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Distributed Urban Energy Systems (Urban Form, Energy and Technology, Urban Hub)

Comparison of individual and microgrid approaches for a distributed multi energy system with different renewable shares in the grid electricity supply

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Abstract

The transition to 100% renewable energy systems is an important factor in the transition to sustainable energy systems. A top-down approach is often used to study the design of such energy systems on a country or continental scale. Results of these studies are useful for developing energy roadmaps but they lack the details about how distributed multi energy systems should be designed and operated at local level. An optimisation model of distributed multi energy systems is applied in order to investigate how urban districts should be optimally designed in the (near) future when the goals of energy roadmaps are achieved. The impact of individual and microgrid approaches on distributed multi energy systems is analysed on an urban district level for scenarios with different levels of renewable energy in the electricity grid supply.

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Keywords: multi energy systems, optimization, distribution grid, district heating

1. Introduction

The transition to 100% renewable energy systems is an important factor in making energy systems sustainable. The transition path towards 100% renewable electricity supply has been analysed for many countries such as Denmark [1], Portugal [2], Macedonia [3], Croatia [4], China [5], and New Zealand [6]. A top-down approach is often used to study

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the design of energy systems with 100% renewable electricity supply on a country or continental scale. Results of such studies give the optimal energy mix of different energy sources and are useful for developing roadmaps and energy policies for the cost effective transition to decarbonized energy systems. However, it lacks the information about how energy systems in urban areas should be designed and operated, and their impact on the low level networks such as distribution grid and district heating.

In most of the studies, the customers are assumed to be *individual* (passive) users where they only satisfy their individual demand. However, the future of power systems likely lies in the implementation of *microgrid* concepts which will additionally increase the complexity of designing and operating distribution grids. A *microgrid* is defined as a network structure based on the control of all aspects related to the network operation (distributed generators, storage devices, controllable flexible loads, etc.) at the distribution level, which allows the network to coordinate efficiently all its resources as if it was a single energy system [7]. With customer involvement it can improve the overall energy efficiency and reliability of the grid, and decrease energy consumption [8].

In this paper the impact on energy systems of different levels of renewable energy in the electricity grid supply is analysed on district scale (at the low voltage distribution grid level). We examine how urban districts should be optimally designed in the (near) future when the goals of energy roadmaps are achieved. The main goal of the analysis is to compare the differences in the design and operation of distributed multi energy systems for two approaches – individual and microgrid.

2. Model and case study

The optimisation model used for the analysis can simultaneously determine the optimal design and operation of a multi energy system (with district heating network layout and electrical distribution grid upgrades needed) while ensuring that the solutions are within the distribution grid limits using linearized AC power flow. The considered technologies are combined heat and power (CHP), photovoltaics (PV), heat pump (HP), gas boiler and heat storage. The model is based on the energy hub modelling approach [9] extended and applied to buildings, and coupled with electrical distribution grid and district heating model. The optimisation is performed for two objectives– cost (investment plus operational) and carbon emissions for a given electricity renewable share. For more details about the model, the reader is referred to Morvaj et al. [10].

The optimisation is carried out for the current individual and the future microgrid approaches as shown in Fig. 1. In the individual approach the buildings are owned by different owners, and minimize their own individual objective(s). The electricity demand is met at the building level and the buildings cannot share directly electricity between each other. In the microgrid approach all buildings are owned by the same owner and buildings have common objective(s). The electricity demand is summed over the whole district and only the flows leaving the microgrid boundary are accounted for. In this way buildings can share the electricity between each other and utilize it more efficiently.

