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Short communication

Re-examining historical energy transitions and urban systems in Europe

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ABSTRACT

This contribution questions the implication of energy use in the evolution process of urban systems and examines the role of energy systems, their evolution, socio-economic and technological factors related to them, in differentiations or regularities observed. Then, this evolutionary approach asks about future urban dynamics in an energetic crises context. This analysis is based on historical energy consumption data (Centre for History and Economics, Harvard) and on e-Geopolis database for population of urban areas 10 000 inhabitants and more. The targets are exploration and recognition of the role of energy in urban dynamics, growth and structuration in hierarchies during 200 years.

1. Introduction

Recent research has focused on the analysis of past energy transitions to better understand their factors and determinants, with a view to drawing lessons for the future transition [6,11,14,15]. If all factors of transition have been widely studied by focusing on the influence of historical and economic contexts, especially the development of prices [1], the demand for energy services and the penetration rate of technological innovations in the markets [5], the evolution of urban systems and urbanization are often presented as an ad hoc consequence without links between these processes and those that drive energy transitions which are clearly determined [29]. This research allows for reconsideration of this question under good methodological conditions. “The relationship between energy use and population is positively correlated” [2], but what are the relationships between the evolution of energy systems and the hierarchical structuring of urban systems in the Europe from 1800 to today (France, England and Wales, Sweden, Netherlands, Spain and Italy)? A city can be seen as a node in a hierarchical network of relations. It is then defined by its relative position in a complex hierarchy of productive, social and territorial functions that are not exercised at the local level but at the network level, regional or national [22,23]. Our hypothesis is that occupation of space by human activities and intensification of settlement forms can indeed be seen as a consequence of a gradual degradation and increasing energy over time, what Nicholas Georgescu-Roegen described as the production of entropy by a degradation of natural resources, with reference to the laws of thermodynamics [8]. Degradation refers to the irreversible transformation or irreversible use of energy and/or natural resources. Our societies have become dependent on energy inputs that allow continuity, development or expansion of their spatial organizations (expansion of networks and infrastructures, urban growth, urban sprawl, etc.). Energy inputs are essential to urban systems to ensure their existence and sustainability, like all living organisms. To test this hypothesis, we have measured correlations by crossing the historical national data on energy developed by the Center for History and Economics and the Center for the Environment at Harvard University and Cambridge UK,[1] and the e-Geopolis population database.[2] The evolution of urban systems shows breaks and discontinuities in time and in space. Therefore, this contribution questions the implication of energy use in the evolution process of urban systems and examines the role of energy systems, their evolution, socio-economic and technological factors related to them,

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[1] www.energyhistory.org.
[2] www.e-geopolis.eu.

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in differentiations or regularities observed. Then, this evolutionary approach asks about future urban dynamics in an energetic crises context.

2. The drivers of energy transitions

The energy transition is a major concern of the twenty-first century policies, but it is however not new. The first modern energy transition occurred by passing a variety of traditional energy carriers[3] to fossil fuels [15]. The operating capacity of arable land facing the population growth has placed a limit from which energy sources found themselves in competition, particularly due to the increased transportation cost of wood [1,29]. The ability to answer this constraint with the mechanization of agriculture laid the foundation of modern energy transitions. The shift to fossil fuels marked the beginning of modern energy transitions that operated both in the exploitation of new resources such as coal, oil and natural gas, as in the development of new vectors, the most important being electricity [15]. The history of energy transitions is partly a story of a substitution dynamic animated by shifting consumer demand between different energy sources according to their price [5,15,18]. The substitution of one energy source by another, results from competition to enter a consumer market according to the classical model of logistic growth, like *S* curve [4,16,37]. A strong complementarity exists between energy vectors and technologies associated with them. Electricity is necessary for the running of a wide range of equipment (computers, industrial engines) and vehicles are far more efficient in operating from energy carriers in liquid forms. The most important changes in energy systems depend indeed upon great innovations and technological developments but also society allowing their diffusion and integration into usage. These changes come from the evolution of technical knowledge and innovations derived from it, but this progress does not occur only in energy production techniques and the invention of new processes (steam power, combustion engine). They also fit into a broader socio economic framework beneficial to the use of these new technologies [1]. The level of economic development is essential and justifies a time lag between the invention of a technique or process and its widespread adoption that requires capital and investment to enable wide diffusion [6,11,28]. New companies must be created, and the old must adapt. New infrastructures are necessary, and on this point, public institutions have an impact through their investments, planning or adjusting legislation to facilitate the development of new socio-technical systems [15].

