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Complex Systems and Social Practices in Energy Transitions

Framing Energy Sustainability in the Time of Renewables

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Foreword

The social, ecological, and economic effects of a radical transition from fossil energy to renewable energies cannot be known, but there is a history of human civilization that can inform our thinking. As a hunter/gatherer society, we accessed high-gain food energy and low-gain fuel (wood). Moving about the land allowed a renewal of both once a local area was depleted. As human population in an area expanded to the point where moving was no longer an option, we switched to agriculture. When grains became our dominant, low-gain food energy source, the sun became society's dominant energy source for food and fuel. Land ownership greatly altered the structure of society, and excess energy moving through the system supported a more complex social hierarchy. That additional complexity demanded more energy to maintain it, so empires went next door and took over the lands of others. Yet another substantive change in society, and the beginnings of a global economy, based on taking sun-based fuel from others to support city-state structures. With the switch from renewable energy for food and fuel to fossil sun for both (coal and oil, and machine-based crop harvests) we hierarchically complexified society yet again, working from both a high-gain fuel energy and a high-gain food energy system (though still based primarily on four low-gain grains).

We are nearing the end of this present form of society, as the technology to extract and burn fossil fuels is peaking, as is the amount of food energy that can be extracted from a finite land base, despite fossil fertilizers and gene manipulation. The complication in all of this is that it is not a simple path back to hunting and gathering, as both the global population reliant on these energy sources is increasing, and the once-stable climate that provided for our complex global society is becoming less constant. The experts assembled for this book explore the ways, means and implications of just how a transition from high-gain fossil fuels back to a primarily low-gain renewable energy sources might unfold. What does it mean to return to our roots, to our initial condition of renewable energy as a sole-source fuel?

Despite being presented as simply a matter of technological innovation that will not substantively alter our societal structures, this energy source transition very likely entails dramatic and permanent changes in our social-ecological systems. The

specifics of these changes are unknowable, but a plausible narrative of future scenarios and system trends can be woven. Narratives about how close to the rising oceans most humans live, how and where food is grown, how much of the land base will be needed just for renewable energy infrastructure (windmills, solar arrays, wave energy capture), and what level of complexity individual societies will be allowed to maintain. Who gets to keep a middle-class? Who has first rights to contribute to the greenhouse gas reservoir? Who pays for relocations of villages, cites, or whole nations caused by sea level rise? These are wicked questions, and the nexus of food-water-energy provision in light of an increasing population and a changing climate is at any level a wicked problem. The sections of this book tease apart and look at those possible levels from many viewpoints, and reach some actionable conclusions.

Increases in food production result not in better nutrition alone, but also in more humans on the planet. Increases in locating, extracting and burning fossil fuels lead to greater use of such energy sources, not less. This is Jevon's Paradox—that increased efficiency results in a greater use of a resource, not a reduction in use. When there is excess from increased efficiency, either someone will come along and take it, or the producer will seek out new markets to enhance overall profits. More food, more people. More fossil energy, a larger middle-class. A larger population living a middle-class lifestyle, a greater consumption of goods and services. Increased consumption demands greater efficiency in production, and we start all over again. The transition from high-gain, energy-dense fuels to low-gain, highly processed and organized energy carriers, will materially affect this cycle, the underlying economy, the societies from which the economy emerges, and the landscapes that support it all. It is not a mere change in where our energy comes from, but a material change in how we as a society use our landscapes, and that material change in demand and supply of ecological services will have substantive and permanent effects on our current, unsustainable global society.

By using the science of complexity and complex systems theory as the reference framework to study our transition to renewables, the contributing authors produce a series of relevant insights concerning what can be anticipated from this transition. They provide new insights, and some very interesting and non-conventional observations, that students, researchers and policy makers involved in the current energy transition will find useful in understanding the issues at hand, as well as the opportunities and pitfalls offered by a total transition to renewable energy sources.

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Preface

When in 2015 we resolved to organize the experts' round-table discussions that led us to decide to write this book,[1] we were aware of two central problems affecting current mainstream policy and research activities for a sustainable energy transition.

