FUTURE ENERGY SCENARIOS IN AALBORG EAST

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Introduction

The aim of FLEXPOSTS (FLEXible energy POSitivity districTS) is to develop effective and replicable strategies to enhance the process of establishing Positive Energy Districts (PEDs). WP5 investigates how a PED can be established in the demo site Aalborg East in Denmark. The aim of this report is to develop future energy scenarios for how to develop Aalborg East into a PED, taking effectiveness (business models) and sustainability aspects (life-cycle assessment) into account (D5.4).

First, we introduce the general scenarios for how PED status can be achieved. Second, we outline the energy requirements of the future energy system in terms of energy demand and energy production. Third, we outline three types of (?) PED developments in Aalborg East and compare the results. Fourth, we present our preferred scenario and discuss how PED development has contributed realising wider goals of transitioning towards 100% renewable energy at city, regional and national levels.

This report on future energy scenarios in Aalborg East (D.5.4) builds on previous reports published in the FLEXPOSTS project outlining the Local Energy Balance Assessment, Aalborg East (D5.1), the Barriers and Potentials for Implementing PEDs in Denmark (D5.2) and Mapping Existing Partnerships and Networks (D5.3). Furthermore, the preferred future energy scenario presented in this report will form the foundation for a PED Implementation Plan for Aalborg East (D5.5). An overview of the reports that will be published about turning Aalborg East into a PED is presented below.

Textbox 1: Reports in WP5 – Demo Site Aalborg East

D5.1: Local energy balance assessment

D5.2: Barriers and potentials for implementing PEDs in Denmark

D5.3: Mapping of existing partnerships and networks

D5.4: Future energy scenarios in Aalborg East

D5.5: Business models and implementation strategy in Aalborg East

Introducing PED scenarios

This report seeks to illustrate the potential future of the Aalborg East district in the context of establishing a Positive Energy District (PED). It is founded on an analysis of the current energy consumption in this area, as detailed in the report Energy Balance Assessment, Aalborg East (D5.1) [1].

As stated in White Paper on PED by JPI Urban Europe and SET Action Plan, Positive energy districts are defined as "*energy-efficient and energy-flexible urban areas which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy*" [2]. The concept has been developed based on buildings with high energy efficiency, such as nearly zero-energy, net-zero, or even buildings that produce more energy than they consume [3]. Now, PED can include only several connected buildings (examples [4–7]), or major parts of the city, including universities and public buildings. (example [8–11]), and it often takes into account only electricity demand in city areas [9,12]. So far, only few case studies analyze systems beyond buildings, such as transportation [10], and the influence of industry [9] [13] on achieving PEDs. While considering that industry and transport are sectors with significant energy demands, it raises the question of whether excluding them from the context of PED is justified. If PED is meant to drive energy change, is it justified to neglect entire sectors in our efforts to reduce CO_2 emissions? Therefore, it is essential to approach PED through the lens of intersectoral and the creation of smart energy systems[1].

Also, in most of the literature published so far, the analysis of PED began with finding the most suitable part of the city for achievement the PED framework [14] which most often includes buildings with high energy efficiency. However, this approach limits the application of the concept to only a small number of buildings, while excluding households affected by energy poverty. The integration of renewables should adhere to the principles of a just energy transition. This means that access to renewable energy should not be limited to affluent individuals, and efforts must ensure that no one is left behind. Additionally, since energy districts are seen as valuable

[1] Smart energy systems rely on the integration of different energy sectors, which enhances the overall efficiency of the energy system.

components of the energy transition, they should also encompass buildings that lack sufficient energy efficiency.

Establishing a PED within a specific geographical area, such as the Aalborg East case study defined by the postal code 9220, presents significant challenges. The existing literature lacks a clear definition of procedure how to create a PED [15]. This brings into question which energy sectors ought to be considered when planning the future energy scenarios for city districts.

