Evolutions in energy conservation policies in the time of renewables

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Abstract

Renewable energy sources are starting providing a substantial part of the energy supplied to end-users in many countries of the world because of a series of environmental and economic benefits associated with their usage. This progressive shift towards renewable energies may entail a very scarcely investigated change concerning how time and space are perceived and used within social practices. By drawing on complex adaptive systems theory the authors of this conceptual paper provide a series of insights on the nature of this change. They focus in particular on renewable energy sources being integrated into electricity networks and show how this change is essentially driven by the fact that renewable energy sources can constitute interconnected funds of energy distributed over a large spatial area and regenerated according to fluctuating rates. Then, they discuss how these aspects have an impact on the evolution of the complex energy systems at stake and which are their implications for energy related decision making. Based on these preliminary observations, they finally address the main subject of the paper and contend that the complexity and the ever increasing power capacity of these energy systems require that energy conservation policies will have to include a new generation of policies. In doing so, they show how these new policies have to increasingly address the temporal dimension of energy consumption and have to complement so-called "smart" ICT based energy management approaches with policy solutions relying on new social practices. In particular, they provide a series of arguments and practical examples illustrating why the sustainability of the complex energy systems under investigation can in principle be more effectively pursued by implementing energy conservation policies integrating technological solutions with governance rules envisaging an active and collective participation of local communities in the management of energy.

Introduction

All important social changes are driven by a specific type of collective imaginary. In case of the on-going massive shift to renewable energies, this imaginary suggests that renewable energies use is always consistent with nature and the environment. The rhetoric of this imaginary tells also that these energies are infinitely abundant and that the shift from non-renewable to renewable energy sources is just a solvable technical issue not significantly affecting how our lives are organized. According to this rhetoric, the entailed changes in energy demand can be dealt with by automatized technologies. Computer automation should indeed be able to provide appropriate top-down energy demand management solutions whereby decision making is mostly delegated to machines supposed to compete in a completely liberalized market to get the energy they need to accomplish on persons behalf a long series of boring daily routines. This paper tries to provide important elements to complement this imaginary and shows how a large-scale transition to renewable energies can imply a radical re-organization of society. In doing so, it indicates a series of fundamental and complementary transition options that can be generated by new social practices and energy conservation policies allowing a more sustainable use of the necessarily limited amount of renewable energy sources available. This objective is achieved through the following steps. Under the *paper section 1* the authors show first how renewable energies sources impose severe constraints on the amount of energy that can be generated per unit of time and illustrate how the larger openness of systems relying on renewable energy sources may cause that time is not perceived as something flowing homogenously. They argue that this may induce fundamental modifications in human practices. Rather than energy, it is indeed the amount of energy that can be generated per unit of time from existing resources that has an actual and measurable impact on existing practices. In subsequent paper sections these considerations serve to illustrate how the modifications induced by renewable resources in energy production rates may entail the need for a radical re-organization of societies. After having discussed the modifications induced in the temporal dimension, the authors discuss under the *paper section 2* the important modifications that can be caused by the high spatial distribution that may be observed in energy systems relying on interconnected renewable energy sources and characterise these modifications in terms of a *complexification* of the energy systems. This fact allows them to argue that the evolution of these systems has to be studied by using complexity theories, notably complex adaptive systems theory. Under the *paper section 3* they show that complexification has fundamental implications concerning the role that information on existing energy flows can play for energy systems management, because the evolution of these systems is affected by a deep uncertainty that cannot be controlled by traditional approaches relying on probabilities and statistical methods. Moreover, under the *paper section 4* they can illustrate how the energy and material flows constituting the metabolism of complex systems can be deeply affected by the on-ongoing shift towards renewables, how these systems tend always to increase their overall power capacity and energy metabolism and how energy efficiency improvements in systems components serve ultimately to allow that this general increase can be maintained in the long term. This being the situation, the authors discuss then how the increasing energy impacts of the complex renewable energy systems at stake can be limited. To this aim, they examine how effective energy conservation policies can be devised by taking as a starting point the need to address the time dimension of practices, the need to curb the power capacity growth of these systems, the fact that these systems can evolve and reorganize unpredictably and require therefore management strategies that are continuously adapted to ever changing local conditions. This analysis allows them achieving the conclusion anticipated in this introduction, i.e. the on-going transition to renewable energies cannot be faced by relying exclusively on the technical solutions offered by smart computer based technologies. It is indeed primarily necessary that resistances and flexibilities associated with social practices affected by this transition are analysed in detail. Moreover, it is fundamental to acknowledge that the complex systems under investigation can be managed more sustainably when collective systems governance approaches relying on local communities are integrated within purely market based approaches where energy related decision making is mostly delegated to computer based technologies.

Considerations presented in this article might generally be applied to any energy system relying on distributed and interconnected renewable energy sources that can be used by the inhabitants of a given geographical area to generate the final energy needed for their daily activities[1]. Nevertheless, this article will focus on energy systems where the final energy employed by end-use technologies is *electricity*. The reasons for this choice are manifold. First of all, these energy systems seem to be destined to supply most of the final energy used in many regions of the world because of the environmental and economic benefits linked to the distributed generation of electricity from renewable energy sources. Secondly, some important properties of energy systems discussed in the paper derive from the ample delocalisation of the energy sources used and from the mutual interconnection of all energy end-use technologies within these systems, and existing electricity networks[2] may and already tend to fulfil this condition. Thirdly, and most importantly, renewable energy systems supplying electricity share with the energy systems discussed the very relevant feature that all its energy end-users may potentially decide or are even stimulated to play a very active role by becoming also energy producers.

It has also to be clarified that the energy conservation policies considered in this paper include any policy measure that can be implemented at the local, regional, national or international level to save energy so preventing that the limited energy capacity of any source and transmission and distribution system that can be used to supply final energy to energy end-users can negatively affect these end-users. No matter how abundant renewable energy sources can be, policy makers and energy end users will always have to confront with a problem of final energy scarcity and will have to implement suitable policy measures to ensure security of supply through the generation of energy savings. This scarcity comes from several different origins[3]. One of these has to be found in the fact that, as also partially showed in this paper, energy systems, if not properly managed, tend always to increase related outputs and associated production rates so using more energy inputs. Energy conservation policies have therefore a fundamental role to play also in the time of renewables.

