[1]Energy Supply Security in the EU: Benchmarking Diversity and Dependence of Primary Energy

Konstantinos J. Chalvatzis and Alexis Ioannidis

[1] Norwich Business School, University of East Anglia, Norwich, UK

[2] Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK

Highlights

- Paradigm shift from dependence to diversity emerging throughout the EU
- EU primary energy supply dependence rising to 58%, mainly driven by transport fuels
- EU primary energy supply diversity improved by 14.2% (SWI) and 22.6% (HHI)
- Small countries and islands have high dependence of 96% and low diversity of 0.48.

Abstract

We evaluate energy supply security in all the EU countries. For the first time a proxy indicators for diversity and concentration Shannon Wiener index and Herfindahl-Hirschman index and dependence metrics are used for the detailed primary energy fuel mix of all EU member states. The geographic coverage of this work allows for useful comparisons between countries and for a means of benchmarking against the indices. Overall, it is found that energy supply diversity in the EU has been significantly improved since 1990 by 14.2% (SWI) and 22.6% (HHI). We demonstrate the interrelations between dependence and diversity and the role of renewables on dependence and diversity. Renewable energy, particularly wind, solar and biomass has been the main driver for diversity growth and has a positive contribution to indigenous energy use; thus reducing energy import dependence. We argue that alongside renewable energy there exists a wide range of factors contributing to energy dependence and that renewable energy has had a positive contribution to almost all EU28 country's diversity.

Keywords

Energy security; diversity; dependence; primary energy; benchmarking; EU

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1. Introduction

1.1 Background on Energy Supply Security

Access to energy is one of the most important aspects of the well-being and sustainable development of modern societies [1]. Mainstream commodities cannot be produced, delivered or used without the use of energy. In that context, the role of energy is directly linked to the economic, social and environmental development of a country [2].

The global energy system faces several distinct governance and policy challenges. World energy demand is expected to grow by 45% between 2015 and 2030, and by more than 300% by the end of the century, necessitating a tripling for infrastructure investment [3]. These figures illustrate the significant growth on energy demand globally and in particular within the existing European energy market. The depletion of fossil fuel reserves and the increasing demand for clean, affordable and secure energy are issues considered under the umbrella of energy security which is therefore an important aspect of a country's economy [4].

The scope of energy supply security can be challenging to define [5]. The definition of energy supply security given by Grubb et al. (2006) [6] and the formal definition of the International Energy Agency (2016) could be summarized as "*affordable price that does not disrupt the economy is a presupposition for a secure energy supply"* [7,8]. The term has evolved from the previous simplified approach which was based just on resource availability, to a new paradigm that takes into account international trade and competitive markets [9,10]. Political stability, market liberalization, foreign affairs and environmental concerns are concepts that are strongly linked to the new reality of energy supply security [11]. In the case of less developed countries energy security is defined as the access to modern energy services [12] but the rise of industrial consumption is emerging economies should not be disregarded [13].

1.2 The case study of E.U

Energy supply security is complex mainly because of its impacts on every aspect of economic activity and its sensitivity to a wide range of uncertainties [14]. The concept benefits from increased attention in the recent years and is considered a priority issue in the European Union and Member States' agenda [15]. Rising demand, increased import dependence of European countries, geopolitical tensions along with the structural change of commodity markets from regional to global and the need of proper regulatory response gave significant importance to the multi-dimensional term of Energy Security [16].

The objective of the EU to transit to a low carbon sustainable economy premediates a reduction in fossil fuels use, both at industrial and household level. In line with COP 21 (Paris 2015) EU set a 40%

reduction target in emissions compared to 1990 and advocated a binding target of 27% in energy efficiency savings [17]. This emissions reduction required sweeping changes in the ways energy is produced and used, therefore challenging the availability and accessibility of energy resources impacting on the overall energy system resilience [18].

Challenges such as energy resources scarcity, global warming and commodity price fluctuations set the agenda for what is known as the "Energy Trilemma" [19]. The EU, a global leader in emissions reduction, suffers from a chronic lack of indigenous energy resources which results in higher energy prices and an anaemic recovery from the 2008 financial crisis. At the same time, technological innovations with the potential to disrupt the energy supply and consumption landscape emerge with electric mobility [20], energy storage [21,22], and demand-side management joining large scale deployment of renewable energy sources.

Latest European Commission studies show that the EU imports more than half (53%) of its energy with a particularly high import dependence on crude oil and natural gas [17]. In addition to the high level of dependence on certain energy products the majority of European countries are locked in their reliance on a single supplier [23]. This dependence leaves them vulnerable to energy supply disruptions. The recent incident of 2014 dispute between Russia and the transit country Ukraine left many EU countries with severe gas shortages and propelled energy security back to the top of the EU's policy agenda. To respond to the uncertainty caused after Russian actions in Ukraine, global warming and commodity price fluctuations, a series of measures has been initiated with the "Communication from the Commission to the European Parliament and the Council: European energy security strategy" [15] with little progress.

Most of the existing literature on energy sector resilience and sustainability establishes a quantitative or theoretical assessment framework [24,25]. Constantin et al. (2007) [26] in their analysis of the import dependence of European nations, used dependence and vulnerability indicators to build scenarios based on different degrees of supply concentration and diversity indices, focusing only on oil and natural gas. Grubb et al. (2006) [6] considered fuel mix diversity in the electricity sector as a strategy against interruption of supply. This study along with most other studies, do not consider any economic or political aspect that might involve price volatility. Sovacool et al. (2011) [27] and Kruyt et al. (2009) [28], proposed composite indices applied on OECD countries, using mainly indicators focusing on oil and fossil fuels. More recent studies provide some indicators of the current energy import dependence and diversity situation [29] but the majority are based on a brief snapshot using a single diversity approach relying on fossil fuels and they do not suggest a benchmark of the diversity indices used.

The lack of benchmarking in resilience metrics has been previously identified by Hickey et al (2010) [30] who mentioned that there is no particular range that would indicate satisfactory or insufficient fuel diversity. While no mathematically driven response exists to this issue, we address it by evaluating energy security metrics for all the EU countries. Our contribution is in providing a real range of values, as it exists in the EU countries, which represent a rich variety of fuel mixes. The adopted approach is straight-forward and novel. It is straight- forward because we use the most established concepts to assess supply security; dependence and diversity. Both are estimated with indices that were previously used in the energy security literature and our approach focuses on the primary energy supply; therefore, covering all sectors. The novelty of this work is in offering a workable, real-world range of values for energy security indices that provide an overview of the comparative energy supply security of EU countries and most importantly to facilitate benchmarking for any country.

2. Methodology

Diversity and dependence present two different paradigms of energy supply security [30] and alongside other propositions [24,27,28], present a straight-forward approach to resource supply security evaluation. It can be argued that dependence has given way to diversity as the dominant security paradigm and that the latter is indeed more fitting for an increasingly interconnected world [10]. A country's import portfolio is evaluated based on the variety of suppliers and balance in the volume of the commodities imported from each supplier in respect to the country's fuel mix. For this research the two most widely used indices Shannon-Wiener [32–34] and Herfindahl-Hirschmann [6,30] are evaluated alongside import dependence metrics. All primary fuel options are taken into consideration, as an extension of previous research that has considered specific fuels such as oil and gas or focused on the power sector [28,35,36].

Each fuel represents an option for HHI and SWI. There is no absolute guidance over the appropriate fuel mix diversity (as measured by SWI) or concentration (as measured by HHI). Hickey et al. (2010) acknowledge that one of the main disadvantages of using the Shannon–Wiener Index in energy supply diversity appraisal is that there is no "explicit range of values that would indicate excessive or insufficient fuel diversity" [30]. The fact that there are no particular thresholds providing a clear benchmarking direction has been previously identified as a general weakness of diversity indices [37], which are beyond doubt useful for comparative purposes.

For this research, time series data were sourced from IEA [38] for 65 products which were classified in 11 categories based on fuel type. For homogeneity purposes the data were converted in TJ using IEA conversion factors [39] where appropriate. The latest available data is for 2013 and for certain islands for 2012. For comparison Eurostat import dependence data [23] were also plotted to highlight certain issues with import dependence. The main difference is that IEA accounts "international marine bunkers" and "aviation bunkers" as export fuels not consumed within the country, on the calculation of primary energy supply, although they are imported. Thus, it provides larger import dependence compared to Eurostat [29], where "international marine bunkers" are not included in the equation and there are no estimates of "aviation bunkers". Besides this energy accounting issue, the most recent Eurostat data provide information for 2014 which is more recent than IEA, making it a preferable database for this manuscript. However, the Eurostat breakdown of energy products does not allow for a detailed diversity analysis which is why we have used IEA data for diversity and both IEA and Eurostat data for dependence.