In addition to the lack of a clear definition regarding which sectors and geographical boundaries the PED should encompass, there is also a division concerning how the PED can achieve its positive energy balance [16] as follows:

- PED autonomous: Designated area with well-defined geographical boundaries where all renewable energy is generated within those limits, ensuring self-sufficiency. In these districts, while it is permitted to export energy to nearby systems, importing energy from external sources is strictly prohibited at all times.

- PED dynamic: Districts that have well-defined geographical boundaries and generate more renewable energy annually than they consume. These districts can exchange energy with other local systems, allowing them to import energy when needed and export surplus energy when production exceeds current demand.

- PED virtual: A district capable of generating energy from Renewable Energy Sources (RES), including sources beyond the system's geographical boundaries, where the total energy balance must ensure that production exceeds consumption

Therefore, this report shows the consequences of involving different sectors, through an analysis of different scenarios:

1. **Scenario 1** covers the energy demand of the household sector
2. **Scenario 2** covers local energy demand, including households, the service sector and public buildings, as well as electricity and heat consumption in industry
3. **Scenario 3** covers the total demand of all sectors, including industry, transport, and the buildings sector, in line with the ambitious national decarbonization strategy.

As shown in Figure 1, for each scenario, the possibilities of establishing the concept of PED depending on the mode of energy production in terms of geographical constraints (PED as PED virtual, PED dynamic, or PED autonomous) were analyzed.

After analyzing the results, obtained on the basis of simulations carried out in the EnergyPLAN software package [17], Aalborg East future scenario was chosen, which is a proposal for a vision of the energy district that contributes to the achievement of regional, national and global goals.

