Intermittent electricity generation and storage in the Reunion Island: A long-term economic analysis using a detailed power system TIMES model.

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1. Overview

The decarbonization of modern economies is now recognized as a major issue of this century (IPCC, 2014). Limiting the average terrestrial temperature increase at acceptable levels will require long-term actions with even longer-term effects. Energy consumption and production are responsible of an important part of GHG emissions. Also energy systems are vulnerable to climate variations. As the energy systems are characterized by important inertias, anticipation of system-wide impacts and effectiveness of different energy policies require strategic actions.

This strategic planning could be performed by means of global energy-economy-environment models (Bhattacharyya and Timilsina, 2010), which provide frameworks for drawing potential energy futures while maintaining internal consistency across scenarios. This broad portfolio addresses climate change mitigation and adaptation issues in a variety of timeframes, technology detail levels, sectors included, etc. TIMES model is a representative example of technology-rich models used to produce long-term outlooks (Giannakidis et al, 2015; IEA, 2015). However, as the amount and the complexity of decarbonization solutions grow, so does the need to improve models.

This need for improvement is especially true for the power sector. Electricity is widely acknowledged as a privileged sector to reduce GHG emissions (IEA, 2014), especially because abatement costs are relatively low compared to other sectors. Existing scenarios often exhibit very low (even null or negative) carbon contents of power generation (see e.g. ADEME, 2015). This generally implies high penetration rates of renewables, energy storage, etc. However, the characteristics of electricity force to pay particular attention to their modeling. Firstly, the demand for electricity varies instantly. Secondly, power requires a physical network to link production and consumption. The network adds investment requirement and operational restrictions to the power system. Thirdly, some electrical systems have or will have, high shares of renewable sources for generating electricity. These sources are characterized by their variability and intermittency. Thus, planning for long-term growth of such technologies must (i) be reconciled with the restrictions of short-term operation of intermittent and conventional generation technologies and (ii) account for the management issues of transport infrastructure, since optimal power flows and the availability of transmission lines will also affect the potential of alternative technologies (e.g. because of spatial resource availability constraints). The assessment of new power generation technologies or the cost of the transition towards low-carbon power systems may crucially depend on these elements.

Recent research has already been conducted to quantify the short-term consequences (operation) of long-term, low-carbon compliant energy systems (Welsch et al, 2014). These are often based on soft-coupling strategic and operational models. On the other hand, the short-term management of production units (the so-called unit commitment models) raises complex modelling issues which correspond to a long research stream (especially because it generally calls for MIP; Gollmer et al, 2000). The introduction of dispatch adds a layer of complexity above the generation problem (see Van den Bergh et al (2014) for a presentation of linearization techniques). **This search for adequate description of power systems leads us to elaborate more complete hybrid electricity models combining long-term objectives and short-term constraints**. To achieve this objective, we will rely on the TIMES paradigm, which allows a totally flexible timescale and time resolution. Thus, it is possible to have a study horizon covering several decades and, at the same time, consider higher frequency (within a year, a season and even a day) time slots. Additionally, these tools can be extended to add the interactions between energy chains and the economy in one or more regions.

In this paper we will develop a long term energy model with capabilities to accurately represent the short term requirements and the operational restrictions of the power system. We will do so for the Reunion Island, aiming to extend the methodology to assess much bigger and complex energy systems in the future. Additionally, there are policy goals set for reach a huge participation of renewables (some of them intermittent) on the future electricity. We decided to work with a small region, that have good meteorological information, a place with a political commitment to introduce more renewables and with a manageable size to simplify the result analysis. This work use Reunion Island as the modeled region, but the final goal is to extent the analysis to a full national energy. This will allow us to consider the cross impacts between power sector and the remaining energy carriers within a country in the context of climate change mitigation.

2. Methodology

As mentioned before, we developed a Reunion Island **TIMES model with a detailed electricity sector** that can run independently from the other energy chains. This electricity model should (i) use a time resolution that allows the user to capture the shape of the electricity consumption and the variations in the availability of renewable resources in a short term operation (ii) integrate the major operational constraints of conventional power plants (start-up constraints and costs,

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ramps up and down, minimum stable generation) as well as renewables (curtailment) and storage (control strategies) (iii) provide a simplified – e.g. linearized, continuous formulation – representation of power transmission and congestion and (iv) be able to be fully integrated into a larger full energy system TIMES model. We will compare results of, at least, 24 technology development scenarios.

3. **Expected results** (This exercise is currently in its final stage. Most of the results are available at this moment).

Model TIMES allows the modeler to obtain long term configurations (investments and operation) of the energy system to meet the demands at least cost while respecting constrains[4]. In our model, the Reunion Island TIMES model is divided into 20 regions (corresponding to the main nodes of the islands's transmission grid), with the power generators, availability of renewable resources and consumption allocated to the corresponding. This geographical division allow us to model a linearizer power transmission grid. The time horizon of the model is 40 years. Each year is divided into two seasons (according to the island´s weather) and each season is divided into three kind of days: Workday, Saturday and Sunday and public holidays. Each kind of day is divided in blocks of one hour. By doing this time division, we are able to capture the shape of the power demand, to include the operational constraints of the power plants, take into consideration the intermittency in the availability of the renewable resources, the operational constraints of the power plants (ramp up and down, minimum idle times, minimum stable generation among others) and the introduction and use of batteries linked to the intermittent sources or plugged into the grid. By using this tool, we will:

1- Evaluate the least cost energy mix that satisfies the energy requirements in a 40-year time horizon for the isolated system of the Reunion Island. In at least 24 future technology and policy scenarios (depiction will be shown in the full paper).
2- Assess the impacts, in terms of costs and investments required expanding the penetration of renewables in the power sector. This impacts will include not only cash flow differences between several power plants, but also the associated costs derived from the geographical location of the renewable resources, the cost of the backup required to provide firm energy, among others derived from the short term operation of the power system.
3- Evaluate the impacts of the installation of batteries and other devices as an alternative to increase the reliability of the power system and to compensate the intermittence inherent to some renewable sources (wind and solar).
4- Evaluate the incremental cost and GHG mitigation potential of specific actions taken on the power sector. By using the proposed modeling approach, this evaluation will take into account the operational constraints of power sector reducing by this mean the optimism bias that can be derived from a yearly or seasonal time granularity or by lacking a proper representation of the short term operation constraints.

4. **Conclusions**

Conclusions from the study will be presented in the full version of the paper (as well as the references omitted here by space restrictions). We will use this section provide more information regarding this work.

- Why you did not use a dispatch model of the power sector to do this? Because we aim to consider the interaction between power and other energy carriers as well as the substitution between sources.
- How this approach is different from a standard TIMES model? We are using novel features to model the grid and the operational constraints of the power plants and to capture the shape of the power consumption (standard TIMES model have a more general representation of the power sector).
- What do you expect to do with the information obtained? To provide policy maker with information regarding the hidden costs and requirements derived from the increase of intermittent renewables in the power sector and to provide them with quantitative information of alternative mitigation actions that can be addressed in the full energy sector.
- How the outputs of this work can be used? We are using an isolated and relatively small Island to test the new features of the TIMES model. Authors are working on a full Colombian TIMES model that will include all the features of the model presented here. This Colombian model will be used to assess long term energy planning and mitigation actions for the country contained its current, and expected future, Nationally Determined Contribution to the Climate Change mitigation (NDC). We aim to provide this information to the policy makers in order to allow them to adopt informed decisions while increasing the mitigation ambition at the least, but technically feasible, cost.

[4] See TIMES model: http://iea-etsap.org/index.php/etsap-tools/model-generators/times