2.1 Import Dependence

Import dependence metrics can be considered as the most commonly used paradigm for calculating security of supply especially when it refers to particular fossil fuels such as oil, gas and coal [28,35,36]. It can provide a simple indicator of supply dependence; however, it is considered more useful in markets with perfect competition [28] which is not the case here especially when accessing energy supply security [40].

Hence:

$$Energy\ Import\ Dependence = \frac{Net\ Imports}{Primary\ Energy\ Supply}$$

for which

Net Imports= Total Imports - Total Exports

The calculations were made for each product separately to allow for better evaluation of our findings. In that manner, we could cover circumstances where a country might produce an adequate certain level of a fuel but import a sub-product of the same fuel due to issues relevant industrial capacity (e.g. lack of downstream industry) or short-term shortages especially during winter times where demand for energy is higher.

2.2 Diversity Indices

2.2.1 Shannon–Wiener Index:

The index is widely used in a variety of contexts such as statistical mechanics, information in cybernetics, entropy in thermodynamics, economics [41] and in disciplines of ecology and genetics to evaluate diversity in specific genomes and species populations [14]. It was introduced in energy supply security by Stirling (1994) [32] to evaluate the diversity of UK electricity supply sector.

For n number of energy sources (options) available in the energy fuel mix portfolio the Shannon–Wiener Index (SWI) is:

$$SWI = -\sum_{i=1}^{n} S_i \times ln(S_i)$$

Where:

n is the number of options

S_i is the proportional reliance on the i^{th} option.

ln is the natural logarithm.

For the calculation of the SWI, each primary energy source available in the fuel mix represents one option. Each option is added as the percentile of the calculated number. For example, if an option accounts for 10% of the total energy mix then it will be treated as 0.10 in the index.

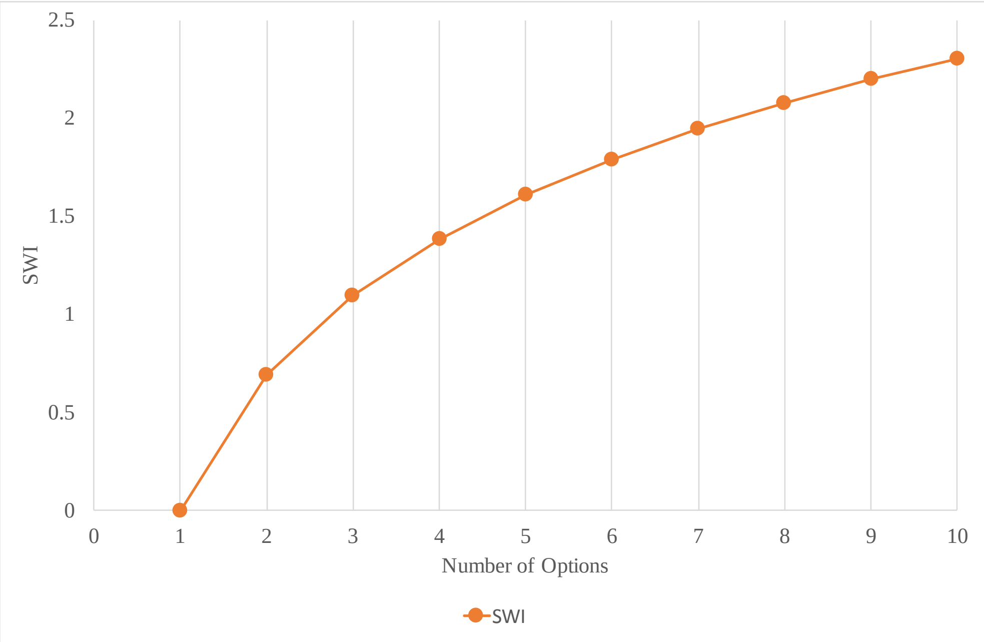

Figure 1: *SWI for equal contribution options as number of options grows.*

As Figure 1 shows, the minimum value that the index can take is zero when the system relies on one option. Since the number of options n>=1 then SWI cannot be negative. A system with two equally weighted options will have a diversity of 0.69 (2dp) and so on. The index increases with the number of options but the increase rate declines gradually. Grubb et al. (2006) [6] in an attempt to provide benchmarking for Shannon-Wiener index, indicated that a SWI value below 1 shows a less diverse system relying on 2 or 3 options, where energy supply is more vulnerable to any possible destructions and a value above 2 indicates a system with multiple options, more secure to interruptions of particular supply components. The diversity is used based on the assumption that each different option is independent from each other.

2.2.2 Herfindahl–Hirschman Index:

HHI is an index used in competition economics to measure the concentration, instead of the diversity, of the individual market share of the participants. The higher the HHI, the higher the concertation so the less diverse is the system examined. Its origin is in ecology where it is known as "Simpson Index" [14]. It is used by the US Federal Trade Commission for the assessment of likely competitive effects of horizontal mergers [10,42].

For n number of energy sources (options), available in the energy fuel mix portfolio, the Herfindahl-Hirschman Index (HHI) is:

HHI=$-\sum_{i=1}^{n} S_i^2$

Where:

n is the number of options

S_i is the proportion of option i expressed as a percentage.

The HHI index is calculated by summing the squares of the share of each primary fuel in the corresponding fuel mix. For example, an option contributing 30% of the total will be treated as "30" and in the index calculation "30" will be squared.

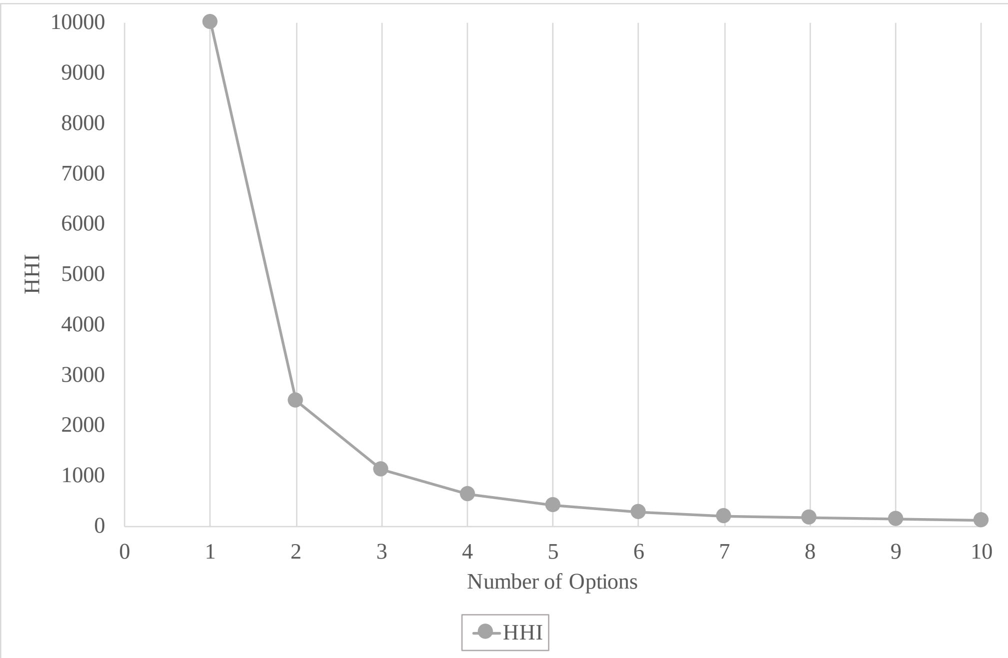

Figure 2: *HHI for equal contribution options as number of options grows.*

As Figure 2 illustrates, the minimum value HHI can take is approaching 0 when the system relies on infinite options; in economic terms that implies perfect competition. A system with two equal options will have an index of 2,500 and so on. The index takes its maximum value when there is only one option available and this is 10,000. This connotes that the index ranges between 0<HHI<=10,000. A suggestion from the US Department of Justice sets the benchmark of 1,500 for a competitive marketplace and 2,500 for a highly concentrated one [43]. Additionally, it illustrates that transactions that may disrupt HHI by more than 200 points in highly concentrated markets are more likely to increase market power. Similarly, with the SWI index, the assumption that each different option is independent from each other is necessary.

2.3. Different Indices and Development of a Benchmark Range

Although both diversity and import dependence indices are widely used for estimating energy supply security most of the literature rules out one of them to be the "best" index to examine the energy supply security of a country. Stirling (1998) [41] favours SWI since he finds that HHI disrupts the concepts of variety and balance. On the other hand, Cohen et al (2011) points out that SWI gives greater impact on the contribution of options and HHI on the number of options [44]. Le Coq and Paltseva (2009) favour HHI for EU energy security on the basis that the EU countries have less diverse energy portfolios and HHI is better suited to capture those risks [45].

