Economic efficient application of flexibility management: A case of the Netherlands

Abstract:

Whole neighbourhoods in the Netherlands are collectively renovated and equipped with similar distributed energy resources, as a new law makes it attractive for housing corporations to perform these collective renovations. The main distributed energy resources which are being applied are heat pumps and photovoltaics. The high penetration of distributed energy resources causes congestion on the low voltage grid. This forces the distribution system operator to perform new grid investments. Furthermore, sunk investments in the maintenance of the grid are lost. This results in economic inefficiencies. This research investigates means of applying grid oriented direct control flexibility management on photovoltaics and heat pumps, to reduce grid congestion and thereby reducing economic inefficiencies. A spreadsheet model was constructed. Results show that only rigorous peak clipping and valley filling measures are able to reduce economic inefficiencies. Rigorous peak clipping and valley filling could feasibly be applied to hybrid heat pumps and PV. Full electric heat pumps however do not have this possibility.

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1 Introduction

The penetration of distributed energy resources (DERs) in the Netherlands is rising (Netbeheer Nederland, 2013). However, the penetration is not evenly distributed among different areas, but rather is clustered in certain neighbourhoods (Van DERs Schoor & Scholtens, 2015). Some of these neighbourhoods have been subject to neighbourhood distributed energy resource projects (NDP), where housing corporations are renovating all houses in a neighbourhood at the same time with a combination of DERs. DERs generally being installed are photovoltaics (PV) and heat pumps (DHPA, 2015). The goal of these projects is often to reduce carbon emissions, as well as lowering a household's variable energy costs (Koirala, Koliou, Friege, Hakvoort, & Herder, 2016). Two types of heat pumps are possible for existing neighbourhoods: hybrid heat pumps and full electric heat pumps. In practice, often a combination of full electric heat pumps and PV is installed. In these cases, the gas grid connection of the house is removed.

A recent change in Dutch regulation stimulates the development of NDP by housing corporations. In 2016 the Dutch government adopted a new law called the 'energieprestatievergoeding' (energy performance commission) (Rijksoverheid, 2016). This law is aimed at stimulating housing corporations to renovate their housing stock and equip their houses with DERs. This regulation stipulates that in exchange for investing in these houses, the housing corporation may charge a surcharge from its tenants. For the tenants this means that their energy bill is reduced. However, their total costs remain unchanged, because instead of paying the energy bill they now pay an amount to the housing corporation. This regulation fixes the previous situation, in which the housing corporation was not allowed to charge tenants without their consent, which resulted in the situation that applying DERs was not attractive for housing corporations (SER, 2016).

Applying a high penetration of NDP causes a number of challenges for the distribution system operator (DSO). Firstly, the current low voltage electricity grid was not designed to incorporate such a high penetration of DERs on a neighborhood level (Netbeheer Nederland, 2016). This high penetration of DERs causes electricity peaks which the grid cannot handle. This leads to black outs: Houses being cut off from electricity supply. To prevent this from happening, the low-voltage grid will have to be strengthened (Hers, Rooijers, Afman, Croezen, & Cherif, 2016). In the case of the Netherlands the distribution system operator (DSO) will be responsible for this, and will have to pay for the investments needed for the strengthening of the grid. These investment costs are high (approx. €2k to €3k per house (Korver, 2014)) and are currently being socialized by the DSO over all its customers (Netbeheer Nederland, 2015). As such, the house owners installing these DERs do not directly pay the costs of the grid problems they are causing.

Secondly, sunk costs in the maintenance of the existing grid are not recovered (Stroomversnelling, 2016). Both the gas grid and the electricity grid have a maintenance cycle of about 40 years. The DSO recovers these investments over the course of the maintenance cycle. As the appliance of DERs causes this maintenance cycle to be disrupted, the sunk costs are not able to be recovered. The electricity grid maintenance cycle is disrupted as new investments have to be made to strengthen the electricity grid. The gas grid maintenance cycle is disrupted as the gas grid connection is terminated when a combination of PV and full electric heat pumps are installed. Again, the DSO will have to socialize the loss of sunk investments over all its customers, resulting in economic inefficiency.