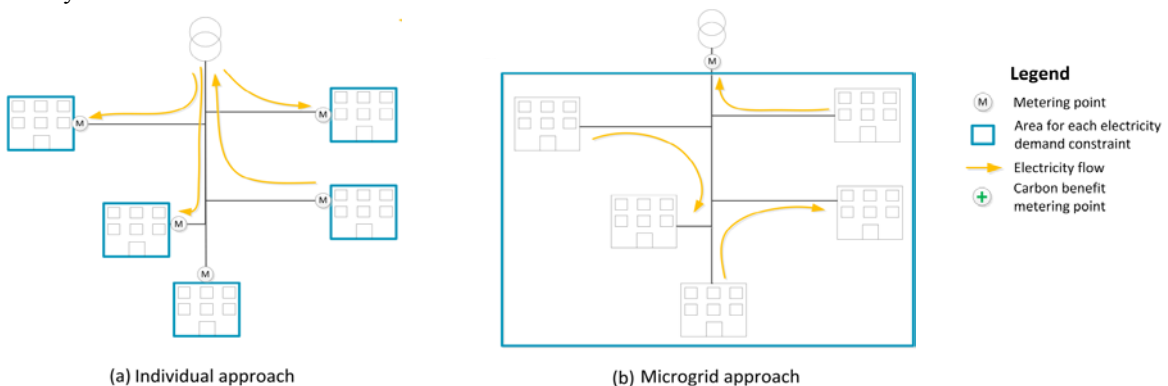


Fig. 1 Graphical representation of (a) individual and (b) microgrid approach

The model was applied to a large urban case study which is based on the IEEE Low Voltage Test Feeder case [11]. It consists of 55 residential buildings and a radial network with 4 branches. In order to reduce the computational complexity, buildings that are connected to the same grid connection point were aggregated. As a result the case study has been reduced to 37 residential buildings connected by a three phase low voltage (0.4 kV) radial distribution grid. The grid is assumed to be balanced and the mutual impedances are taken as zero.

The line parameters are shown in Table 1 for the reference grid and the upgraded grid. The cost of upgrading the grid is assumed to consist of the cost of reconductoring (80 €/m) and the cost of upgrading the transformer (21'000€ for 630 kVA) [12].

Table 1 Line parameters for the low voltage distribution grid

Grid	Cable type	Resistance R_{ph} (p.u./ km)	Reactance X_{ph} (p.u. / km)	Ampacity (A)
Reference	70 AL	0.8431	0.1342	160
Upgraded	300 AL	0.1890	0.1300	465
S_{base}	100 kVA	V_{base}	0.23 kV	

The current level of renewables in the electricity grid in the EU is 25% [13]. It is reasonable to assume that the transition to a 100% renewable system will be gradual and that new energy systems will be built before achieving the goal. As a result, a number of scenarios have been defined with increasing renewable energy shares in the electricity supply - 40%, 55%, 70%, 85%, 100%. As the renewable share gets larger, the carbon factor of the electricity supply gets smaller; it is assumed that the carbon factor of the grid supply remains constant within each scenario. The first scenario evaluates the current state (25%) as a reference point. The carbon factor of the grid electricity at the current state in Europe is 0.5 kg CO₂/kWh [14]. For other scenarios the carbon factor is incrementally decreased to 0 kg CO₂/kWh which corresponds to a 100% renewable share. This provides an insight into how the energy systems in cities should be designed as the integration of renewables increases as defined by various energy roadmaps. The carbon factor of natural gas is 0.2 kg CO₂/kWh [15] and is constant for all scenarios.

3. Results

The individual and microgrid approaches have been compared in terms of the total cost for different carbon emissions, overall design, and minimal achievable carbon emissions with and without the grid upgrade.

Fig. 2 shows the total cost for common carbon emissions limits for both approaches for all scenarios. The percentage difference between the total cost of the approaches is shown as an orange line. It can be seen that the difference in the 25% and 40% scenarios is the biggest, followed by the 55% scenario. In the 25% and 40% scenarios, the difference is the biggest in the (near) carbon optimal solutions (up to 20%) and then gradually decreases as the carbon emissions increase. This is due to the fact that in the microgrid approach less PV is needed to achieve the same decrease in the carbon emissions as the exported electricity can be used by all buildings in the district. In the cost optimal solutions PV is not used as much, hence the difference is lower. In the 55% scenario, the difference is lower in the 160 tCO₂/y solution than the 175 tCO₂/y solution. The reason is that in this scenario the carbon factors of the natural gas and grid electricity are the same (0.2 kg CO₂/y), so the carbon optimal designs are similar (mostly based on the PV and HP). In the 175 tCO₂/y solution it is still possible to use CHP in the microgrid approach, which decreases the operational costs. In the remaining scenarios the difference is not so big with the difference being largest in the carbon optimal solution. This is again the result of microgrid's opportunity to exchange the electricity locally between buildings.

Fig. 3 shows the comparison of installed capacity of HP, CHP and PV for the 25%, 70% and 100% scenarios. The capacities are summed over the whole district and plotted for the common carbon emissions limits of the individual and microgrid approaches for all scenarios. Looking at HP capacities, it can be seen that less HP is needed for the same carbon limits in the microgrid approach than the individual approach. This is because of the ability to share electricity within the district in the microgrid approach, which makes the system more efficient. In the individual approach more HP capacity is needed so that the excess PV electricity is used as much as possible (more PV electricity is needed than in the microgrid approach). In the scenarios with 70% and greater renewables share the difference decreases as the PV electricity is not that crucial anymore for decreasing the carbon emissions. The only exception is the carbon optimal solution for 100% scenario (0 tCO₂/y) where HP capacities are the same in both approaches since it is the common lowest achievable carbon emissions point and the heating is electrified in both approaches.



