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The renewable energy revolution of reunion island

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ABSTRACT

Reunion Island, a French overseas region located in the Indian Ocean, is facing a three-fold challenge combining demographics, the environment and energy. To limit its heavy dependence on imported fossil fuels, Reunion Island aims to achieve energy autonomy by 2030 based on greater energy efficiency and renewable energy alternatives. The objective of this study is to analyze different scenarios to reach electricity autonomy and, at the same time, consider the wide-scale integration of renewable energy in the island's power system using the bottom-up optimization energy model TIMES-Reunion. Despite the tremendous potential of renewable energy sources present on the island, the transition to 100% renewable energy needs to be supported by incentives or constraints. Strong energy policies can both direct the choice of renewable resources and accelerate the renewable transition. The development of biomass on Reunion Island is economically interesting. The transition scenarios show that by 2030, electricity from biomass advantageously replaces electricity from coal and represents slightly more than 50% of electricity generation. Solar and wave/ocean energies are not the most cost effective option, but wind energy tends to disappear in the face of these energies more politically supported. A network regulation rule benefits biomass and is more detrimental to solar than to wave energy. The decarbonized transition of the power system incurs higher total discounted system costs due to the additional costs induced by the different incentives to promote certain renewables, with some pathways toward energy autonomy appearing more costly than others.

1. Introduction

Declared a UNESCO world heritage site in 2010, the French overseas region of La Reunion – Reunion Island – located between Mauritius and Madagascar in the Indian Ocean, is facing a three-fold challenge involving demographics, the environment and energy. From 1970 to 2012, the island's population nearly doubled from 450,000 to 837,900 inhabitants. According to INSEE 2012 projections [1], the number of inhabitants is expected to reach 1061 million in 2040. In a context of demographic and economic growth, between 2000 and 2012, primary energy consumption increased by 3.1% per year and final energy consumption by 2.5% per year. Whereas in the 1980s all of the energy produced on Reunion Island came from renewable hydroelectricity, the island has gradually become dependent on imported fossil fuels. In 2015, petrol, coal and gas represented 86.1% of primary energy consumption and renewable energies only 13.9%, while 64% of the island's power was generated by fossil fuel (coal and oil) power plants [2]. This strong dependence on imported fossil fuels is frequently observed in the island's energy system [3] and leads to power outage risks in case of supply disruption as well as increasing greenhouse gas emissions. Most of the world's islands are in a similar situation and have to import fossil fuel for their energy demands, which is increasingly expensive for island nations [4–7]. Yet, although Reunion Island is isolated, located far from mainland France, and equipped with a poorly meshed grid that makes it vulnerable, it does possess significant potential in terms of renewables, such as hydropower, solar, wind, biomass, geothermal energy and marine energy in the form of ocean thermal energy and energy waves [8]. As for some other islands, renewable energy sources are thus sufficiently abundant to explore opportunities for an autonomous, sustainable power system [9,10].

Like other French overseas territories, Reunion Island has been significantly investing in renewable energy since 2000 [8] and, notably, since 2007 it has adopted a strategy for sustainable development that aims to achieve energy autonomy by 2030 based on greater energy efficiency and renewable energy alternatives [11–13]. Although half of the island's power is currently generated by coal-fired power plants, this unique European territory in the Indian Ocean has considerable potential for renewable energy generation (solar, marine, wind and biomass), and so is largely targeting developing these renewable energy sources to achieve its goal. Until recently, Reunion Island had

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implemented the GERRI project [14], Green Energy Revolution Reunion Island. This economic and social development program centered on the sustainable development of Reunion Island and resulted from the “Grenelle Environment” French environment roundtables. It established an energy self-sufficiency target for Reunion Island by 2030, by replacing fossil fuels with renewable sources. This project aimed to build a model of production and energy consumption by 2030 promoting all low-carbon innovations for integration into society by 2030; this included transport, energy production, storage and use, town planning and construction, and also tourism, with La Reunion aiming to develop an ecological tourism sector receiving 600,000 tourists by 2020. Reunion Island's plan for making its electricity system 100% renewable involved a multi-fold process. This ambition was established in the law "Grenelle 1" No. 2009–967, whereby the French Ministry of Ecology mandated in April 2009 that all new constructions in overseas departments must install solar water heating. Additionally, biomass was to gradually substitute coal, entailing the development of more fibrous sources of sugarcane, and thus an increase in the number of cane farms It was established that more hydropower and geothermal energy should enter the mix, accompanied by experiments on tidal power. These measures were also designed to help the island achieve its goal of satisfying all of its heating and cooling needs with renewable resources. The GERRI project was dissolved in 2013, but energy autonomy remains a challenge and a goal to reach, enshrined by the Energy Transition for Green Growth Act launched in France in 2015.