Grubb et al (2006) for the first time used both indices to forecast the role of renewable energy in electricity supply security in the UK [6]. Taking a step further Chalvatzis and Rubel (2015) [14] examined China's electricity portfolio using both methods for a wider range of historical data. Both argued that the parallel use of the indices provides a way to discount diversity uncertainties and the results of the two indices are consistent (Figure 3). The correlation for equally contributing options is -0.85 where the large correlation value provides evidence of the two indices' consistency and the negative sign indicates their opposite nature, since HHI measures concertation and SWI diversity.

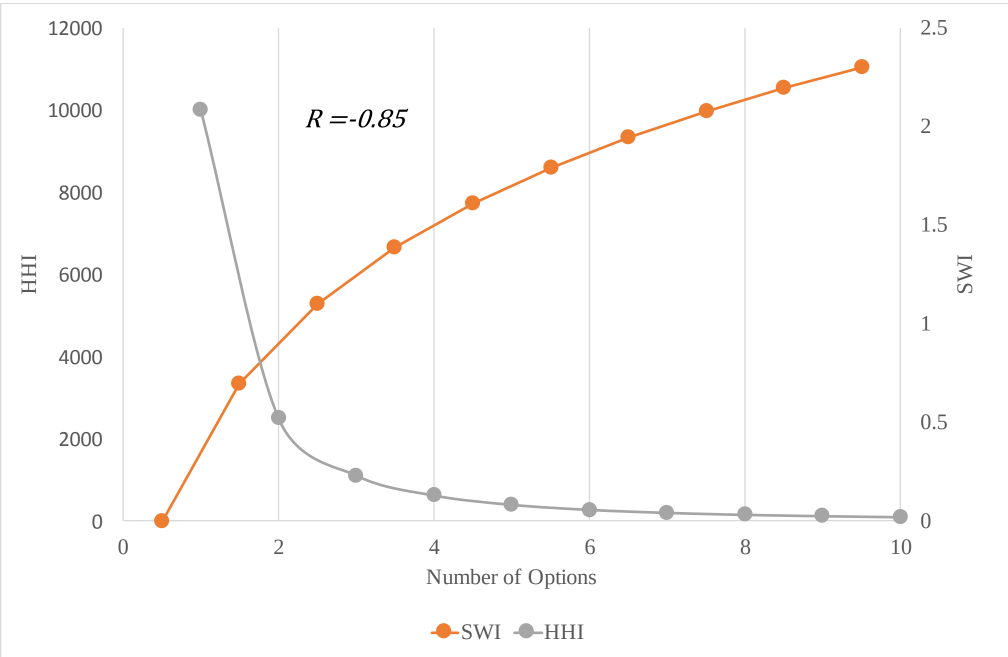

Figure 3: *HHI and SWI for equal contribution options as number of options grows.*

3. Results

3.1 Primary Energy Sources Dependence

European Union member states follow a similar path during the last half century; importing more than 50% of their primary energy fuels since 1990 with 18 individual countries being locked in that trajectory. It is estimated [15] that the EU imports more than half of its consumed energy and around 50% of its current primary energy mix is based on crude oil and coal.

It is important to have a look at the EU total primary energy supply and the average contribution of each country since 1990 in order to gain a better understanding of the trajectories leading to recent results. Germany, France and the UK are the countries with the highest contribution to the EU's import dependence (Figure 4). On the other hand, Malta, Cyprus and Luxemburg are the countries with almost negligible contribution. Not surprisingly, Germany, France and the UK are also the countries with the largest population and GDP in the EU. Almost 47.28% of the EU's total primary energy supply is used by these countries; hence they play a catalytic role in the composition of EU weighted average metrics.

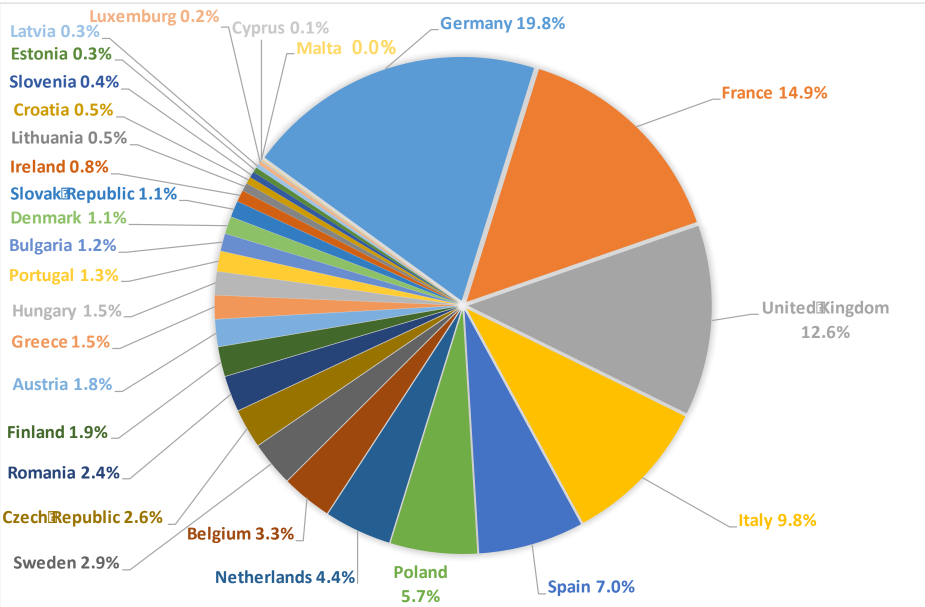

Figure 4: *Average primary energy supply contribution in EU between 1990-2013. Data Source: IEA*

Energy dependence is estimated with Eurostat (Figure 5a and Figure 6a) and IEA (Figure 5b and Figure 6b) data. As previously mentioned the main difference between the calculations of the import dependence via the two different data sources is that IEA accounts "international marine bunkers" and "aviation bunkers" as export fuels not consumed within the country on the calculation of primary energy supply, although they are imported. Thus, it provides larger import dependence compared to Eurostat

[29], where “International marine bunkers” are not included in the equation and there are no estimates of “aviation bunkers”.

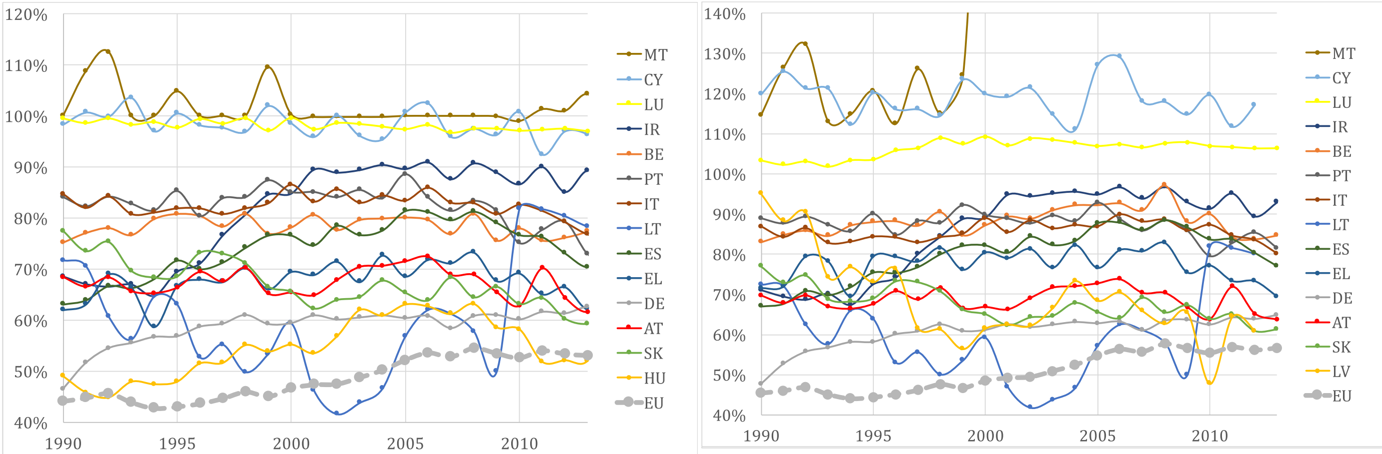

Figure 5: *Import dependence for countries categorized in higher dependence group. Data Source: (a) 1990-2014, Eurostat; (b) 1990-2013, IEA.*

With the EU average benchmark for import dependence hovering at approximately 55% in the most recent years, it is clear that more EU countries are above it than below it. It is reminded that the benchmark line occurs as the weighted average for the EU; hence it considers each country’s individual contribution in the primary energy supply and its dependence. On the higher import dependence group, we can find the five crisis-hit countries and smaller countries such as Malta, Cyprus and Luxemburg. Malta and Cyprus present a dependence much higher than 100%, mainly because of their role as international trade centres for re-exporting energy products and the fact that they have not yet integrated renewable energy within their energy systems [46]. In the case of Luxemburg excess values come from its large aviation sector which accounts for 9.42 % of its total primary energy supply.