The first problem relates to a very controversial dichotomous approach still mostly adopted by scientists and policy makers when carrying out these activities. On the one hand, they indeed still mostly aim at identifying and implementing solutions that may increase the sustainability of human activities by fostering the substitution of *single* technologies with assumed equivalent models functioning with less energy inputs and causing less harmful emissions in the atmosphere. On the other hand, they aim at finding and stimulating the adoption of policy approaches that can change the behaviour of technologies end-users. In doing so, they assume that end-users can somehow be individually persuaded to buy these alternative models or be induced to modify their conduct when employing single energy consuming technologies and do not take into account systemic factors may impede achieving expected policy impacts.

This dichotomous approach can certainly contribute to improve the energy efficiency of single technical applications in important ways, this result representing a very relevant result. When assessed against the possibility that it can lead to an overall reduction in the consumption of natural resources caused by human activities, it results nevertheless highly problematic in so far as it misses to take into account how individuals and technologies are nowadays interlinked within complex systems which evolve according to logics that it cannot capture. Indeed agency (i.e. the power to generate change) has to be considered nowadays as distributed over large series of human and non-human actors,[2] including a variety of technological products, institutional settings, rules and habits that co-determine people behaviours and all together induce a trend of energy consumption growth which neither

[1] See http://iet.jrc.ec.europa.eu/energyefficiency/round-table/experts-round-table-practice-theory-and-complex-adaptive-systems-theory for further information on this round-table.

[2] On this point see, for example, Latour (2005).

individuals, nor more energy-efficient technologies can reverse. Individuals taken alone cannot for example change the social constraints obliging them to commute every day or to buy houses where it is impossible to live without air conditioners. Moreover, the dynamics of growth triggered by the above-mentioned complex systems make often practically inevitable that the energy saved by one technology is then used as input for another technology in order to sustain this growth. In addition, the high level of power output that people composing societies can presently generate through these complex systems could be hardly achieved when renewable energy sources substitute on a large-scale non-renewable energy sources.

Although capable of determining relevant reductions in the consumption of energy inputs and in the production of greenhouse gas emissions that can be associated with the employment of single technical applications, the above-described dichotomous approach is hence affected by important limitations, which have to be ultimately considered as a consequence of two facts: it cannot significantly alter the overall energy consumption dynamics developing within current complex socio-technical systems, and it does not consider that a radical transition to renewables entails a radical reorganization of societies.

These are the main considerations that convinced us about the absolute relevance of alternative research and policy approaches that can take these complex dynamics into account.

At the same time, however, we were also aware of a major reflexivity problem affecting policy and research approaches informed by complexity. This problem relates to how social aggregates are mostly erroneously identified with kind of motors and information processors simultaneously maximizing their power output and energy efficiency while consuming abstract units of energy, time, information, money, etc. that are taken as actual ontological entities. Researchers and main stakeholders involved in the design and implementation of policies for energy sustainability tend indeed to identify socio-technical systems with input–output systems, while often forgetting that behind the abstract flows of resource units that they take as real entities and try to change there are very concrete and specific social habits, and there are people made of flash who can, on the one hand, potentially actively contribute to face contemporary sustainability challenges and, on the other hand, may not react as expected to implemented policies.

This problem, however, does not only affect policy approaches and solutions developed by specialists and experts. It actually concerns societies at large and the way in which people currently imagine the world around them. We think that this problem is the result of a large-scale social construction that has led motors and computers to become central metaphors whereby the functioning of societies and human beings is explained and being reorganized. The complex systems resulting from this social construction can generate enormous material benefits but are also responsible for an increased dependence on the technological supply and efficient utilization of given homogenized and standardized resource units while causing the disappearing of a variety of alternative practices established by people to provide for their necessities.

The dynamics of growth that can be triggered by these complex systems certainly contribute to increase material well-being in important ways. Moreover, the complexification of energy systems that might accompany the ongoing massive transition to renewable energy sources can generate huge environmental benefits. It is for example the possibility of generating an organized complexity that makes possible to conceive that highly distributed renewable energy sources can substitute non-renewable sources and be used to supply the energy needed by present large social aggregates. At the same time, however, the dynamics of these complex systems seem to obey abstract logics escaping any form of social control, whilst an increased complexification of existing energy systems can determine more frequent cases of crash and disengagement from rules and principles established by societies to regulate themselves due, among others, to an associated increased dependency on energy flows that can change unpredictably.

