prevalent energy source for these four countries between mid-1960s and early 1970s, right before the oil crisis. The entrance and eventual prominence of oil in their energy baskets implied greater diversification of their energy mixes in general terms. For sure, other sources participated in the diversification of the energy mix over the second half of the 20th century –most notably hydroelectricity, nuclear, and natural gas– but the battle between coal and oil as principal energy source prevailed. The shifts in energy consumption patterns and the dominance of one or another fuel are highly conditioned to the countries' energy endowments. It explains the noteworthy concentration of the energy mix of England and Wales and Germany, based on coal. Actually, United Kingdom and Germany have been the two major coal producers in the European continent until 1970[11] (excluding the U.S.S.R. and Russian Federation, which became the greater producer in Eurasia from the second half of the XX century).

[11] Then Germany kept the leading position for two more decades, but Poland reached the second position as the most prominent coal producer in 1971, and then rose to the first one in the nineties.

The period beginning around the first oil crisis opens the oil era, after the coal dominance, but brings some differences across the early comers' energy mixes. While the British Isles and Germany continued to diversify their energy matrixes, France and the Netherlands had a short phase of increasing concentration before exhibiting further diversification that extends to the 21st century. These transitions were driven by revolutionary economic and technological changes, but most of the European countries do not have significant reserves of oil (of the selected countries only the United Kingdom has have a relevant role as an oil producer from late seventies).

A further difference is that in two cases –England and Wales and most notably the Netherlands– endured a further transition where natural gas replaced oil as the prevalent energy source. In fact, the transition to natural gas was relatively fast. In the Netherlands natural gas supplied 50 per cent of total primary energy by 1971, a little bit more than a decade after the discovery of the giant Groningen field in 1959, becoming the major gas producer in the continent until mid-nineties (again excluding the rich U.S.S.R. and Russian Federation). For its part, the United Kingdom has been at the top of the gas production in Europe (together with Norway and the Netherlands) from mid-seventies until now.