Finally, it may be worth clarifying that the authors deliberately chose to focus on the physical principles that can steer the evolution of the energy systems under study to draw some relevant implications for the social and policy actions that can be undertaken to limit or optimize the final energy consumption of these systems. The amplitude of the topics addressed has not allowed going into the details of policies design or technical innovations involved in the on-going developments of electricity networks. Although the above mentioned principles are themselves the result of a social construction, the authors think that they play such a fundamental role in the present times that their influence can be hardly overestimated. It may be true that the ability of social actors to shape technical/material conditions could somehow counteract and nullify this influence. Never-

1. By energy system it is meant the wide aggregate including all the machinery used to convert and transform primary energy into final energy, all the transmission and distribution systems used to deliver the final energy to all energy end-use technologies, the end-use technologies themselves, the human beings using these technologies and all energy sources and energy forms involved in their operation.

2. The notions of "system" and of "network" are used interchangeably in this paper.

3. For a nice analysis concerning how scarcity can originate within economies see Schroyer (2009).

theless, this possibility remains for the time being on a theoretical level, whilst the potential impacts described in paper are the result of forces and dynamics that are already in action.

Energy vs. time

Energy and time are closely related physical quantities. As in this context it will not be possible to describe the theories behind these two theoretical notions, the nature of their relation will be illustrated based on some analogies[4] by starting from the notion of "energy".

It is widely known that "energy" is mostly used to refer to the capability of objects to produce work. The common sense suggests that its meaning is related to *action*, *movement*, to its capability of producing *change*. Clearly, physics provides an operative definition of this quantity by establishing the related measurement units and measurement methods. The relevance of this abstract notion is however due to a conservation principle whose violation has so far never been observed experimentally and whose origins get lost in the nights of times[5]. Energy can be transformed from a form to another, but it is never created, nor destroyed. This is what everybody has learnt during his/her apprenticeship since elementary schools. What is less known is that this conservation principle is a logical consequence of a time property: *homogeneity*. It can indeed be proven that if energy were not conserved, time would not be homogeneous, i.e. time would not flow uniformly. The consequences of this implication are hardly imaginable. Roughly speaking, if time were not homogeneous this would imply that the outcomes of any action might depend on the time of its initiation. If time were not homogeneous, the outcome of an experiment might depend on the time when the experiment is performed. The main pillar of scientific knowledge (i.e. experiments repeatability) would certainly collapse if time would lose its homogeneity.

Despite the violation of the energy conservation principle is something practically looking as untenable, the fact that energy conservation is implicated by time homogeneity can be exploited to understand how time perception and time usage can change within *non isolated* systems when different types of energy sources are used. The energy conservation principle holds indeed only within isolated systems, i.e. within systems exchanging neither energy, nor matter with their surrounding environment. The thesis supported by the authors of this paper is that the substitution of non-renewable by renewable energy sources within a real system (as defined by proper system boundaries) determines an increase in the system openness and a consequent change in how time is perceived and used within this system. To a certain extent, the first part of this thesis may seem quite obvious. Renewable energies possibly employed within a real system are typically generated by energy exchanges and transformations with energy sources located outside any circumscribed system (e.g. solar radiation and the wind originate mostly thanks to matter and energy sources typically located outside possible bounded systems that can be under investigation). It may hence seem obvious that whenever certain types of renewable energies are used within a system, this system may undergo higher energy and matter exchanges with the surrounding environment compared to a situation where non-renewable energy sources located *within* the system are used. Nevertheless, the kind of system openness which the authors refer to has nothing to do with the location of the energy sources used. It rather relates to the fact that the utilization of renewable energy sources increases system dependency on exogenous *rates* of energy supply. Renewable energy sources are indeed by definition "renewed" according to given rates and this implies that their utilization must generally obey to given time constraints. Moreover, their utilization rates and, consequently, the power capacity that they can generate cannot increase at will. On the contrary, no constraints generally apply on the consumption rate of and on the power capacity that can be generated by non-renewable energy sources. Clearly, the distinction criterion proposed cannot be applied too strictly. Renewable energy sources can indeed be stored and existing rate constraints on their consumption can hence be modified. On the other hand, existing physical constraints generally impose limitations also on the possible consumption rates of non-renewable energy sources. Although quite loose, the difference highlighted can nevertheless induce important modifications in how time is perceived when highly distributed renewable energy sources become the main energy source employed on wide geographical areas. Broadly speaking, non-renewable energy sources can indeed generally be employed at any time to produce work. As such, these types of energy sources can be assumed as capable to induce human practices based on a perception of a *homogeneous time*. In this respect, they can be roughly considered as potential generators of practices which are informed by a conservation principle and rely on the possibility of being reproduced at any time. On the other hand, non-renewable energy sources can induce practices that have to adapt to exogenous rates of energy supply[6]. Whenever these rates can be assumed to be constant, time can still be perceived as something homogeneous, despite the power capacity that can be generated is limited by the rate at which funds are regenerated. Whenever these rates become aperiodic, time can be sensed as not homogeneous and the system depending on these rates of energy supply can undergo important qualitative changes that will be described to a greater extent in the following paragraphs. Before doing that, it is necessary to further explore the very peculiar relationship existing between energy and time. This will hopefully allow better understating why the constraints generated by the rates at which energy can be produced are so relevant for the evolution of human activities and which might be the implications of large scale utilization of renewable energy sources within electricity networks.

Another important aspect of the relation between energy and time can indeed be highlighted by trying to scrutinize

4. For a rigorous illustration of this relationship, see for example Kosyakov (2007).

5. Although their theses cannot be directly linked to an energy conservation principle, ancient philosophers like Thales of Miletus in 550 BCE had inklings of the conservation of some underlying substance of which everything is made. Shortly afterwards, Empedocles maintained that among the four roots of any universal system (earth, air, water, fire) "nothing comes to be or perishes" and that these elements are subject to a continuous rearrangement.

6. These considerations do not forget that the mediating power of technology and the ability of social actors to shape technical/material conditions might cause that the effects described are not generated. They highlight fundamental constraints associated with the different energy sources at stake. The larger the scale and the intensity at which these energy sources are used, the more likely these constraints will have the described effects on energy end-users' practices.

more closely into the nature of "energy". Strange as it may seem, the absolute energy of whatever isolated system is a physical quantity that is *per se* meaningless. This energy can indeed always be defined up to an additive constant. This implies that any numerical value that might be considered (under a given system of measurement units) as representing the energy of the given system can be used to analyse the evolution of this system. Put in other words, it might be stated that the energy of a given isolated system is either 100 GWh, or 1,000 TWh, or 1 Wh, or any of the infinite numerical values available, without making a difference in the future evolution of this system. This is due to fact that, rather than energy (E), the physical quantity that can actually be measured and assumed to have some degree of concreteness is always a variation of energy (ΔE) over a given amount of time (Δt). Whenever we deal with an isolated system, the notion of energy is of some utility in so far as this notion is employed by referring to a system transformation and is used under a conservation principle. All that this principle allows establishing is just that, whenever the energy of one part of our isolated system varies by ΔE over a given amount of time Δt, the energy of the remaining part of our system shall vary by $-\Delta E$ in the same amount of time. In other words, what can be defined and be measured unambiguously is not energy. What can be measured is a flow of energy ($\Delta E/\Delta t$) passing from a part of an isolated system to the remaining part of this system. Strictly speaking, this implies that the energy content of whatever matter or substance can never be properly defined in absolute terms[7]. What can be defined is instead the amount of energy that can be transferred from this matter to another matter under a given transformation and in a given amount of time. This is why energy rates are so important. It is the analysis of the conversion rates that characterize the transfer of energy from renewable and from non-renewable energy sources that can provide deep insights concerning the implications of the wide diffusion of renewable energy sources.

