Distributed Energy Resource Adoption for Campus Microgrid

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Abstract—Security of energy supply and energy efficiency are challenges for many university campuses. Campus microgrid with distributed energy resources is considered as a solution for solving these challenges. However, the microgrid adoption for university campuses has to consider various factors due to the cost of DER installation and operation, campus activities and energy regulation etc. This paper investigates the possibility and feasibility of microgrid adoption for a university in Denmark, by analyzing the electricity and heat consumption patterns, the capacity of existing installed DERs, and the benefits and barriers for future installation of possible DER technologies. Based on this analysis the paper proposes three energy scenarios with different potential DER solutions, and provides simulations for investigating the energy balance and economic feasibility of each scenario.

Keywords—campus microgrid, distributed energy resources, DER adoption

I. INTRODUCTION

A microgrid acts as a single controllable entity and can operate in both grid-connected or in islanded mode [1]. Microgrid components include: distributed energy resources (including both energy storage and generation), control and management subsystems, secure network and communications infrastructure, and assured information management [2]. Microgrids allow a better synergy between an electricity grid and renewable energy sources, it can be considered as a sustainable solution for a cluster of buildings with large energy consumption.

University campuses consume large amounts of energy including electricity, heat, and hot water for educational, research, and administrative activities. Security of energy supply and energy efficiency are challenges for many university campuses. With the development of energy technology and Danish government goals of reducing 2% of university campuses’ energy bill each year, universities consider campus microgrid with DERs (distributed energy resources) as a solution, especially since a majority of campus buildings are equipped with building control systems in Denmark.

DERs operating within a microgrid are a viable energy efficiency option and have the potential to greatly improve the grid reliability issues [3]. Renewable energy resources usually are the form of small wind or solar plants, waste-to-energy, and combined heat and power systems. However, the DER adoption for university campuses has to consider various factors due to the cost of DER installation and operation, campus activities and energy regulation etc.

Therefore, this paper aims to investigate the possibility of DERs and feasible adoption for a selected university campus in Denmark. This paper firstly starts with an investigation of the electricity and heat consumption patterns at the selected campus, as well as an analysis of the existing DERs installed on campus to examine the possibility of installing additional DERs. Secondly, the paper explores possible technologies for future DER installation with benefits and barriers. Lastly, several energy scenarios are set up to investigate the feasibility as well as the energy balance with different potential DER solutions.

To analyze optimal solutions that might mix multiple generation technologies for different scenarios, the program DER-CAM (Distributed Energy Resource- Customer Adoption Model) is employed. The program has been developed by The Lawrence Berkeley National Laboratory since 2000. It is a decision-making tool that helps to select an optimal investment mix for a number of different DER technologies in microgrids or buildings/facilities, including solar panels, solar heating, wind power, heat pumps, onsite batteries, electric vehicle battery employment as well a number of conventional, fossil-fueled generation technologies. District heating is also supported, although a few workarounds are required.

DER-CAM attempts to find an optimal solution by minimizing two objectives (CO2 footprint and economic cost) that relative weightings can be adjusted according to the purpose of a study. The optimization in this paper only focuses on the economic cost and does not put weight on CO2 emissions because there are no conventional fossil-fueled technologies considered in this project [4, 5].

The work-flow in this paper is structured in the following way:

- Gather and prepare data regarding heat and electricity consumption patterns at the selected campus.
- Gather and prepare data regarding existing DER installations/services at the selected campus.
- Identify a number of potential technologies that might be usable in the DER mix at the selected campus.
- Consider the feasibility of those technologies to make decisions for DER adoption.
- Gather all relevant parameters and information for the selected DER solutions in the DER-CAM optimization.
• Run the optimization for the pre-defined energy scenarios and attempt to find the best investment decision from an economic point of view

II. ENERGY CONSUMPTION FOR THE SELECTED CAMPUS

A. Electricity Price and Price structure

In Denmark, universities can negotiate electricity price with electricity retailers. For instance, the electricity price (Fast Pris) for the selected campus is 0.2979 DKK/kWh. The payment for the distribution (Transportbetaling, dit Lokale netselskab) is 0.07 DKK/kWh and the subscription to the distribution company (Abonnement, dit Lokale netselskab) is 824 DKK per month. The transmission payment (Transportbetaling, Energinet), the system payment (Systembetaling, Energinet) and the PSO-tax are 0.038 DKK/kWh, 0.042 DKK/kWh and 0.149 DKK/kWh. The fee for the actual consumption (Gebyr på faktisk forbug, Energinet) is 0.0014 DKK/kWh. The electricity tax (El-a gift, Staten) is 0.914 DKK/kWh and part of it can be refunded. The VAT is 25%, but all of it is refunded partly by SKAT and partly by the Ministry of Education.