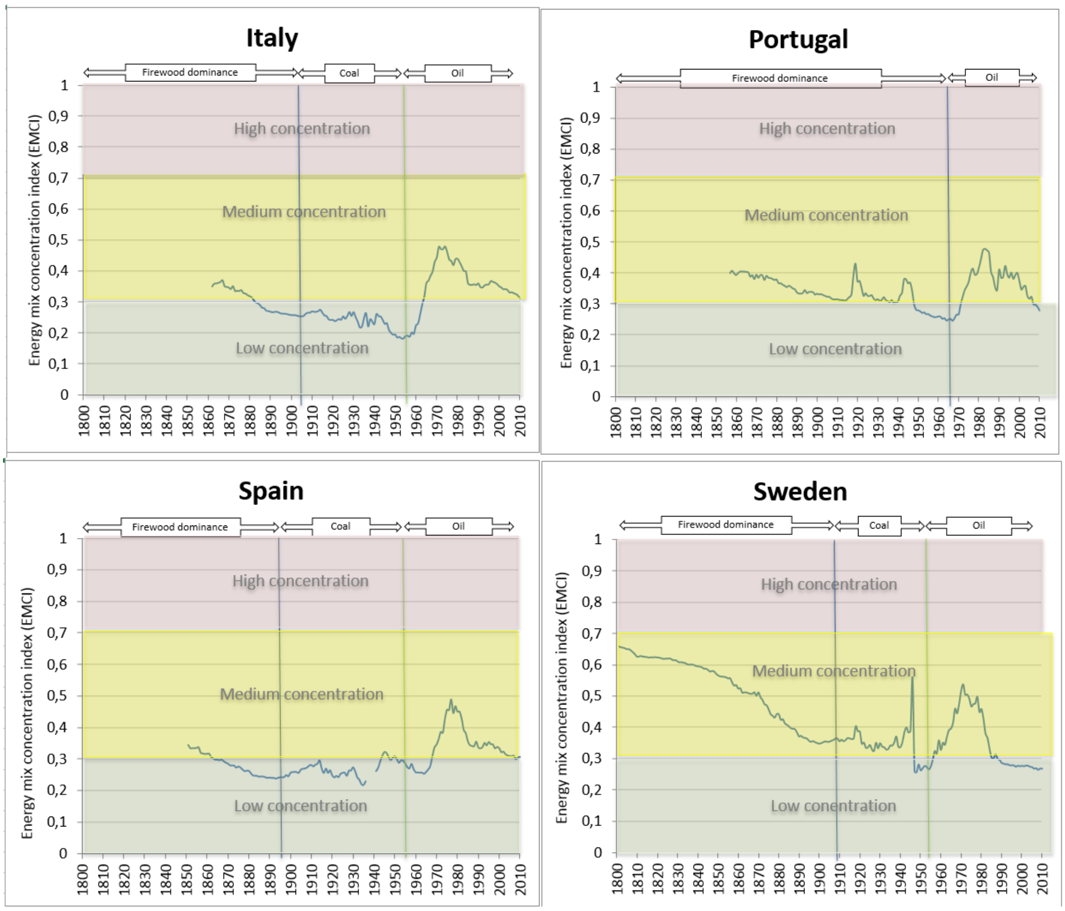

Fig. 2: Energy Mix Concentration Index (EMCI), dominant fuel, and year of transition for 4 European latecomers from the 1850s to 2010.

Sources and notes: Ibídem.

The latecomer group of European peripheral countries in Fig. 2 share some features of their own. They arrived some 50 years later than the early comer group to the coal era, but by the beginning of the 20th century peripheral Europe had made their transition to coal.

Exception made of Portugal, the poorest country of the lot, which took much longer to abandon firewood as predominant fuel and leapfrogged straight into oil by the mid-sixties. Coal never dominated the Portuguese energy basket. For the rest of peripheral Europe, coal reigned over the first half of the 20th century but around the mid-1950s (Portugal by mid-1960s) oil became the major energy source.

The transition from firewood to coal implied a larger diversification their energy baskets – a smaller EMCI– while the oil supremacy that began in the 1960s conveyed an increasing concentration of their energy mixes, reaching maximum EMCI levels in between the oil crises of 1973 and 1979. In any case, none of these countries reaches high concentration indices along the full period. On the contrary, they show medium and low concentration of their energy baskets, and particularly low in the Mediterranean countries until the sixties and now again in recent times. The events of the 1970s made evident the need for diversification away from oil, and the four countries pursued energy mix diversification strategies. Sweden diversified faster its mix than the Mediterranean countries, although all countries tended to converge towards similar levels at the end of the century.

Besides the obvious classification criteria –latecomers' transit to modern energy sources happened some half a century later than early comer's transition– the differences in the evolution of both groups are striking. Latecomers endured much shorter coal dominance (some 50 years versus over a century of the early comers). Latecomers also shifted earlier to oil as predominant energy source –with the exception of Portugal, over a decade earlier– probably due to their scant coal resources. On the other hand, none of the latecomers initiated the transition to the natural gas age yet.

Furthermore, these results show very different diversification paths of the energy baskets of European early comers versus latecomers. The early comers achieved the maximum level of concentration during their coal era somewhere on the first half of the 20th century. The latecomers reached the maximum concentration of their energy baskets in the early days of the oil dominance, right about the oil crisis of 1973. These two maximums are not only distant in time and predominant fuel, but also differ in their magnitude. Early comers maximum EMCI almost doubles the maximum EMCI of latecomers. In other words, early comers endured much more concentrated energy baskets than latecomers would ever do.

Table 1: Average level of energy consumption, energy consumption per capita and Energy Mix Concentration Index (EMCI) of European early comers vs latecomers 1870-2010 (selected periods)

	Total average energy consumption (PJ)		**Total average energy consumption per capita (GJ per habitant)**		**Average EMCI**	
	Early comers	*Latecomers*	*Early comers*	*Latecomers*	*Early comers*	*Latecomers*
1870-1913	9,336	1,300	74.8	21.7	0.73	0.29
1920-1938	14,663	1,956	95.8	25.7	0.77	0.25
1950-1973	23,029	5,215	128.1	52.7	0.54	0.29
1980-2010	31,144	12,700	151.1	109.5	0.27	0.31

Sources and notes: Ibídem. Weighted average over each of the periods. Early comers refer to the average of England and Wales, Germany, France and the Netherlands. Latecomers refer to Italy, Portugal, Spain and Sweden.