It becomes hence extremely relevant to understand how these dynamics are generated by existing social practices and how the development of new practices can possibly allow accomplishing the above-mentioned transitions in a more sustainable way while allowing preventing unwanted systems crashes or coping with these generally very unpleasant situations whenever they may occur.

These are the considerations that led us to conclude that the sustainability challenges posed by complex systems have to be necessarily also addressed by trying to take existing social practices and related theories as main research and policy target.

The policy approaches that can be designed and implemented in this way are generally radically different from approaches informed by complex systems theories. Whilst policy and governance strategies informed by these latter theories are inevitably based on considerations concerning existing and future energy, material and monetary flows, strategies informed by theories of social practices are supposed to take existing possibilities to reorganize the outputs of concrete actions undertaken by people as main starting point. Whilst the former strategies are informed by abstract considerations concerning inputs needed and outputs produced, the latter strategies can be designed based on considerations concerning what people say and do and how they organize and can concretely change own habits in a given context. Finally, whilst the former strategies are mostly based on technical considerations and do generally foresee a very limited active involvement of people in their design, the latter strategies are more genuinely political in so far as they relate to aspects that people can actively contribute to modify. In the case of future large-scale transitions to hypothetical renewable energy distribution networks, the former strategies are, for example, often focused on technical and economic interventions allowing an automated and mutual adaptation between energy demand and supply, whilst the latter strategies target people practices in their entirety and can be focused on whether and how these practices can be actually changed or reorganized by people in order to make them compatible with the increasingly intermittent energy availability that might be expected from these networks.

We are convinced that the different characteristics of these two strategies reflect a fundamental and unescapable complementarity that can be identified in the approaches that can be followed when developing or employing rules, material

artefacts, institutional settings and know-how whereby societies are organized. On the one hand, these societies can develop or rely on general and abstract rules and principles that can be blindly applied to all of its members who are in this way mostly identified with kinds of passive users (this might happen for example in case of rules and technical solutions that can be implemented to allow that aggregated electricity demand and supply can be balanced in future smart grids). On the other hand, they must cultivate a particular practical sensibility allowing that these general rules and principles can be adapted and subordinated to the initiatives undertaken by individuals and to their specific conditions (in the previous example of the smart grids this might for example entail a subordination of these rules and principles to practices developed by people who could in this way be made collectively responsible for the management of the energy resources, the technical apparatus and the institutional settings whereby these grids can be administered). We think that the insights provided by social practices theorists can help policy makers and researchers to cultivate this particular sensibility, given the fact that a suitable way to combine the two above-mentioned approaches has always to be found and the fact that the prevailing of one out of the two approaches within policy making is generally destined to cause disasters of various nature.

Based on the above considerations, we decided to gather around a table a series of acknowledged scientists working on complex systems and social practices. Given the interdisciplinary character of the questions we wanted to address, very different competences were represented. The invited scientists are indeed acknowledged sociologists, physicists, engineers, economists, anthropologists, biologists, ecologists and policy analysts. During the two-day event we organized we managed to discuss some of the above questions with them, whilst other experts that could not be with us were sent the proceedings of our meeting and were involved in the e-mail discussions that took place during the following weeks. Altogether we then decided to produce a publication that could hopefully serve to make the scientific community and policy makers more aware of the relevance of the analysis approaches discussed and of the insights that can be gained through their application.

The present book is the result of this interdisciplinary effort.

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Abbreviations

ANT	Actor–Network Theory
ATP	Adenosine Triphosphate
CBE	Community-Based Energy
DNA	Deoxyribonucleic Acid
EROI	Energy Return on Investment
GDP	Gross Domestic Value
GVC	Global Value Chain
IEA	International Energy Agency
IT	Information Technology
KWAPT	Kilowatt at Peak Time
KWOPT	Kilowatt Outside of Peak Time
OECD	Organisation for Economic Co-operation and Development
OM	Order of Magnitude
OPEC	Organization of Petroleum Exporting Countries
PVC	Polyvinyl Chloride
RE	Renewable Energy
REE	Rebound Effect
RES	Renewable Energy Sources
SES	Social-Ecological System
SPT	Social Practice Theories
TMC	Toyota Motor Corporation

Abstract

This book is the result of an interdisciplinary effort undertaken by a series of sociologists, physicists, engineers, economists, anthropologists, biologists, ecologists and policy analysts who participated or were involved in the discussions that took place during a round-table organized by the Joint Research Centre of the European Commission in February 2015. That gathering allowed discussing fundamental issues at stake with policies for energy sustainability that are largely neglected by stakeholders involved in policy making. The participating scholars decided hence to produce a publication that could hopefully serve to make the scientific community and policy makers more aware of the relevance of the analysis approaches proposed and of the insights that can be gained through their application.