B. Electricity Consumption

The electricity consumption for the campus in 2016 and 2017 is shown in Fig. 1. The average annual electricity consumption for 2016 and 2017 was 14,246,000 kWh. The lowest consumption for one hour during 2016 and 2017 was 1012 kWh, and the highest consumption was on 2876 kWh. The reason for a high minimum consumption is because the activities on campus are constant, such as supercomputers, laboratory processes, server rooms and ventilation.

III. EXISTING DISTRIBUTED ENERGY RESOURCES AT CAMPUS

Photovoltaics have been installed on the rooftops of the selected campus for several years and more photovoltaics are expected to be installed after 2018. However, this is the only existing DER at the campus at this moment. The electricity production of the existing photovoltaics is analyzed in this section to investigate the influence on the electricity consumption pattern.

A. Electricity Consumption and Production in 2016 and 2017

Fig. 3 shows the electricity production from the photovoltaics at the campus in 2016 and 2017. Both the production pattern and the average production curve show the differences among seasons. The blue curve shows the hourly production in 2016 and 2017. The annual production in 2016 from the photovoltaics was nearly 342,000 kWh and around 320,000 kWh in 2017. The hourly production has not exceeded a total production of 280 kWh.

B. Photovoltaics Installation in 2018

At the end of 2017 and at the beginning of 2018, a large number of new photovoltaics was installed at campus. The expected annual electricity production from the total photovoltaics is 555,000 kWh.

The electricity consumption subtracted the total electricity production from the photovoltaics at the campus is shown in Fig. 4. The amount subtracted has been calculated by taking the production ratio between the existing photovoltaics (the average of 2016 and 2017 is on 331,000 kWh) and the newly installed photovoltaics (with the annual production of 555,000 kWh). The highest hourly consumption with subtracted solar production is 2716 kWh, and 581 kWh for the lowest hourly consumption.
IV. IDENTIFICATION AND ANALYSIS OF POTENTIAL DER TECHNOLOGIES

Several technologies of distributed energy resources can be considered for sustainable campuses, such as wind turbines, photovoltaic panels, electric vehicles, and heat pumps. Each technology has its benefits and disadvantages. It is important to investigate the disadvantage barriers of potential DER technology adoption for the campus microgrid.

A. Photovoltaics

Photovoltaics is already a much-used technology at campuses because of its easy installation on rooftops and the rapidly decreasing price. Photovoltaics is undoubtedly still one of the most viable technologies in the future. Bloomberg NEF expects the price of photovoltaics to fall by 34% in 2018, and it could be a great opportunity to increase the installation of photovoltaics if there are rooftops available on campuses [6]. Meanwhile, the surplus electricity by photovoltaics can be sold back to the electricity grid. Currently, the selected university campus in this paper belongs to the net settlement group 5 which means that no money is gained from selling electricity back to the grid [7].

The majority of the rooftops at the selected campus have been covered with photovoltaics. However, there is still space for extra photovoltaics. The Technical service at campus estimated that there would be space for installation of about 300 kW photovoltaics on the remaining rooftops.

Fig. 5 shows the production from a scenario with 300 kW extra capacity of photovoltaics. The extra photovoltaics can deliver an annual amount of 308,100 kWh when using the full amount of 1027 production hours [8]. The highest production peak in this future scenario is 1059 kWh. Fig. 6 shows that there would be no excess electricity generation even with the additional 300 kW capacity.

Fig. 7 shows the electricity purchased from the grid in the week from the 2nd of May 2016 to the 8th May 2016. The black curve is the actual consumption, while the red curve is the grid consumption which is the electricity purchased from the grid. The blue curve is the electricity generation from photovoltaics. The green curve is the electricity generation from the total installed photovoltaics (including the 300 kW extra capacity).

There was a low electricity consumption on Thursday (the 5th of May 2016) because it was a public holiday.

Fig. 7 illustrates that an increased amount of photovoltaics can shave the peak of the electricity consumption that almost the whole peak of the electricity consumption on Monday, Wednesday, and Friday has been shaved off (on the green curve).