Another potential solution to the problem, besides strengthening the grid, is flexibility management of applied DERs (Eid, Codani, Perez, Reneses, & Hakvoort, 2016). Through recent advances in ICT technology, the flexibility management of DERs has become possible (Blumsack & Fernandez, 2012). Up to a certain level, the demand and production of DERs is flexible: It can be time-shifted in order to reduce electricity peaks (Siano, 2014). As such, the DSO might not have to strengthen the low-voltage electricity grid in order to facilitate a high penetration of DERs. However, it is unclear how the DSO could manage the flexibility of DERs, what this would mean for the DSO, and what this would mean for house owners.

In this research the possibility for the DSO of applying flexibility management options on PV and heat pumps is analyzed. This is done by using a spreadsheet model simulation study. This research translates the result of the simulation study into policy recommendation. Furthermore, this research discusses the implications of applying flexibility management in regards to the Dutch market context.

2 Spreadsheet model simulation

In this research a spreadsheet model simulation study is used. In (Goessen, 2016) the model is more extensively described. In the following paragraphs a summary is given of the most important information for understanding the model.

Conceptual model

The constructed model consists of 6 different sub models (figure 1). The main sub model is the 'Neighbourhood distributed energy resource project system'. This sub model incorporates the calculations and makes the connections between all other sub models. There are two input sub models. The first one consists of policy options for house owners, and includes the technical characteristics of different DERs. The other sub model consists of policy options for the DSO, and includes the technical characteristics of different flexibility management options. There are two environment sub models. The first one consists of the Dutch technological environment, and includes Dutch gas and electricity consumption details as well as Dutch grid constraints among others. The second sub model consists of the Dutch institutional environment, and includes current Dutch energy prices as well as tax and netting regulations among others. The last sub model is the output sub model. This sub model calculates the different KPI and stores experiments and their outcomes.

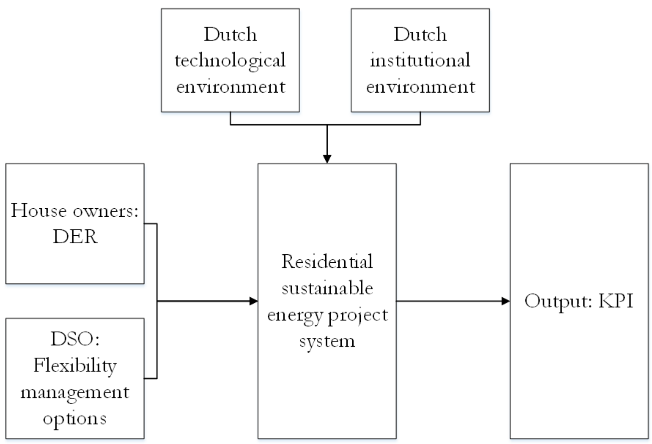

Figure 1: Conceptual model

DERs

There are three different DERs in the model: PV, hybrid heat pumps and electric heat pumps. PV are modeled to deliver output equal to the base demand of electricity of a household. Heat pumps are modeled to deliver output equal to the base heat demand of a household. Hybrid heat pumps make use of an air-to-water heat pump for heating base demand. A gas fired boiler is used for peak demand. The electric heat pump makes use of an air-to-water heat pump for heating base demand, and additionally has an electric module for peak heating.

Input parameters and load profiles

The model has a number of input variables, based on the Dutch institutional environment. The following DERs parameters were used in the model (table 1).

Table 1: DERs input parameters

Parameter	Setting	Parameter	Setting
PV		**Hybrid heat pump**	
Solar panel size	1,65 m2	COP	3,75
Solar panel capacity	0,26 kW	Cost price	€6500
Cost price	€1,7 / W	Max electric consumption	0,65 kW
Yearly average production	220 kWh / panel	Gas boiler efficiency	95%
Static curtailment convertor cost reduction	€500	**Electric heat pump**	
Panels per installation	15	COP	3,75
		Cost price	€12000
		Max electric consumption	1,6 kW

The following assumptions are made regarding the energy consumption of households and costs of grid investments (table 2). The energy demand of a house is based on an average sized household with a house with energy label A. The grid investment costs are €2000 / house when the grid limit it exceeded within 100% of the existing grid limit. If the grid limit excess is larger than 100% the grid limit, grid investments amount €3000 per house. A DSO has to dig to the existing cable, which accounts for the base amount of investment costs. When the existing cable has been dug up, the difference between putting a smaller or bigger cable is less prominent.

