Energy 39 (2012) 100–111

Contents lists available at ScienceDirect

Energy

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

Net modelling of energy mix among European Countries: A proposal for ruling new scenarios

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ARTICLE INFO

Article history:
Received 2 February 2011
Received in revised form
30 June 2011
Accepted 4 July 2011
Available online 3 September 2011

Keywords:
Energy mix
Small-world net
Energy import/export
European Countries

ABSTRACT

European energy policy pursues the objective of a sustainable, competitive and secure supply of energy. In 2007, the European Commission adopted an energy policy for Europe, which was supported by several documents on different aspects of energy and included an action plan to meet the major energy challenges Europe has to face. A farsighted diversified yearly mix of energies was suggested to countries, aiming at increasing security of supply and efficiency, but a wide and contemporary view of energy interchanges between states was not available. In a previous work of the same authors, energy import/export interchanges between European States were used to develop a geographic overview at one-glance. In this paper, the enhanced Interchange Energy Network (IEN) is investigated from a modelling point of view, as a Small-World Net, by supposing that connections can exist between States with a probability depending also on economic/political relations between countries.

1. Introduction

Energy is essential to daily life; it is actually fundamental to face big energy challenges as a consequence of climate changes, increasing dependence on imports, pressure on energy resources. At the same time, energy supply at affordable prices for all the consumers is must.

In 2006 the European Commission invited Member States to properly choose their Energy Mix, namely, the diversification of national energy supply, following the guidelines set out in the Green Paper [1]. This goal has to be reached by taking simultaneously into account the different nature of energy exchanges between pairs of countries. In most cases energy trade may not be optimal. On this proposal, the Green Paper [1] can be considered as an important step in the development of EU energy policy, aiming at achieving economic, social and environmental challenges by facing Europe in the energy sector: increasing dependence on imports, volatility in fuel prices, climate change, increased demand and barriers to domestic energy. Successively, in [2,3] the European Commission states that the implementation of an ambitious European energy strategy, covering all available energy sources, whether fossil fuels (oil, gas, coal), renewable (solar, wind, biomass, geothermal, hydro, tidal) or nuclear ones, aims at beginning a new industrial revolution, with the objective of making EU more secure, competitive, sustainable and at a low energy consumption from an economic point of view.

Thus, European energy policy must pursue the objective of a sustainable, competitive and secure energy supply [1,4]. In 2007, the European Commission adopted an energy policy [3], supported by several documents on various aspects of energy and including an action plan to meet the major energy challenges Europe has to face [2,4–10]. For this purpose, the adoption of an *ad-hoc* diversified yearly mix of energies was suggested to all Member States, aiming at increasing an energy supply both secure and efficient. Unfortunately, a wide and contemporary view of energy interchanges between states was not available. On this proposal, in [11] energy import/export exchanges between European States were firstly used to identify the existence of a European interchange energy network at one-glance. The same network is herein investigated from a modelling point of view, as a *Small-World Net* [12], by presuming that existing connections between States depends also on then economic/political nature of relations between countries. In this paper, the basic idea introduced is that the *small-world phenomenon* is not only a feature of social networks [12], but a valid model for the European Interchange Energy Network (EIEN).

Whenever exchanges of energy are left free, the related emerging structures might present unpredictable features: in this work, the logic behind the structure of these networks is explored from a systemic point of view, to derive sound hints for eventual

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doi:10.1016/j.energy.2011.07.006

Nomenclature

n	number of vertices in a given network
k	number of edges in a given network
d_{ij}	geodesic distance (shortest path) from vertex i to vertex j
CPL	characteristic path length
CC	closeness centrality
CC_i	Clustering Coefficient of the i-th vertex
OCC	Overall Clustering Coefficient
DIAM	Diameter of the network
REC	Reciprocity Index
SMW	Small-World Coefficient
DEG	Degree of a vertex
MUT%	Mutual connection percentage
ASYM%	non-mutual connection percentage (asymmetry of network)
BTW	Edge *betweenness* of vertices
τ	Shifted exponential distribution coefficient

regulations or possible improvements of the overall efficiency. By taking into account national economical agreements and exchanges, the resulting network involves both social issues and technical ones. Scientific research questions can be articulated as follows: what kind of global pattern can be found in the European energy network, as a whole? Which network model could be considered the most adequate in order to represent the overall dynamics of European energy exchanges between countries?

