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Energy Transition

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Foreword

"Energy transition is certainly one of the most important challenges of our time, but it already started many years ago". This quote from Bernard Lachal in his final lesson illustrates the added value of the studies his group has carried out on the reality of energy systems for more than 30 years. These studies are designed to evaluate innovative energy systems, but carried out in the traditional organization of construction and energy infrastructure, they allow all stakeholders to take a step forward and better understand the context in which their actions must take place. They also produce accurate data and analyses that lead to the optimization of the energy systems they have set up. This learning through use is essential in order to reproduce and improve the innovations needed to achieve energy transition.

The University Centre for the Study of Energy Problems (CUEPE) of the University of Geneva was created in 1978 by Professors O. Guisan, F. Carlevaro and B. Giovannini, at the end of the first oil crisis, to initiate interdisciplinary research in the field of energy. In this context of concerns regarding the sustainability of energy supply, CUEPE quickly became interested in the potential for energy savings and renewable energies. It is worth noting the relevance of these pioneers' vision, which has now become of primary importance, as concerns about energy resources have been replaced by the environmental effects of energy consumption, particularly the greenhouse effect. CUEPE disappeared in 2006, but a large part of the activities have continued within the new Energy Systems Group.

Energy transition is therefore underway. Per capita consumption in Switzerland is declining for both electricity and fuels, with the exception of air transport.

However, this progress is not sufficient because the climate emergency requires us not only to think about a gradual reduction in the consumption of petroleum products, but also to imagine a solution without CO_2 emissions, i.e. without fossil fuels, in the most immediate future.

Technologies are already at a level that makes this image credible, but the political consensus formalized in Paris at the COP 21 is unfortunately not reflected in national public policies that would allow these technological advances to be implemented. Politicians in many countries consider energy transition primarily as an additional cost factor that would affect the competitiveness of companies in the context of international competition.

However, energy transition is already a source of value creation, as demonstrated by the eco21 program of the *Services industriels de Genève* (SIG) (Industrial services of Geneva). In this energy efficiency program, launched in 2007, SIG invested 86 million francs in 10 years, more than half of which in direct financial incentives to consumers. They were then able to invest some 193 million francs in goods and services, mainly with local companies. And these consumers were able to reduce their energy bills by more than CHF 290 million, generating a net profit of CHF 140 million. The energy targets were exceeded, jobs were created and consumers spent less, making this a perfect example of value creation, which unfortunately could not be easily replicated in other cantons due to a lack of political involvement.

This is the case for many other local initiatives, here as elsewhere. Unfortunately, these best practices have not been studied enough to understand how they have become successful, often overcoming many obstacles. The documentation of this learning through use would thus enable other actors to benefit from these innovations. This is why the analysis of experience feedback is essential and why this approach, initiated by the pioneers of CUEPE and developed by Bernard Lachal and his group, is so important. Let us take a concrete example: the 20-MW GLN lake deep-water network, which was commissioned in Geneva's international organizations district in 2009. Five years of measurements and analyses carried out by the Energy Systems Group as part of a European project – and the subject of a doctoral thesis – have enabled SIG to improve energy and economic performance in a substantial way, making it possible to exceed the initial objectives of the project and making its replication possible. The GeniLac project was thus launched, targeting a territory more than 10 times larger than GLN's.

These 40 years of CUEPE's experience, from 1978 to the present day, are offered to you by Bernard Lachal in this reference book, which will certainly convince you that research made by involved scholars is essential in the field of energy transition.

Gilles GARAZI
Energy Transition Director
Services industriels de Genève
April 2019

Marcel RUEGG
Institutional Relations Director
Services industriels de Genève
April 2019

Preface

> "I don't think we can know everything simply through science. It is too accurate and too hard an instrument. The world has a thousand different ways in which it can be experienced in order to understand the sum of its parts… In other words, only the sailor knows the archipelago" [GIO 74].