Table 2: Energy system input parameters

Parameter	Setting	Parameter	Setting
House		**Grid**	
Heat demand	12900 kWh	Grid limit	1 kW / house
Electricity demand	3300 kWh	Cost of new capacity > 1x grid limit < 2x grid limit	€2000 / house
Energy prices for households		Cost of new capacity > 2x grid limit	€3000 / house
Fixed gas grid costs	€148		
Variable gas costs	€0,66 / m3		
Fixed electricity grid costs	€211		
Variable electricity costs	€0,2 / kWh		

The load profiles of the basic electricity consumption and DERs are based on historical data, for which the following data sources were used (table 3). The hybrid heat pump profile was constructed from a modified electric heat pump profile.

Table 3: Load profiles used

Load profile	Data name	Source
Base electricity consumption load profile	EDSN standard electricity consumption load profile	(Van Langen, Van Tol, Quak, & van Bruggen, 2016)
Base gas consumption load profile	Zonnedael – slimme meter dataset gas load profile	(Kaas, 2013)
Solar PV production load profile	Zonnedael – slimme meter dataset PV load profile	(Kaas, 2013)
Electric heat pump	Dagprofiel stroomversnellingswijk	(Bhagwandas, 2016)
Hybrid heat pump	Dagprofiel stroomversnellingswijk	(Bhagwandas, 2016)

PV flexibility management options

For PV two flexibility management options are considered: Dynamic curtailment and Static curtailment. Static curtailment is an already applied technology (Bird et al., 2016). It involves peak clipping the maximum output a PV installation can give, thus 'valley filling' the load profile. Dynamic curtailment also uses valley filling. However, dynamic curtailment makes use of a convertor which adapts its output to the grid limit.

Electric heat pump flexibility management options

For electric heat pumps two flexibility management options are considered: Switching off and Shifting heat production. Switching off is a peak clipping option for electric heat pumps, where the heat pumps are switched off when grid limits are exceeded by the stacked electricity load. Shifting of heat production can be considered load shifting. The production of heat is shifted to other time periods, and the thermic mass of the house is used to temporarily 'store' heat energy.

Hybrid heat pump flexibility management option

For hybrid heat pumps one flexibility management option is considered: Switching to gas. A hybrid heat pump already uses gas for peaks in heat demand. With this flexibility management option the electricity consumption is peak clipped. The heat pump is now forced to switch to gas when grid limits are met.

3 Results

To obtain results from the model, experiments were constructed from combinations of different flexibility management options. In the first experiment batch, combinations were made between PV and electric heat pumps, resulting in a total of 7 experiments. In the second experiment batch, combinations were made between PV and hybrid heat pumps, resulting in a total of 6 experiments. Figure 2 shows the base load profile of one household.

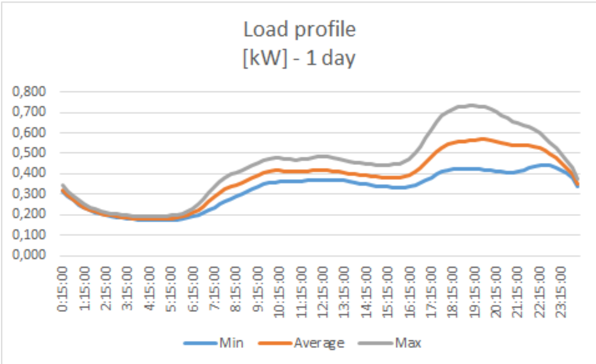

Figure 2: Base load profile

PV and electric heat pumps

Experiments which included a combination of PV and electric heat pumps showed the following results: All PV and electric heat pump combinations cause grid limit exceedance. Only a combination of Dynamic curtailment and Switching off of electric heat pumps results in a reduced need for investment for the DSO. The following detailed results are obtained:

Without flexibility management, a combination of electric heat pumps and PV produces unwanted behavior for the DSO. Figure 3 shows the load profile of this combination. The grid limit exceedance is 224%, which can be seen in table x. This is caused by the outflow of PV. The Shared net present value (NPV) is negative valued at €-3964 per house, as the electric heat pumps do not pay themselves back, result in sunk costs. Furthermore, the DSO has to perform grid investments. The reduction in carbon emissions is high, being 61%. This is caused by the PV producing lots of emission free electricity and the electric heat pump producing less carbon emissions then a gas fired boiler.