It is noteworthy that all EU crisis hit countries’ (Portugal, Italy, Greece and Spain) import dependence appears to decrease since 2009 [47]. This is explained by a shrinkage of energy consumption linked to reduced economic activity. This in turn, led to the abandonment of expensive imported energy resources. At the same time, growth of renewable energy production facilitated use of indigenous resources and reduced imports further. The lowest increase in renewables production is observed in Ireland with 28% and 11% decrease in the country’s import dependence since 2008. Ireland is the most import dependent country in this category exceeding 80% consistently during the last 40 years. It is essential to notice the significant gap between the primary energy import dependence of the examined countries. Greece presents the lowest dependence while Ireland is the most import-dependent country of that group. One more issue that becomes evident is that Italy and Portugal have always had an almost constant degree of dependence, which during the financial crisis they have started reducing. However, Greece, Spain and even more Ireland have experienced a strong growth of import dependence between 1995 and 2005.

Latvia has the biggest improvement since 1990, reducing its dependence by 34% in 2012 according to IEA data and by 48% according to Eurostat data. In line with the effects of the 2008 financial crisis the country's energy needs fell by 8.2% in 2009, in relation to 2007, with import dependence remaining constant. A significant increase in exports, mainly sourcing from biofuels and oil products, the same period, resulted in a reduction of import dependence in 2010.

For the period of 2010-2011 along with economic recovery, import dependence seems to have gradually increased mainly because of the increasing import quantities of oil and natural gas fuels by 8.3% and 35.9% respectively. In addition, total primary energy supply was reduced by 9.1% contributing to import dependence increase of 16%. However, the forthcoming year's hydro production increase covered a fair amount of the increased imports quantities reducing natural gas imports and keeping oil imports at a constant level.

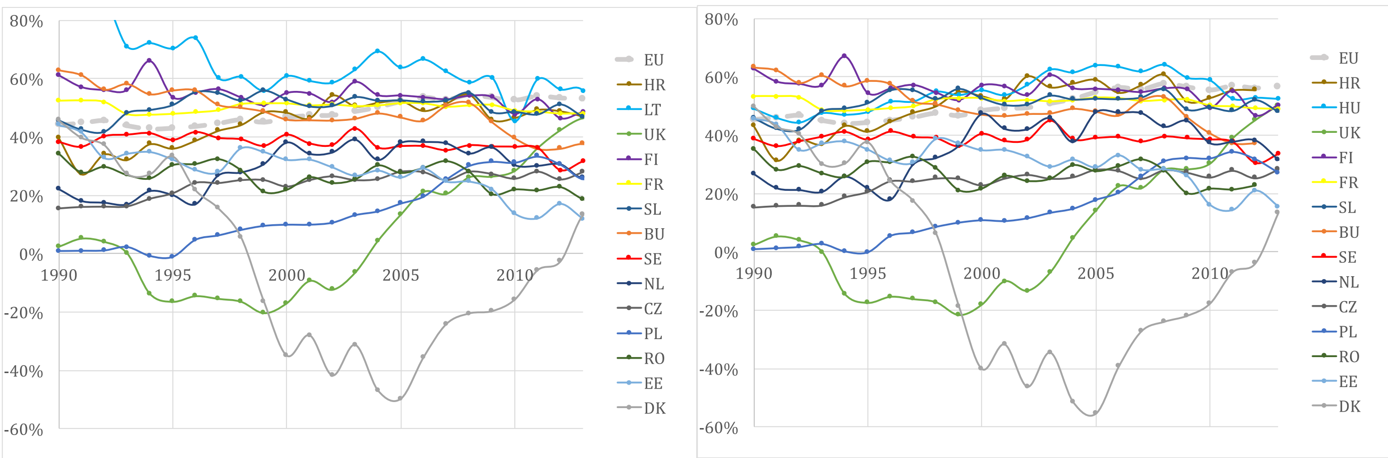

Figure 6: *Import dependence for countries categorized in lower dependence group. Data Source: (a) 1990-2014, Eurostat; (b) 1990-2013, IEA.*

The EU average import dependence has increased by 8% since 2002. Most of this growth has been accumulated between 2002 and 2010 and since 2010 the average has been hovering at approximately 55%. This increase comes along with a significant increase of 68% of the UK's dependence since 2001, which from a net exporter, has become a net importer of 50% of its total energy demand. The UK accounts for 12.14% on average of the total primary energy supply of the EU since 2001; therefore, it has a significant impact. UK dependence might be just 6% below the EU average in 2013 but there is a trend to reach and even overcome EU benchmark if we consider that the corresponding difference was 67% back in 1999. The UK has been slow to escape a fossil fuel based energy mix accounting for more than 80% of its primary energy supply. The highest level of renewable energy reached in 2013, accounts for 5.06% of the primary energy supply with the majority sourcing from offshore wind and biomass energy.

Likewise, Denmark has experienced a significant increase (59%) since 2000; however, since Denmark accounts for only 1.1% of the EU primary energy supply, the impact on the EU import dependence is negligible. North Sea declined production affected both the UK and Denmark. Moreover, Denmark has invested heavily in renewable energy sources to mitigate the effects of indigenous fossil fuels scarcity [48]. Since 2000, a reduction of 16.6% of fossil fuels has been substituted by a corresponding 15.87% growth of renewables, mainly wind and biofuels. Denmark has 13 incentives in force supporting the renewable energy sector with particular focus on wind energy making it one of the leading countries in renewable energy generation [49].

4. Energy Supply Diversity

The paradigm of energy independence for supply security is gradually downgraded with the elimination of resource nationalism, the depletion of high quality indigenous resources and the emergence of international competition. Import dependence is only one aspect of energy supply security. In order to develop pathways to a sustainable, decarbonized energy future, diversity of energy resources is, at least, equally important [50]. The EU has adopted a long-term strategic approach prioritizing energy diversity within the context of climate change mitigation policies in an attempt to reduce its reliance on expensive and environmentally damaging fossil fuels [51,52]. Two indices are being used to measure diversity and concentration respectively as described extensively in Section (2).

Before discussing the specific results, it is important to mention that while countries use a variety of energy resources to meet their needs, the vast majority of their imported energy is oil and gas. When countries rely heavily on coal that is because they can meet most of their demand with indigenous coal resources. Likewise, for EU countries oil has been the main imported fuel, followed by gas.

In visualising diversity results the 28 countries were split between those with lower diversity (Figures 7 and 8) and those with higher diversity (Figures 10 and 11) as measured by SWI. In keeping with HHI, the countries with higher concentration are plotted separately (Figure 9) from the countries with lower concentration (Figure 12). As previously discussed in the methodology both SWI and HHI are sensitive to the number of energy supply options which can show disproportionately improved diversity even when several of the options have only small contribution. This is the case frequently with new renewable energy sources [30]. Normally, all options, even those with negligible contribution, are used to plot the results. However, to acknowledge this issue and to provide a means to mitigate it, specifically in the case of SWI, additional figures are provided with the index results plotted only for options contributing at least 5% (Figures 8 and 11). Moreover, it is clarified that the split between high and low diversity (low and high concentration) is based on the EU average benchmark for 2013.

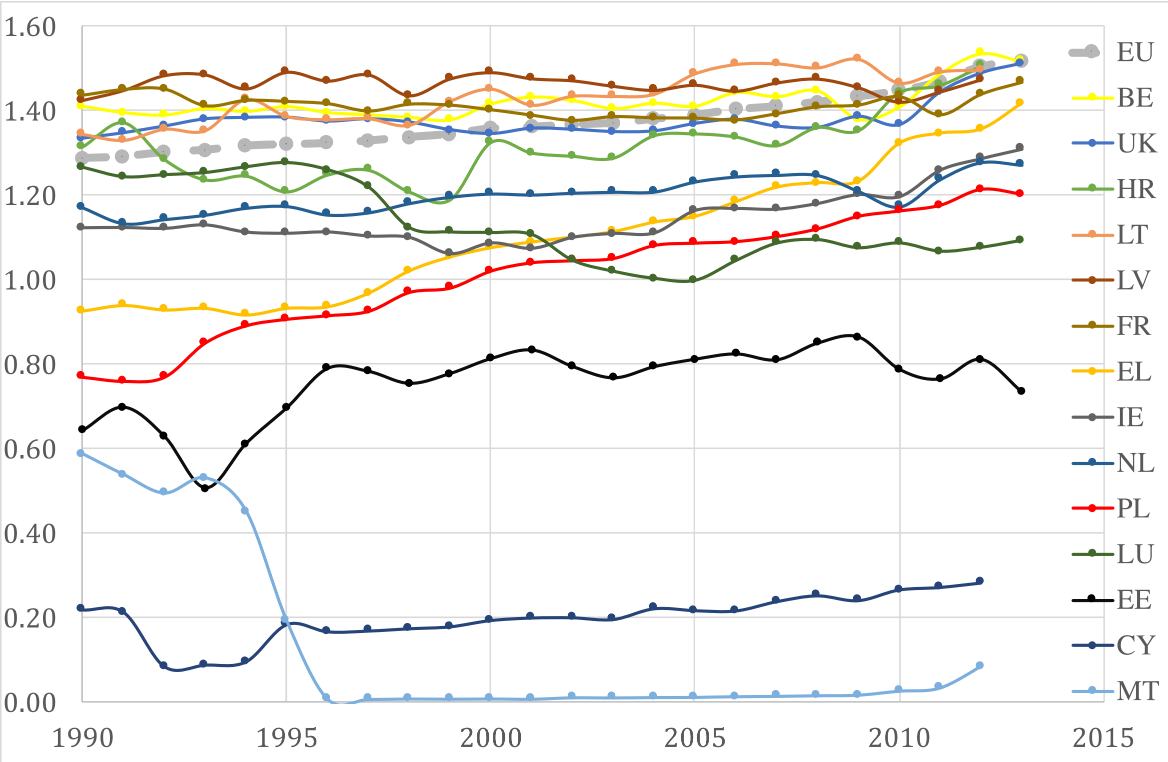

Figure 7: *Primary energy supply diversity, measured with SWI for all fuel options contributing at countries belonging on the lower diversity group between 1990-2013. Data Source: IEA.*