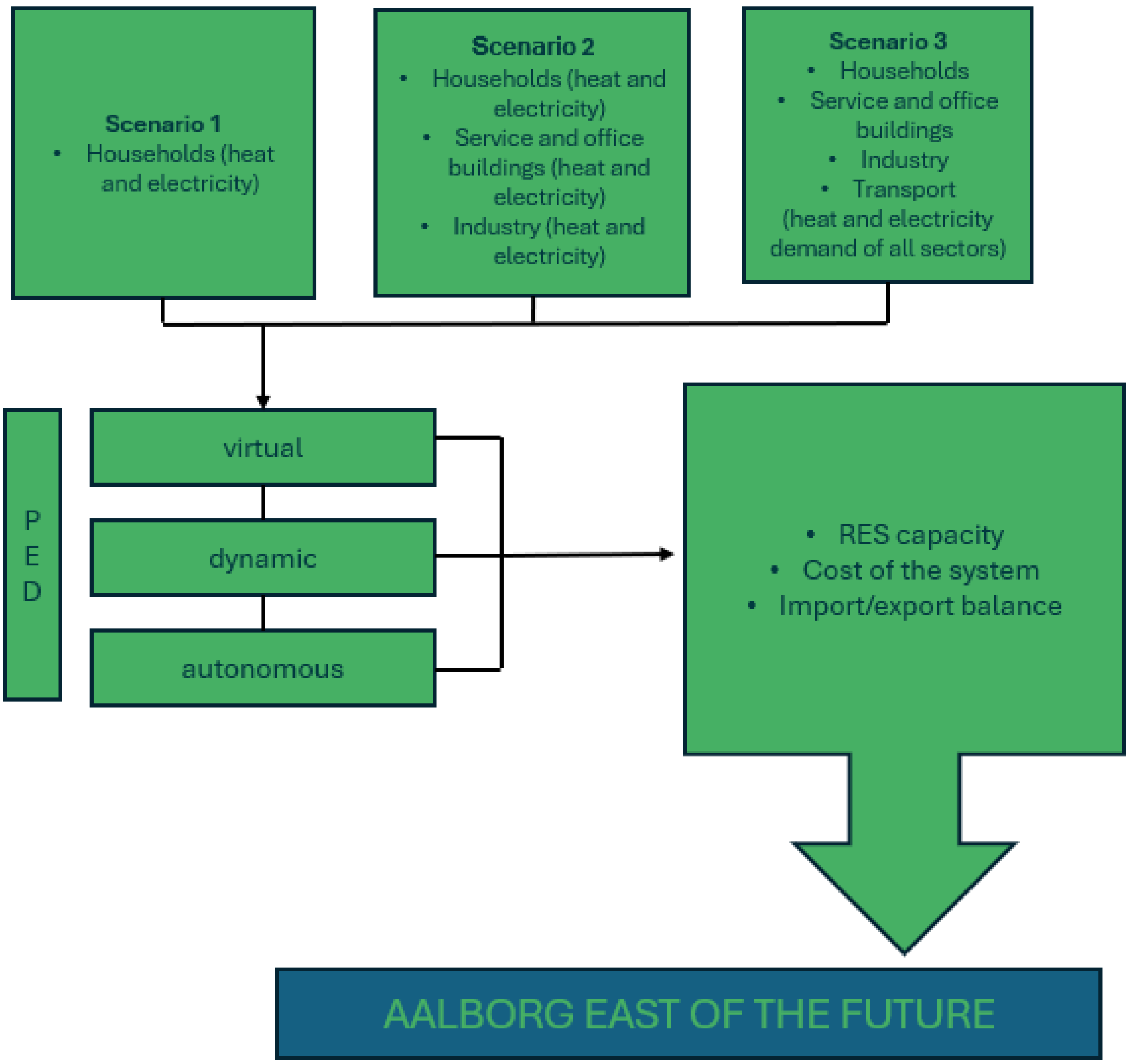

Figure 1. Steps towards choosing a future scenario

Energy Requirements of the Future Energy System - General Principles

Up to now, analyses of PED have primarily focused on the current energy demand of the specific area being examined. However, decarbonization is a long-term process, and it is reasonable to anticipate changes in the behavior and energy needs of end users over time. Furthermore, the PED must align with projections of future energy demands that are consistent with the national goals of the country in which PED is situated.

In this regard, it is necessary to establish the principles guiding the analysis of future energy districts, which should be grounded in fairness detailed further in the Report *Local Energy Balance Assessment, Aalborg East* [1]. In the case study of Aalborg East, the principles defined in the IDA Climate Response 2045 were applied [18]. This national document is the product of collaboration between researchers from Aalborg University and the Danish Society of Engineers (IDA). Its purpose is to present an ambitious scenario aimed at achieving the national goal of the first fully decarbonized society by 2050 [19].

The following assumptions pertain to the district of Aalborg East, derived from the national scenario:

- Households that are not connected to the district heating (DH) will install individual heat pumps;
- A 30% decrease in heat demand is anticipated for individual households;
- The heat demand for the DH is calculated based on a projected 30% decrease in current[2] household consumption. This assessment also considers the anticipated rise in energy demand resulting from the planned construction of new residential units, in addition to the heat demand attributed to the industrial sector;
- Waste incineration is expected to decrease by 50% due to increases in recycling rates;
- Biomass availability is based on a sustainable share of 27 GJ per capita annually at the EU28 level [20];
- The heat storage capacity is designed to last for 14 days, accommodating the average heat load.

[2] Current energy demand in Aalborg East is defined and shown in detail in the Local Energy Balance, Aalborg East [1].

The energy analysis is performed on an hourly basis, considering the energy demand and supply across all sectors. When there is a surplus of energy production, the system will export this excess energy to the grid in the form of heat or electricity during times when demand is met or exceeded. Conversely, if the energy demand surpasses production levels, the system will import the necessary energy to satisfy that demand. In the current energy market, the growing integration of RES, particularly photovoltaic systems, is anticipated to lead to minimal pricing for energy exports. In contrast, the pricing of energy imports is established according to the Danish Energy Agency's projections for 2045 [21]. These projections are adjusted to align with the current production profiles of variable renewables. The system's price is defined according to the projections for the price of technologies presented by Danish Energy Agency [22].

Energy demands

The demand for electricity and fuels used in industrial and transportation sectors should be assessed based on the proportion of the district's population in relation to the total national energy demand for these areas, as detailed in the Local Energy Balance Assessment for Aalborg East [1]. This approach advocates for a fair distribution of energy demand across the specified sectors, recognizing that industrial products are utilized extensively at both national and international levels, despite the location-specific nature of production demands. Similarly, it is important to consider transportation in the same manner, including international travel, as individuals frequently move beyond the district's borders, crossing PED's geographical limits.