The book takes complementarity seriously and presents a double analysis perspective by taking complex systems and social practices as complementary references. It does so by acknowledging that Western societies have quite recently entered the age of *complex systems* and that our ideas and material artefacts are for this reason being shaped by a relatively new paradigm whereby complex systems are being extensively built. The *first part* of the book is indeed dedicated to discuss how complex systems are socially constructed and how they are framing the issue of energy sustainability within mainstream research fields. The *second part* analyses the ongoing transition to renewable energies and policies that can be generally implemented to conserve energy in the light of theories informed by complexity. On the other hand, the *second* and the *third part* discuss how complex systems take with them important drawbacks for energy sustainability that are linked to some phenomenological principles regulating their evolution. These drawbacks are mainly identified by adopting the alternative and complementary analysis perspective offered by social practice theories. Practice theories complementarity stems principally from their acknowledging of the primacy of *practical knowledge* over the abstract notions of energy, time and information that constitute some of the main elementary bricks whereby complex systems are being built. Axiomatically, this means that, rather than by very abstract concepts, the elementary units of the analyses performed under a practice theory perspective are given by the actions

undertaken by people, by what people *do* and what people *say*. A series of contributions collected in the *third part* discusses therefore some main lessons for policy making that can be learnt by this complementarity and by integrating social practice and complex systems theories. Overall, the adopted analysis approach has then allowed drawing a series of relevant conclusions and indications for researches and policy makers involved in the ongoing energy transition that have been summarized in the *fourth and final part* of the book.

Introduction

Several countries in the world are currently engaged in an energy transition entailing a massive shift to renewable energies and a progressive increase in the efficiency of processes whereby energy inputs are used by economies. According to existing projections, in a few decades renewable energy sources will make most of the world's electricity production,[3] will provide almost 50% of the heat needed by buildings,[4] will provide a consistent share of the fuels used in the transport sector[5] and, above all, will allow markedly reducing anthropogenic emissions of greenhouse gases. Energy efficiency is then supposed to substantially contribute to this energy transition by reducing the burden of an ever-increasing energy demand on the existing natural resources system.[6] Researchers and policy makers rightly describe the realization of these scenarios as highly necessary and capable of contributing to the environmental, economic and social sustainability of human activities in important ways.[7]

There are, however, two very relevant areas of methodological improvement that are usually not sufficiently considered. The first one relates to the need of adopting an actual complex system perspective when performing the above-mentioned studies or designing and implementing energy transition policies, whilst the second one concerns the need for a better understanding of the role that people can have in the realization of this transition.

Concerning the first point, it cannot pass unnoticed how agents of resources consumption and associated emissions are nowadays mostly identified *either* with existing technological instruments *or* with individuals using these instruments and resources. As a consequence, adopted research and policy approaches mostly exclusively appeal either to the substitution of single technologies with more

[3]See, for example, IEA (2011a).

[4]See IEA (2012).

[5]See IEA (2011b).

[6]See, for example, C2E2 & IRENA (2015).

[7]On this point see, for example, UNEP (2015).

energy-efficient and less polluting ones, or to future so-called smart grids allowing continuous and automated exchanges of energy and information among all points of the energy network, or to behavioural changes expected from individual persons acting within competitive market settings. These approaches unfortunately miss recognizing that the actual agents of resources consumption are often represented by large and complex socio-technical systems wherein technologies and persons are nowadays integrated and made dependent on mutually reinforcing flows of energy, material and monetary resource units. They certainly can allow achieving a reduction in the energy inputs as well as a better integration into the environment of single technologies, but they are typically inadequate to face the dynamics of resources consumption growth that can be triggered by these complex systems and do not allow identifying suitable policy strategies and measures to counteract them.