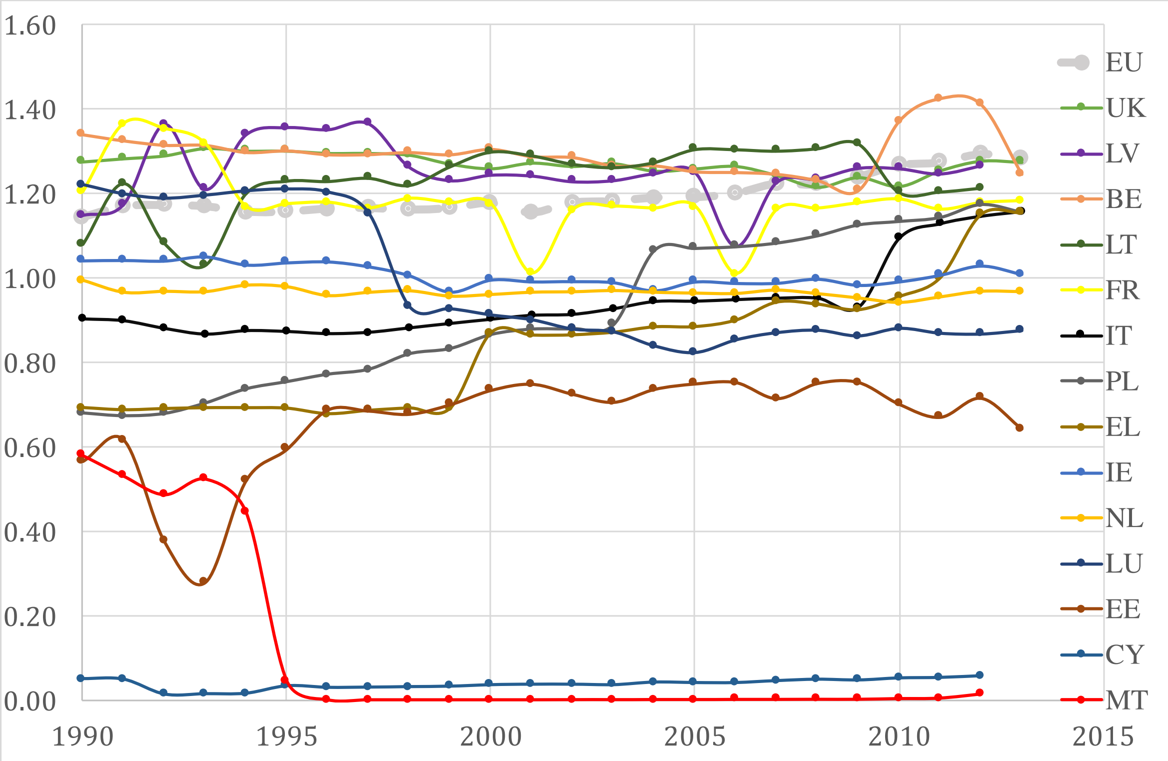

Figure 8: *Primary energy supply diversity, measured with SWI for options contributing more than 5% at countries belonging on the lower diversity group between 1990-2013. Data Source: IEA.*

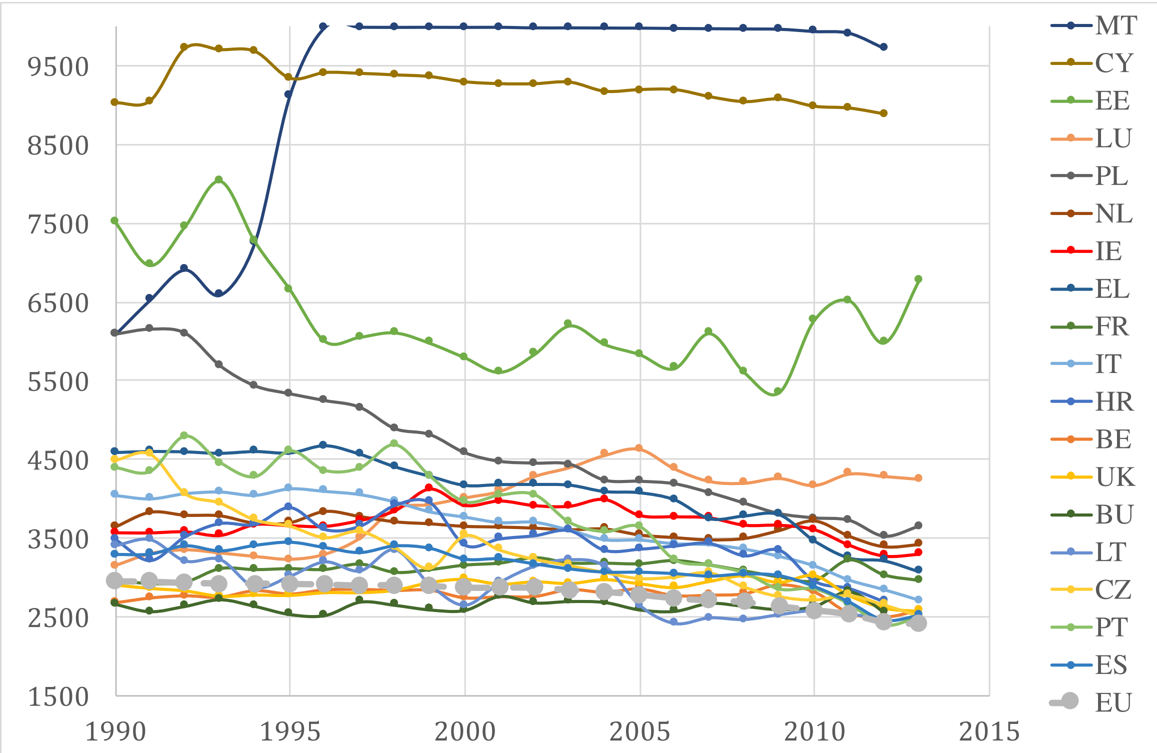

Figure 9: *Primary energy supply concentration, measured with HHI for all fuel options at countries belonging at the higher concentration group between 1990-2013. Data Source: IEA.*

The EU significantly improved its diversity with an increase of SWI by 14.2% and decrease of HHI by 22.6% since 1990. This improvement accelerated after 2002 along with the increase in oil prices and the wider use of renewable energy sources by all member states. However, this growing trend is stronger when all options are included (Figures 7 and 9) and weaker when only >5% options are included (Figure 8). This indicates that a large proportion of diversity growth relies on underdeveloped options and more specifically renewable sources of energy which play a small role in national fuel mix. This discrepancy on the benchmark line should not take away from the fact that diversity is improving across the EU. In fact, the aforementioned <5% renewable energy options have a growing trend which will result in significantly more robust diversity improvements in the next few years. The main drivers for diversity growth have been reduction in transport fuel use and increase in renewable energy sources. Those trends help balance the total fuel mix and increase the diversity metrics.

Cyprus, Malta, Estonia and Luxemburg are the counties with the least diverse fuel mix. These countries share similar characteristics such as small total primary energy supply, small population and land area, compared to the rest of EU countries. Moreover, there is no evidence that the primary energy diversity of these countries converges with that of the rest of the EU. It is also important to note that the total average contribution of these four countries to the EU total primary energy supply is 0.72%, meaning that their low diversity does not affect the total picture of EU supply diversity.

