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Research paper

The potential role of waste biomass in the future urban electricity system

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ABSTRACT

The share of intermittent renewable electricity (IRE) in the future urban electricity system is expected to increase significantly. Sufficient back-up capacity is needed in the period when IRE output is low. Bioenergy is both dispatchable and carbon-neutral, and can hence be a promising option to back up IRE. The objective of this study is to explore the potential of urban waste biomass in backing up IRE in an urban electricity system. An urban electricity system model is developed to project future electricity generation configurations. Given the projected electricity generation configuration, the potential demand for bioenergy as back-up capacity is estimated by simulating hourly electricity demand and the supply of IRE for a whole year. The estimated potential demand for bioenergy is then compared with the potential supply of bioenergy from the urban waste stream. We apply our model using data for the city of Amsterdam, the Netherlands. The complementarity of wind and solar energy is found to reduce the demand for back-up capacity from bioenergy. An extreme weather day with hardly any wind and solar energy supply requires about 2800 tonne waste biomass per day in an emission reduction scenario and 1300 tonne waste biomass per day in a renewable energy quota scenario, respectively. The average daily waste biomass generated in the city is about 1400 tonne. Bioenergy storage as a buffer is found to be necessary due to the monthly fluctuations in both the supply and demand of waste biomass.

1. Introduction

The Paris Agreement set a target of achieving a global net-zero carbon economy within this century [1]. The transition of urban electricity systems, as part of the low-carbon city development, is essential in cutting carbon emissions, since cities account for 75% of global energy consumption and 80% of global greenhouse gas (GHG) emissions [2]. An urban electricity system can be defined as a system that combines different processes of electricity production to meet the electricity demand of a given urban area [3,4]. Megacities in the world are leading the transition and taking actions to reduce GHG emissions (e.g. the formation of C40 Cities, which is a network of the world's megacities taking actions to reduce the emissions), to achieve sustainability, self-sufficiency and climate-resilience. The share of intermittent renewable energy (IRE) is expected to increase significantly in a decarbonized urban electricity system. The consequence is that in the period when the IRE output is low, sufficient back-up capacity is required to meet the demand. According to [5], the increasing penetration of intermittent renewable energy will lead to an increasing demand for grid balance. Flexible bioenergy supply has the potential to contribute to grid balance and decarbonization considering its advantages in being both dispatchable and carbon-neutral [6–8].

An open question is how much bioenergy will be required as back-up capacity in the future electricity system of cities. It is of high interest to answer this question in order to make robust energy policies and strategies. The future demand for flexible bioenergy will be affected by renewable energy policy measures. Currently, in some regions inconsistency between the renewable energy policy ambitions and biomass availability exists [9]. Furthermore, strategies for securing a sustainable biomass supply are absent from most national strategies [10]. A related question is how much back-up capacity can be obtained from the urban waste stream. There is an increasing interest in developing biomass feedstock from the urban waste stream to avoid the food versus fuel trade-off [11] and the sustainability disputes of first generation bioenergy [12,13]. Furthermore, using biomass from the waste stream for electricity generation can contribute to more effective urban waste management. In this paper, biomass feedstock from the waste stream will be addressed as ”waste biomass”. Waste biomass in cities includes the organic part of municipal solid wastes, urban green residues, food processing wastes and manures.

The objective of this paper is to develop a framework to assess the low-carbon electricity system for cities and the potential role of waste biomass in backing up intermittent renewable energy. We apply the

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framework using data for the city of Amsterdam, the Netherlands. The research questions studied in this paper include: (1) What are low-carbon electricity generation configurations in Amsterdam in 2050? (2) What is the required back-up capacity in the urban electricity system for these low-carbon scenarios? (3) How much of this back-up capacity can be obtained from the urban waste stream in the city?

This paper contributes to the biomass and bioenergy literature by using an energy system modelling approach to provide insights into the potential of bioenergy from urban waste streams in balancing the future electricity system. The novelty added is the focus on the city level, and the linking of demand for bioenergy to the biomass availability in the urban waste stream. The methodological framework and analysis can support policy-makers in cities in making robust policies and strategies and in avoiding inconsistencies between urban bioenergy policy ambitions and local biomass availability.

From the biomass resource availability perspective, a number of studies have estimated the bioenergy potential at the global level [14–17]; the regional level, such as the EU [18]; or the national level [19–21]. Only a few focused on the city level [22–24]. The link to the demand for bioenergy from the urban electricity system has not yet been studied. The potential of bioenergy has been analysed using a cost-supply analysis [25,26] or an energy system modelling approach [27–29] at regional level (e.g. the EU) or national level. To the best knowledge of the authors, no study has investigated the bioenergy potential from the waste stream on a city level using an energy system modelling approach.

