Final report

1. Project details

Project title	Smart Citizen-centered Local Electricity to Heat Systems (SMARTCE2H)
File no.	64018-0563
Name of the funding scheme	EUDP, Det Energiteknologiske Udviklings- og Demonstrationsprogram
Project managing company / institution	Neogrid Technologies ApS
CVR number (central business register)	32773818
Project partners	Aalborg University, Skive Kommune, Suntherm (until 2022), Neogrid Technologies ApS
Submission date	01 May 2023

2. Summary

English summary

The objective of the SmartCE2H project was to develop and demonstrate scalable concepts for heating in rural communities in Denmark, to support transition away from fossil-based heating. The project included 2 approaches: (1) a collective district heating supply for relatively densely populated neighbourhoods including a booster heat-pump to allow for a low temperature source, and (2) a collection of individual heat pumps at household level. On top of technological demonstration, community engagement and outreach were carried out, with an objective to contribute to the climate objectives at municipal level in the Skive area.

The project successfully demonstrated the feasibility of a collective heat supply from a low temperature source and booster heat pump for a street of 20 houses with a phase-change material (PCM) storage tank, optimising heat production at times of cheaper electricity. This set up is first analyzed via simulation cases, and with application of different control strategies, before some of the control strategies were applied at the demonstration site. The solution would however require further development and heat source adjustment to achieve 24/7 robust operation. Joint control of individual heat pumps with PCM tanks as well as price responsive operation of these was also first simulated and next demonstrated, although not at the scale initially envisioned due to the bankruptcy of the key operation partner (Suntherm). When it comes to usage of PCM storages, the project however raises a clear question regarding the optimality of such an approach and exploitability of its full potential in such a context given the significant challenges encountered with the application in the demonstrators. Some of the issues relates partly to the high melting point of the used PCM material, but also the dynamic

response of the material, is seen as a topic for further investigations. This work will continue in two new EU H2020 projects SERENE[1] and SUSTENANCE[2].

On a commercial level, significant progress was achieved in the last phase of the project as reframing happened due to Neogrid becoming the only commercial partner left with a specific focus on optimised control of heat pumps.

Dansk résumé

Målet med SmartCE2H-projektet var at udvikle og demonstrere skalerbare koncepter til opvarmning i landdistrikter i Danmark for at støtte overgangen væk fra fossilbaseret opvarmning. Projektet omfattede 2 tilgange: (1) en fælles fjernvarmeforsyning til relativt tætbefolkede kvarterer, herunder en booster-varmepumpe til at tillade en lavtemperaturkilde, og (2) en samling af individuelle varmepumper på husstandsniveau. Ud over teknologisk demonstration blev der udført fællesskabsengagement og formidling med det formål at bidrage til klimamålene på kommunalt niveau i Skive-området.

Projektet demonstrerede succesfuldt gennemførligheden af en fælles varmeforsyning fra en lavtemperaturkilde og booster-varmepumpe til en gade med 20 huse med et faseskiftsmateriale (PCM) lagerbeholder, der optimerede varmeproduktionen på tidspunkter med billigere elektricitet. Opsætningen blev først analyseret via simulationscases og med anvendelse af forskellige kontrolstrategier, før nogle af kontrolstrategierne blev anvendt på demonstrationsstedet. Løsningen vil dog kræve yderligere udvikling og justering af varmekilden for at opnå 24/7 robust drift. Fællesstyring af individuelle varmepumper med PCM-tanke samt prisresponsiv drift af disse blev også først simuleret og derefter demonstreret, dog ikke i den skala, der oprindeligt var planlagt på grund af konkursen af hoveddriftspartneren (Suntherm). Når det kommer til brug af PCM-lagre, rejser projektet imidlertid et klart spørgsmål om optimaliteten af en sådan tilgang og udnyttelsen af dens fulde potentiale i en sådan sammenhæng, givet de betydelige udfordringer, der er stødt på med anvendelsen i demonstratorerne. Nogle af problemerne relaterer delvist til det anvendte PCM-materiales høje smeltepunkt, men også den dynamiske respons af materialet betragtes som et emne for yderligere undersøgelser. Dette arbejde vil fortsætte i to nye EU H2020-projekter SERENE[1] og SUSTENANCE[2].