France, as the country with the second largest primary energy supply and third largest economy of the EU, has a relatively low diversity. France accounts for 14.8% of the EU's total primary energy supply for the last 26 years. Its primary energy supply relies mainly on nuclear energy, as it has an enormous net capacity of 63,130 MWe, six times larger than that of Germany, which is the second largest [53]. There is no significant improvement in France's diversity, over time. In fact, diversity gets worse until 2006 and then is improved until it reaches the same level with 1990. Improvement from 2006 onward is linked to increase in renewable energy sources particularly biofuels and waste energy and a substantial decrease of crude oil and petroleum products (Figure 12). However, France's heavy reliance on nuclear energy is a source of vulnerability for the EU electricity market as it has been evidenced after the recent unplanned closure of EDF's several reactors for inspection and maintenance [54].

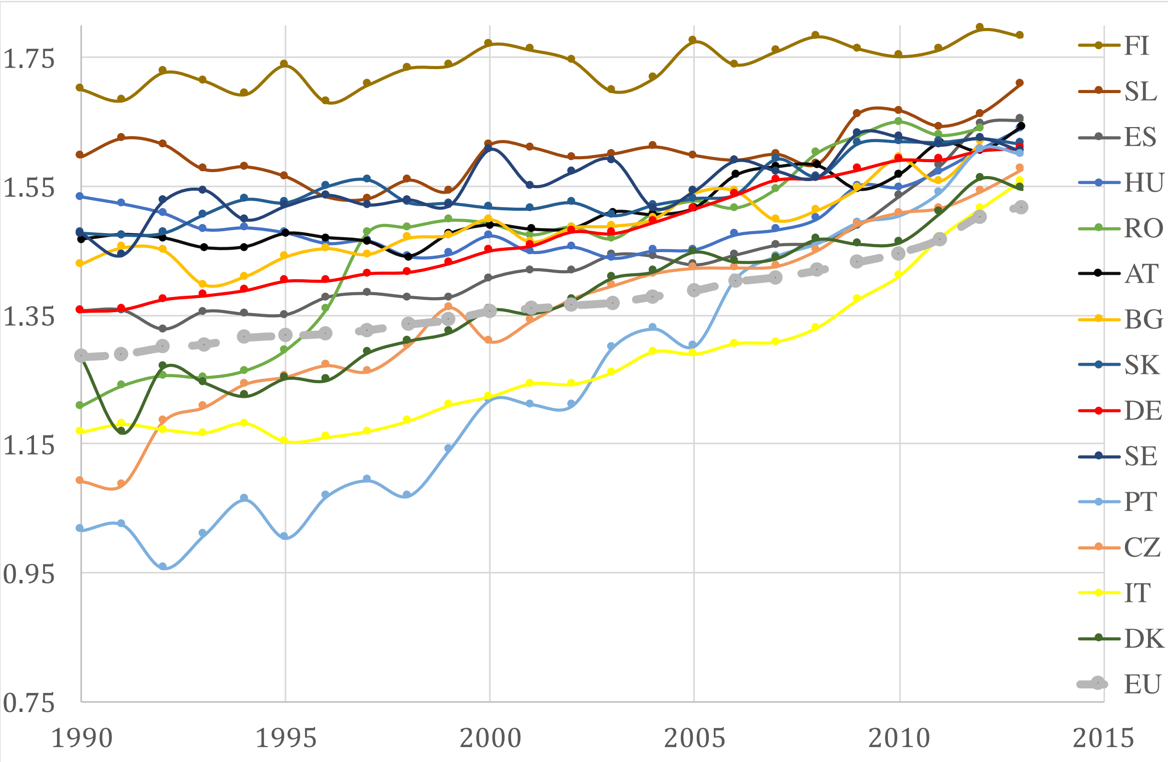

Figure 10: *Primary energy supply diversity, measured with SWI for all fuel options at countries belonging on the higher diversity group between 1990-2013. Data Source: IEA.*

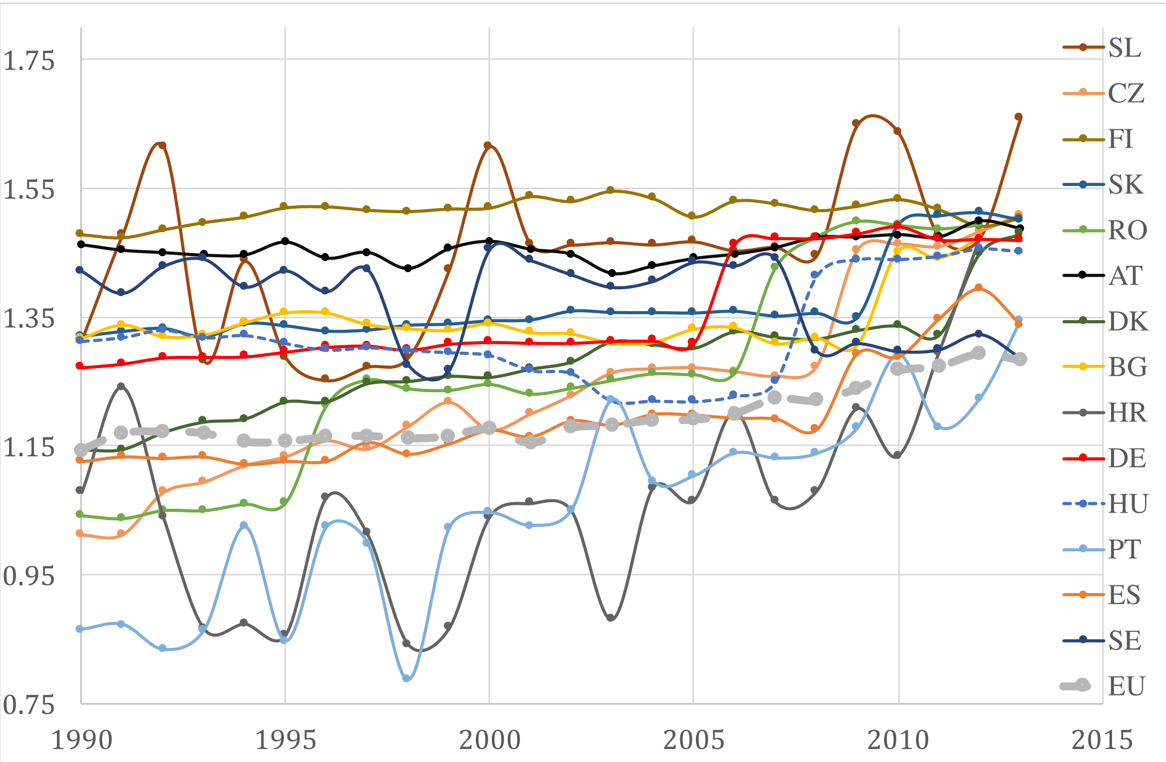

Figure 11: *Primary energy supply diversity, measured with SWI for fuel options contributing more than 5% at countries belonging on the higher diversity group between 1990-2013. Data Source: IEA.*

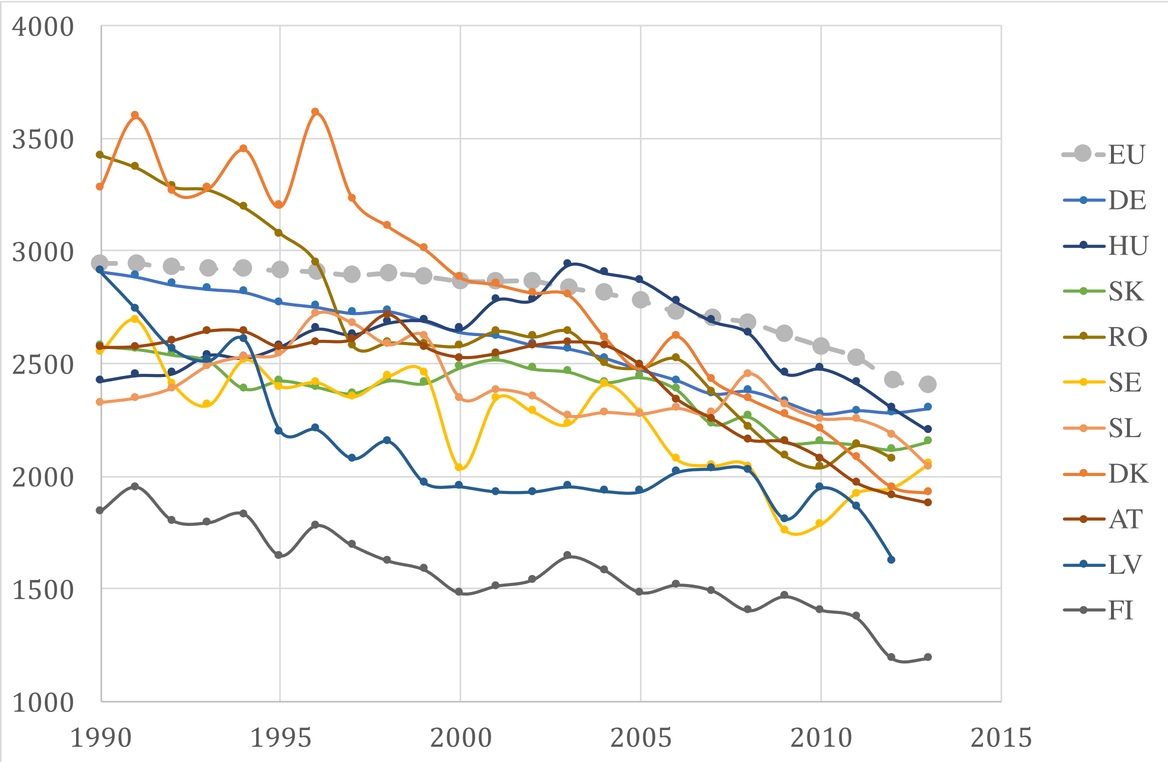

Figure 12: *Primary energy supply concentration, measured with HHI for all fuel options at countries belonging on the lower concentration group between 1990-2013. Data Source: IEA.*