Fig. 2 Total cost for the individual and microgrid approaches for different carbon limits for all scenarios.

CHP capacity is similar in both approaches for the 25% scenario since the grid is more carbon intensive than natural gas and the design is predominantly CHP based (CHP has positive impact on both economic and environmental aspects). In the 70% scenario CHP capacity is higher in the microgrid approach. The reason is that the excess electricity from CHP can be used by other buildings and PV electricity can be used to meet a larger share of the electricity demand locally without importing electricity from the grid to offset the carbon negative impact of CHP, which is economically preferable. PV capacity is installed less in the microgrid approach since less PV electricity is needed for the same emission limits due to the excess generated electricity that can be used by other buildings in the district. The exception is the 100% scenario where the installed capacities are roughly the same because the grid is carbon neutral and PV is not needed for decreasing carbon emissions but only if it is economically beneficial.

The minimum achievable carbon emissions for the individual and microgrid approaches for all scenarios are shown in Fig. 4; categories are different renewable energy shares and the variables are carbon emissions for the individual and microgrid approaches. They are shown for the case without grid upgrade (a) and with grid upgrade (b). In both cases the minimum carbon emissions are lower for the microgrid approach for all scenarios except the 100% scenario. The microgrid approach has lower emissions because exported electricity from CHP and PV can be used by other buildings in the district which increases the local utilization. In the 100% scenario, there is no difference because the electricity from the grid is carbon neutral so the carbon optimal solutions are based on importing electricity from the grid and using it for HP to meet the heat demand.