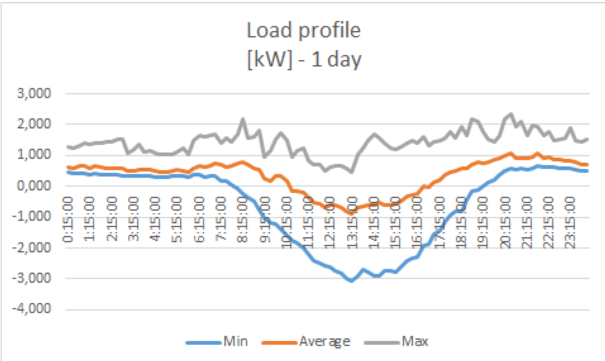

Figure 3: Load profile of PV and electric heat pumps

Regarding flexibility management, the following results are obtained. There is a limited number of combinations of flexibility management which totally take away grid limit exceedance, or produce a higher Shared NPV. In table 4 combinations of flexibility management are shown with the most positive effects. The only combination eliminating grid limit exceedance is a combination of Dynamic curtailment for PV and Switching off for electric heat pumps. A combination of Static curtailment and Shifting heat production shows positive results as well. However, the grid limit is still exceeded by 127%, and Shared NPV is only slightly higher, but still negative, valued at €-3969 instead of €-4464.

Table 4: Main results PV and electric heat pumps

	Unit	Zero option	Dynamic curtailment + Switching	Static curtailment + Shifting heat production
Grid limit exceedance	[%]	224 %	0 %	127 %
Shared NPV	[€ / house]	€ -4464	€ -1354	€ -3969
Percentage yearly carbon emissions saved	[%]	61 %	62 %	61 %

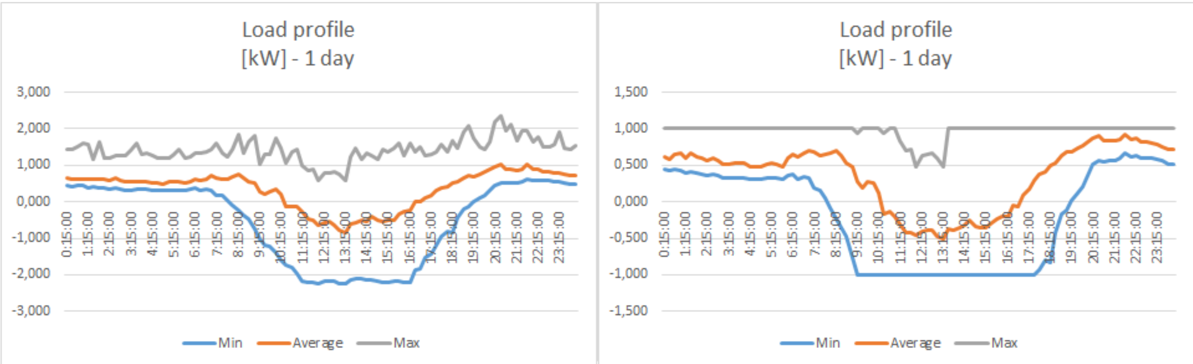

Figure 4: Load profiles: Static curtailment and Shifting heat production (left), Dynamic curtailment and Switching off (right)

PV and hybrid heat pumps

Experiments which included a combination PV and hybrid heat pumps showed the following results: All PV and hybrid heat pump combinations cause grid limit exceedance. Only a combination of Dynamic curtailment of PV and Switching to gas of hybrid heat pumps results in zero need for investment for the DSO. Furthermore, only applying Dynamic curtailment of PV reduces the need for investment for the DSO by about €1250 per house. The following detailed results are obtained:

Without flexibility management, a combination of PV and hybrid heat pumps causes a grid limit exceedance of 224%. Figure 5 shows the load profile without flexibility management. The Shared NPV is slightly positive and 59% carbon emissions are saved yearly. The Shared NPV is slightly positive, although a big difference exists between the NPV of house owners (€3270) and the NPV of the DSO (€-3000).