På et kommercielt niveau blev der opnået betydelige fremskridt i den sidste fase af projektet, da der skete en omstrukturering på grund af, at Neogrid blev den eneste kommercielle partner med specifik fokus på optimeret styring af varmepumper.

Project objectives

The overall objective of the SmartCE2H project was to develop and demonstrate community-level heating solutions to support the transition away from fossil-based heat in rural Denmark. This was based upon 2 demonstrators: a first one with a collective heat supply to a street relying upon a common large heat pump, and a second one using a pool of smaller heat pumps in single family houses.

In the first demonstration, a booster heat pump using a low temperature source (simulated with a return line of the district heating) was demonstrated in combination with a large storage tank containing phase change material (PCM) to increase its heat capacity and a 'smart' controller to optimise its operation according to grid

[1] https://h2020serene.eu/ - funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 957682.

[2] https://h2020sustenance.eu/ - funded by the European Union's Horizon 2020 research and innovation programme un-der grant agreement No 101022587, and the Department of Science and Technology (DST), Government of India.

conditions. Both the design of the booster station with integration of existing components and development of the controller were key innovations of this project.

In the second demonstration, heat pumps were installed and operated directly in the houses. These heat pumps were fitted with a storage tank filled with PCM and operated in an optimised manner with a ‘smart’ controller according to grid conditions. Here again, the key innovations of this part of the project was the integration of existing component into a functional hardware solution, as well as the controller to operate it.

3. Project implementation

The project experienced a number of challenges and adjustments along the way, together with successes in its implementation.

The first challenge encountered has been the identification of a suitable area to test the collective heat supply using a booster heat pump, which ended up being installed on a return line in a residential area as a way to simulate a far-lying area with low temperature supply as these were not found yet. The local district heating company (Skive Fjernvarme) has been very supportive, despite not directly being a partner in the project. Establishment of the demonstrator faced delays related to technical planning and required adjustments on the local connection to support safe coupling/decoupling of the street and booster station, which was a first-of-its-kind experiment. Later, the return line turned out to be a very challenging heat source, as the flow in it was much lower than initially envisioned, which resulted in both design adjustments and strong limitations to the demonstration in a later stage.

Just as many other projects running in the same period, the combination of the Covid-19 pandemic and geopolitical situation have had an effect on both the operational context and business landscape. The pandemic has significantly complexified outreach events and stakeholder engagement, while later also resulting in tensions on materials and equipment for the demonstrations (the latter having luckily a very limited impact in this project, as the demonstrators were already established at that stage). On the other hand, the geopolitical situation in Ukraine has opened up for greater interest in the solutions developed in the project, which has been helpful in the business development phase. It has however created specific power price conditions which are hard to extrapolate into the future when evaluating the economic gains from the solution (especially from an energy-flexibility perspective).

This being said, the main challenge in the project has been the bankruptcy of Suntherm in early 2022. Given the company’s main role in owning, operating and maintaining the hardware installations, this has had a major impact for the operation of the demonstrators and the availability of the heat pump test sites. It was however lucky that Neogrid managed to hire some of the key resources of the company and overtake some of the remaining work from Suntherm in order to complete the project with the remaining few installations. EUDP has been understanding and a great support to the transition for the best interest of the project and test hosts, which was achieved by the late addition of a new work package to carry out reframing of the business development by Neogrid alone and adjustment of heat pump installations.

On a technical level, the PCM design at both household and community scale has been very challenging to exploit to its full potential. This is due to the complexity of the heat transfer between the PCM core and the water in the storage elements, where the non-linear behaviour made it extremely challenging to exploit in an optimised controller (as well as with the lower level ‘simple’ controllers) and get it to work as the required temperatures for the households and their hot water production, since temperature differences between the PCM’s melting point and the delivery/tapping of heat should have been much higher than was actually possible in the setup.

Regarding the potential for the individual heat pump solution, the market has developed rapidly in response to the skyrocketing of the energy prices. The war in Ukraine has both led to an acceleration of conversion of gas-powered installations to heat pumps and an increased uncertainty about price fluctuations. Both of these combined meant higher interest for solutions able to move the demand of heat pumps away from expensive hours.