The heating demand for residential units, public and office buildings are defined based on actual heating demands, which consider the hourly distribution of demand throughout the year.

The projected of future energy demands in the different sectors in Aalborg East for 2045 are presented in Table 1.

Table 1. Aalborg East Energy demand in 2045

	sector		GWh/year
electricity	Households		32,58
	Industry & service		71,84
	additional electricity demand for production processes in industry		40,29
District heating	House holds		29,49
	Industry & service		108,07
Individual households	Heat pump		12,66
Industry	N. gas		11,61
	Biomass		11,61
Transportation	electrofuels	Jet Fuel	34,66
		Diesel	10,65
		Ammonia	12,43
	Hydrogen		4,1
	Electricity (dump charge)		24,35
	Electricity (smart charge)		27,18

Energy Production

As noted in the report Local Energy Balance Assessment, Aalborg East (D5.1)[1], buildings in Aalborg East are primarily supplied by DH. In Aalborg East, there is a highly energy-intensive cement industry. Waste heat generated by cement factory-Aalborg Portland is delivered to DH. The energy demand of this facility accounts for 12% of the total industrial energy consumption in Denmark, while Aalborg East represents only 0.34% of the country's population. Therefore, to uphold the principles of fairness, the energy demand from Aalborg Portland is included in the overall industrial demand for Denmark and is distributed according to the population share. On the other side, excess heat can only be utilized locally, and Aalborg Portland generates sufficient excess heat for 25,000 households. However, this energy is not distributed solely to Aalborg East; it is accessible to all buildings connected to the DH in the city of Aalborg. To ensure fair distribution, only the portion of excess heat corresponding to the population of Aalborg East to the overall population of city of Aalborg will be considered.

In addition to Aalborg Portland, the incineration plant Nordværk is in Aalborg East, which generates both heat and electricity. This facility processes residential waste collected from Aalborg and neighboring municipalities. Consequently, the amount of heat and electricity distributed to the Aalborg East is defined based on the population share, under the assumption that each citizen generates a similar volume of waste. To illustrate the impact of the geographical boundaries of the PED on the energy balance, Figure 2 shows the total waste heat from Portland alongside the energy from Nordværk, as well as the share allocated to Aalborg East Aalborg East.

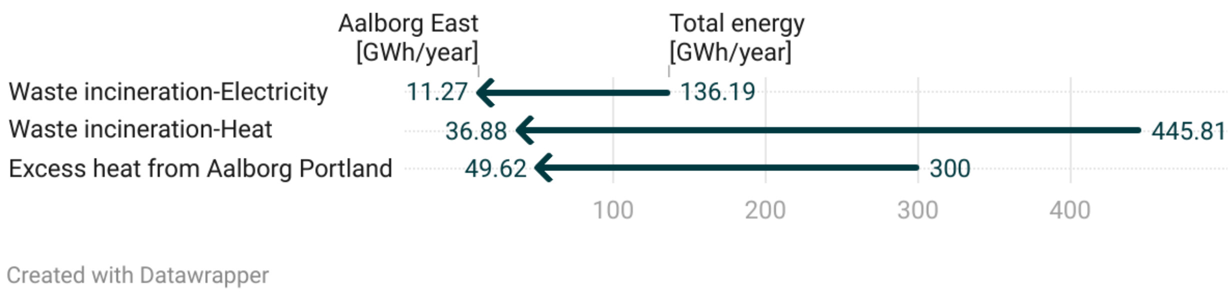

Figure 2. Energy supplied to the grid from Nordværk and Aalborg Portland.

Since there are currently no other producers of electricity in the Aalborg East district, Table 3 shows the planned RES capacity and production in accordance with IDA45.

To meet the fairness criteria, which have already been discussed, when achieving PED virtual, the installed capacities must remain within the ranges for Aalborg East shown in Table 2.