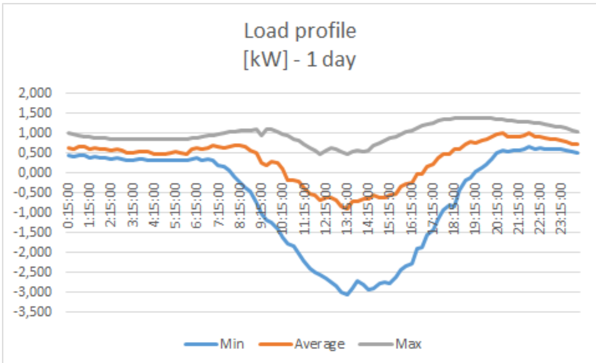

Figure 5: Load profile PV and hybrid heat pumps

There are multiple flexibility management options which reduce grid limit exceedance drastically. For example, applying only Dynamic curtailment of PV already reduces grid limit exceedance to 40% (table 5). The combination of Dynamic curtailment of PV and the Switching to gas of hybrid heat pumps eliminates grid limit exceedance altogether to 0% (figure 6). Combinations which include Static curtailment reduce grid limit exceedance to 127%, even when combined with the Switching to gas of hybrid heat pumps. A combination of Switching to gas and Static curtailment still has high grid limit exceedance, but the payback time of households is reduced with half a year. Combinations which include Dynamic curtailment slightly raise the payback time by half a year.

Table 5: Main results PV and hybrid heat pumps

	Unit	No flex	Switching to gas + Dynamic curtailment	Dynamic curtailment only
Grid limit exceedance	[%]	224 %	0 %	40 %
Shared NPV	[€ / house]	€ 270	€ 2302	€ 451
Percentage yearly carbon emissions saved	[%]	60 %	55 %	57 %

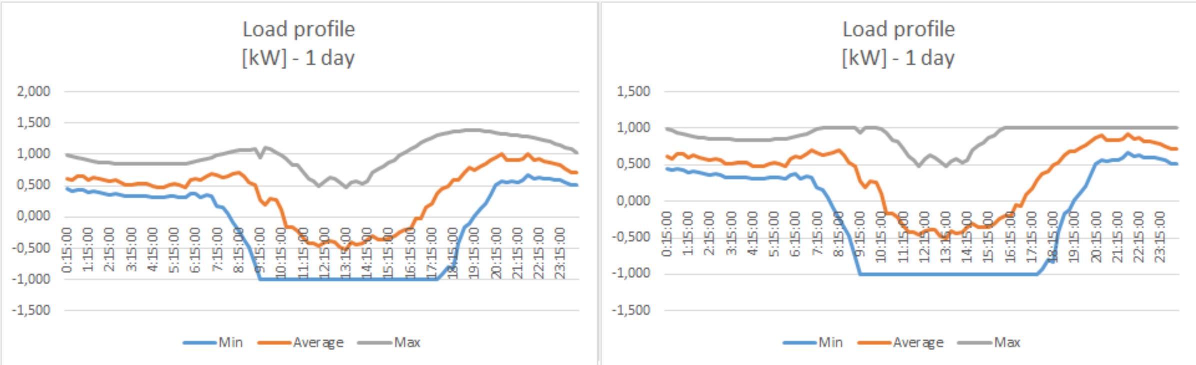

Figure 6: Load profiles: Dynamic curtailment only (left), Dynamic curtailment and Switching to gas (right)

Comparing electric heat pumps and hybrid heat pumps

Both for the DSO as for house owners, hybrid heat pump combinations are more favorable financially, but electric heat pump combinations have slightly better carbon emission reduction and slightly better grid independence.