B. Wind Turbines

Wind turbines provide a useful complementary electricity generation to solar power, as the two technologies depend on different intermittent energy resources. Energy demand needs to be sustained by distributed energy units if campuses reply on less electricity from the grid. It is not only during the daytime but also during nights when wind power can provide an advantage.
The ideal wind turbine solution would consist of a few small or medium-sized units with individual 15-2 kW capacity rather than numerous units of a micro-sized model (1-5 kW), as larger turbines provide significant economies of scale. According to the technology catalog provided by Energinet.dk for installations of electricity and heat production, the investment cost including installation and grid connection varies from 6 ME/MW for 5 kW units to 3 ME/MW for 25 kW units for small wind turbines (capacities below 25 kW) [8]. Although this is just a generic estimation, the capacity costs are still too high for university campuses.

One of the most significant disadvantages of wind turbines is the appearance. The wings and gearbox produce noise at normal and low frequencies. Therefore, wind turbines need to be at least several hundred meters away from campus buildings to avoid disturbing working and educational activities. Meanwhile, wind turbines need to be at a certain height to catch favorable wind velocities that are present at higher altitudes.

On the selected campus, there is an open field seems suitable for a few turbines of reasonable heights and capacities. The distance to the nearest buildings is approx. 200 meters and the field is surrounded by trees. However, the local municipality and university have decided that the area is going to be a recreational area. This plan conflicts with the placement of wind turbines.

Another solution can be the installation of a large number of relatively small wind turbines at the top of the existing and new buildings. Especially, one new campus building is suitable due to its height and relatively large roof area. However, some literature argues that wind turbines placed on roofs are prone to turbulence and weak winds due to insufficient altitudes and obstacles such as nearby trees and other buildings [9, 10]. At the same time, wind turbines might cast shadows on the existing photovoltaics and thereby reduce their production. Wind turbines might also cause discomfort for people inside buildings by producing too much noise and vibrations [11]. One research recommends that the height of a roof turbine needs to be at least 1.3 times high of the building to avoid turbulent winds [8]. This might not work for campus buildings that the roofs might not be able to support without reinforcement. Due to the challenges of wind turbines, the installation of wind turbines is not a feasible DER solution for the selected campus.

C. Vehicle-to-Grid

Electric vehicles (EVs) will become a large part of the future transport sector, so EV charging should be considered for the campus microgrid. In this scenario, EVs perform as storage units, and they can be discharged to deliver electricity to the grid/building (V2G).

There can be a monetary benefit with V2G if university campuses adopt a flexible electricity price, and discharging EVs when the electricity price is high and charging again when the electricity price is low. However, EVs can be charged but not discharged currently. Studies regarding V2G have debated about whether batteries should be able to sustain V2G due to the battery degradation challenge of a shortened battery lifetime [12]. Therefore, V2G is not a feasible DER solution for campuses because the technology is not mature.

D. Heat Pumps

Heat pumps can be a useful approach to utilize surplus electricity generated by photovoltaics. Electricity can be converted into heat by using heat pumps with higher heat output compared to direct electric heaters. A major obstacle is a comprehensive restructuring and extension of heat pipes to install a significant capacity of heat pumps. One way to overcome this issue is to install pumps near district heating connection points, thereby using a common inlet for district heating and heat pumps. This solution should not cause any change to the piping system after the inlet points but might cause some technical difficulties.

Potential saving by heat pumps can be estimated as follows: if the electricity price is set to 0.909 DKK/kWh and an average COP (Coefficient of Performance) of 3.6 [8], the heat price becomes 0.2525 DKK/kWh. This is cheaper than the district heating price of 0.28 DKK/kWh [13]. However, this calculation does not include O&M cost and investment cost, and the average COP might be below 3.6. Heat pumps might complement well if the large capacity of DERs installed on campus with large surplus electricity. However, due to the high cost of heat pipe system refurbishment, heat pumps are not considered as a feasible DER solution for the selected campus.

• Waste Heat

A crucial parameter that affects the feasibility of heat pumps is COP. COP depends on the difference between the input temperature of refrigerants and the desired output temperature. The larger the difference is, the lower the COP and thereby the lower the efficiency. To improve COP, the output temperature has to be decreased or the input temperature has to be increased. Currently, a lot of heat on campus is produced from server clusters, e.g. supercomputers, lab processes, etc., and this heat is not utilized. It could be useful to combine this waste heat with a heat pump to boost COP. This study does not consider waste heat due to the lack of sufficient data regarding waste heat production patterns.

• Reduced District Heating Temperature

One future investigation of heat pumps can be the possibility of inlet temperature reduction of district heating network that district heating companies can reduce losses in the network. However, inlet temperature might become too low to provide sufficient hot domestic water, but still warm enough for space heating. In this situation, heat pumps can be installed at the district heating connection points and could be a solution for the campus to increase the temperature of domestic hot water.