For future system analysis involving both dynamic and autonomous PED, the potential for photovoltaic was assessed using Geographic Information Systems (GIS). This analysis mapped all available rooftops larger than 500 m^2 in Aalborg East, which cover area of 0.41 km^2 **[23]**, with the

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possible electricity production of 44,5 GWh[3]. Also, according to characteristics of district, it is feasible to install 6 MW of wind turbines.

Table 2. Expected future RES capacity for Aalborg East (as PED virtual) according to IDA45

	IDA45_DK		Share of Aalborg East	
	MW	TWh/year	kW	GWh/year
wind	5,000.00	16.13	17,074	55.08
offshore	14,075.00	61.00	48,062	208.30
wave	132.00	0.46	451	1.57
PV	10,000	12000		40.98
biomass		40.67		138.89

Possible future energy scenarios in Aalborg East

Scenario 1- PED for Households

If the analysis of the future energy scenario of Aalborg East is approached using the most common method, considering only the energy (heat and electricity) demands of households, Aalborg East can become a PED autonomous, dynamic or virtual.

As illustrated in Figure 3, it is most economically advantageous to extend PED electricity generation beyond the system's boundaries. In this context, Aalborg East has the potential to operate as a PED virtual if it is able to generate onshore wind energy. In this way, installed PV capacities can be significantly lower than the allowed shares, which positively influences grid congestion during the summer months.

On the other hand, if the energy was produced locally, as in case of PED dynamic, it is physically possible to install only 6 MW of onshore wind and combine it with the production from PV panels. To achieve an annual balance of imported and exported energy produced in this area, it is necessary

[3] Due to the shades, the position of the roof and the possibility of installing PV panels, half of the total area of the roofs were considered.

to install 16.5 MW of solar panels. This approach results in an increased electricity import demand on an annual basis, as well as the production of energy that cannot be used within the PED.

GWh/year

	households_virtual	households_dynamic	households_autonomous
Wind onshore	29	19.35	19.35
PV	6	16.45	114.75
Wind offshore			
Biomass	48.15	48.15	48.15
Export electricity	8.1	10.1	99
Import electricity	7.8	9.1	0
Battery storage			650

kEUR

	households_virtual	households_dynamic	households_autonomous
COST	3,180	3,215	10,978

Created with Datawrapper

Figure 3. Aalborg East as PED in the case in which only households are included

In the end, it can be concluded that PED autonomous cannot be considered a feasible and justifiable solution for Aalborg East, even in a scenario in which only includes energy demand in buildings. Namely, the analyzed climate is characterized by short days in winter, when the demand for heat energy is highest. On the other hand, this results in PV capacities that need more than double the area of rooftops. Also, this approach leads to a fragmentation of the country in terms of the interconnection of energy systems and is therefore not in line with the national strategy. The observed lack of coherence results in substantial photovoltaic energy production coupled with inefficient battery utilization. Therefore, this system tends to be significantly more expensive compared to the other two types of photovoltaic energy distribution systems. Moreover, it is anticipated that it may contribute to network congestion during the summer months.

Due to all the above, PED autonomous is excluded from the remainder of the report.

Scenario 2- PED for Local consumption

When focusing only on the electricity and heat energy requirements of buildings and the industrial sector, while setting aside the fuel needed for industrial production processes, Aalborg East has the potential to become a PED in a virtual and dynamic framework (refer to Figure 4).

However, the realization of the PED dynamic triggers questions of rules and agreement of urban planning since the installation of the necessary capacity of possible renewable energy sources, in this case PV, requires significant areas (1.1 km^2), which exceed the potentials of roof structures.