If the economic growth process over time is rather smooth and continuous, it becomes reality through the processes underlying facts of breaks and discontinuities involving major structural changes but sometimes this requires time to occur.

The temporality of energy transitions is due to a set of socio-economic and technological factors: population growth, location of resources, energy price and cost, but also of energy services, the standard of living, the level of economic development, the emergence conditions of technological innovations and the time of adoption of these technologies. These factors overlap and act systemically. If the costs are involved in turning to the cheapest energy, changes in standard of living activate the energy demand, but also promote the conditions of innovations emergence (literacy, progress of science and technology . . .). But in the same time, innovations also respond to a social demand (lighting, home comfort, mobility . . .) and industrial (process performance, increase in productivity) [1]. How fast energy transitions of the second half of the twentieth century took place is linked to the low cost of oil compared to coal, to activation of the demand for energy services related, to improving life conditions, population growth, falling prices for energy services, and therefore the speed of adoption of new technologies, especially those related to individual transport modes and the use of household electricity [29]. This combination of factors has led to rapidly increasing energy demand [28]. But the variability of these factors from one country to another in Europe has involved different energy systems and different timeframes in their evolution [7] (Fig. 1).

If the shift to a coal-based economy is prior to the nineteenth century in Britain, it was not until the mid-nineteenth century that this transition takes place in France and the Netherlands, while it happens at the beginning of the twentieth century in Sweden, Spain and Italy. The importance of the share of traditional energy carriers also differ widely from one country to another. Wood remained the dominant energy source in Sweden until World War II while human and animal labor power ensured the bulk of productivity in Spain and Italy.

The Netherlands are characterized by a relatively large share of wind use. The major drainage projects of this territory located at and below sea level explain the major share of the use of windmills for pumping [7]. Coal also varies considerably from reaching very different peaks at different times (96% in England and Wales during the last twenty years of nineteenth century, 80% in France in 1920, 84% in the Netherlands in 1940, but just over 50% in Sweden in the 1930s, and after World War II in Spain, and barely 40% in Italy in the 1930s). In contrast, the 1960s marks clearly the shift to oil in all six countries to reach peaks between 60 and 70% during the first oil crisis, except in the Netherlands and in England and Wales where natural gas has rapidly become an important resource. Recent periods which succeed the peak-oil of the 1970s show a diversification of energy carriers. While Great Britain, the Netherlands, Spain and Italy become consumers of gas, the production of primary electricity has increased very rapidly in France and in Sweden by the combination of nuclear and hydropower, and then wood gradually becomes a dominant resource in Sweden (30% in 2010).

3. Energy transitions and evolution of urban systems

The energy transitions contribute to spatial differences and heterogeneity of geographical space. The first industrialization marked by coal mining is associated with the phenomena of urbanization and rural exodus that have changed the spatial organizations. Similarly, the second industrialization characterized by the oil operations generated particular urban forms of urban sprawl process by the massive use of automobiles [19]. Show that the occupation of space by human activities and intensification of settlement forms are part of Entropy concept, according with Nicholas Georgescu-Roegen in reference to the laws of thermodynamics, is the central aim of this research by analyzing relationships between increasing energy over time and the evolution of urban systems. Our societies have become dependent on energy inputs that allow continuity, development or expansion of their space organizations. Energy inputs are essential to urban systems to ensure their existence and sustainability, like all living organisms. From this point of view, urban systems can be considered as dissipative structures that appear and are sustained through a constant flow of energy [26]. The level of energy consumption is equivalent to a measure of their production of entropy [27]. In this conceptual framework, the spatial organization of the territories appears as a slow process whose structures are produced with very high inertia. This structuring is an irreversible phenomenon, fueled by growth processes (population growth, urban growth, economic growth. . .). Cities grow and meet. Urban areas are expanding and energy demand is

[3] Human and animal labor power, wind and water mill, peat and especially fuelwood.

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