As Table 1 reflects, the path of the two groups also varies. Taking the long-term perspective, the early comers followed a path of increasing diversification, achieving by 2010 their most diversified energy basket of the past two hundred years –except for the Netherlands. This is not the case for the latecomers –except Sweden– who enjoyed much more diversified energy mixed in the past. Thus, the early comers reduced the concentration level of their energy mixes by 63% from the first period to the most recent one, while the latecomers remain more or less the same moderate levels, on average.

Taking into account the size of the countries in energy terms, the level of concentration/diversification reacted differently to new technologies in large and small energy consumers [12]. While coal adoption contributed to increase the energy mix concentration of the large energy consumers (England and Wales, Germany, France and the Netherlands) during the19th century and the early years of the 20th century, the diffusion of coal did actually imply a larger diversification of the energy basket of the smaller consumers (Italy, Portugal, Spain and Sweden). The arrival of oil predominance over the 1950s and 1960s also implied opposite results for the diversification of the energy mixes. Oil predominance had the effect of increasing concentration of the energy basket of the small consumers, but reducing the level concentration of the energy basket of the large energy consumers. Towards the end, however, when the levels of energy consumption per capita levelled out, the concentration index of both groups also equalised in the frontier between low and medium concentration of the energy mix.

4 CONCLUSIONS

We find that countries had converged to similar levels of diversification of their energy mixes only from the second half of the 20th century and more crucially after the oil crises of the 1970s–that is, only for the last quarter of the period under consideration. However, the path towards today's level of diversification of the energy mix diverged over the past 200 years. While the early comers came from above (increasing their diversification levels during the coal era) latecomers –which tended to be also smaller energy consumers– enjoyed historically lower levels of concentration in their energy mixes. Thus, the process of reducing the energy mix concentration has been much more intense in the early comers. For some countries –all the early comers but the Netherlands, and Sweden–, today's degree of diversification is the largest in their energy histories but it is not the case for all of them –the three other latecomers.

We also find that the alteration of the energy basket took far more time in the 19th century for the early comers, producing a longer coal dominance era (about one century) and far higher concentration levels than the energy baskets of the latecomers (versus half a century and much lower EMCI).

Finally, the question about size remains part of the explanation behind the differences observed: consuming large amounts of energy in the 19th century required a huge concentration of the energy basket on coal consumption. Smaller consumers could get by

[12] Germany, France and United Kingdom are the three top countries with highest primary energy consumption in Europe (excluding the Russian Federation, which would be the first one of the ranking if we include it). However, in the two last decades the Netherlands is behind Italy and Spain. These two last countries would not be considered as small consuming countries in recent times in general international comparisons, but the group of the latecomers represent small consuming countries in comparison to the selected early comers for most of the time we are covering in our research, even though they have increased their demand and have become important consumers nowadays.

with a variety of pre-modern sources to add to a modest consumption of coal. Moreover, when the latecomers required larger amounts of energy by the mid-20th century the array of available energy technologies had widen considerably.

Rubio and Folchi and Marcotulio and Sulzt advanced that large and small energy consumer –i.e. developed and underdeveloped countries– may not behave likewise in terms of their energy transitions. The evidence we present here points in the same direction: size matters at the time of altering the level of concentration of the energy mix –it was more difficult for large consumer than for small consumers to achieve diversification. This has to do with the strong inertia of some energy systems that have well-established infrastructures on both the supply and demand sides, and powerful political support due to the tremendous wealth associated with the sale of those fuels. It was the case of coal in the 19th century, or oil and nuclear in the 20th centuries. Energy related capital (from energy generating, distributing to energy consuming capital) tend to be long-term investments with long amortization periods. The more vested capital related to energy the larger the energy consumption. Small energy consumers have the advantage conferred by minimum pre-existing investment and the opportunity of leapfrogging in the energy ladder (as shown by the Portuguese case above).

Would diversification be the definitive trend in the future? Is it desirable above all things? Imagine we could get hold on a Nikola Tesla's type of ubiquitous, unlimited and free energy present in the ether around us. Then it would make sense to switch to it swiftly, giving up lower quality, limited and more expensive energies, and concentrate as much as possible on this new free/renewable/safe/clean energy. In such scenario, and in general, in any other energy transition, our results suggest that small energy consuming countries will be able to do faster transitions than large energy consumers. All in all, economic and energy transformations are speeding up, and it is presumable that the next energy transitions will be much faster in all cases (e.g. the shift form oil dominance era to natural gas in the Netherlands and England and Wales).

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