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Assessing the life cycle environmental benefits of renewable distributed generation in a context of carbon taxes: The case of the Northeastern American market

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ABSTRACT

Distributed generation (DG) using renewable energy systems (RES) can play an important role in reducing greenhouse gas (GHG) emissions. Given that DG could overlap with carbon tax implementation, the objective of this work is to assess the implications of introducing different carbon tax levels (from 0 to 100 US$/tonne of CO_2) and to assess the GHG abatement performance when DG is applied.

To reach the paper objective, different levels of carbon taxes were assessed by using the developed partial equilibrium model for the North-eastern American electricity market. The developed model is crucial to (1) estimate the increase of the hourly market price for different carbon taxes scenarios, and (2) identify the hourly marginal electricity production technologies reducing its production as a consequence to DG.

Results show that the increase of carbon taxes significantly decrease the environmental benefits as a consequence of DG. When considering GHG emissions, the 30 kW micro-wind turbine efficiency gets from −6.3 to −3.8 kg CO_2 eq/kW h, when carbon tax increases from 0 to 60 US$/tonne CO_2eq (60% reduction). Same trend is observed for other environmental impacts, such as resource, human health and ecosystem quality. These results help in giving more insight on how two overlapping clean air policies interfere and how efficient they are in reducing GHG emissions at the same time.

Contents

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1. Introduction

Distributed generation (DG) from renewable energy systems (RES) can play an important role in meeting different energy policy goals, such as reducing greenhouse gas emissions. Given that DG arise amidst talks of implementing a carbon mitigation policy. Mitigation strategies often combine different policies to disincentive polluting technologies (e.g. carbon taxes) or incentivize desired but more expensive technologies (e.g. subsidies to production or feed in tariffs). However, the combination of different polices could result in desired or undesirable outcomes, depending on how policies interact [1,2].

To assess the GHG reduction behavior as a consequence to the deployment of DG when different carbon tax level could be implemented, Life cycle assessment (LCA) is suggested as the appropriate tool for such assessment. Indeed, using LCA will help to avoid any environment impact displacement from a life cycle stage (e.g. operation stage) to another (e.g. production stage) or from an environmental impact indicator (e.g. GHG emissions) to another (e.g. ecosystem quality) [3]. LCA researchers agree that there are two main approaches to life cycle assessment (LCA): attributional LCA (ALCA) and consequential LCA (CLCA) [3]. ALCA aims to describe the environmentally relevant physical flows to and from a life cycle and its subsystems [4], whereas, CLCA seeks to describe how environmentally relevant physical flows will change as a consequence of the analyzed decisions, such as RES incentives or carbon taxes implementation [5]. The distinction between ALCA and CLCA bring the issue of the choice of data [6]. Average data, used for ALCA, represent the average environmental burdens for producing a unit of good or service in the system [6], while marginal data, used for CLCA, represent the effects of a small change in the output of goods or services in the environmental burdens of the system [5]. In case of using RES or carbon taxes, the change in the output will be the displaced centralized electricity production (i.e. not produced due to this new change).

Until now, simplified approaches are taken to model marginal electricity production [5,7], often just considering a single marginal technology [8,9], even in cases where several are at the margin at different times. A stepwise procedure was proposed to avoid unjustified assumptions [10]. This procedure consists in determining the scale and time horizon of the studied change, the market delimitation and trend, the production constraints and the technologies most sensitive to change. Nevertheless, this procedure also only highlights one single marginal technology [10]. Earlier work has identified long-term marginal electricity production technologies for the Nordic and the German electricity systems as a function of time by using an energy system analysis model in combination with LCA [11,12]. Results from this work clearly showed how long-term effects include consequences for investments in multiple technologies rather than solely on one marginal technology. From a short-term perspective, the consequences of an increased RES production are likely to concern a mixture of technologies producing peak load and base-load electricity [5,7]. Power plants that turn on to provide power on the margin use different fuels types which change in time [7,13]. Despite frequent focus on the short-term perspective [10], LCA studies taking into account the time varying nature when modeling short-term marginal data for electricity supply are surprisingly missing from the literature. The few identified papers integrating such temporal aspects faced different limitations such as approximating the dispatch order of power plants [14] or not accounting for the energy flows between electricity markets [15,16].

The integration of the short-term dynamics of marginal technologies is important in refining the estimates when environmental impact abatements are assessed, as it is the case with the increased implementation of renewable portfolio standards [13], including DG, and will be even more important in case of overlapping with carbon taxes implementation. Recent work modeling DG life cycle environmental impacts using RES, and more precisely grid-connected photovoltaic panels and micro-wind turbines in the province of Quebec (Canada), showed the potential environmental impact abatements as long as Quebec adjacent electricity markets (i.e. Northeastern American market) are considered [17]. However, in the Northeastern American context RES are not profitable at current costs [18], thus the effect of carbon taxes is here analyzed. Studied RES would not be economically competitive even at high c. tax [18].

The purposes of the study is to take previous work one step further by assessing the environmental impact abatements of distributed generation (DG) using renewable energy system (RES) in a context of carbon taxes. More precisely, temporal variations of electricity supply are modeled and the results are used to estimate displaced types and quantity of fuel from the short-term marginal electricity production, and, thus, to assess the environmental impact abatements using RES and in a context of different carbon tax levels (from 0 to 100 US$/tonne CO_2eq). The obtained results will help in answering the following questions: What are the potential abatements in terms of environmental impact of the PV and micro-wind RES, when a time varying marginal electricity production technology is taking into account? And how do these estimates vary when increasing carbon tax levels?

The paper is structured as follows: The methodology section (Section 2) begins with (1) estimating the RES hourly production, and (2) their life cycle emission rates. The latter are also estimated for the centralized power plants composing the grid mix. The identification of the hourly electricity marginal technologies is also conducted (3) in the absence and (4) for different levels of carbon taxes. Finally, (5) the avoided emissions as a consequence of RES generation are estimated. The results section is divided into two parts. The first one describes the environmental impact abatements in the absence of carbon taxes and the second one in the presence of the carbon taxes. Conclusions and outlook are combined in Section 5.

2. Methodology

The assessment of RES environmental impact abatements for different carbon tax levels follows the proposed steps, explained in more details. First, hourly production of RES is determined. Second, life cycle emissions rates (from the production stage to end-of life) of different production technologies are assessed, using the IMPACT 2002+ method [19]. Afterward, marginal technologies for each Quebec's neighboring jurisdictions are identified on an hourly basis and for different carbon tax levels (from 0 to 100 US $/tonne of CO_2). To do so, a partial equilibrium model is developed. The last step of the method consists on subtracting from RES life cycle emissions the displaced centralized production emissions (marginal technology), to estimate the environmental impacts reductions (or increases).

This work considers both photovoltaic panels and wind turbines: mono- and poly-crystalline photovoltaic panels (3 kWp) with slanted roof mounting systems are selected because of their frequent installation as well as micro-wind turbines (1, 10 and 30 kW) including their respectively commonly used tower heights (10, 22 and 30 m).

2.1. Estimating RES hourly production

To assess the selected RES (i.e. micro-wind turbine and photovoltaic panels) environmental profiles, it is necessary to