While everyone is aware of the crucial importance of the development of new energy technologies, particularly those oriented towards renewable energies or the rational use of energy, the importance of their evaluation is only now beginning to be fully recognized. However, assessing the effective interest of these innovations is fundamental to enable them to be truly useful. However, a systematic analysis of methods for evaluating the performance after installation of the various non-conventional energy systems is still lacking. Our current practice and our permanent contacts with stakeholders in the field have also shown us that the way in which the energy efficiency of these new technologies is currently assessed suffers from this lack of a synthetic tool.

This book, *Energy Transition*, therefore has two objectives. The first one is to provide researchers, engineers and anyone working in the energy sector with a summary of methods for evaluating energy systems, the result of several decades of work in this field. The book, based on examples from real cases, is intended to be both synthetic and concrete, presenting as exhaustive a view of the field as possible while at the same time providing a tool that can be easily used by the target audience. The second objective is to break the vicious cycle that still leaves *in situ* evaluation somewhat neglected today, because it is sometimes considered as a long, apparently expensive, difficult to value and low value work. By attempting to scientifically organize the experience gained over more than 30 years, *Energy Transition* hopes to convince the reader of the considerable usefulness of the approach, both economically and humanely.

This book is organized into four parts.

The first one provides a general overview to situate the context in which the types of CSF (case study feedback) that will interest us evolve. After a reminder of some concepts related to energy, its transformation and its consumption, it is necessary to clarify the concepts of systems (energy and technological), innovation, learning through use and finally feedback (CSF).

The second part presents the relevant tools of CSF and sets some milestones for their use. In particular, it revisits the notion of measurement, presents different types of models for understanding a system in a quantitative way and also discusses the integration of human aspects.

The third part illustrates the practice of evaluation by analyzing some real cases representative of various situations. It situates the use of the tools presented in the previous section in the CSF process.

The fourth part is a reflection on the scientific nature of CSF. It is a question of asking how this approach is truly original, of presenting the particular type of knowledge it provides and of situating it in relation to other more recognized approaches such as Big Data. Neither is it fundamental research too far in advance of concrete problems, nor is it applied research too limited to its immediate objectives; feedback should be considered as "involved" research.

Bernard LACHAL
March 2019

Acknowledgments

This book is the result of more than three and a half decades of collaboration with a large number of players in the energy sector, within the stimulating framework of the University of Geneva. It is therefore impossible to try to thank all those who have, in one way or another, contributed to it. May those whose names I do not explicitly mention not resent me too much.

I would like to express my gratitude in the first place to all the owners, project managers, engineers, architects, tenants and users of energy systems who have been scrutinized, the key players in energy transition, for their dynamism, patience and open-mindedness, and without whom REX, *in vivo* experiments, are simply not possible. Then I thank T. Seal and J. Faessler for the many discussions on the book and their constant support, as well as all the reviewers, especially my colleagues C. Ançay, M. Bonvin, V. Schroeter, J.-M. Zgraggen, J. Khoury and L. Quiquerez as well as S. Schiano for her sharp eye. I have special thoughts for O. Guisan, W. Weber and P. Hollmuller, colleagues responsible at one time or another for the "Energy Systems" group, P. Ineichen, A. Mermoud and E. Pampaloni as well as for all the many other colleagues and students with whom I shared moments of work with, often combined with friendship. Without funding from the Cantonal Office of Energy and the Federal Office of Energy, many REXs would not have been possible. Many thanks also to M. Ruegg, G. Garazi and their colleagues at *Services industriels de Genève* for the many fruitful exchanges as part of the partnership with the university and for their unfailing financial support – including for this book.

Finally, I would like to express my sincere thanks to Catherine Rosselet, my partner and wife, for her continued support and my affectionate thoughts for her, for our children and for our jovial grandchildren.

Part 1

The Context of Case Study Feedback (CSF)

Energy Transition, First Edition. Bernard Lachal.

1

Energy Transition

The human problem has always been not to create energy, but to transform in a more or less rational way the energy resources available for use. Unlike other natural resources, the Earth is an open system in terms of energy: it receives a permanent and enormous flow of solar energy. This incidental solar radiation is intrinsically a good quality source since it comes from a 6,000 K thermal source; it could therefore be transformed into energy that can be used for our various uses with high efficiency. However, natural annual yields (photosynthesis) are generally well below 1%, and are at most 2.5% for the best plants, such as maize.