The rest of this paper is structured as follows: Section 2 introduces the research method. Section 3 gives an overview of the data required and introduces the case study of Amsterdam. Sections 4 and 5 introduce the model scenarios and present results. Section 6 and section 7 give the discussion and the conclusions, respectively.

2. Methodology

2.1. Methodological framework

Fig. 1 shows an overview of the methodological framework. First, a cost minimization electricity system model is developed to project the future electricity generation configuration for cities. The structure of the developed model shows strong similarities to other long-term energy system investment models such as MARKAL [30], HOMER [31], Balmorel [32], and LIMES-EU [33]. Our model can be applied for the questions at stake because it focuses on cost minimization from a social planner's perspective. It has limitations because the setting of energy provision in Amsterdam, and in cities in general, is currently much more complex than the setting of the model. Despite this, our paper contributes to understanding the potential role of biomass in the energy system. Our model adds the vintage concept to indicate the effect of embodied and disembodied learning on the cost parameters of the electricity generation technologies. The learning effect is given exogenously in the model.

Second, three scenarios are developed to analyse the effects of different climate and energy policy goals on future electricity generation configurations with our electricity system model. A detailed introduction of the scenarios is presented in section 4.

Third, given the projected electricity generation configurations, the daily demand for bioenergy as back-up capacity for extreme weather days is estimated by simulating the hourly electricity demand and hourly supply of intermittent renewable energy in the future, using data for the city of Amsterdam, the Netherlands. Similarly, the annual demand for bioenergy as back-up capacity is estimated by simulating the hourly electricity demand and the supply of intermittent renewable energy for a whole year.

Finally, waste biomass flow data have been collected for the city of Amsterdam. We use the higher heating value (HHV) to calculate the bioenergy supply potential from the urban waste stream. The estimated potential demand for bioenergy is then compared with the bioenergy supply potential from the urban waste stream.

2.2. Model description

The urban electricity system model generates the optimal electricity technology investment and generation configuration by minimizing the urban electricity system cost. The system cost includes the investment cost, operation and maintenance cost, fuel cost, and the trade cost of importing and exporting electricity. We assume that the salvage value of the energy generation infrastructure can offset the dismantling cost of the old power plants. Therefore, the decommissioning cost is not

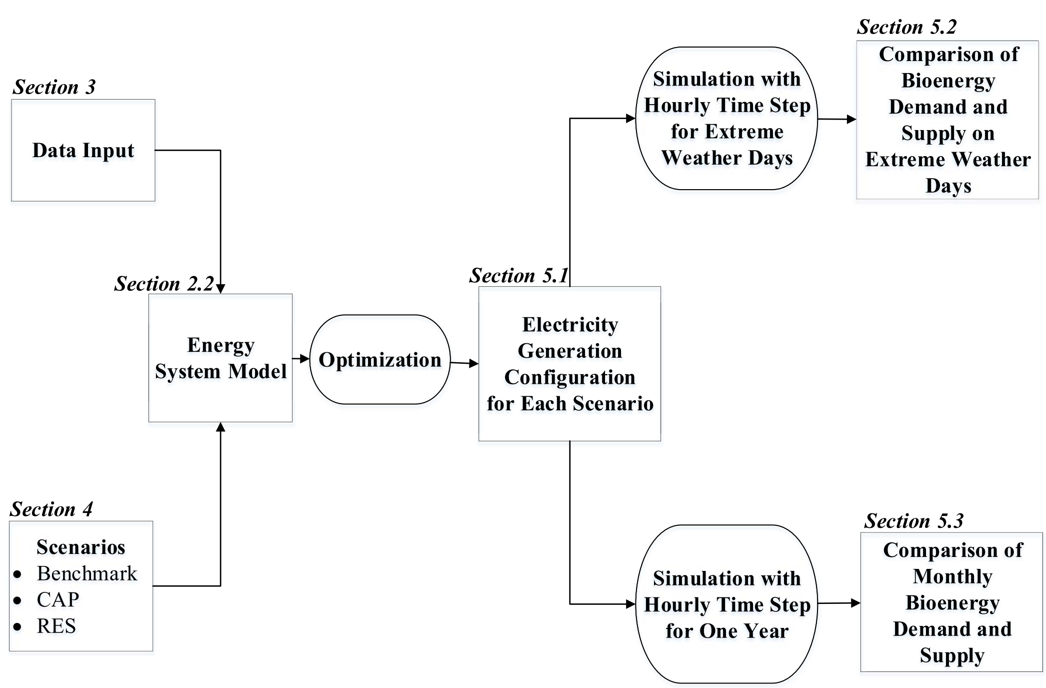

Fig. 1. Overview of the methodological framework.