Concerning the second point, the issue at stake relates to how the current energy transition is mostly envisioned as a problem of technological substitution where people will have to adapt to new technologies without having to significantly change their ways of life. The problem associated with this type of vision is that social practices reproduced by people are actually deeply embedded, co-evolve with and deeply affect the possible development of current energy systems. Research and policy approaches exclusively focused on technological substitutions or on individuals' behavioural changes around single technologies are hence problematic at least for two orders or reasons. Firstly, because they do not consider that existing social practices might not be as adaptable as expected and might hence represent an insuperable obstacle to the energy transition envisaged. Secondly, because social practices can provide an innumerable amount of alternative solutions and approaches that can better adapt to the ever changing local conditions that can be expected from this transition.

The objective of this book is therefore twofold. On the one hand, it wants to illustrate to researchers and policy makers the necessity to move from an instrumental to a complex system approach when studying socio-technical systems and policies that can be implemented to increase their sustainability within the current energy transition. On the other hand, it aims to show how relevant it is to perform this move by studying these complex systems by combining a positivist perspective with a constructivist one focused on the social practices wherefrom these systems emerge. Somehow, the book invites researchers and policy makers to perform a double change of gear when addressing problems linked to the finitude of existing energy and material resources and to greenhouse gas and polluting emissions generated by technologies and human activities.

While illustrating the research and policy insights that can be gained by studying the current transition by focusing on the complex systems dynamics that this transition can generate, it wants also to show that these complex dynamics do not have to be considered as an inevitable natural phenomenon. The constructivist perspective being proposed in several chapters of this publication aims indeed at showing that these dynamics are actually the outcome of social practices reproduced by people and that, due to this fact, research and policy approaches which are

alternative and complementary to those taking complex systems dynamics as the ultimate reality can be devised to possibly counteract them.

Whilst positivist approaches informed by complexity tend to take phenomenological principles related to how natural systems optimize resources consumption and outputs production as a benchmark to study and design suitable policies, this latter perspective allows in principle *disaggregating* the energy, material, information and monetary flows circulating within complex systems into the myriad of human practices generating these flows and permits to take these practices as the starting point to possibly design and implement suitable energy transition policies. The study of the environmental sustainability of a transport system in a city can for example be informed by complexity and be focused on vehicles and persons flows and on associated emissions and energy consumption. This typically implies that the solution of optimization problems concerning how flows density can be increased while maximizing energy efficiency and minimizing polluting emissions of involved socio-technical systems becomes the main target. When studied under a social practices perspective, these flows may be disaggregated into trips made by people to go to school, trips to go to the supermarket, trips to commute, etc. Rather than being based on technical and abstract optimization problems, research and policy approaches that can be developed in this way can devise a reorganization of these different mobility practices which is subordinated to the specificity of the social context at stake and can therefore allow people doing better while reducing the environmental impacts of their activities. Why, for example, children go to school by cars in this city? Why people prefer cars to bikes or public transport to go to work in that municipality? What can be done to change these practices? By starting from this type of questions, these approaches acknowledge the primacy of what people concretely do and say over solutions exclusively informed by technical considerations and implicitly assume the irreducibility of the outcomes of these doings and sayings to what can be predicted by any type of modelling.

The constructivist perspective being presented offers therefore the possibility to effectively complement policy and research strategies treating the fluxes generated within complex systems as actual and ahistorical ontological entities and aiming at changing the associated dynamics by suitable technical solutions. In addition, this perspective allows interpreting the consumption of energy and material resources by complex systems as the outcome of an at least partly negotiable social construction that transforms standardized resources units supplied through specific technological artefacts into the necessary input needed for the reproduction of any kind of practice. How is it that nowadays we need kilowatt-hours supplied by utilities or by micro-generation systems installed in our houses to do anything? How is it that most of our daily tasks are being progressively associated with the transmission of bits of information throughout computer technologies? How is it that a temporary interruption in the supply of electricity or in the internet can nowadays potentially inhibit most of the activities performed in a city? Can our social practices be rearranged to reduce this dependency whilst improving the quality of our life?

All in all, the proposed constructivist perspective allows to not see the consumption of the standardized resources occurring within current complex socio-technical systems as the inevitable outcome of any human activity and in so doing allows conceiving valid policy alternatives resulting from the active involvement of people while permitting to understand the social dynamics whereby dependency on these resources can be unnecessarily reinforced.

