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Systemic approach for local energy mix assessment

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Abstract –Whereas energy mainly comes from main national power plants, distributed energy resources and storage technologies would allow local territories to choose their energy sources and increase their autonomy. This paper presents a decision-support tool that propose to find new system architecture based compromises between economic, technical and environmental objectives. Based on a systemic approach, it takes into account a broad range of technologies and assess multi-scale territories thanks to a physical modelling. Numerical simulations show the influence of different parameters on the ability of a system to balance power demand.

Keywords: Multi-energy system, Microgrids, Systems modelling, Optimization, Decision support.

1 Introduction

Initially independent from a location to another, energy production has been aggregated and huge networks were developed in the previous century. This has increased the ability to balance energy production between regions/countries and thus improved the supply reliability. Nevertheless this centralisation has also caused a dependence for local territories to the national/continental production. Also, a majority of the primary energy still comes from fossil resources (oil, coal and gas) that needs to be imported by many countries [1]. Therefore, local territories do not control the origin or the management of their energy. On the opposite, the recent increase in distributed energy resources (DER), like wind turbines or photovoltaic (PV) panels, and storage facilities could allow a local management of energy. Thus, it is possible to develop a local network that can be managed independently or connected to the main network, also called a microgrid.

The subject of the work presented here is the development of local energy systems, focusing on the electricity vector. A local energy system is defined in this

paper as a set of energy production, storage and transport technologies installed in the local territory (from a building to a region), with known control strategies. The chosen method consists in modelling and simulating systems in order to compute their performance indicators, defined here-after, and thus compare them.

Currently, the development of DER technologies serves the national interest and lacks a local strategy. The point of view of this work consists in finding a satisfying combination of technologies that balance the consumption and the production at almost any time – according to the level of autonomy from the main grid granted – while responding to today’s economic, environmental and social challenges. Nevertheless, studies on this topic mainly focus on economic performance to choose the best system [2], [3]. When several indicators are taken into account, they are usually pre-weighted so only a single solution is proposed [4], [5]. However, due to the coexistence of antagonist indicators, there is no best combination but only compromises between the different indicators.

Comparing a huge number of energy systems and get an accurate description of the physics of the energy generation and transport requires much computation time. A trade-off is usually made between the range of energy systems considered and the accuracy of the modelling. Two kinds of studies on energy systems can be defined: studies on control strategies considering a fixed system and analysing its dynamic behaviour [6], [7], and studies on the system design comparing multiple energy systems for a given consumption but with less accuracy in technologies’ modelling [8]. At a large scale (region, state), it seems easier to focus on the main power exchanges and to aggregate the detailed parameters to get a correct approximation. However, at a small scale (group of buildings), where every technology/strategy/transport choice is significant, technological variables take a greater importance. The multi-scale challenge this work intends to answer is to optimise quickly a large number of energy systems and keep at the same time a detailed physical modelling. In order to link local parameters to global performances and underline the systemic consequences of each technological choices, various models are developed and related to fit the simulation and optimization goal.

This paper presents a tool using a systemic approach to support decision-making and raise awareness about the complementarity of energy sources and the good use of storage at local scale. The purpose is to propose several optimums among energy mix, trade-offs between different economic, environmental and technical objective-functions, without prior weighting. To be adapted to multi-scale territories (from building to region size), the analysis offers the most exhaustive range of potential energy systems (production/storage technologies and control strategies) while keeping an accurate technological and physical modelling.

The paper is organised as follows. Section 2 describes the chosen methodology. Section 3 presents the case study. Eventually, the results are discussed in Section 4 and perspectives are underlined.

2 Methodology

Considering the multi-scale challenge, different levels of modelling are needed from an energy system point of view, allowing a quick resolution, to a detailed modelling of each element. This study considers an energy system as a combination of four main components, as shown on Figure 1: technologies, control strategies, demand and losses. Each of these is developed in several modelling levels going from a global pattern to detailed models close to technological parameters. Models are represented by interconnected blocs. The simulation and the optimisation of energy systems can use different levels in order to answer specific questions. The advantages of this systemic approach are its modularity (one bloc can be easily replaced by another), its ability to show the influence of a technological parameter on the whole energy system and thus to analyse the physical and technological frontiers of energy systems. The tool designed can adapt to all situations.