Achieving energy autonomy by 2030 will require a 100% renewable electricity mix by this date. Owing to its rich natural environment, this unique European territory in the Indian Ocean has exceptional potential for renewable power generation. Reunion Island is endowed with many types of renewable energy sources (RES) such as solar, wind, geothermal, sea energy (ocean thermal energy conversion and wave energy), biomass and hydropower. However, reaching this 100% renewable electricity mix will involve many structural changes in electricity production in a short time-frame. Hydroelectricity is the island's main renewable resource. It accounted for 17,2% of its total electricity production in 2015 (133,6 MW of installed capacity), spread over six sites in the eastern part of the island [2]. An additional capacity of 50 MW should be deployed by 2030 [15]. Reunion Island's biomass potential is considerable. The bagasse (sugar cane residue) resulting from the sugar cane industry is entirely energy-valued in two co-firing bagasse and coal power plants. Biomass will have to be largely deployed to substitute coal in the long term, which will entail the development of more fibrous sources of sugarcane, the reclamation of wood and green waste energy and the development of gasification technologies. Due to the island's location, solar energy is an abundant energy resource. Over the last ten years, a large increase of photovoltaic (PV) installations has been observed. The first PV systems set up were stand-alone systems specially in isolated mountain places that couldn't be easily connected to the grid. Nowadays, PV farms connected to the grid are developed mainly on the coastal part of the island due to its high solar potential. the PV farms are mainly set up on residential houses and industrial roofs due to landscape constraints. In 2015, the installed capacity of photovoltaic solar energy was 186,6 MW [2]. To meet the autonomy target, more PV farms connected to the grid will have to be developed [8].

The southeast and northeast regions of the island are suitable for wind power generation [8]. Currently, two wind farms are operating with a total installed capacity of 14,8 MW in 2015 [2]. The potential of wind power generation is estimated at 50 MW for the island. During the summer season the island is exposed to violent cyclones. Therefore, special wind turbines insured for cyclonic conditions (pull-down wind turbine technology) have been developed in the two farms. The investment extra cost and the non-exploitation during cyclonic winds thus limit the investment in wind power on the island despite an important potential on the coast [2,8]. Furthermore, several other renewable technologies will have to enter the mix, such as geothermal and marine energies. Research projects on marine energies are under development [8]. Ocean thermal energy conversion (OTEC) will have to be largely deployed as well as wave energy. Geothermal energy also has significant potential thanks to a high thermal gradient with the Piton de la Fournaise volcano. However, this potential is still under study as the volcano is located in a protected natural zone.

The high penetration of RES in the power mix raises key issues: What will be the cost of electricity autonomy by 2030? How will the significant deployment of intermittent energies affect the reliability of the electrical system? A quantification of these issues is useful to define a road map to meet the goal of electricity self-sufficiency. To address these issues, we have conducted a prospective analysis of the Reunion Island electricity system by 2030. The objective is to examine the changes in current production patterns in order to move toward a 100% renewable mix by 2030. The aim of this study is to evaluate the impact of differentiated large-scale integration of renewable energy on the composition of the electricity mix, the total additional cost to the system induced by this 100% renewable objective, and the effect of a limitation of intermittent penetration due to network reliability consideration. This analysis is conducted with the bottom-up energy model TIMES-Reunion [16–18]. The paper is organized as follows: Section 2 describes the model used for the analysis and the energy scenarios. Section 3 presents the results of the long-term modeling. The final section provides some concluding remarks.

2. Methodology and energy autonomy scenarios

2.1. The TIMES-Reunion model

This analysis was developed with the TIMES-Reunion model developed by the MINES ParisTech Centre for Applied Mathematics [16]. The TIMES model is a widely used, linear programming family model developed under the IEA's Energy Technology Systems Analysis Program (ETSAP). It is a bottom-up optimization model that offers a technology-rich representation of Reunion Island's electricity system [19–21], which it depicts with a detailed description of different primary energy sources, electricity production, transport and distribution technologies constituting the reference electricity system (Fig. 1). The RES network links these commodities to numerous technologies characterized by their economic and technological parameters in the power sector.

The time horizon of the model ranges from 2008 (reference year) to

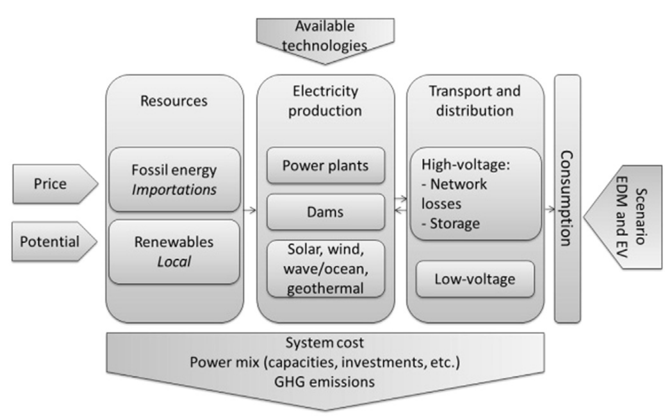

Fig. 1. Reunion island reference energy system.