The decision to combine a positivist perspective with a constructivist one is neither casual, nor opportunistically due to the additional research and policy insights that this combination seems to allow gaining. The complementary approach adopted in this book reflects in my opinion the presence of a fundamental complementarity and separation existing between know-how, institutional settings, social norms and rules validated through technologies and science, on the one hand, and the social tissue on which these know-how, technologies and social settings operate, on the other hand.

Complex socio-technical systems are not generally seen in this book as natural and ahistorical entities whose presence and properties can be completely understood by science. They are rather interpreted as the result of a social construction based on a series of implicit and usually undisputed assumptions concerning the nature of energy, information and monetary value which are shared among scientists, technologists, economists and within society at large. The fact that science has necessarily to proceed by means of assumptions and working hypotheses is nothing new. What however is generally neglected is that some of these abstractions and the technological instruments through which their properties are validated are at the same time the result and a reinforcement factor of a social imaginary concerning what we and the world around us are that informs current social changes. For example, energy, information and related technologies are nowadays the bearer of messages concerning the nature of our world which propagate through societies while causing their reorganization. The complex systems they constitute have therefore to be studied also in relation to how they act on societies and in relation to the needs for reciprocal adaptation and possible tensions that can arise between them and the social tissue on which they develop. If the properties of complex systems can be studied by referring to the dynamics of associated energy, information, matter and monetary flows, this process of mutual interaction however generally resists the reductions and the reification processes that science has to operate to possibly capture them. These two entities (i.e. the wide complex systems that are being constructed and the social tissue made of concrete and lively persons) have for these reasons to be considered as constituting a duality made of two separate and complementarity parts.[8] Technologies, institutional settings, know-how, social rules and norms constituting current complex systems have to be

[8]To a certain extent, this duality and the tension that may arise among its two parts is the same that can be found whenever people have to develop, learn or employ languages, artefacts, institutional settings and know-how whereby societies are organized. While rules and norms can be established to allow generating, using and understanding these material and conceptual artefacts, these artefacts actually result from and act upon a preexisting substrate made by what people practically do and say during their everyday life.

constantly enacted and lived by people through their bodies and their personal and collective experience.

Within this enactment process, these material and conceptual artefacts have to be adapted to all the specific cases represented by people to whom they are applied, whilst people have to conform their feelings, particular situations and inclinations to them. Their use requires a continuous process of confirmation and mutual adaptation which can never be taken for granted or be considered as achieved once and forever. The two dimensions being discussed and the tension and complementarity existing between them can be identified at all levels of societies, from the level of single persons to small social groups, to cities and countries.[9] Either people are engaged in artistic activities, or in the employment of technological artefacts, or in the enforcement of laws and policy measures, they are always called to personally live and possibly resolve the tension existing between the general principles and ideas that may inspire their action and the particularity of the case they have to face. Either complex systems at stake are represented by the general principles, know-how, institutional settings, technologies, social norms and rules whereby energy is (or will be) produced and consumed, or are constituted by the conceptual and material artefacts whereby the current global economic market is organized or by the information systems being created to timely respond to emerging threats (wars, nuclear accidents, environmental accidents, etc.), there are basically two options to deal with them. Their evolution can either be subordinated to people decisions and be adapted to various social circumstances, or they can become abstract entities whose evolution is passively determined and accepted by people despite the very high social and environmental pressure this may determine. The vital and sometime violent force exhibited by social phenomena has to be ultimately found within the long and short term interactions taking place between aggregates of people and the material and conceptual artefacts they put in place to carry out their daily lives also in case these artefacts end up constituting the very complex systems addressed in this publication.

The binocular perspective proposed in the book to study the current energy transition reflects at a speculative level the presence of this duality and tension. This publication has indeed been structured into four parts.

The *first chapter* included in the first part describes the social construction of present complex systems and discusses the transformations they are inducing in how human artefacts are conceived. The *second chapter* illustrates instead the role of energy in the dynamics exhibited by these complex systems and how this social

[9]When, for example, people have to learn a language, to play an instrument or dance a music, they can refer to general rules and methods established within grammars, music or dance scores. These general rules and methods, however, do not determine the practices of speaking, playing or dancing. They have to be confirmed by and adapted to the practical knowledge that people use for their creation and generally develop around them. The fact that languages or play and dance arts can be learnt also without these rules is, among others, an index of the primacy of this practical knowledge over standards and methods that can be established to facilitate their creation and reproduction.

construction frames the issue of energy sustainability within mainstream research fields. Moreover, it discusses some main implications of this social construction for policies that can be implemented to foster the current energy transition.