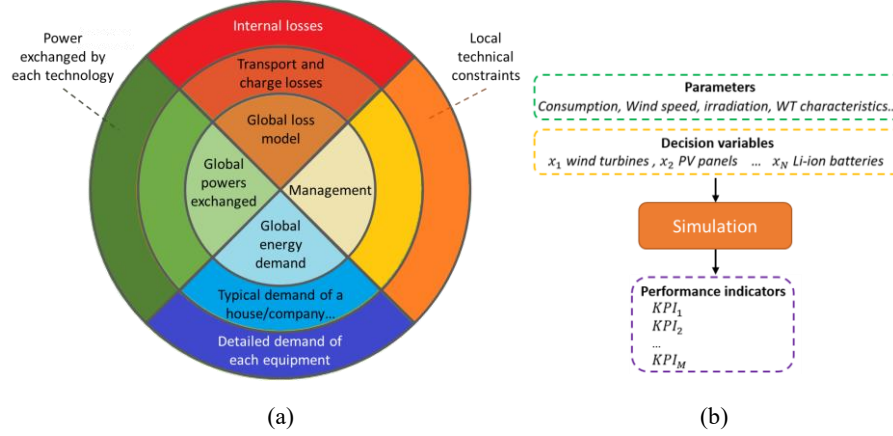


Fig 1. (a) Basic elements of an energy system (core) and the different modelling layers; **(b)** Simulation inputs and outputs

2.1 Simulation

As explained above, Figure 1. (b), decision support is based on economic, environmental and technical indicators. Decision variables are the number of element of each technology or more technological parameters according to the scale of the study. A simulation is used to determine indicators' values. The latter computes the powers produced, stored and consumed by each technology and the state of energy of all storage systems at each time step based on parameters, such as consumption power curve, meteorological data (wind speed, solar irradiation...) and technologies' characteristics. Time steps can range from minutes to days: without considering the dynamic behaviour of the system, it allows an accurate description of phenomena.

2.2 Control strategies

An example of technological parameter that can be modified with the systemic approach is the control strategy. A control strategy is a set of rules describing the operation of an energy system, i.e. which power should be generated by each producer/storage system at every time. Even though this work isn't about the analysis of control strategies, they have to be considered due to their influence on the efficiency of an energy system.

In this work, all control strategies are based on the principle of a priority order. The power balance over a time step is sequential: each production system is called following a defined order until the consumption and sometimes the storage capacity are balanced or the production capacity is reached. Most studies consider a fixed priority order, often sorting technologies by increasing marginal cost [8]. For each power plant, a strategy defines the power that has to be produced/stored considering the technical parameters and the power balance. Whereas many articles analyse a case study with a fixed strategy, it is here possible to compare a same combination of technologies with different strategies.

The presented tool thus allows to consider the priority order and the control strategies as new decision variables of the optimization.

3 Case study

The purpose of this case study is to show the ability of the systemic approach to underline the influence of technological parameters – here the presence of storage devices, the priority order and the control strategy – on global performance indicators, here the resources consumption.

Technologies considered are one 2MW-wind turbine, 20000m² of PV panels, a run-of-river dam (r-dam), a 1MW-biomass power plant, a 1MW-gas power plant, a 2MWh-battery and 10MWh-pumped hydroelectric energy storage (PHES). The chosen control strategies presented here are: technology can generate power to balance consumption and charge storage devices (Strategy 1) and technology can only generate power to balance consumption (Strategy 2).

Figure 2 represents the cumulated power produced/stored along with the power demand of 6000 typical homes – the size of a small town – isolated from the main grid. It shows that the production sources alone (a) does not balance the consumption at all time steps – (21:00 ; 00:00) period. Adding storage devices (b) and changing the priority order allows to balance the consumption all the time with time steps when production is above consumption to charge the storage system and others when the storage systems discharge. The operation of the same

set technologies with different control strategies (c) is then presented. Changing the control strategies modifies the solicitation of the storage devices, ends the renewable energies' restrictions and therefore reduces the gas and biomass consumption. Indeed, approximately 5.3 tons of resources (gas and biomass) are consumed in situation (a), 6.4 tons in (b) and 3.6 tons in (c) and greenhouse gases emissions are respectively 99, 121 and 69 geqCO₂/kWh.