The Scandinavian countries are in the higher diversity range group (Figures 10 and 12). In Finland, coal and petroleum products supply has been below 50% since 1998, following a declining path which reached its lowest level of 37.8% in 2013. The rest of the country's primary energy supply is met with nine different options out of the 11 sub-categories we have used, since 2013. As SWI provides great sensitivity on the number of options, we can see that the corresponding diversity drastically decreases when we do not include options with contribution lower than 5%. Significantly, biofuels and waste are the leading primary energy source in Finland since 2012, followed by crude and petroleum products and nuclear. Sweden's diversity follows a more stable pattern with low reliance on fossil fuels, constantly below 35% and high reliance on nuclear energy accounting on average 35.36% since 1990. Germany, which accounts for 19.81% of the EU total primary energy supply, has increased its diversity by 18% since 1990. Although big part of the electricity generated is sourced from renewables, Germany is locked in expensive and environmentally damaging fossil fuels. More than 80% of the country's primary energy supply is provided by fossil fuels.

5. Discussion

As previously mentioned there is a paradigm shift from a focus on dependence to a new focus on diversity. However, growth in indigenous renewable energy sources is responsible for dependence improvements alongside diversity improvements and not instead of them. Using 2012 as a snapshot, we have plotted diversity (as SWI for all options) against dependence for all countries (Figure 13). Acknowledging that a combination of high diversity and low dependence warrants the most secure approach, countries at the upper left corner (Denmark, Romania, Sweden and Czech Republic) are better placed to respond to potential perturbations of their energy supply systems. On the contrary, countries placed at the lower right corner (Malta, Cyprus and Luxemburg), experience the highest exposure to a less diverse and predominantly imported fuel mix.

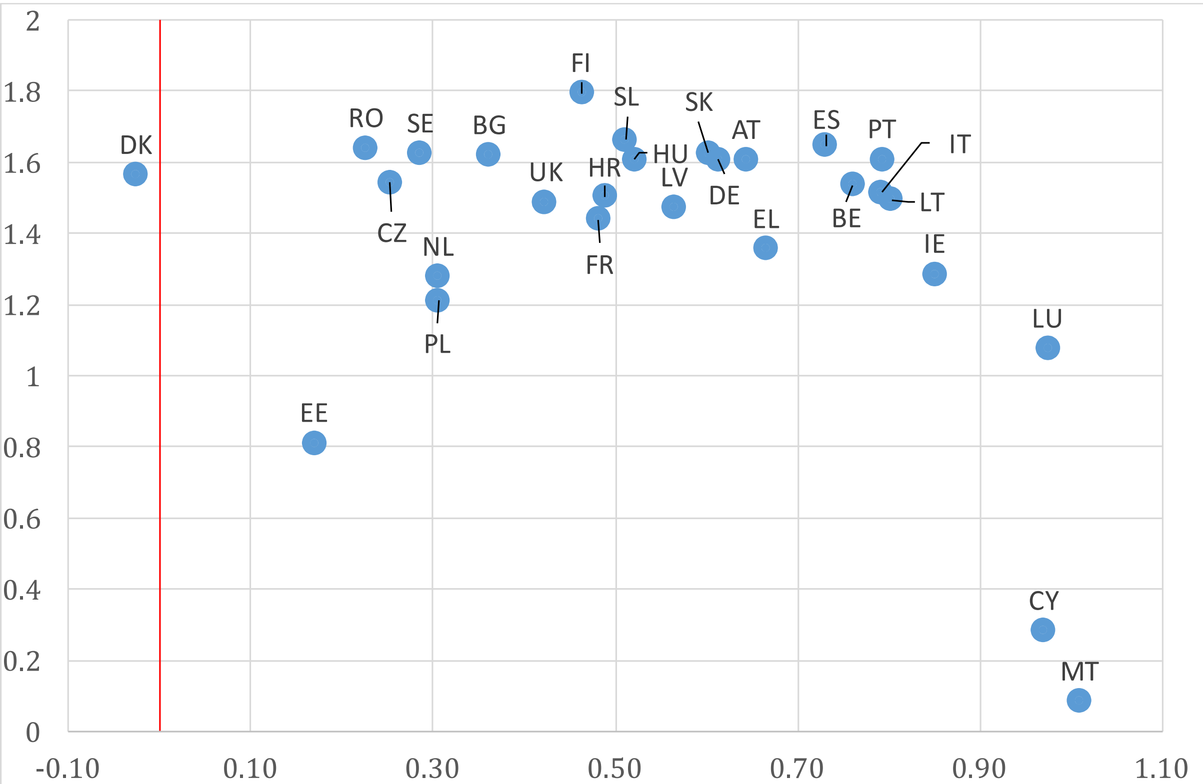

Figure 13*: Import dependence (horizontal axis) against primary energy supply diversity (vertical axis), measured with SWI for all fuel option at 2012. Data Source: IEA.*

Renewable energy is often how countries achieve simultaneous improvements in their fuel mix diversity and energy import dependence. However, not all countries that introduce renewable energy in their fuel mix experience a reduction in their energy import dependence which is why we have explored this issue further. The first observation in Figure 14 is that all countries have increased renewable energy sources in their fuel mix. By doing so, some countries such as Denmark, Sweden, Latvia and Estonia have reduced their import dependence (upper left corner). At the same time countries at the right side have increased their import dependence despite increasing renewable energy use.

These observations do not invalidate that growth in renewable energy contributes to reduction in energy import dependence assuming it concerns indigenous renewable energy resources (and not imported biomass). Nevertheless, this issue must be contextualised in the complicated mix of parameters that influence import dependence. Firstly, in the period of the study renewable energy contributes only to the electricity sector which feeds substantially into other sectors but less so in the transport sector. Considering that oil and gas are the main imported fuels in across all EU countries growth in private vehicle ownership and increased demand for oil derivatives could lead to increased dependence. Secondly, some countries have experienced a production decline of their indigenous oil, gas and coal reserves during the study period. This may have been a result of reserve depletion such as the case of North Sea oil and gas, that has affected the UK, or it might have been a case of abandoning coal use to mitigate climate change. Therefore, it is important to clarify that although renewable energy has an impact on dependence it is one of the factors contributing to the energy dependence level of the examined countries.