At the biological level, human energy needs are covered exclusively by solar energy through photosynthesis – 2,500 kcal per day, or 10.5 MJ, which corresponds to an average power of about 120 W. The conversion efficiency of the human "machine", despite being one of the highest in the animal kingdom, does not exceed 20%: a human therefore has relatively little power biologically and is constantly seeking additional energy (see Figure 1.1, the evolution of world energy consumption since 1800 [MAR 03]).

1.1. The global energy system and its evolution

Each year, humanity consumes nearly 15 billion tons of[1] oil equivalent, a quantity contained in a cube of about 2.5 km of ridge. This represents approximately 1.8 tons per inhabitant or 2,000 W of continuous power. The price of energy, which has remained relatively stable over the past few decades, although things are beginning to change, can be described as low since heating oil has the same price

1 The various energies are expressed in Gtoe or billions of tons of oil equivalent. One ton of oil equivalent (Toe) corresponds to the energy released by the perfect combustion of one ton of oil. 1 Toe = 42 GJ = 11.70 kWh.

as bottled mineral water, which is a renewable, abundant and regional resource. The inhabitants of the countries of the North therefore very easily have all the necessary energy at their disposal and do not deprive themselves of what is superfluous. For citizens who are unfamiliar with the realities of energy problems, this may seem to indicate a very high abundance of energy, while nearly 85% of the resources used are not renewable (Figure 1.1).

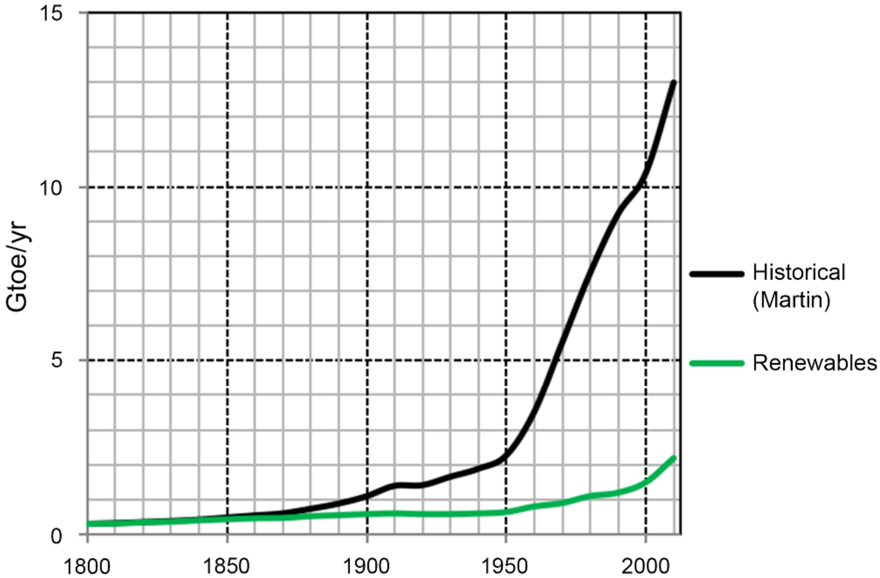

Figure 1.1. *Evolution of world energy consumption, according to [MAR 03]*

This first observation must be put into perspective by the deep inequalities between the consumption of individuals on different continents. Thus, an average American will consume 8 tons of fuel oil per year compared to 0.3 tons for the citizens of some African or Asian countries. This is an average; we should not compare the energy consumption of the richest 5% of the world with that of the poorest 25%. An estimated 2 billion people live without electricity.

The current trend in energy consumption is worrying: a headlong rush at a rate of about 2% per year of growth, i.e. a doubling of this consumption every 35 years and its multiplication by seven times every century. However, we must be careful not to extrapolate this observation too far into the future: in a finite world, growing exponentials also have an end!