4. Project results

This section presents the results obtained throughout the project.

4.1 Modelling and Simulation activities

During the project AAU together with Neogrid has set up and verified several simulation models for the smart integration of flexible heat units and storages. The models were developed both for the individual household scenario where first models for the heat-pumps and belonging PCM-storage and their control were set up, together with a grid with 20 households which were simulated to explore aggregated solutions. Also models for the booster heat-pump solution were set up. Different control objectives were set up for the two cases. Most of the model work are done in DigSilent Power factory, since this is a good simulation tool for exploring the electrical concepts and the dynamics of the systems. In the simulations a system model with the grid-infrastructure for a test case "Solbakken" was set up, where 14 heat-pumps together with 3 EVs and 27 PV systems were integrated into the electrical grid, to try to show how the active loads can be dynamically controlled according to the PV production and grid capacity. In the simulations it was found that with the set up control method, which takes into account day-ahead electricity prices as well as tariffs for transport of electricity, the proposed demand response scheme ends up in reduced costs for the costumers without jeopardizing both grid limitations and consumer preferences in relation to heat and charging needs. Also, for the booster heat-pump more intelligent control is performed. But it was also found that more forecast needs to be done, to find an even better solution for how to control the booster heat-pumps to give the best business case (more information about these models and the control can be found in the two deliverables belonging to WP2 of the project D2.1 and D2.2 – see sec 7.1 in Appendix, and also the two published papers given in sec 7.2 in Appendix reflecting these findings). For the flow in the in the storage tank around the PCM material more detailed models have been explored seen from the thermal point of view, and this has been made available in open-source format[3].

4.2 Individual heat pumps solution

The demonstration of heat pumps in single family houses with local PCM-based heat storage was successful in the sense of meeting the tenants comfort needs and allowing the control development to be developed and tested, although to a less advanced level than initially hoped for. 8 systems were installed as part of the project, which joined a pool of other prior installations from Suntherm bringing the total amount of installations to 25 until the summer of 2022, where most of the installations were taken out of the project following Suntherm's bankruptcy. This pool size reduction has had a strong impact on the final stage of the control development and possibility to test these on a larger scale.

A number of irregularities were however observed on some of the heat pumps, including:

- Loss of connectivity between the heat pump and the cloud
- Corrupt/faulty readings from the meters and sensors
- Excessive electrical backup operation
- Nearly constant operation indicating under-dimensioning for the given house's real needs

[3] See https://github.com/OpenTerrace/openterrace-python

- A COP factor lower than expected

These indicate the need for regular maintenance on installations as part of the service, which needs to be accounted for in the development of the business model and confirms the value of an online monitoring system. While this may be surprising for some readers on such a small number of installations, the scale of the performance shortcomings are not differing wildly from a previous larger scale investigation by Teknologisk Institut[4].

Challenges were also faced with the PCM part of the design, which are summarised in a dedicated subsection below.

Full scale implementation of the intelligent controller integrated with local PV production has unfortunately not been achieved in the timespan of the project. However, price-optimising operation of the individual heat pump was achieved in winter 2023 in first prototypes, with a cost reduction in the order of magnitude of 8% was observed in the first three months of 2023. Further development of this solution, which also integrates local PV production in the optimisation is ongoing at Neogrid, as part of the domOS[5], SERENE and SUSTENANCE EU-financed projects.

Aggregated control of the heat pumps was also trialled as part of the project, running on a pool of 33 heat pumps (including assets from other projects), where forced start/stop were carried out indirectly through adjustment of the indoor temperature setpoints. The experiment showed that the method was rather reliable (> 50% success) on a majority of installations with clear differences between houses that were reliably activated while others never responded adequately. This indicates a need for further work to achieve sufficient robustness as well as a requirement to have large pools with more than 100 assets to control in order to achieve a market-ready solution on this level.

Further details on the demonstration of the individual heat pump demonstration can be found in the deliverable D3.1 referenced in Appendix.