Energy vs. space

Besides potentially affecting our relationship with time, the large use of renewable energy sources can also be responsible for a series of transformations caused by how these sources may be spatially distributed and interconnected. The term that can be used to characterize this transformation is *complexification* of the energy networks. Complexification is the result of a large scale transformation from uni-located to multi-located and interconnected energy production centres when these centres can also possibly play the role of energy consumption centres[8]. By applying the same characterization adopted by Ruzzenenti & Basosi (2008), it can indeed be showed that complexification results from the creation of hierarchical control systems at multiple levels in the energy supply network and from the presence of geographical energy gradients[9] leading to an increase in the average distance from the points where energy is produced to the points where energy may be consumed. This transformation involves also the creation of more interconnections and more frequent interactions (i.e. an increased *connectivity*) among the different energy production and consumption points of the energy network. Here it will not be possible to go into the details of demonstrations and it will hence be taken for granted that the large scale employment of multi-located and interconnected renewable energy sources within electricity networks entails this kind of networks complexification. Some words deserve however to be spent to better describe the type of connectivity that can exist among the nodes of these complex networks. These networks show higher connectivity primarily because a large number of their nodes are both points where energy can be conveyed from other nodes in order to be consumed and points where energy is produced and redirected towards other network nodes. It is indeed obvious that the possibility of redirecting energy inputs determines more potential connections with other nodes[10]. This aspect contributes to confer on the end-users located at the nodes of complex energy networks a higher degree of *flexibility* and possibility for *self-organisation*. This possibility however depends ultimately on the creation of additional hierarchical control systems whereby decisions can be taken concerning e.g. whether to redirect the energy produced to the network or to consume it locally, whether to exploit one type of energy source or another, etc. A complex character is ultimately conferred on energy networks by the establishment of these additional hierarchical control levels[11]. It has also to be stressed that complex energy networks can be more *adaptable* to changing conditions within and outside the energy network in so far as energy end-users located at their nodes can decide to switch from an energy source to another or can decide whether to consume or to input into the network the energy they can possibly produce. At the same time, however, these networks are also exposed to more uncontrollable and unpredictable factors (linked e.g. to the decisions that can be taken at the different network nodes, or to changing conditions in the wider geographical area where the energy sources used to provide energy inputs are located) compared to centrally managed energy networks. Interestingly, the energy supply that can be provided through complex energy networks can fluctuate unpredictably not only because of the intermittent availability of renewable energy sources possibly used, but just because of the complex character of the energy supply network. As complexity of the energy network depends on how the energy gradients whereby energy is provided are *spatially* distributed[12], it can hence be concluded that the *spatial distribution* of energy can determine unpredictable conditions solely generated by complexity. Complexity can hence be considered as the vehicle whereby the *space* dimension affects the *time* dimension of energy.

7. Although under a different perspective, this aspect is analysed also by Giampietro et al. (2013) and by Diaz-Maurin & Giampietro (2013)

8. When this transformation takes place, energy end-users can decide whether to use renewable energy sources for self-consumption or to sell the energy produced in the energy networks, so becoming prosumers.

9. Geographical energy gradients are spatial regions where energy flows pass from a condition of higher concentration and intensity to a most likely arrangement made of more diffuse and less intensive flows.

10. Compared to other energy networks, complex electricity networks fed by renewable energy may however show a higher connectivity also because energy generated from more diversified energy source types can be conveyed to their nodes.

11. Additional links to the nodes of a network do not per se make this network more complex. On this point, see e.g. the distinction between *complication* and *complexification* formulated by Allen et al. (2003).

12. On this point see e.g. Ruzzenenti & Basosi (2008).

Overall, the transformation towards complexity entails that, rather than conventional planning based on relatively few hierarchical structures controlled by a small number of actors with a limited number of choices, the organization of the energy networks are much better described by complex adaptive systems (CAS) theories nowadays used in very different research fields ranging from ecology, to biology, to economy. Complex adaptive systems (CAS) are a relatively new research field developed mainly by researchers like Holland (2012), Gell-Mann (1994), Morowitz (2002), Arthur (2009). The brain, the immune system, ant colonies, swarms, the internet and the human society are often presented as examples of CAS. Although encompassing different theoretical frameworks, CAS are usually described as large aggregates of highly interconnected and interdependent components delimited from the external environment by specific boundaries and operating under far from the equilibrium conditions. As such, the dynamics of these systems cannot neither be described by collections of linear equations, nor by the laws of equilibrium thermodynamics usually employed to explain the evolution of simpler systems. New CAS properties can indeed continuously emerge from interactions and information exchanges among their components and with the external environment. As also pointed out by Eidelson (1997), these components are interconnected in a hierarchical manner in such a way that organization persists, grows over time and adapts to changing environmental conditions without centralized control. It is finally worth mentioning that the strong coupling among CAS components makes their evolution path dependent, i.e. what CAS can become in the future depends on what they have been in the past.

CAS theories generally rely on a series of notions and phenomenological principles verified within real experimental settings which can help shed light on the future evolution of complex renewable energy networks. Some of these notions and phenomenological principles will hence be briefly described in the following sections. Energy markets and big utilities have only quite recently started understanding how important it can be to study CAS and self-organization dynamics in order to understand the evolution of future electricity networks[13]. In this paper the attention will be mostly focused on the role played by information and energy metabolism within these systems and on two phenomenological principles regulating their evolution. These are, in the opinion of the authors, important characteristics of CAS that can help illustrate how renewable energies can change energy conservation policies.