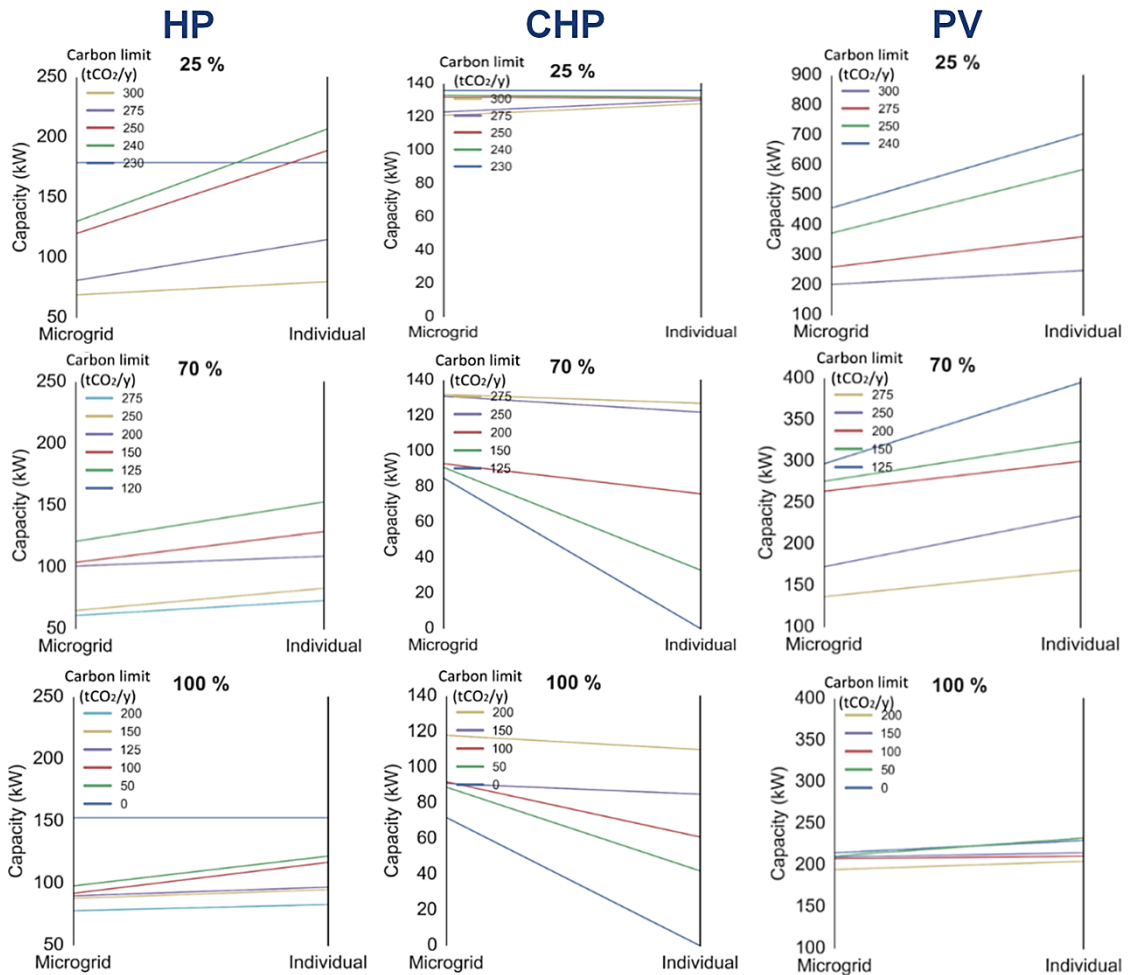


Fig. 3 Comparison of total installed heat pump, combined heat and power and photovoltaics capacities for different carbon limits for individual and microgrid approaches.

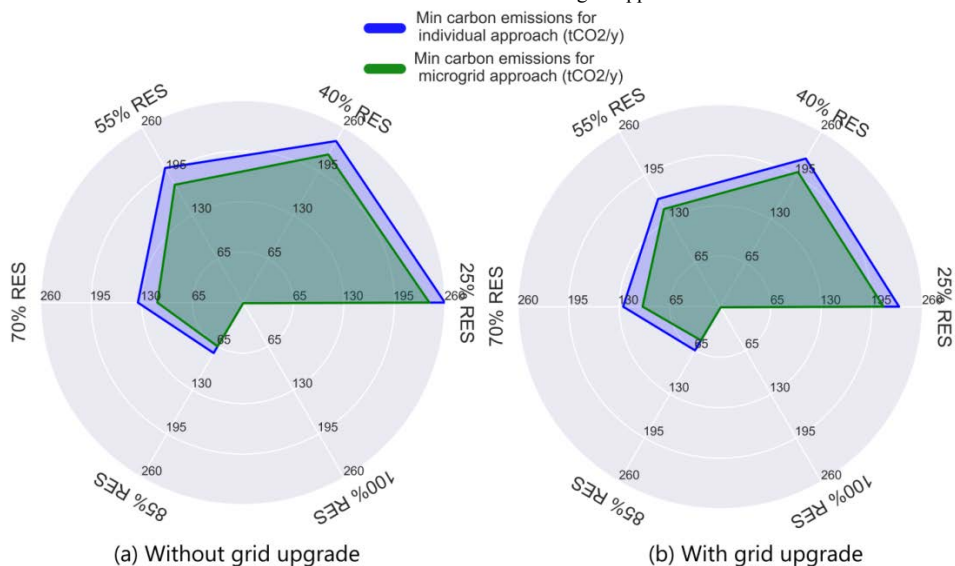


Fig. 4 Minimum achievable carbon emissions for both approaches without grid upgrade (a) and with grid upgrade (b) for all scenarios.

4. Conclusion

The optimisation model of distributed multi energy systems has been applied to an urban case study for different renewable shares in the electricity grid, and the differences between individual and microgrid approaches have been compared. Overall the microgrid approach has better performance than the individual approach. The installed capacity of heat pumps is generally lower in the microgrid approach because PV electricity can be more efficiently used, and smaller HP capacities are needed to transform excess electricity into heat and store it in the heat storage. When the grid is more carbon intensive than the natural gas, CHP is equally used in both approaches since it has positive impact on both economic and environmental objectives. However, when natural gas is more carbon intensive, CHP is used more in the microgrid (even though it increases the emissions it is still economically preferable option) since PV electricity can satisfy a larger share of the electricity demand of the district. The installed PV capacity is smaller in the microgrid approach because of the microgrid's opportunity to exchange electricity between buildings. Only in the 100% scenario are capacities roughly the same.

The total cost of the microgrid approach is generally lower for the same carbon limits because less PV is needed to achieve the same carbon emissions. The difference is most significant in (near) carbon optimal solutions when this PV benefit is most expressed. As for carbon emissions, microgrid approach can achieve smaller emission both with and without grid upgrade. Only in 100% scenario there is no difference because the grid is already carbon neutral. In summary, the results show significant between approaches, and it is necessary to carefully select the approach for which the energy strategy will be based on.

Acknowledgements

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