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A life cycle assessment approach to the electricity generation of French overseas territories

Vanessa Rakotoson*, Jean Philippe Praene

Laboratory of Physics and Mathematical Engineering for the Study of Energy, Environment and Building, 117 Rue Du General Ailleret - P.O. Box 97430, Le Tampon - Reunion, France

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A B S T R A C T

Due to the high reliance on fossil fuels in the electricity production and transport sectors, completing the energy transition holds a particular importance for non-interconnected territories. The environmental impacts from electricity generation are mainly imputed to fossil fuel based technologies, for instance in the case of French insular territories. This paper summarizes the present electricity situation in these territories and aims to determine their different emissions and environmental impacts through a life cycle assessment (LCA) approach. To deliver 1 kWh of electricity to the power grid from the studied regions, the electricity mix is defined as the functional unit. The results refer to a life cycle cradle-to-gate electricity production model. The impact categories discussed in this paper are related to global warming potential, acidification potential, tropospheric ozone precursor potential, and the cumulative energy used. Due to its high share of renewable energies sources, French Guyana has the lowest greenhouse gases (GHG) emissions per kilowatt-hour produced compared to the other islands (373 g CO_2-eq/kWh, 4.29 g SO_2-eq/kWh and 2.65 g NMVOC-eq/kWh). Combined with other social, economic and environmental parameters, these results will be also used to determine the typologies of islands in order to define a common energy strategy for each group.

1. Introduction

Electricity production in France shows variation: in 2013, the mainland electricity mix was dominated by 74% nuclear and 13% hydroelectric, while French overseas departments and territories have an average coal and oil contribution of 73% (SOeS, 2015). This high share of fossil fuels in the energy mixes of these territories can be explained by the general disadvantages that insular areas face in relation to their remoteness and size (Erdinc et al., 2015). In order to overcome the environmental challenges in the current French energy transition policy, it is important to have an accurate overview of the existing production. This study seeks to analyze the individual electricity generation influence and the GHG emissions of each French department studied to define the path to achieving a low environmental impact in future electricity demand. Section 2 presents the electricity mix for each of the studied territories. Section 3 provides an overview the LCA method and the hypothesis tested. The results of the evaluation of emissions by energy source, energy mix and infrastructure are presented and discussed in Section 4. A classification of the studied territory using socio-economic and environmental criteria is presented in the last section.

2. Overview of the electricity sector

In a previous study, Notton provided the geographical locations of power installations in French territories and the average annual generation in 2012 (Notton, 2015). This paper focuses primarily on the following territories for the base year of 2013: Corsica, Guadeloupe, Martinique, Mayotte, French Guyana and Reunion Island. Remoteness implies an increase in the average supply distance of petroleum products. Fuel transportation is a major driving force for CO_2 emissions in the global LCA evaluation.

As can be seen in Fig. 1 and Table 1, only Corsica benefits from the network interconnection with Sardinia, which plays an important role in the supply/demand balance, particularly during high consumption periods. Martinique and Mayotte represent the French overseas territories (FOTs) that are the least developed in terms of renewable energy sources (RES) in the electricity mix, with

* Corresponding author.
E-mail address: vanessa.rakotoson@univ-reunion.fr (V. Rakotoson).

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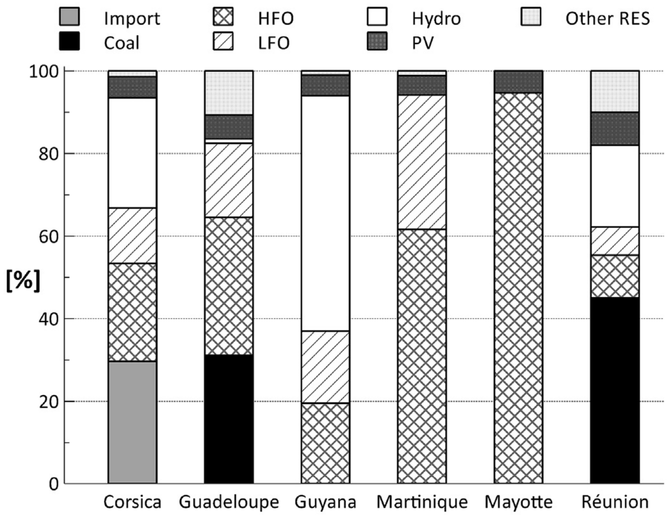

Fig. 1. Overview of the energy sources in the studied departments' electricity mixes. HFO: Heavy fuel oil; LFO: Light fuel oil. Other RESs include bagasse, biogas, biomass, and wind energy production.

