HOW CAN FLEXIBILITY OF BIOENERGY PLAY A ROLE IN FUTURE URBAN SMART GRIDS?

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Overview

In many cities that are pursuing low-carbon and sustainable development, urban energy systems are in a transition to reduce greenhouse gas emissions, to improve system reliability, and to increase local energy production. This transition contributes to the decarbonization target set in the Paris Agreement. Increasing proportion of renewable energy has been observed in the past decade. This poses challenges to system integration and stability, because of the intermittent nature of wind and solar energy. A smart grid will be a key element in the future urban electricity system for integrating more intermittent renewable energy, and for balancing supply and demand. By integrating information and communication technologies into local energy systems, consumers on the demand side that are conventionally inactive as suppliers in the electricity market are able to participate, both as producers and consumers of electricity. For example, smart grids enable prosumers (i.e. consumers who can produce their own electricity) to have peer-to-peer exchange in a local community.

Bioenergy has the potential to be both dispatchable and carbon-neutral. A smart bioenergy concept has been recently proposed aiming at a more flexible bioenergy provision in the future instead of today's continuously operated bioenergy plants (Thrän, 2015). Biogas is a versatile form of bioenergy, as it can be produced from a range of feedstocks and utilised in all energy sectors. Currently in the EU, about 69% of biogas is produced by anaerobic digestion of feedstock such as agricultural, industrial or household wastes and energy crops (Kampman et al., 2016). The use of biogas contributes to the EU's decarbonisation, renewable energy and energy security objectives. Biogas is highlighted as a key technology in the future for controllable electricity generation and can play an important role in the future urban smart grids (Häring et al., 2012). However, the use of biogas, or bioenergy in general, for flexible power generation is often overlooked in studies of smart grids. It is therefore necessary to study how flexibility of bioenergy can contribute to system integration and balance in future urban smart grids. In this study we are specifically interested in the potential role of a biogas plant that uses anaerobic digestion (AD) and combined heat and power (CHP) technology in future smart grids. We study the potential role of a biogas plant that will use biomass feedstock from the urban waste stream, because it also improves resource efficiency and facilitates the development of a circular economy.

The objective of the study is to explore the future role of the flexibility of such a bioenergy system in solar energy driven urban smart grids. A key research question answered by this paper is "What are the effects of flexibility of a biogas plant based on AD and CHP technology on the system stability of future urban smart grids?" The results of this study are useful for the current debate on the urban energy system transition, not only for cities in the Netherlands, but also for other cities in the world.

Methods

Agent based modelling was used to simulate an urban smart grid. We conducted our study with an illustrative case based on data from the city of Amsterdam. The description of the agent based simulation follows the Overview, Design concepts, and Details (ODD) protocol (Grimm et al. 2010). The agents include households that consist of both consumers and prosumers, and a biogas plant to back up the grids when the solar PV generation cannot meet the demand. Some prosumers only have PV systems. Other prosumers have also private battery storage with their PV systems. Stochasticity and heterogeneity of electricity demand and solar energy production are taken into account. For uncertainty quantification, we run simulations in a reasonable range of parameter values (e.g. the share of households with PV systems). We developed four scenarios to take the possible combination of technological and market options into consideration.

Scenario 1 represents a situation where prosumers have PV panels for self-consumption but without storage capacity and peer-to-peer exchange with neighbours. In this scenario, all surplus electricity is assumed to be fed into the external grids. In Scenario 2, households combine PV systems with battery storage. The surplus production of the PV panels feeds into the battery storage to a maximum charge, and then to the external grids. Electricity consumption is first satisfied by real-time solar energy production, then by discharging the battery storage, and then by bioenergy production from the biogas plant, and lastly by external grids. Households are operating individually and no local electricity exchange is included in this scenario. The peer-to-peer exchange is included in Scenario 3, but battery storage is excluded. The peer-to-peer exchange means that the surplus electricity from a prosumer is delivered to neighbours demanding electricity. Scenarios 4 combines battery storage and peer-to-peer exchange. All households prefer peer-to-peer exchange to the energy supply by the biogas plant in Scenario 3 and 4 because in this way the utilization of energy produced within the community is increased. Two operational modes (i.e. baseload and flexible mode) of the biogas plant were modelled in each scenario to make a comparison.

To make a comparison and to assess the usefulness of the flexibility of a biogas plant in urban smart grids, we used an indicator that calculates the yearly reduced variance of the electricity imported from external grids (RVEI) when flexibility of the biogas plant is introduced to replace the baseload operational mode. A larger value of RVEI indicates that the biogas plant has a larger impact on the system balance and stability, as it reduces the pressure on the external grids.

Results

As shown in Table 1, the flexible operational mode of the biogas plant significantly reduces the variance of the electricity imported from external grids, which indicates that the system stability is significantly enhanced when flexibility of bioenergy is introduced into urban smart grids. The values of the RVEI indicator are higher in Scenario 3 and 4 when compared to Scenario 1 and 2. The difference is the inclusion of peer-to-peer exchange in Scenario 3 and 4. Therefore this result shows that flexibility of the biogas plant has a larger impact on the system stability when the peer-to-peer exchange is introduced in urban smart grids.

Table 1 Yearly reduced variance of the electricity imported from external grids (RVEI) for 4 scenarios.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
RVEI percentage	94.3%	95.1%	96.6%	96.1%

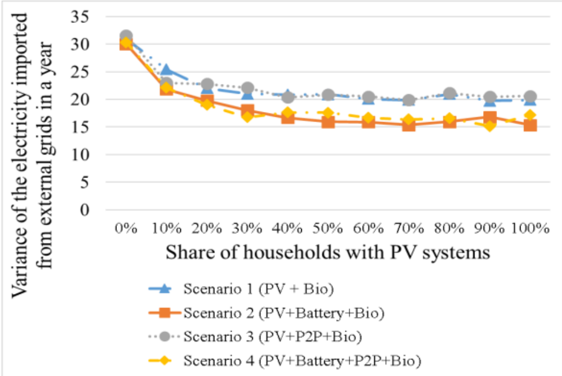

Figure 1 Variance of the electricity imported from external grids in a year, when flexible operational mode of the biogas plant is introduced in four scenarios, respectively.

Figure 1 shows the variance of the electricity imported from external grids in a year, when flexible operational mode of the biogas plant is introduced in each scenario. When comparing Scenario 1 with Scenario 2, or Scenario 3 with Scenario 4, it was found that adding battery storage to the system increases the system stability; while when comparing Scenario 1 with Scenario 3, or comparing Scenario 2 with Scenario 4, it was found found that adding peer-to-peer exchange (i.e. P2P in Figure 1) hardly affects the system stability. This indicates that there is a synergy between battery storage and flexibility of bioenergy. But no interaction effect was found between peer-to-peer exchange and flexiblity of bioenergy.

Conclusions

Our findings show that flexibility of the biogas plant has a larger impact on the system stability when the peer-to-peer exchange is introduced in urban smart grids. A synergy was found between battery storage and flexibility of bioenergy. But no interaction effect was found between peer-to-peer electricity exchange and flexiblity of bioenergy.

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