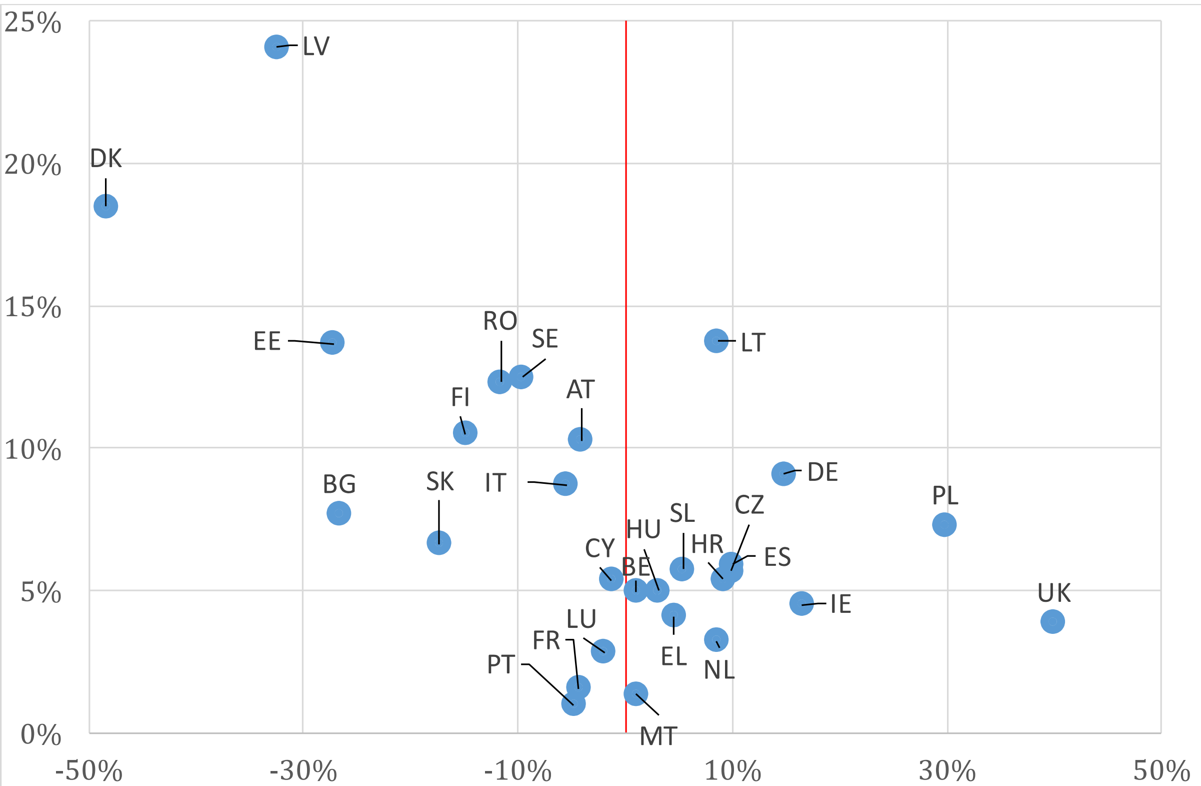

Figure 14: *Import dependence difference (horizontal axis) against growth in renewable energy use (vertical axis) for 1990-2012. Data Source: IEA, Eurostat.*

Following the discussion over the relationships between growth in renewable energy and growth in import dependence (Figure 14), it is necessary to consider the relationships between growth in renewable energy and growth in diversity (Figure 15) to gain a complete understanding of the role that renewable energy plays on energy supply security. All countries have increased renewable energy in their fuel mix and most of them have improved their diversity during the same period (1990-2012).

For example, Portugal (PT) achieved 0.6 improvement in SWI by only adding 1% more renewable energy and Latvia (LV) achieved 0.03 improvement in SWI by adding 24% more renewable energy. In fact, Portugal achieved that diversity increase by introducing 3 new options to its fuel mix; specifically, natural gas, wind and geothermal energy which mostly substituted coal, oil and hydro power. Latvia's renewable energy growth has been mostly attributed to increased use, from 8% to 31%, of biomass which substituted coal and oil. This in turn, made biomass a dominant new fuel that had a negative impact on Latvia's fuel mix balance which is reflected in the almost negligible diversity growth. Moreover, Malta and Luxemburg added a small share of renewables and experienced a diversity reduction. As previously mentioned, Malta shut down its coal power station and substituted it with oil which resulted in a drastic fall in diversity. That diversity fall has not been possible to recover which a modest addition of renewables. Furthermore, Luxemburg grew its reliance on oil (to almost 60%) which hurt its balance and SWI index.

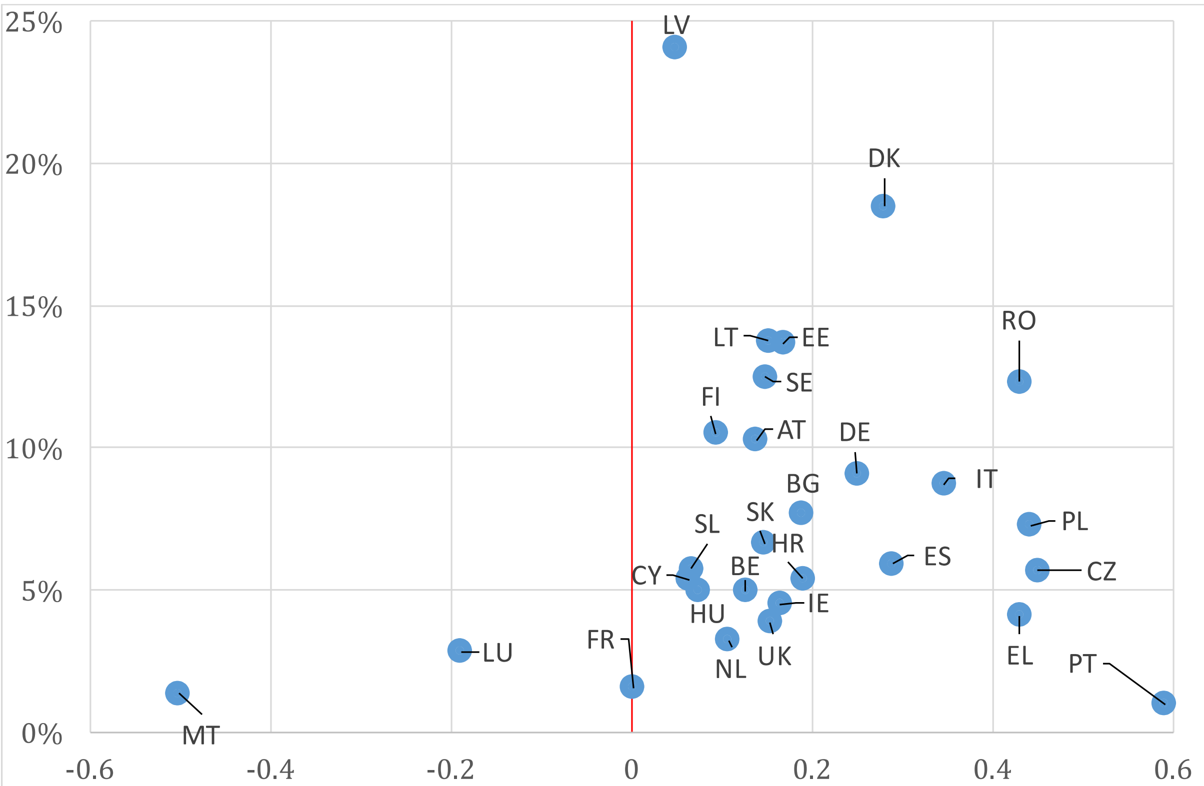

Figure 15: *SWI index difference (horizontal axis) against growth in renewable energy use (vertical axis) for 1990-2012. Data Source: IEA, Eurostat.*

6. Conclusion

Energy security is important for all countries and substantially more important for countries that are simultaneously exposed to multiple supply vulnerabilities. As such, EU countries present a distinct case study since ambitious GHGs reduction targets, 2008 financial crisis and the turbulent situation on EU peripheries challenge their capacity to strategically secure their energy supply. We have identified that the smaller EU countries such as Luxemburg and particularly islands such as Malta and Cyprus present both the highest import dependence at 96% and the lowest fuel mix diversity with SWI at 0.48. This compares with 58% average import dependence across the EU and SWI 1.44 diversity across the EU.

On the contrary, Scandinavian countries, particularly Denmark present the lowest import dependence at just 13% and Finland the most diverse fuel mix at 1.78 respectively. Independently of the specific countries in focus, we contribute a fisheye's view to metrics of energy supply diversity and dependence while we estimate them for all EU countries. This facilitates a straight-forward benchmarking across countries with different primary energy portfolios and the contextualisation of the used indices.

In all cases, renewable energy sources are the main driver for the growth of energy supply diversity that we have showed across most EU countries. Therefore, increased investment in renewable energy sources provides the optimal option to reduce dominance of legacy fossil fuel power stations and grow the role of indigenous resources. Clearly, this will have additional benefits in controlling GHGs and air pollution and support EU to reach its emissions targets by 20% and 40% in the 1990-2020 [55] and 1990 and 2030 [56] periods..

In concluding, it is essential to assess the role of energy and energy security in the broader context of the examined countries. Potential negative impacts sourcing from high initial capital investments or power prices can be countered within a strategy that makes use of improved energy supply security and encourages investment in innovation. This approach should include investment in energy storage facilities which can play a bundle of roles at small, facility scale [57], and equally, at larger regional scale [58]. Within the energy security literature, the role of energy innovation with technologies including various forms of energy storage is not embedded methodologically. Equally, demand side dynamics are important and they are driven mainly by the consumer's preferences. Solutions such as introduction of EVs as an alternative to conventional cars in the transport sector could serve as a measure to increase diversity decrease dependence and on the same time reduce various pollutants and emissions. As there is a positive link between environmental predisposition and reduction of energy consumption through the wider use of more efficient and environmental friendly technologies we believe that consumer green pedagogy could reduce future vulnerabilities surrounding energy security in the long run [59,60]. In this context, we argue that future research should consider how to methodologically incorporate advances in energy systems that will include demand side management and energy storage technologies.

Certainly, one size does not fit all and each one of the examined countries should focus on the types of resources that offer a competitive advantage depending on their geographical location, indigenous resources and existing national grids. Acknowledging the role of strategic coordination in energy investment and planning, the EU Commission may have to provide leadership. This should fit alongside the EU's agenda for leadership for the abatement of climate change and the burden sharing for emissions reduction between the EU States [61].

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