Therefore, the designed tool's ability to assess the global impact of technical parameters is proven. The choice of an energy system then relies on the worth given to each indicator.

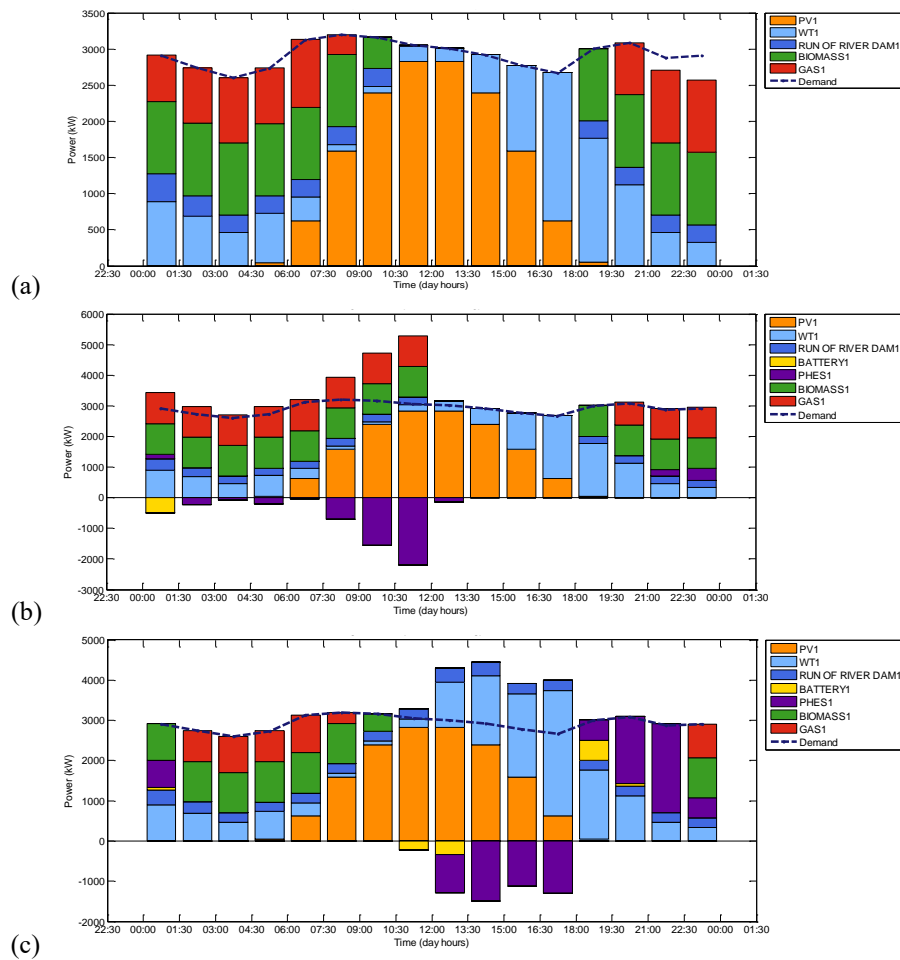


Fig 2. Cumulated power (kW) produced/stored along with the power demand of 6000 typical homes isolated from the main grid: **(a)** System with production technologies only; **(b)** System with producers and then storage technologies; **(c)** System with storage technologies before controllable producers and a change in control strategy;

4 Conclusion

In order to support the choice of local energy systems, this article presents a systemic approach based on physical modelling. The developed tool proposes compromises between antagonist objectives representing environmental, economic and technical concerns. Systems ability to balance energy demand over one day have been tested through several simulations. Moreover, results underline the flexibility of the tool and its capacity to assess technical parameters usually considered as fixed – e.g. technologies and management strategies. However, comparing manually energy systems takes time and does not ensure to find all the systems able to balance the demand. To support decision-making, the goal of the future work will be to automatize the procedure in order to first sort the energy systems corresponding to the local needs and then to compare their performances, with appropriate indicators.

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