Applied Energy xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Energy supply security in the EU: Benchmarking diversity and dependence of primary energy

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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.

ARTICLE INFO

Article history:
Received 2 February 2017
Received in revised form 13 June 2017
Accepted 10 July 2017
Available online xxxx

Keywords:
Energy security
Diversity
Dependence
Primary energy
Benchmarking
EU

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.

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. [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

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http://dx.doi.org/10.1016/j.apenergy.2017.07.010

Please cite this article in press as: Chalvatzis KJ, Ioannidis A. Energy supply security in the EU: Benchmarking diversity and dependence of primary energy. Appl Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.07.010

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. [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. [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. [27] and Kruyt et al. [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. [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 [24,27,28,31], 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.