V. SIMULATION SCENARIOS

A Reference Scenario, which is business as usual, has an annual cost for heating and electricity of 17,375,000 DKK. A list of the input parameters is shown in Table I with references. Three scenarios are conducted with DER-CAM to determine optimal solutions: 1) standard scenario, 2) 15 % electricity tax return, 3) heat pumps without pipe refurbishment costs

In the three scenarios, investment cost for adding PVs with 300 kW capacity has been calculated by using the 2018 investment cost. The 2018 investment cost is not stated here due
to confidentiality, but the investment cost for 300 kW capacity equals to 1,823,000 DKK.

Global solar radiation data is from the Danish Meteorological Institute (DMI) and is set up as an average for each hour for every month. As the dataset operates with standard time, the values for the months from April to October are moved one hour behind to accommodate for the summer time and align the solar production correctly with the consumption. The dataset is obtained from the measuring station, no. 6141, which covers the western part of Zealand and Funen [14].

Electricity price is constant at all time, regardless of any peak hour, time of year, weekends and other conditions because there is a fixed electricity price for the selected campuses, that might have an influence on the electricity costs.

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Data</th>
<th>Unit</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate</td>
<td>4</td>
<td>%</td>
<td>Standard rate</td>
</tr>
<tr>
<td>Utility grid efficiency</td>
<td>100</td>
<td>%</td>
<td>Set up to 100 % for simplicity. Only important if carbon footprint is considered</td>
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<tr>
<td>Total available roof space</td>
<td>7476</td>
<td>m²</td>
<td>Includes occupied space by existing PVs</td>
</tr>
<tr>
<td>Peak solar panel efficiency</td>
<td>17</td>
<td>%</td>
<td>[8]</td>
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<tr>
<td>Connection fee (DH)</td>
<td>65093.75</td>
<td>DKK/month</td>
<td>[13]</td>
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<tr>
<td>Connection fee (Electricity)</td>
<td>806.25</td>
<td>DKK/month</td>
<td>D</td>
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<tr>
<td>DH price</td>
<td>0.28</td>
<td>DKK/kWh</td>
<td>[13]</td>
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<tr>
<td>Electricity price</td>
<td>0.9125</td>
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<td>D</td>
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<td>Electricity storage lifetime</td>
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<td>Based on previous PV offer</td>
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<td>Photovoltaic lifetime</td>
<td>30</td>
<td>Year</td>
<td>[8]</td>
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<td>Photovoltaic O&amp;M</td>
<td>84.4</td>
<td>DKK/kW/year</td>
<td>Average between 2015 and 2020 [8]</td>
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<tr>
<td>Existing photovoltaic capacity</td>
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<td>kW</td>
<td>Information provided by the University</td>
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<tr>
<td>Air source heat pump COP</td>
<td>360</td>
<td>%</td>
<td>[8]</td>
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<td>Air source heat pump capacity cost</td>
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<td>DKK/kW</td>
<td>[8]</td>
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<td>Air source heat pump lifetime</td>
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<td>Year</td>
<td>[8]</td>
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<tr>
<td>Air source heat pump O&amp;M</td>
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<td>DKK/kW/year</td>
<td>[8]</td>
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<tr>
<td>Pipe refurbishing cost</td>
<td>15000000</td>
<td>DKK</td>
<td>Self-estimation</td>
</tr>
</tbody>
</table>

TABLE I. LIST OF INPUT PARAMETERS FOR ALL SCENARIOS

A. Standard Scenario

The standard scenario aims to investigate whether it is feasible to install photovoltaics with a capacity of 300 kW on the remaining rooftops of the campus. The simulation shows that there will be no excess electricity generation with the 300 kW extra capacity.

In this scenario, the 66 % refund electricity tax is used as the refund percentage that is 0.909 DKK/kWh. A typical June weekday dispatch (shown in Fig. 8) demonstrates how photovoltaics generation shaves the peak of the electricity consumption. The payback period for the standard scenario is approximately 7 years with an annual total saving of 0.9% compared to the reference cost.

Fig. 8. June weekday electricity dispatch in the Standard Scenario

B. Scenario of 15 % Electricity Tax Return

The electricity tax is the largest part of the electricity bill, but part of the bill can be refunded. The amount that can be refunded depends on the purpose of electricity usage. A tax can be refunded when the electricity is used for services that are subject to VAT. This percentage has been around 66% for recent years which means around 66% of the electricity tax has been refunded. The subsidy that universities get per student for finishing their education is not included in the 66% calculation. However, an EU rule states that subsidy per product has to be included in the percentage calculation which changes the electricity tax refund to around 15% instead [15].