95% of fossil-fuel and 5% of RES. The difference between the two situations lies in the contribution of wind energy and biogas production in Martinique. Recognizing their high potential for RES, Guadeloupe and Reunion diversified their mixes by integrating hydropower, solar energy, geothermal energy, biogas and bagasse (Praene et al., 2012; ADEME, 2014). However, the RES component of Guadeloupe's generation is half that of Reunion's. French Guyana is the only territory that has used 63% RES for its electricity production, mainly using hydroprower. Data in Table 1 will be used for the electricity generation GHG emissions assessment.

3. Materials and methods

To date, a significant number of LCA analyses examining electricity generation technologies (EGTs) at different levels are available in the literature. Studies provide range of values of GHG emission for different technology (Asdrubali et al., 2015) gives an overview of LCA results of renewable technologies (RETs) (Turconi et al., 2013) focused on 167 studies to provide a basis for making choices on technology and methodology approach. A comparison of the environmental impacts of fossil fuel-based technologies (FFTs) are presented by (Atilgan and Azapagic, 2015) in Turkey and (Tan et al., 2010) in Singapore (Ramjeawon, 2008) presents LCA results of electricity from bagasse in Mauritius, and (Silva et al., 2012) in Brazil. Comparisons between FFTs and RETs performed by (Hondo, 2005) in Japan or (Smith et al., 2015) in Singapore, can help select the most appropriate technologies for an electricity generation system. Papers also provide LCA results by country, as Mexico (Santoyo-Castelazo et al., 2011), Portugal (Garcia et al., 2014) or Greece (Theodosiou et al., 2014) (Herbert et al., 2016) developed a series of GHG emissions assessments for selected countries, from which four types of countries were identified. However, few papers concern islands (Brizmohun et al., 2015). This study will provide an initial evaluation of the environmental burdens of electricity generation in these FOTs and will enrich the literature review on LCA studies on insular territories. This work is conducted within the framework of cleaner production, because it shows the current status of the production mode of electricity in the French overseas territories. It helps to understand which part of the life cycle stage contributes the most in the greenhouse gases emissions. The energy balance report for Reunion in 2014 provided a comparison of FOTs by in the electricity and transport sectors (SPL Energies Réunion, 2015). However, the assessment methodology and the assumptions used are not explicitly mentioned.

3.1. Scope and system boundary

In this study, LCA is used to identify the environmental burdens and impacts throughout the electricity generation process. The LCA methodology applied here is regulated by ISO standards 14,040 and 14,044 (International Standards Organisation, 2006a,b). The study boundaries are from cradle-to-gate, including acquisition, transportation, infrastructure construction and electricity production. Transportation concerns the port-to-port carriage of direct-use energy. Fig. 2 represents the boundaries considered in energy production. The functional unit (FU) is defined by 1 kW-hour produced; in the rest of the document, we will denote an FU as 1 kWhe.

3.2. Life-cycle inventories and modeling

To identify the potential impacts, standard LCA software GEMIS version 4.9 and its database have been used and adapted here (Öko-Institut, 2015). Due to the lack of information about the efficiency of each power plant, the GEMIS database has been used. However, parameters such as transportation, scale, power generated have been adapted to the islands' conditions as a lack of information on islands' technologies has been identified as a limitation of the software. The proposed tool has been implemented in a MATLAB environment in order to link the LCA results from GEMIS software to an another energy scenario tool in a unique environment. Results can be treated as a method to highlight the most emissive life-cycle stage and also can be used as constraints in future scenario modeling research.

The MATLAB code was developed in two parts. First, GEMIS provides the data emissions of each electricity generation, through its life cycle: raw materials extraction and its necessary quantities to produce 1 kWh electricity, the existing means of transport, the infrastructure construction and the production. These data are then manipulated in MATLAB. Second, in line with the LCA methodology, several inputs are required: the total electricity production, the installed capacity, the distance of the raw material supply, and the mean of transport used. These data help to determine the quantity of the raw materials, the adapted emission factor (EF) related to the size of the installed power plant, and indicates the remoteness of the territory. The total emission E_{Tot} of the electricity mix of the studied territory is obtained by Eq. (1)

$$E_{Tot} = \sum_{i=1}^{n} E_{ext,i} + E_{trans,i} + E_{cons,i} + E_{prod,i} \quad (1)$$

where E_{ext} is the emission of raw materials extraction, E_{trans} the emission of the raw materials transport, E_{cons} the emission due to the construction plant, E_{prod} the emission due to the production operation, and i represents each power plant. For each technology and life-cycle stage inventory, the calculation of emission is based on the Eq. (2) principle:

$$E_{lcs} = \sum_{i=1}^{n} EF_i \times q_{p,i} \quad (2)$$

where E represents the emission value of the life cycle stage (extraction, construction, transport and production), EF the corresponding EF for 1 FU of the life-cycle stage and q_p the quantity of the product expressed in the FU. Fig. 3 illustrates the methodology used in this work and shows which parameters are considered in