Energy vs. information

In the complex adaptive systems (CAS) theory the notion of information goes hand in hand with the concept of energy and matter flows. Like ecosystems, CAS are generally described as networks of interconnected nodes where energy and matter flow at given rates. Besides nodes and internal links where through energy and matter flow, these networks are defined by their boundaries, connections and energy and matter exchanges with the external environment. The status of CAS can be characterized statically by identifying each flow within the system or, equivalently, by identifying the probability that a matter or energy unit can be transported from each node to any other node of the system. These probabilities can be used to define the information content of the system by using the well known Shannon's formula as a quantifier[14]. Energy flows within CAS are hence defined by the previously mentioned probabilities and constitute the information content of these systems. Interestingly, the higher the connectivity of each CAS node, the higher its information content and the higher the value assumed by the Shannon's formula[15]. The above mentioned probabilities are the building blocks of any energy management system that can be adopted to forecast energy outputs at each network node for time lags during which the network identity (i.e. its nodes and its interconnecting links) can be assumed to remain unchanged. Within CAS theory, information is reduced to numbers and decision making is downgraded to a computer solvable problem concerning the probability of having an energy or matter unit flowing into any of the channels constituting the CAS under analysis. Existing linkages between CAS theory and computer technologies are not a mere coincidence. Computer technologies and CAS theory are indeed deeply integrated. Epistemologically, computer technologies somehow represent the material support of CAS theory. Both have their foundations in the research field of cybernetics and reduce information to a number of possible alternative combinations that can be estimated by using the Shannon's formula. They speak a same language and reinforce each other. This fact would perhaps not be so relevant if present computer technologies would not allow us to track and manage a huge bulk of digital information concerning energy consumption and production rates characterizing each of our daily activities. They allow to literally build, monitor and manage the energy and matter flows that can be associated with any human and not human activity within energy systems. This task is accomplished by transmogrifying each change in this activity into elementary energy and matter flows and by converting these flows into numerical information that can be processed by suitable algorithms calculating the probabilities whereby energy systems inputs and outputs can be estimated. As it may be imagined, the large scale deployment of distributed electricity generation from renewable energy sources represent a formidable push to reconstruct and monitor the above mentioned energy flows. The main reasons for this push are due to the need to manage energy demand and to adapt it to the fluctuating supply of electricity generated by renewable energy sources and, above all, to the possibility that can be offered to energy prosumers to manage and sell the electricity they generate from renewable energy sources. The problem is, however, that any energy management approach that can be developed based on the above mentioned probabilities is intrinsically static and this assumption has to be released when the energy networks to be managed evolve.

13. On this subject, see for example Schleicher-Tappeser (2012).

14. The Shannon formula is given by $S = k^*\Sigma_{ij} P_{ij}{}^*\ln P_{ij}$, where K is a suitable constant and P_{ij} is the probability that an energy or material unit can flow from node i to node j per unit of time.

15. It can be easily demonstrated that, for a given input of energy into the system, the value of the Shannon formula increases when the number of connections of each node is higher. Moreover, this value is higher when the distribution of the total energy flux entering and exiting from each node is more even (e.g. in case of a node with two links, this value is higher when p_1=50 and p_2=50, than when p_1=90 and p_2=10).

As further discussed in the following sections, the evolution of CAS is affected by a much deeper uncertainty compared to uncertainties that can be controlled by using probabilities and statistical methods. It is for this reason that policies that can be implemented for CAS management must be designed and implemented by relying on complementary analysis tools and techniques.

Energy metabolism and evolution of complex adaptive systems

As mentioned in a previous paper section, energy is a mere abstraction if the process and the rate whereby it is transformed are not specified. Rather than energy, it is therefore much more useful to refer to concepts linked to the amount of energy produced and/or consumed per unit of time within given transformation processes. The notion of energy metabolism can very well serve this scope for a series of reasons. Like living organisms remain alive thanks to specific rates of nutrients intakes and outtakes, socio-technical systems represented by group of persons or households within technological environments, cities or whole countries have to rely on specific energy inputs and energy dissipation rates for their survival. Existing structures within these systems can persist only thanks to a balance between given energy input rates and energy consumption and dissipation rates. Whenever these structures change, these rates do also change and vice versa. The energy metabolism of these systems can be measured by adopting a very particular definition of power capacity that takes into account the amount of *personal* time spent when accomplishing a given task. More specifically, this power capacity can be calculated as the ratio between the energy consumed or generated by persons accomplishing a given (technologically mediated) task over the amount of *personal* time spent for this accomplishment[16]. This definition of power capacity is particularly relevant because it connects an important parameter used to assess human activities (i.e. the personal time consumed) to energy consumed by machines so linking together a variable used to assess a social aspect with a variable measuring a technological aspect (i.e. the energy consumed or generated while accomplishing a given task).

The proposed definition of power capacity can be used to measure the energy metabolism of any socio-technical system (e.g. a person, a given practice reproduced by a person, a household, a city, a country, etc.). Whatever the system, its energy metabolism consists always of a power input that is partially transformed in some kind of useful energy consumed per unit of time and is partially dissipated in the surrounding environment. When applied e.g. to a city, this notion may serve to identify its underlying energy structure. Like any organism, a city is indeed kept alive by specific energy input rates and associated energy consumption and dissipation rates. Energy is consumed and dissipated at given paces in a city depending on factors like number of total personal hours dedicated by households to leisure, chores, commuting, etc. and on the final energy consumed by technologies used while performing these activities. On the other hand, energy input rates to a city must be commensurate to the rates of consumption and dissipation and depend in their turn on the total amount of total personal hours spent by citizens for energy production and on the amount of energy that can be generated per each unit of personal time consumed from the specific energy resources used[17]. There is a balance between energy inputs and energy consumption and dissipation rates that must always be maintained by using given amounts of total personal time at the city level while consuming or causing the production of the involved energy amounts. Whenever consumption and dissipation rates change in a city, input rates must be changed accordingly and vice versa. Reasons for a change in consumption and dissipation rates at the city level depend on a variation in the total personal time used to consume and dissipate energy or on a variation in the amount of total energy consumed and dissipated per unit of time by its citizens[18]. Variations in the total personal time spent to consume may be due e.g. to increased delegation to machines for the reproduction of given practices, to a variation in the age structure in households causing a change in the overall time available for consumption and dissipation[19], to a change in the number of unemployed people or even to a change in the relative amount of males and females living in the city. Variations in the total energy consumed by citizens may instead depend on a variation in the energy efficiency of technologies used by households, on a variation in the age structures within households, on the installation of additional energy end-use technologies, etc.[20]

Although most of the factors that can affect the energy consumption rates of a city can also alter the energy input rates, these latter rates can change for additional reasons, including e.g. a change in the energy sources used[21], a change in the rela-

16. The paper authors are here proposing a definition of energy metabolism that has already been adopted e.g. in Polimeni et al. (2009)

17. By following Polimeni et al. (2009) it can be roughly assumed that all the personal time spent at work by people contribute either directly or indirectly to the generation of the energy input to the city (either this work is accomplished in the tertiary, or in the industry or in the agriculture sectors).