4.3 Collective heat supply solution

The demonstration of the collective heat supply using a booster heat pump in a local district heating area was carried out with partial success in the project. While the design, installation and commissioning of the installation was successful, operation was drastically challenged by an insufficient available energy in the line used as a heat source for temperature boosting. The solution has therefore demonstrated the feasibility of temperature boosting in a local area based upon a low temperature heat supply, but also raised the key issue of having to ensure adequate energy supply on the cold side (which can be a strong challenge in networks operated as 'black boxes' in the far ends).

Suntherm and Neogrid entered discussions with the local district heating operator (Skive Fjernvarme) early on in the project to identify a suitable area. After a period of discussion and alignment, a specific street was designated by the district heating operator as a place where the system could be installed. This required an adjustment of the initial requirements of the project, where the aim was to have a dedicated low temperature line from a remote area, but was unfortunately not a practicable possibility in the current system. Instead, the low temperature line was 'simulated' by using a return line from the neighbouring streets. This ended up being a challenge later, as the demand of the streets providing the return line had been overestimated, resulting in an insufficient flow (and therefore available energy to extract) in the return line.

Neogrid was provided with historical data from the houses by Skive Fjernvarme, and carried out data-driven dimensioning of the booster heat pump, with the help of an intern from the planning department from Aalborg

[4] Poulsen et al., Den gode installation af varmepumper (in Danish), January 2017 https://ens.dk/sites/ens.dk/files/Varme/den_gode_varmepumpeinstallation.pdf (accessed 28/04/2023)

[5] https://www.domos-project.eu/ - funded by the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 894240.

University who mastered the simulation software EnergyPro[6] excelling for such purposes. This work resulted in recommendations for the dimensioning of the booster heat pump and its storage.

Suntherm then carried out the design and installation of the heat pump according to the drawing in the figure below. An AERMEC heat pump with rated power of 21.2 kWe / 93,1 kWth was chosen, with 2 ON/OFF compressors giving a possibility to operate at 0, 50 or 100% power. This design included a tank on the primary side to act as a buffer for flow variations in the low temperature line, as well as large heat exchangers to ensure pressure isolation of the installation (on the primary side) and a security against PCM leakage (on the secondary side). Usage of these heat exchangers and PCM also meant that a stronger pump had to be used inside the booster in order to reach a high flow required for proper heat transfer between those elements. In order to ensure comfort of the occupants of the street in case of an error, a possibility was retained to bypass (and decouple) the booster station and supply them directly with heat from the main district heating.