The selected university does not agree with the fact that they can only get 15% refunded. The university claims that it receives a subsidy per product (subsidy per student for finishing their education), but it does not use it as a subsidy per product. The money is instead shared in other ways, e.g. more money is used for science students than linguistic students even though the university receives the same subsidy per student and some money goes to research. The case is submitted to the Danish High Court and the result of the case will tell how much the university has to pay in the future. With the 66% of the electricity tax refunded, the electricity price that the university pays for is 0.909 DKK/kWh, while the electricity price is 1.38 DKK/kWh when the refund is 15%. For 2017 and 2018, the university received compensation from the state for not getting as much money refunded, but this might not continue in the future.

In this scenario, the annual electricity cost will be 23.24 million DKK without DER investments. The simulation with DER-CAM shows that the installation of 300 kW photovoltaics capacity (as the same in the standard scenario) can generate an annual saving of 312,500 DKK or 1.3 % of the reference cost. The payback time is approx. 4½ years. Therefore, DER investment becomes more viable with higher electricity prices.

C. Heat Pumps without Pipe Refurbishment Costs

Heat pumps are not included in the optimization due to the high cost for refurbishment of the pipe system. The
refurbishment cost is estimated as 15 million DKK but can be significantly higher. A simulation in DER-CAM without the consideration of the refurbishment cost is conducted to investigate if heat pumps can be feasible if the pipes are available. In the simulation, the cost of an air-to-water pump is set to 17,820 DKK/kW, the fixed maintenance is 1.25 DKK/kW/month, the average COP is 3.6 and the lifetime is 25 years. Water-to-water heat pumps are not considered in this simulation due to lack of information about potential areas for pipeline installation.

DER-CAM does not include any heat pump capacity in the mix, mainly because of the high pipe refurbishment cost along with little saving compared to district heating. This simulation does not add a battery for electricity storage although DER-CAM has this function because there is no flexible electricity price or surplus production from PVs that can make electricity storage redundant. The simulation with DER-CAM shows that annual saving can be 312,500 DKK/year, and it corresponds to a saving of 0.9 % compared to the reference scenario. The payback time is approx. 7 years that is reasonable for medium-term investment. Approx. 9.5% of the annual electricity consumption is expected to be covered by renewable energy resources at the campus, corresponding to 1,357,879 kWh that is entirely constituted by solar power. The remaining 91.5% of the demand is covered by the grid (12,910,562 kWh).

VI. CONCLUSION

This paper investigates the possibilities of DER solutions in a campus microgrid for the selected case study university in Denmark. This paper analyzes the potentials of several DER solutions including PVs, V2G, and heat pumps. The information for the investigation of the heat and electricity consumption patterns and the electricity production from existing solar panels for the selected campus is obtained through interviews with the university service department. A number of optimizations are simulated with the micro-grid/distributed energy investment decision tool, DER-CAM. The analysis result shows that heat pumps are not feasible for the selected campus unless with a large self-electricity production and low refurbishment cost of the heating pipe system. Although these two conditions can be fulfilled, a heat pump can deliver 259 kW heat that is not much compared to the consumption of more than 3000 kW (that is typical during the winter periods). Therefore, heat pumps is not a viable solution currently.

A comparison is made between the scenarios with a 66% electricity tax return (the standard scenario) and 15% return. Annual saving with 66%, compared to the reference case, becomes 0.9 % and a payback time of 7 years is achieved. If the electricity tax return decreases to 15% due to new taxation rules, the electricity price will increase, and DER investment becomes significantly beneficial. With the decreased tax return, the annual saving compared to the reference case reaches 1.3 % with a payback time of 4½ years.

Currently, the university campus pays a fixed electricity price. Therefore, storage, e.g. stationary batteries or EVs, can be considered as feasible DER solutions for campus microgrid with flexible electricity price. Flexible electricity price can also increase benefits from PVs. Meanwhile, demand response can be beneficial for campuses if the loads of electricity or heat can be shifted with electricity and heat price signals.

The adoption of DER solutions should also consider the development of campuses, e.g. new buildings or campus extension. For instance, a new building with a size of 4200 m² is expected to be completed in 2019, and a new university hospital with 500,000 kWh photovoltaics on the rooftops will be completed in 2022. These changes will influence the DER solutions in the future.

ACKNOWLEDGMENT

This study was conducted as part of the EBC Annex 67-Energy Flexible Buildings project.

REFERENCES