18. As already mentioned, it can be assumed that activities performed by people while at home are related to energy consumption and dissipation, whereas activities performed while at work are directly or indirectly linked to energy production. If energy rates are calculated on a daily basis, the total amount of personal time spent in energy consumption and dissipation in a city can be estimated based on the age structure in the households of this city by multiplying the number of citizens falling under each age range by the average daily time spent at home by these citizens, this average daily time clearly depending on the age range considered. The total amount of daily personal time dedicate to generate energy input can instead be assumed to equal the time spent at work under each age range, this time corresponding approximately to 24 hours minus the time spent at home. For further information on how to perform these estimates see Polimeni et al. (2009). Clearly, these estimates of the daily personal time used for energy consumption and dissipation are very rough. The personal time used for energy consumption should for example include also the amount of time spent for traveling for leisure activities, whereas hours spent at home during teleworking should be considered as hours spent for activities related to energy production.

19. It can e.g. be reasonably assumed that the oldest and the youngest people in households spend a larger part of their daily personal time in energy consumption compared to middle age people in households who usually have an employment and are hence involved also in activities related to energy production. Whenever the age structure within households changes, also the average personal time used by persons to consume is supposed to change.

20. Notice that variations in the total number of citizens affect the total amount of energy produced and consumed in a city. Nevertheless, these variations can be roughly assumed to not alter the energy metabolism of a city in so far as they do not determine structural changes affecting the total amount of energy produced or consumed per capita. The energy metabolism of a city is indeed a ratio between a total amount of energy consumed or produced and the total amount of personal hours spent in energy consumption or production by citizens.

21. Notice that, as mentioned in previous paper paragraphs, renewable energy sources can typically generate lower energy input rates compared to non-renewable energy sources.

tive distribution of people working in the different economy sectors directly or indirectly linked to energy production, a change in the amounts energy inputs made available to the energy system, a change in the efficiency of the energy production system, a change in the production volumes, etc.

The few considerations so far illustrated concerning the energy metabolism of socio-technical systems should suffice to grasp the huge impacts on energy systems organization caused by a massive shift towards renewable energy sources for the provision of the energy inputs needed by these systems. Besides deeply affecting the human relationships with time and space, when taking place at the city or at the country level, a shift to renewable energy sources and the consequent changes in the rates at which final energy can be supplied can entail a radical reorganization of the activities in all sectors of the economy. Before discussing the implications of this issue for energy conservation policies, it is nevertheless necessary that two different phenomenological principles regulating the evolution of CAS are briefly described.

According to a series of scholars, two main principles regulate the evolution of these systems depending on energy and time availability. Minimum entropy production or minimization of the input needed to obtain a given output are the expressions coined and most frequently used to refer to the first principle which dominates in a situation of energy scarcity and stable system boundary conditions. This phenomenological principle has been formalized by Prigogine (1961), Glansdorff & Prigogine (1971), Nicolis & Prigogine (1977) for energy-dissipating systems in a steady non-equilibrium state and applies to systems which are close to the thermodynamic equilibrium. Broadly speaking this principle implies that, in a condition of energy supply limitation and quite stable boundary conditions, system structures and components requiring a lower energy input to produce a given output have a competitive advantage and will prevail over less efficient ones (i.e. over system structures requiring more energy to produce a same output) determining a system reorganisation that can be characterized in terms of local efficiency increases. This reorganisation causes therefore a lowering in the diversity of options available to perform a same function in the short term and may put system survival at risk in case of a change in the boundary conditions. On the other hand, it diminishes system stress on the environment supplying energy and contributes to liberate energy whereby new structures can be created and contribute to successful system re-organisation in case a new situation of energy scarcity and new stable boundary conditions occur in the long term.

The second principle has been instead formalized in terms of maximization of energy flows and has been proposed for the first time by Lotka (1922). Several names have been proposed for this principle by different scholars. It has been defined e.g. as "maximum power principle" by Odum & Pinkerton (1955), as "maximum exergy degradation" by Morowitz (1979), Jørgensen (1992), Schneider & Kay (1994). It establishes that in a situation of energy abundance and time scarcity CAS tend to increase the speed of energy intake in order to speed up the activity of existing structures and generate new structures. This enhanced diversity and intensification of the activities performed takes place at the expenses of system efficiency. The overall effect of the augmented energy intake is hence described in terms of a system growth and increased system power capacity accompanied by a decrease in system efficiency. The higher system power capacity may determine a higher stress on the environment and on the boundary conditions. On the other hand the higher diversity achieved increases the possibility of a system reorganisation in case of significant systems boundary conditions change. System maximum power capacity corresponds to a status of higher diversity which is indeed a prerequisite for a higher system adaptability. This status enhances the chances of system survival whenever the conditions of energy resources scarcity and minimum entropy production are possibly achieved.

The two principles just illustrated are constantly at work during CAS evolution and co-operate to increase systems adaptability in the long run. CAS evolution is indeed driven by a tendency to increase power capacity and their increased efficiency is functional to a further power growth and to a better system integration into the environment[22]. These systems tend always to augment their energy metabolism and the diversity of their outputs and the energy saved at a given scale during a phase of energy scarcity serve generally to allow maintaining this trend. Polimeni et al. (2009) provide an example of household management to illustrate how the principles of efficiency and power output maximization can generally co-operate within CAS. According to them, economies made by families during routine activities comply with the above mentioned minimum entropy production principle and allow to save money amounts that can be subsequently reinvested in additional activities. What is saved at the lower level of the routine metabolism associated with specific activities can indeed be transformed into investments enhancing social interactions and create new activities at a higher level of household organization in accordance to the maximum power output principle. The final outcome of this co-operation process would be a better integration of families' metabolic systems with the environment during their evolution. It should not be difficult to grasp that this mutual reinforcement between energy efficiency and power capacity increase may take place in several ways also in the case of the complex electricity networks addressed in this paper. Whenever energy end-use efficient technologies consuming the electricity produced at one network node are installed at this node, the energy saved thanks to these technologies may e.g. be made available for other nodes so allowing performing additional activities. Or, it may happen that electricity prosumers at the nodes of these networks are highly incentivised to produce more electricity by installing additional and more efficient electricity production plants in such a way that they can either sell more energy to the network or consume this extra energy by installing additional energy end-use technologies. Complex electricity networks unfold plenty of possibilities to establish these mutually reinforcing mechanisms between energy efficiency and power capacity because these mechanisms increase their adaptability and possibilities of survival. These considerations will serve to illustrate the fundamental role played by energy conservation policies in complex electricity networks evolution.