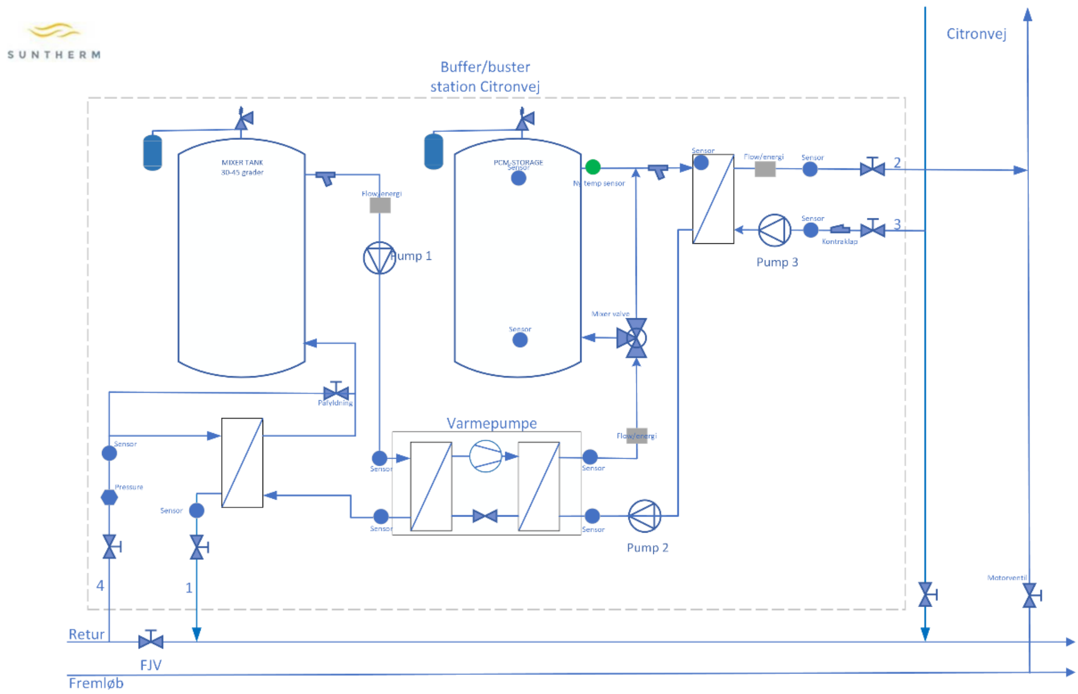

Figure 1: Technical drawing of the booster station design

Tests were carried out, which quickly showed that the low flow in the heat source line was going to be a limiting factor in operation, both in terms of energy available, but also ability of the booster to boost its temperature (as the COP falls quickly with the temperature difference in boosting cases) leaving us with a limited room for manoeuvring and carrying out experiments. That being said, successful operation of the booster was achieved over several weeks in multiple occasions, including price responsive operation that ensured that times of high prices would be avoided as much as possible by leveraging the storage. However, the reduction of experiment time available also meant that we never managed to get to deploy a combined optimisation of household's heating controllers (as Neogrid's control was installed in them to do so) jointly with the booster, as was initially the ambition.

A number of learnings were derived along the way, among which the main ones have been:

- Heat loss in the collective part of the heat supply can be significant in older networks at small scale, and significant margin (25-30%) should be accounted for if total historical demand is not available and demand is estimated from the sum of end-user's demands.

[6] https://www.emd-international.com/energypro/ - provided by EMD International, one of the neighbour companies of Neogrid.

- PCM is a challenging material to use in this environment, given the temperature uncertainties and constraints (more details in the next subsection)
- Safety triggers require careful attention in contexts with such distributed assets in a network, as these require sending a technician on site. In our case, an erratic flow switch issue has caused multiple needs for unplanned interventions on site.
- The heat pump used for boosting should have a control system allowing input setpoints compatible with the temperature ranges desired. Here, we had to develop a more complex control strategy to make a robust regulation as there was a software limitation on the setpoint range allowed in the Modbus register entry.
- Tight coordination with the district heating is required to make such a development successful. This includes considering future planning and their uncertainty given the evolution of the possible flow and temperature (i.e. available energy) on the line used as the heat source.

Further details on the demonstration of the individual heat pump demonstration can be found in the deliverable D4.1 referenced in Appendix.

4.4 Value of PCM for thermal storage

One of the key hardware-based innovations in the project was the development of solutions integrating phase change material (PCM) into water-based storage to increase their heat capacity. Beyond the novelty of such a system, the expected advantages were (1) a higher heat capacity of the storage for a given volume, compared to plain water storage, and (2) a more concentrated heat capacity in terms of temperature, as most of the capacity lies in the phase change around the melting point temperature.

These storages were implemented in both household-level and community-level demonstrations. In both of these places, they however quickly showed complexity in terms of actually activating the PCM core and thereby unlocking this key value from the component.

First, from a simple physical perspective, loading of the PCM requires a relatively temperature difference between the melting point and the water heated by the heat pump (typically > 5°C). Similarly, discharging the PCM requires a similar difference between the water and the PCM core. This both means that the melting point has to be carefully dimensioned over the minimum temperature requirement (typically set by hot-water production in our demonstrations, at above 50°C), but also that whenever loading the heat pump has to operate at a temperature considerably higher than the requirement (typically 10°C) which degrades the COP accordingly.

Second, from a data-driven control perspective, PCM is a very difficult element, due to its inherently nonlinear and hysteresis-heavy (in case of partial loading) behaviour with a tight coupling to flow temperatures. This means that state estimation of the state of charge of the tank is practically impossible to realise with adequate precision (unless one is only using full charge/discharge or investing in prohibitively-expensive heat metering in and out of the tank), as well as the usage of linear model predictive methods. For this reason, we were not able to use the method initially envisioned for optimised control and had to revert to simpler heuristic solutions, which were luckily still showing some potential, although quite lower in principle.