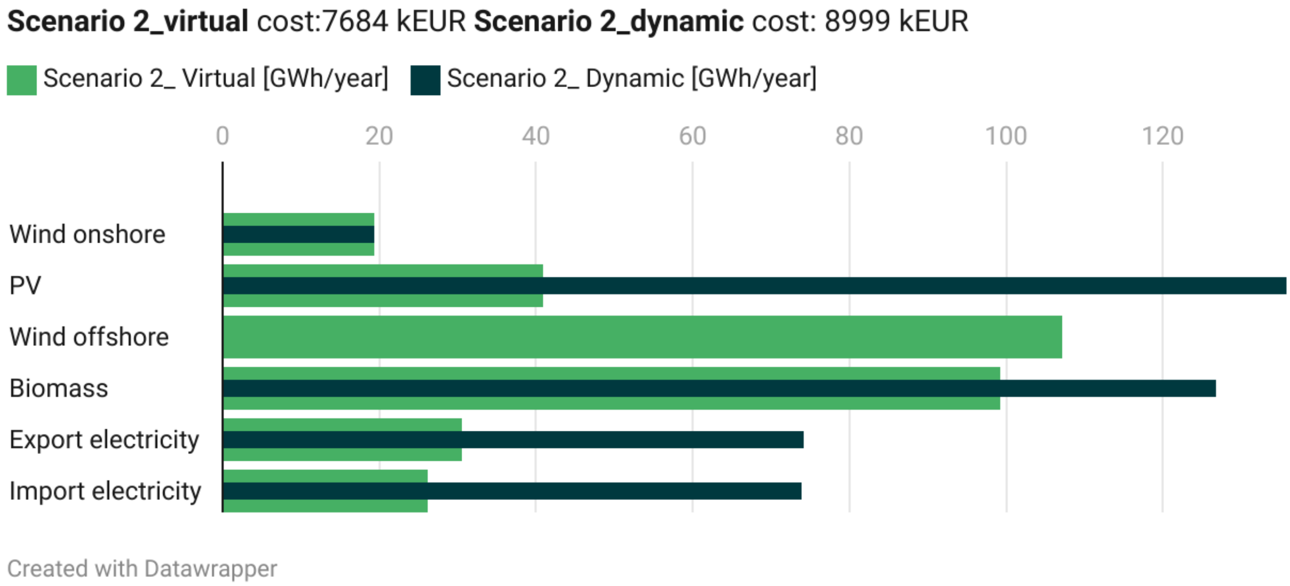


Figure 4. Aalborg East as a PED when demand for production processes in industry is neglected

Scenario 3- PED for ambition National Goals

Compared to today's Aalborg East energy system, the Scenario 3 for 2045 anticipates a substantial transition away from fossil fuels, accompanied by a substantial increase in electricity demand across all energy sectors.

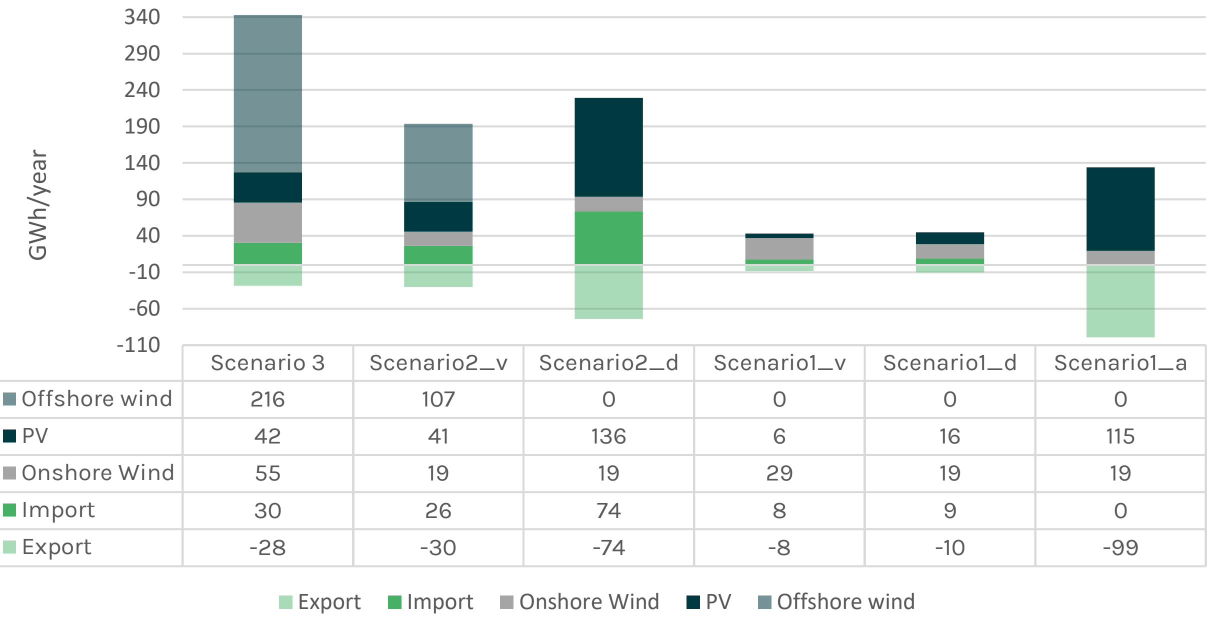
In this scenario, Aalborg East can become PED only as a PED virtual, wherein key technologies may be located outside the district. This approach considers the national share of RES production and energy demands and patterns of consumption across all sectors including industry and transportation (Table 1). Our findings indicate that even under these conditions, electricity imports surpass export capacity. This outcome can be explained by the inherent characteristics of smart energy systems, which emphasize cross-sectoral integration to maximize the utilization of available renewable energy and limit energy exports. Additionally, this scenario does not provide interconnections with external systems for energy storage and balancing purposes. As a result, when assessing renewable energy production exclusively, the PED objective becomes unattainable in systems that include both industrial and transportation sectors, even when renewable energy production outside the geographical boundaries is considered.