4 Discussion

Regarding combinations of PV and electric heat pumps, the following policy recommendations can be made: None of the flexibility management combinations both eliminate grid limit exceedance and will be accepted by house owners as they are too expensive, or require the household to be with insufficient heat during the majority of winter. However, implementing static curtailment of PV improves the NPV of house owners. Additionally, a combination of Static curtailment of PV and Shifting heat production of electric heat pumps could possibly still result in less grid investments on higher voltage grids. As the flexibility management options do not suffice in feasibly eliminating grid limit exceedance, the DSO should choose for investing in the grid. Additionally, the DSO could advice house owners to install static curtailment of PV. Future research could be done on the impact of flexibility management on higher voltage grids static curtailment with shifting of electric heat pump production.

Regarding combinations of PV and hybrid heat pumps, the following policy recommendations can be made: The DSO should pursue the implementation of Dynamic curtailment of PV combined with Switching to gas of hybrid heat pumps. This eliminates grid limit exceedance and improves Shared NPV drastically, while carbon emissions are increased only by a small percentage. However, house owners will gain less financial benefits from this DER combination. Whether or not the DSO should compensate for this "loss" is a topic for future research. As with electric heat pumps, flexibility management options including Static curtailment of PV improve the NPV of house owners, but does not eliminate grid limit exceedance and thus grid investments for the DSO. The DSO can advice house owners to install Static curtailment, but should rather advice installing Dynamic curtailment of PV.

Regarding the choice between hybrid heat pumps and electric heat pumps the following policy recommendation can be made: The DSO should advocate the implementation of hybrid heat pumps over electric heat pumps. Although the carbon emissions saved with them are slightly less (5%) than with electric heat pumps, the cost for both the house owner as the DSO are lower. Furthermore, hybrid heat pumps have the possibility to be integrated in the low-voltage electricity grid without any grid investments when applying flexibility management, where for electric heat pumps this is not possible.

5 Conclusion

It can be concluded that the possibility for the DSO to apply flexibility management on PV and heat pumps is dependent on the type of heat pumps being used. In the case that electric heat pumps are used, no combination of flexibility management options eliminates grid limit exceedance. The only option for the DSO is thus to strengthen the grid by making investments. In the case that hybrid heat pumps are used, various combinations of flexibility management options are able to reduce grid limit exceedance, and one combination is able to eliminate grid limit exceedance altogether: A combination of Dynamic curtailment of PV and Switching to gas of the hybrid heat pumps. This flexibility management combination results in lower carbon emission being saved (about 5%). However, the Shared NPV of the NDP is highest when this combination of flexibility management options is applied.

The DSO should consider advising house owners to install hybrid heat pumps instead of electric heat pumps. Even without flexibility management, this significantly reduces grid limit exceedance and improves the NPV of the project for both the house owners as the DSO, with a limited loss in carbon emission reduction compared to electric heat pumps.

Topics for future research

Considering this conclusion, a number of follow-up studies could be performed:

A first topic for future research regards the influence of the market environment on the applicability of the policy recommendations. Within Europe an open market exists, in which the DSO has a monopoly position and is not allowed to interfere in the free market. If the DSO would apply flexibility management of PV and hybrid heat pumps, this could lead to market dynamics interference. Prices might be influenced and an unfair market advantage might be given to certain stakeholders. Future research could show how big the impact is on the free market if the DSO would implement flexibility management. If the market design would be different, for example with an integrated DSO and energy market, these flexibility management options might be better applicable. Examples of such markets can be found in certain parts of the USA and Canada.

A second topic for future research regards on the way these flexibility management options should be implemented taking into account the behavior of households. Flexibility management now shifts the financial benefits resulting from DERs from the house owner to the DSO. This improves the combined benefits as well. However, households might not agree with this without getting any compensation or sharing in the obtained benefits (KEMA Nederland, 2015). Also, the effects of flexibility management on the quality of living could be researched. Furthermore, an important topic could be the perceived privacy law issues. Flexibility management requires detailed energy consumption information to be shared with the DSO. As the flexibility of DERs is managed in all individual houses, the privacy of the households living there might be interfered with.

A third topic for future research builds on the modelling done in this research. Future research could include more stakeholders within the analysis. For example, an aggregator could be added which could perform some of the functionality of the DSO flexibility management options. The influence on the energy supplier could be research as well. Furthermore, from a model technical point of view, improvements could be made. For example, the current model is deterministic. Future research could use probability ranges both for input variables as well as load profiles. This could result in a more thorough understanding of the effects of flexibility management by the DSO.

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