Moreover, in a booster setting, PCM came with a number of extra challenges both in terms of design, operation and economics:

- An added pump (with associated CAPEX and energy demand) to run at sufficient flow for heat transfer to happen adequately and overcome the pressure loss through the PCM stack.
- An expensive heat exchanger had to be installed in order to ensure that any leakage from the PCM shell[7] would not propagate in the local district heating.

[7] Suntherm had experienced this in the early days of the project on other installations.

- A requirement to operate at least 5°C above the melting point (itself at least 5°C above the minimum temperature requirement) as an output when charging, with consequences on the COP of the heat pump.

The main argument for PCM usage was compacity of the storage solution, compared to hot-water. However, it turned out that the actual gain on the installation was by a factor less than 3 (i.e. a volume a third lower with PCM than with plain water, for same heat capacity). Given the fact that space was not the main issue in a booster setting, this might therefore counterbalance the above-named downsides in future applications.

The conclusion of the project on PCM storage became therefore a strong question-mark with regards to the actual value of the PCM in this kind of heat-pump based contexts, which joins the results obtained within other projects running over the same period.

4.5 Upscaling of the solution in the municipality

The municipality of Skive has carried out work focusing on upscaling the solution in its local context, to foster growth in local energy communities ('energifælleskaber' in Danish). In practise, this work focused on the following dimensions:

- mapping of the existing local energy communities and networks,
- identification of the key actors and engaged citizen that could lead a local community,
- training of the key actors to be able to provide guidance on energy solutions,
- supporting establishment of local energy communities.

The approach was divided in 4 phases:

1- An information and inspiration phase, where citizens were engaged via a 'city tour' of 1-3 hours highlighting the potential of the area, and followed by a citizen meeting.
2- A dialogue phase, consisting of interviews of key stakeholders and citizen meetings.
3- A phase of mapping, mobilisation and coupling of resources, where the resources of the network developed in the previous phases are mobilised and build upon. The key actors start taking responsibilities towards one another and projects are shaped and started formally.
4- An establishment phase, where a formal entity is created, financing is put in place, and technical solutions developed. This is done with the help of qualified professional advisors to support on legal and technical aspects, to ensure that the investment is providing satisfying returns in terms of economics and climate change mitigation.

Skive municipality has made a report on these activities and this is given as deliverable D5.1 which is referenced in sec. 7.1 in Appendix.

4.6 Dissemination activities

Results have been disseminated throughout the project at academic, industrial and community level.

At academic level, Aalborg University has published two conference papers at the IEEE Transmission and Distribution conferences (one in 2022, and another accepted for 2023). Neogrid has also presented project use-cases and results at the international Smart Energy Systems conferences in multiple occasions, as well as at the Applied Machine Learning Days' track on AI and sustainable energy organised by EPFL in 2021.

At industrial level, Neogrid has disseminated the learnings of the project to the 'Intelligent Energi' initiative[8] under 'Dansk Energi' in multiple occasions.

[8] https://ienergi.dk/

At community level, Skive Kommune and Suntherm have organised several citizen meetings to inform the local population about the scheme, as well as promoting further development as part of the upscaling strategy. An article was also published by Suntherm in the local journal (Skive Folkeblad – see press media in sec. 7.2).

The project consortium has continued the developments of the project in 2 Horizon 2020 projects. SERENE, which is aimed developing a community scale energy management system for both new and existing social housing buildings. And in the SUSTENANCE project, where a cluster of individual heat pumps with large storage capacity is being demonstrated in Skanderborg Municipality.

5. Utilisation of project results

The technological solutions developed in the SmartCE2H project will be exploited by Neogrid, which is the only commercial partner still operating at the end of the project. After Suntherm's bankruptcy, no commercial partner was left in the consortium with business interests in hardware integration and PCM-centric heat storage operation (more details can be found in D5.2 referenced in Appendix). Instead, the remaining interests were on the intelligent control part, where the strategy is to get the solutions adapted in order to be able to run on a variety of heat pumps and setups.