The chapters included in the second part of the book are instead informed by a positivist perspective and are specifically dedicated to analyze the ongoing transition to renewable energies in the light of complex systems theories. The *third chapter* of the book included in this part discusses whether the ongoing transition to renewable energies that is taking place worldwide is leading to a higher complexification of associated energy systems. The *fourth chapter* employs instead the concept of energy metabolism to discuss whether the scale at which the present economy has developed is strictly dependent on the energy intensity of fossil fuels and whether this scale can be sustained by renewable energy sources. Its authors use this concept also to discuss the proper scale of governance to be developed for ecosystems and whether circular economy is attainable at the scale of the present global economy. The *fifth chapter* then analyses the role of hierarchies within complex systems. It discusses to what extent the advent of renewable energy sources will lead to a new hierarchical organization of matter and energy and how to cope with it under the viewpoint of governance and policy. The *sixth chapter* included in the second part of the book is instead dedicated to discuss how complexity theory can allow understanding the role of community-based energy initiatives in increasing the resilience of energy systems within current low-carbon transitions. Finally, the *seventh chapter* of this part highlights the urgency of revisiting the role of energy efficiency within the current energy transition and of accompanying energy efficiency policies with policies aiming to achieve an absolute reduction in energy consumption also within the current transition to renewable energies.

Chapters belonging to the third part of the book reflect instead a constructivist perspective. They discuss the problems caused by the processes of energy, time and information reification (i.e. the processes whereby these abstract entities come to be considered as a concrete thing) occurring within current complex systems while showing how a practice theory perspective can serve to very effectively complement research and policy approaches informed by the positivist perspective adopted in the second part of the book. The *eighth chapter* of the book is dedicated to discuss how energy and information play the role of central metaphors that are constantly taken literally in the present age of complex systems. The author of this chapter discusses how people and societies are being constantly identified with motors and information processors and which are the consequences of this aberration for policies that can be implemented to increase the sustainability of the current energy transition. The *ninth chapter* focuses on how current methods of knowing and managing energy that depend on techniques of abstraction, standardization and equivalence (like those leading to reduce different energy sources and end-uses to time independent representations of quantities measured according to a same metrics) prevent researchers and policy makers from engaging effectively with the multiple dynamics of energy demand or with the fundamentally different characteristics of renewable and fossil fuels. Along a similar line of thinking,

the *tenth chapter* discusses the problems generated by energy and time reification, the fundamental differences existing between renewable energy sources and fossil fuels and the risks and problems generated by the fact that they are often treated in equivalent terms by policy analysts and stakeholders dealing with the issue of a low-carbon energy transition. The *eleventh chapter* shows instead how the current energy transition requires a deeper knowledge about the relation between people's daily activities and their electricity use and how to increase existing knowledge through time-use surveys and the visualization of aggregate activity patterns.

The *twelfth chapter* explains how to achieve a deeper understanding of smart grids and analyses them a) as technological zones where metering standards, communication infrastructures and socio-technical evaluation assemble and b) as apparatuses made of asymmetric lines of power, knowledge, information, decision making, energy intensities and artefacts. The *thirteenth chapter* aims to help expand current demand response thinking to include a fuller appreciation of what actions can provide demand response and how changes in technological regimes, policies, social structures and expectations could increase demand response capacity. Finally, the *fourteenth chapter* generally discusses how practice and complex systems theories can be profitably integrated and can inform policies implemented to foster the ongoing energy transition.

The fourth and last part of the book is then dedicated to summarize indications for research and policy making and conclusions drawn by the authors of all book chapters. It has been conceived to facilitate researchers and policy makers in accessing information concerning key research and policy aspects that the authors of this quite voluminous publication have mainly produced for policy makers dealing with the ongoing energy transition at the international, national, regional or even city level.

I hope the book can render with sufficient clarity the importance of the complementary perspectives proposed by its authors.

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