22. The environment includes everything can be considered as staying outside the systems boundaries (including the possible resources from which the energy flowing into the systems is generated).

Energy conservation policies and large scale deployment of renewable energy sources within electricity networks

In the previous paper sections it has been showed that the substitution of non-renewable energy sources by a large scale deployment of renewable energy sources within energy systems supplying electricity as final energy can cause a change in how human activities have to be organized due to the different time and space distribution of renewable energies. Moreover, it has been briefly outlined that these transformations are linked to a complexification of the associated energy systems and that the management of these systems requires therefore to go beyond traditional management and risk assessment approaches based on stationary probabilities or deterministic dynamics. The brief overview provided has also tried to show that renewable energy systems tend always to increase their power capacity and energy metabolism. Moreover, it has been discussed that energy efficiency improvement actions that may be undertaken within these systems serve ultimately to increase system power capacity and adaptability in the long run. This being said, it has to be observed that solutions proposed to face these challenges generally just focus on solving existing short term management issues and do not usually pay sufficient attention to systems long-term sustainability and to the limitedness of available energy sources. The buzzword exemplifying the solutions generally proposed to manage these complex networks is "smart". The text produced by the U.S. DOE (2003) to describe a smart grid can effectively serve to render the nature of this "smartness". According to the US Department of Energy a smart grid can be described as a

> … fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broadband communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric network.

Increased automation, increased two-way flows of energy and information between machines, installation of distributed and automated controls systems allowing energy demand adaptation to an ever fluctuating energy supply, creation of an electricity market made of many millions of prosumers optimizing both their production and consumption of energy to make trading decisions in real time through internet based interfaces to this market. These are the typical ingredients of the solutions proposed to manage complex electricity networks[23]. A lot of literature has been already produced concerning the challenges and promises of these new types of "smart" energy networks[24]. Analyses of their energy sustainability and feasibility under a social perspective are instead much more rare. The remaining part of the paper will be therefore dedicated to discuss this aspect by taking the conclusions achieved in the previous paragraphs as a starting point.

TIME VS. ENERGY CONSERVATION POLICIES

The previously described changes in time perception can be one expected outcome of the large scale integration of renewable energy sources within existing energy systems. It is indeed widely recognized that this integration will require that energy (notably electricity) demand will have to constantly adapt to an increasingly fluctuating energy supply[25]. When examined at a sufficiently large scale, this adaptation can lead to save important amounts of energy because it can significantly reduce the amount of operating reserve that electric utilities have to keep on stand-by and that is typically produced in a less energy efficient way[26]. There are however three main areas of investigation that have to be considered when measures to ensure a certain degree of adaptation and flexibility in the electricity demand have to be implemented. The first one relates to the degree of synchronization or temporal dispersion that it is possible to achieve within social practices relying on electricity. The second one concerns the degree of automation that is desirable to pursue in the technical instruments supposed to contribute to obtain the expected flexibility. The third one relates to the impacts on affected daily routines and social practices. Concerning the first aspect, although most of the on-going discussions assume that the energy demand can be shifted at will, it will be necessary to perform very detailed studies concerning the timing of practices within societies before it can be established which practices can actually be synchronised or dispersed. Human practices (either associated with electricity consumption or not) have typically their own hourly, daily, weekly, monthly, yearly rhythms that are usually context dependent (i.e. they are different within different cultures). Policy makers willing to increase demand flexibility have hence to address this research field in order to establish to what extent the energy demand can be shifted. Concerning this aspect it has also to be stressed that, contrary to what commonly assumed within current debates on energy demand management, practice synchronization or dispersion can be also achieved by policy instruments which do not necessarily concern the installation of smart meters or smart appliances automatically turning on or off based on the elaboration of energy price signals. As resulting from the above discussion on the energy metabolism of cities, other policy instruments can be designed and implemented to this end. Regulations on opening hours (of shops, schools, pubs, etc.), conventions concerning holidays, travel commuting, urban planning and even aspects concerning gender (e.g. wom-

23. For a somehow fascinating description of the approaches commonly proposed to face the challenges of renewable energy networks, see for example Ramchurn et al. (2012).

24. For a survey of existing smart grid and smart metering projects in Europe see e.g. http://ses.jrc.ec.europa.eu/smart-grids-observatory.

25. For further information see e.g. NERC (2010) and Denholm et al. (2010). It might be argued that energy storage systems may make the need for electricity demand adaptation unnecessary. Nevertheless, energy storage solutions cannot compete with demand response policies when associated costs for the society are taken into account. Moreover, energy storage will presumably never be able or never be used to totally compensate the fluctuations in electricity supply that can be expected when renewable energy sources become the main source for the energy provided by electricity networks covering very wide geographical areas.

26. Operating reserves may be used to meet unexpected extra electricity demand or to generate capacity with a short interval of time in case an electricity generator goes down. On this issue see e.g. http://networkcodes.entsoe.eu/operational-codes/operational-security/.

en employment) are just some examples of the several areas where policy makers might intervene to change the timing of practices associated with electricity consumption[27]. Concerning instead the degree of automation that may be desirable to achieve to increase demand flexibility, policy makers would probably do well to take into account that increased automation means increased power capacity of energy systems and increased burden on existing energy sources. Moreover, another important aspect related to the automation in demand side management concerns the lost opportunities for an active involvement of energy end-users and for the implementation of more context dependent approaches allowing to increase demand adaptation. Strengers (2012) and Trentmann (2009) demonstrate e.g. that households can be very creative and effective in re-arranging their daily routines in response to suitable energy price signals without the support of any automated system. Moreover, Strengers (2012) rightly points out that, by analysing how human practices (e.g. related to homes cooling) are co-constructed by a wide range of human and non-human stakeholders, it is possible to devise strategies to change their timing (e.g. by promoting cool destinations like cinemas, pools, shopping centres, etc. that shift peak cooling practices outside the home). The third area needing further investigation concerns finally the impact on daily routines and practices induced by the temporal shifts caused by complex electricity networks. One aspect not usually considered in this respect is that practices temporal shifts needed by these energy supply systems may change unpredictably and that the frequency of these changes is inversely correlated to the possibility given to people to create new habits and daily routines. Too frequent temporal shifts may indeed cause the disruption of many habits people can develop to accomplish their everyday activities. It would hence be advisable that detailed researches on the maximum shift frequency that can be tolerated over given time spans by persons reproducing relevant practices would be performed in order to establish the actual elasticity of these practices against time shifts frequency. In doing so, it could not be neglected that the timing of practices is typically context dependent and its changeability cannot be assessed without taking into account how all practices reproduced by persons are temporally interconnected. As happening with our monetized economic systems, the management of complex energy systems may tend to impose that the most rigid structures and practices are sacrificed in the name of an increased flexibility and adaptability to changing environmental conditions. The extent to which practices can be actually made more "liquid"[28] is nevertheless limited by a series of existing physical and human constraints.