Further development of the heat pump controllers will be (and already is) carried out by Neogrid in three European projects: domOS, SERENE (together with AAU ET) and SUSTENANCE (also together with AAU ET). These will therefore secure continued maturing of the innovation in the part of the solution that is not fully market-ready yet.

Meanwhile, the controllers for heat-pumps which have achieved maturity are now provided by Neogrid as commercial solutions.

6. Project conclusion and perspective

The SmartCE2H project has demonstrated that it is indeed possible to control a cluster of heat pumps to react to control signals from the electricity grid. However, the size of the cluster in the demonstration was too small to reach minimum requirements for the flexibility markets. Ideally, more than 100 heat pumps are required to obtain a meaningful cluster size.

The booster heat pump installation proved to be successful for most of the heating season of 2021/2022. Major flow challenges on the source side have however disrupted it and ended up preventing further trial in the heating season 2022/2023 (due to changes in the district heating grid). The working principles of the booster heat pump are still interesting to investigate further – especially when looking at expanding the grid into natural gas districts, as it can potentially reduce the need to expanding the capacity of existing transmission lines within the district heating network and help reducing temperatures in the system (leading to lower losses).

Many of the control schemes that Neogrid have developed within the SmartCE2H project are currently being commercialized in close cooperation with significant companies within the Danish heat pump industry, and we expect to have clusters well beyond the minimum size, within 2024.

7. Appendices

7.1 List of public project deliverables

All of the deliverables except D7.1 which is confidential can be accessed and downloaded on Aalborg University's VBN archiving system using the following link: https://vbn.aau.dk/da/projects/smart-citizen-centered-local-electricity-to-heat-systems-smartce2.

	Title	Authors
D2.1	Report on developed models and control schemes for heat pump and storage integration in local communities	P. Ponnaganti, B. Bak-Jensen, J. Pillai, P. Vogler-Finck
D2.2	Report on control simulations and their validation with demonstration activities for optimal integration of electrical to heat systems	P. Ponnaganti, B. Bak-Jensen, J. Pillai, P. Vogler-Finck
D3.1	Demonstration of intelligent heat-pump and storage system in residential buildings	P. Vogler-Finck, P. Dahlgaard Pedersen, M. Veis Donnerup, A. A. Sand Kalaee, P. Ponnaganti, B. Bak-Jensen
D4.1	Demonstration of a temperature boosting system in district heating	P. Vogler-Finck, M. Veis Donnerup, R. Sinha, P. Ponnaganti, B. Bak-Jensen, J. Hærvig
D5.1	Roadmap til energifælleskaber – fælleskab omkring løsningen *(in Danish)*	Skive Kommune
D5.2	Report on benchmark technical solutions and business models	P. Ponnaganti, B. Bak-Jensen, J. R Pillai, P. Vogler-Finck, M. Veis Donnerup, H. Lund Stærmose

7.2 List of other project outputs

List of academic publications:

1. P. Ponnaganti, J. R Pillai, B. Bak-Jensen, P. Vogler-Finck, "Intelligent operation of thermal storage systems based heat pump pool for cost efficiency," Proceedings of IEEE T&D 2022- IEEE PES Transmission & Distribution Conference & Exposition, 2022
2. P. Ponnaganti, J. R Pillai, B. Bak-Jensen, Short-term heat demand prediction using deep learning for decentralized power-to-heat solutions, "IEEE PES GT&D May 22-25, 2023 (accepted)

List of software packages developed in the project:

- Openterrace (developed by Aalborg University for PCM simulation): https://github.com/OpenTerrace/openterrace-python

Homepage: https://smartce2h.dk/

Press media:

- Eksperiment på Citronvej skal give mindre varmeregning, Salling Avis 20. october 2020, http://mo.infomedia.dk/ShowArticle.aspx?Duid=e7f2c34a&UrlID=6b1166c7-0e52-4fb3-bb32-3c88e33110fe&Link=http://mo.infomedia.dk/ShowArticle.aspx?Duid=e7f2c34a&UrlID=6b1166c7-0e52-4fb3-bb32-3c88e33110fe&Link=