Table 1.1 shows the world energy balance in 2015. The figures come from the International Energy Agency and have been adapted to account for hydropower in the same way as nuclear power.

Resources	Gtoe	%
Petroleum	*4.38*	*30.3%*
Coal	*3.66*	*25.3%*
Gas	*3.21*	*22.2%*
Fossils	**11.21**	**77.8%**
Nuclear power	**0.59**	**4.1%**
Hydro	*0.91*	*6.3%*
Other renewables	*0.50*	*3.5%*
Traditional biomass	*1.20*	*8.3%*
Renewable	**2.62**	**18.1%**
Total	**14.45**	**100.0%**

Table 1.1. *World primary energy in 2015, according to [INT 16]*

The energy sources are distributed as follows:

– fossil fuels provide nearly 80% of the world's energy (30.5% oil, 25.5% coal and 22% gas);

– the nuclear sector (4%) only plays a modest role in global energy supply;

– the renewable total is approaching one-fifth (18%), hydropower (6.5%) and especially other renewable energy sources (3.5%) are slowly but surely emerging, while traditional biomass (8%) is largely managed as a non-renewable resource (desertification problem).

1.2. The necessary transformation of the global energy system

Several elements show that the current energy system is not sustainable in the long term and that it must evolve.

1.2.1. *Fossil fuels: planned scarcity upstream and environmental problem downstream*

Fossil fuels have exceptional qualities: low extraction prices, ease of exploitation, very easy storage, very easy transport for oil and gas (which does not prevent bad practices, which can be disastrous for the environment). They have major shortcomings (non-renewable resources, emission of various pollutants), but they have been and still are ideal energies for many countries for economic take-off. Their exhaustion will therefore pose problems that must be anticipated at all costs.

On the available reserves, controversies are raging. For the pessimist, there are still enough fossil fuels to disturb the climate but never enough to satisfy all the desires of the inhabitants of this planet. For the optimist, and provided we also believe that we are collectively reasonable, there are plenty of them for basic needs and to develop a sustainable energy system, while limiting climate disruptions. The truth is probably in between.

In addition to the problem of climate change, following the emission of greenhouse gases, a limitation of fossil fuel consumption can only be beneficial in view of other problems such as urban pollution, the geopolitical risks associated with the depletion of oil resources outside the Middle East or the economic consequences of high energy prices for developing countries.

1.2.2. *Nuclear energy: environmental and accessibility issues*

With regard to uranium reserves, we must be very cautious about the figures for the following reasons [FIN 98]:

– these are highly diluted deposits (< 1%), with poorly defined formation conditions;

– uranium is a highly strategic raw material and reserve data is often considered a military secret;

– many actors are inclined to underestimate these figures: those who are anti-nuclear in order to devalue the entire supply chain, and some pro-nuclear to promote other supply chains (breeder reactors that use 70 times more uranium than conventional reactors, thorium reactors or fusion).

Nevertheless, with current technology, uranium resources are a definite limitation to a significant increase in the number of power plants. Several constraints weigh on the development of nuclear energy:

– social acceptability. The specific nature of nuclear risks – very low probability but very high consequence accident risk, long-lived waste management risk spread over an intergenerational period, risk of military proliferation – makes collective preference formation difficult and scientific consensus impossible. However, these two conditions are necessary for a technology to develop;

– economic constraints. These include the inadequacy of nuclear technology with the competitive organization of the electricity industries, competition from combined cycle gas turbines and financing constraints in emerging countries.

1.2.3. *An overall inefficient system*

One-third of primary energy is degraded during successive transformations mainly due to electricity production via heat (two-thirds of the losses), the other major losses being the transformers' own energy consumption and losses during transport and storage. All of these losses will end up as heat.

Final energy is often grouped into three uses: mobility (about 30%), electricity (just under 20%) and heat (a good 50%). It should also be noted that the heat lost during the transformations is approximately equivalent to the amount of heat used.