COMPLEXITY VS. ENERGY CONSERVATION POLICIES

In the previous sections it has been showed that CAS represented by complex renewable electricity networks evolve by increasing their power capacity and adaptability, whereas increases in their efficiency is functional to power capacity growth and to a better integration into the environment in the long term. Under a CAS perspective the debated and troublesome rebound effects[29] of energy efficiency improvements can be understood quite straightforwardly and look even necessary, as CAS possibilities to "survive" depend ultimately on a sound balance between the degree of power capacity growth and of energy efficiency improvements undertaken at the local scale. Given the limited availability of renewable energy sources, it is nevertheless generally fundamental to understand whether and to what extent it is possible to limit the increase in the energy inputs needed by complex energy systems without hampering their adaptability in the long run. In the opinion of many experts this objective could be achieved by promoting energy efficiency and simultaneously and somehow arbitrarily curbing power growth[30]. According to some of them an increase of the energy price and the "artificial" condition of energy scarcity so created could be sufficient to achieve this end. According to others, energy efficiency improvement measures should instead be accompanied by measures limiting power growth directly (e.g. by limits to the speed or engines' size in case the vehicles, by volume limits in case of refrigerators, by a minimum price set for bits/sec. transmitted by communication technologies, etc.)[31]. These two approaches, however, do not take into sufficient account the role that increased CAS outputs diversity accompanying power growth plays for their adaptability. Moreover, whereas the former approach may become questionable for the social equity issues connected to any energy price increase, the latter is often perceived as a limitation of individual freedom. This impasse can perhaps be overcome by a closer look at the specific nature of CAS. Increasing the energy efficiency of complex renewable energy systems is of paramount importance, as this reduces the impact on resource consumption due to an ever increasing systems' power output. On the other hand, the authors of this paper suspect that most of the approaches aiming at arbitrarily limiting or prohibiting systems' power growth and the accompanying technological development would be destined to fail when a perspective spanning a sufficiently large scale or long term is adopted. This however does not mean that the growth in CAS energy resource inputs cannot be limited by policy interventions. As discussed in the subsequent section, existing studies indicate that the development of institutional settings based on the self-organisation and self-governance of technological equipment and resource systems have a very interesting role to play in this respect.

27. On this aspect, see e.g. Mattioli et al. (2013).

28. For more information on the concept of "liquid societies" see Bauman (2000).

29. For a review of the status of the art of existing studies on rebound effects of energy efficiency see e.g. Turner (2013). Notice that the emergence of these rebound effects cannot be generally identified with a reduction in the energy performances (i.e. with the inefficiency) of the systems at stake, notably when so-called *indirect* rebound effects are observed. Energy saved whilst performing a given activity can indeed be used (or can cause that more energy is used) to perform a different activity. For example, energy efficiency improvements concerning the kms/h that can be travelled by cars have allowed the installation of several additional gadgets and services (e.g. air conditioners, four-wheel drive technologies, etc.) within cars and have generally allowed that more kms/h can be travelled. Money saved thanks to the installation of energy efficient solutions within a given economy can be used to perform more energy intensive activities, etc. These systems cannot be assumed to have reduced their energy performances, because energy efficiency improvements have been combined with a change in the *identity* of these systems by increasing the number of systems outputs produced.

30. See e.g. Maxwell et al. (2011) for further information.

31. "Small is beautiful", "slow is beautiful", "sufficiency principle" are some of the expressions employed to describe this kind of approach.

INFORMATION VS. ENERGY CONSERVATION POLICIES

Policy design methodologies generally rely on analysis techniques assuming that the evolution of socio-technical systems can be predicted with reasonable precision. If not mechanistic, the laws supposed to govern their evolution are usually supposed to be at least probabilistic. Unfortunately, the evolution of the CAS represented by complex electricity networks are intrinsically affected by a deep uncertainty that cannot be dealt neither with probabilistic, nor with statistical methods[32]. This uncertainty, however, is not necessarily detrimental to the development of these systems. Such uncertainty is indeed assumed to be the result of stochastic processes whereby new structures can be generated that can potentially improve CAS adaptability in the long term[33]. Contrary to models relying on probabilities or on deterministic dynamics, CAS theory embodies the possibility that new and unpredictable events may constantly occur. These brief observations can suffice to grasp how the role of information, although still fundamental, is somehow weakened in the framework of whatever policy or strategy that can be designed to increase the sustainability of the complex renewable electricity networks under analysis. Information concerning structures, energy and matter flows and interaction rules within these networks at a given time is indeed still highly necessary to identify a series of possible evolution patterns, but it will never be sufficient to establish ex-ante the actual evolution pattern, because this pattern is deeply affected by and extremely sensitive to how local interactions change. As a matter of principle, no model, no matter how detailed is the information available on the status of the system under investigation, can allow achieving this end. This conclusion has as a consequence that no underlying blueprint, no predetermined mechanism, no *planned* strategy can be used to manage CAS and increase their sustainability. CAS sustainability can only be the consequence of an overall systems adaptability that depends critically on the local adaptive behaviour of their constituents. Rather than from planning, an adaptive behaviour results instead from the application of local strategies *in action* that have to confront with the selection operated by an ever changing environment[34]. This is what theory can tell concerning the possibility to govern the evolution of these systems and what has to be taken into account when choosing the organization and technical structures needed to regulate their functioning. This is what has to be considered when rules to administer the usage of equipment, resource systems and resource units consumed by CAS like electricity systems have to be defined to increase their sustainability. Concerning this aspect, we are in a phase where the liberalization of the electricity market has separated the structures of production and distribution in many parts of the world and has made them more transparent. At the same time, however, this relatively new situation has not managed to curb the increasing impact on existing resources by energy systems. If most of the electricity supply has now to rely on common resources like the sun, wind and water, this further re-configuration implies that solutions to the new challenges determined by these energy sources cannot be provided by technical innovations operating within one of the two traditional and alternative institutional settings represented by a liberalized electricity market or by state regulated energy systems. A series of studies has indeed already demonstrated that complex energy resource systems can be administered in a much more sustainable way when collaborative approaches, rather than competitive or authoritarian ones, are adopted[35]. Compared to institutional settings where resource systems and related technical equipment are owned individually (according to competitive market settings) or by a central authority (e.g. the state), commons-based institutional settings designed by establishing that these resource systems and technical equipment are owned in common by people can often achieve much better performances in terms of reduced environmental impacts and energy conservation. The reasons for this are quite intuitive. The self-interest of competing market agents can only achieve sub-optimal and short term solutions to solve the issues linked to the depletion of the energy sources possibly at stake, whereas centralized authorities can only rely on command-and-control and adopt unified and standardised solutions that do not fit optimally to all the local situations where they have to be applied. Local self-governing and self-organised institutions whereby equipment and resource systems are owned and managed in common by people can instead exhibit more of the flexibility and adaptability required by the complexity of the problems at stake while being much more prone to adopt strategies for long term sustainability[36]. Renewable electricity networks offer hence the opportunity to go beyond the conventional two binary usage structures based either on buyers and sellers (in case of competitive market settings) or on a central and unique owner and electricity customers (in case e.g. of governmental settings). These structures can indeed in principle be replaced by a user community whose members are both electricity customers and electricity producers and can develop more suitable and flexible strategies to administer this resource. Lambing (2012) rightly mentions that the creation of these communities requires that consumers participate actively in the creation of rules and sanctions concerning electricity consumption and supply by taking into account local social, natural and technological conditions. Clearly, there are important barriers still hindering the establishment of these administration types. These barriers mostly include still too high costs associated with the installation of technologies and related infrastructures (e.g. windmills, PV panels, etc.) and negative impacts on a large circle of persons affected by the installation of these solutions (whose interests can however be integrated in the associated decision