In this paper a first attempt is performed to evaluate if the mixed nature of structural energy exchanges in Europe, can be dealt with the so-called *small-world phenomenon* [12]. On this proposal, a proper composition of annual National Energy Mix can be explored by an immediate comparison of energy import/export values for each country. Then, a detailed analysis of the proposed methodology developed for the EIEN by considering graph theoretical methods [13] is provided after focussing on the available data set [37]. An interesting case study is selected and illustrated, by considering European collected data in the period 1996–2007. Finally, results are reported and discussed.

2. State of the art of energy system analysis

Most of European States are actually analysing their Energy Mix Strategy to reach Kyoto's aims until 2020 in order to harmonize national energy goals with goals and time framework of strategic documents of the European Union [14–16], but the adoption of a unique Energy Strategy Implementation Program with associated measures is quite far to be adopted due to the fact that energy exchanges are actually unpredictable in several States or independently leaded between countries.

The basic energy objectives of each National Strategy has to include security of energy supply, competitive energy system and sustainable energy sector development. This implies improvement of energy supply, fulfilment of competitiveness due to diverse energy structure of electricity generation and achievement of sustainability of energy sector as main challenges of energy development [17–19]. But energy effectiveness in the European area is globally unpredictable as a whole.

As an example, an interesting analysis on the Danish energy system is reported in [14]. This paper presents the analysis of different ways of increasing flexibility in the Danish energy system by the use of local regulation mechanisms. The authors affirm that significant benefits are connected with an increase in the flexibility of the Danish energy system. On the one hand, it is possible to benefit from trading electricity with neighbouring countries, and on the other, Denmark will be able to make better use of wind power and other types of renewable energy in the future. In [14] this strategy is compared with the opposite extreme, i.e. trying to solve all balancing problems via electricity trade on the international market.

Another significant example is analysed in [15], where the authors deal with the goal of the Strategy Program in Croatia, which consists in creating a sustainable energy system to guarantee a balanced contribution to the security of energy supply, competitiveness and environmental protection in this country. An overview of national energy production, final energy consumption and planned development of energy infrastructure is given to research and stress out the abilities and opportunities of Croatian energy system and aiming at defining possible and adequate measures for Croatian Energy Strategy implementation and possibilities for the development of different energy projects. Furthermore, challenges and opportunities of Croatian energy sector development are given with an analysis of global geopolitical relations and security of energy supply. The challenges, but at the same time the opportunities, arise from the global climate change and other environmental issues, energy geo-strategic position of Croatia, approximation with the existing EU Energy Policy and present and future cooperation with neighbouring countries and countries in Southeast Europe [16,20].

More in detail, in [16] energy efficiency trends and policy in Slovenia are well focused. In this paper the author analyses the structure, trends of energy consumption and energy efficiency indicators by sectors of economic activity in this Europen State. A review of energy efficiency policies and measures is described. The main objective of this paper is to analyse the energy efficiency policy in Slovenia in previous years and how it represents the trends of EE using Odyssee indicators. The trends reflect the impact of the implementation of energy efficiency policy (measures), technology improvement and voluntary improvement of EE by sector.

The necessity of energy modelling and planning has been approached even for ASEAN countries by AEEMTRC in Jakarta as reported in [21]. Preliminary estimates of energy prices based on the available renewable energy technology development in Indonesia were considered. Attempts to include the use of renewable energy sources in the national energy mix and the state of the art of the overall energy effectiveness in Indonesia have been also considered, but the need of energy exchange modelling in that geographic area is not solved. In all considered countries, but not only in considered ones, and even in other continents for which different recommendations have been provided based on existing energy data are under analysis [21–23], the need of a regular reviewing and updating of the available energy planning model reveals fundamental. Other authors consider different approaches, based on specific energy decomposition methods, such as the LMDI method [24], to obtain proper indices, useful to provide aggregation consistency in energy decomposition. However, it has to be taken into account that national energy systems cannot be completely independent one from each other.

National energy systems seem to interact as coupled dynamical networks in large geographic areas. As a consequence, an adequate net modelling of Energy Mix among European Countries needs to be adopted for ruling new scenarios. Until now networks of coupled dynamical systems have been often used to model oscillators, such as ring pulse-coupled ones [25] or neural networks [26] and many other self-organising systems. In most cases, the adopted connection topology was assumed to be either completely regular or completely random. However, due to the fact that most