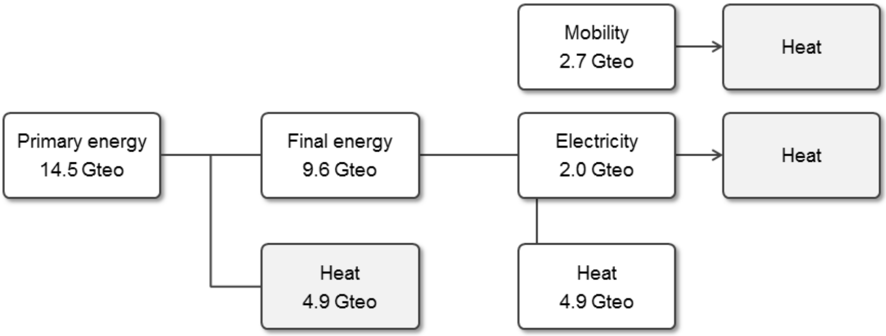

Figure 1.2. *From global primary energy to final energy, 2015, according to [INT 16]*

1.2.4. *A productive and simple-energy vision*

Figure 1.3 shows the evolution since the industrial revolution of the distribution of primary energy consumed annually into three main types of resources: fossil, renewable and nuclear. In this ternary representation, each axis of the equilateral triangle corresponds to a type of energy and the position of the point projection on this axis indicates its contribution. In 2002, fossil fuels accounted for about 80%, renewable fuels 15% and nuclear energy 5%.

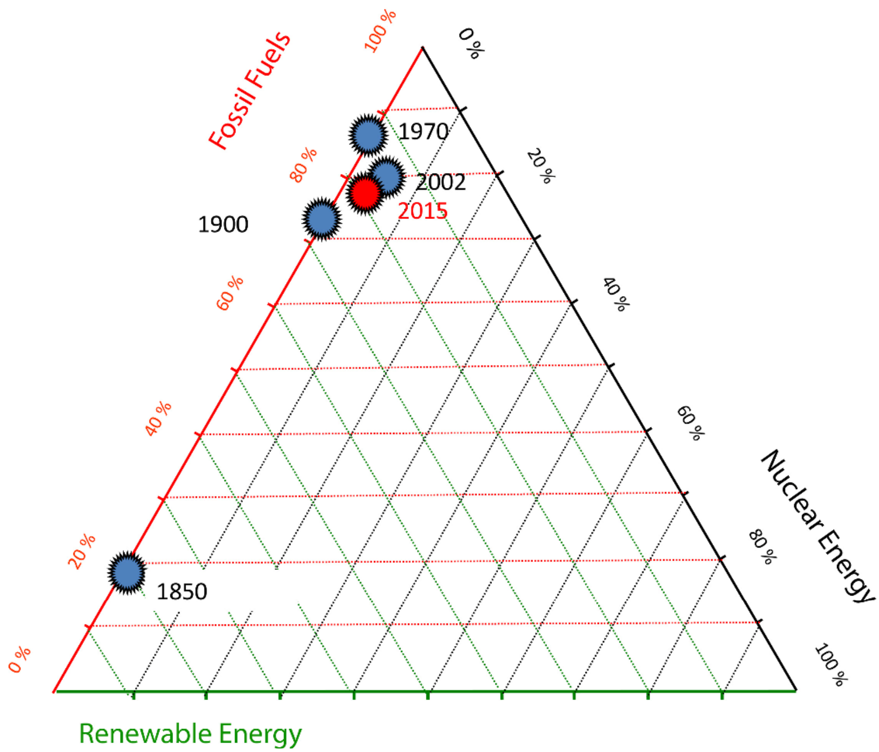

Figure 1.3. *Historical evolution of the global distribution between fossil fuels, renewable and nuclear energy. For a color version of this figure, see:www.iste.co.uk/lachal/energy.zip*

In the past, we have always had a strong predominance of energy over the others: from almost entirely renewable to almost entirely coal during the industrial revolution, joined by oil since World War II. In the 1970s, the heated debate was about which energy would dominate the upcoming energy scene: the nuclear newcomer or a return to solar energy? This productivist and mono-energetic vision