32. There are basically two orders of reasons for this. The first and most fundamental one relates to the changing nature of the identity and of the rules regulating the evolution of CAS. The second one concerns the impracticability of any probabilistic or statistical approach. The heterogeneity of agents typically involved in these problems makes indeed a description of these agents in terms of joint probability distributions very challenging. The application of any agent-based model is therefore of not practical use. Moreover, the *pragmatics* of the communities of stakeholders typically involved is incompatible and cannot be captured by the assumptions motivating the representational choices of probability and statistics. See e.g. Bankes (2002).

33. This improved adaptability results actually from the combination of stochastic processes randomly generating new structures and selective processes eliminating new structures that do not fit with environmental conditions. On this point, see e.g. Allen et al. (2011).

34. See Allen et al. (2011).

35. On this point see e.g. Ostrom (1990).

36. See Ostrom (1990).

making processes). Lambing (2012) also mentions that the natural trend of electricity grids to aggregate and communalise electricity consumption (due to the fact that the larger the grid, the lower the additional power capacity needed to meet peaks in electricity demand) may lead to very large grids that may be quite difficult to administer according to a commons-based approach[37]. Despite these barriers, the implementation of these governance systems looks nevertheless very promising to ensure a sustainable use of renewable electricity. Due to the present situation of existing energy infrastructures, only hybrid solutions where common-based types of electricity supply coexist with a liberalized electricity market can however be realistically hypothesized. The first examples of these types of governance systems are represented by energy cooperatives[38]. Although most of these cooperatives deviate from a "pure" form of communalised electricity consumption (i.e. a model where the cooperative is owner and operator of the production plants and the power grid and where the cooperative includes all the electricity costumers and the decision makers on its electricity infrastructures), the ongoing multiplication of these types of undertakings can already highlight the huge economic interests at stake when citizens self-organization in the field of energy consumption and production becomes a reality[39]. In principle, it cannot be excluded that a further deployment of multi-located renewable energy sources within electricity networks and the associated diffusion of electricity communalisation can even trigger movements in the civil society for a re-appropriation of power industry. These, however, are just speculations. The governance options sketched in the final part of this section have been just briefly described to outline how the sustainability of the large scale deployment of renewable electricity will ultimately depend on the types of rules established for electricity production and consumption. Technological solutions represented by smart meters and smart grids are extremely necessary to use this electricity more efficiently. But the installation of these solutions alone cannot certainly guarantee that a situation of energy security where energy is used with due moderation can be smoothly achieved by exploiting the huge potential represented by local self-organisation initiatives. The thesis supported by the authors of this paper is that energy conservation policies designed by embedding energy decision making in the community itself will very likely be needed to achieve this end.

37. Very large grids could however still be managed based on a commons-based approach. Multistage control systems can indeed be used to allow that overcapacity in one community compensate for demand peaks in other communities. This would certainly require the wide scale usage of smart grids and smart meters, but the resulting management system would be fundamentally different from the usually prospected solutions to the challenges posed by renewable electricity. These solutions propose indeed top-down management approaches mostly relying on price signals processed by automated systems regulating electricity usage in each consumption point.

38. For a brief overview of existing energy cooperatives around the world, see e.g. ILO (2013).

39. One important area where existing interests have started generating power conflicts concerns e.g. access rights to technologies for smart metering and smart grid management and access rights to personal data concerning consumption within households. Self-organised energy prosumerism relies e.g. on citizens sovereignty on data concerning their energy consumption and on the possibility of having free access to smart technologies. The actual realization of electricity commons will depend on the outcomes of existing and future conflicts in this area.

Conclusions

The authors of this paper have tried to explore the role and the future evolution of energy conservation policies under a scenario of large scale integration of renewable energy sources within electricity networks. This has been done by taking the changes determined in the existing relationships with time, space and information as a starting point. The greater openness and the complexification of these energy systems and the consequent need for energy demand adaptation to an increasingly fluctuating energy supply have been indicated as the main drivers of these transformations. Moreover, it has been showed that these modifications entail a constant energy systems power capacity grow and that traditional energy management approaches based on statistics and probabilities concerning the evolution of associated energy flows may lose most of their effectiveness due to the much deeper uncertainties affecting this evolution. These elements have been used to prove the urgency of complementing mainstream policy approaches relying almost exclusively on so called smart demand management approaches with energy conservation policies designed by taking into account how social practices embedded within renewable electricity networks co-evolve with and deeply affect the possible development of these networks. Any planned strategy relying only on technological solutions to ensure a transition to renewable electricity networks is indeed at fault twice. Firstly, because it does not consider that existing social practices might not be as adaptable as expected and might hence represent an insuperable obstacle to the technological transition envisaged. Secondly, because social practices can provide an innumerable amount of alternative solutions to realize a transition that can better adapt to constantly changing local conditions. Clearly, it is not a question of disputing the adoption of smart technologies in the implementation of distributed renewable electricity generation. It is rather a question of highlighting the urgency of designing governance rules relying on local social practices that can empower and ensure a more active role to the millions of electricity prosumers potentially connectable to renewable electricity networks through smart technologies. This objective would have to be achieved not just to defend democracy in electricity consumption and production. It should be achieved because it can represent the most effective way to ensure that electricity consumption and production are performed sustainably.

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