To meet PED targets in such a scenario, it is, hence, necessary to install renewable energy capacities that exceed those determined by the principle of equitable distribution, as outlined in Figure 5. For instance, the installation of an additional 1 MW onshore wind turbine could ensure compliance with the virtual PED framework.

The findings imply that, due to the presence of energy-intensive industries and relatively high transportation demands within Aalborg East, meeting the energy requirements of these sectors within the district's physical limits would be impossible.

Comparison of Scenarios

In the case of Aalborg East, the results of a comparative analysis of all evaluated scenarios are presented in Figure 5.



	Scenario 3	Scenario2_v	Scenario2_d	Scenario1_v	Scenario1_d	Scenario1_a
Offshore wind	216	107	0	0	0	0
PV	42	41	136	6	16	115
Onshore Wind	55	19	19	29	19	19
Import	30	26	74	8	9	0
Export	-28	-30	-74	-8	-10	-99

Figure 5. Comparison of all the analyzed scenarios (_v-PED virtual, _d-PED dynamic and _PED autonomous)

The findings suggest that, within the examined case study, aPED virtual represents the most cost-effective approach. This model allows for the integration of RES not only within the immediate geographical boundaries of the district but also from external sources. Consequently, this leads to reduced requirements for local PV capacities, enhanced energy utilization efficiency, and a decrease in both energy imports and exports. When energy-intensive sectors, such as industry and transportation, are included in system analysis, the PED can most feasibly be realized through the virtual approach. Alternatively, the PED may be achieved as a dynamic model if industrial production is excluded, focusing instead on public buildings, households, the service sector, and industrial heating demands. Moreover, if the analysis is restricted solely to household energy consumption at the district level, the PED can be established under virtual, dynamic, or autonomous frameworks.

The results presented underline the significant role that PEDs can play in advancing the climate neutrality of urban areas. However, conceptualizing PEDs as isolated energy entities or 'islands' does not suffice for achieving broader climate objectives. On the contrary, dynamic PEDs can provide an effective transitional solution, particularly within smaller urban districts. While this approach may entail higher financial investments compared to virtual PEDs, it empowers local communities to act proactively, without dependence on top-down initiatives or large-scale infrastructure developments.

It is essential that the implementation of PEDs is pursued in a manner that balances economic viability with technical feasibility. The definition of PEDs in terms of energy import and export should not be rigidly standardized but rather should be flexible enough to align with overarching national and global sustainability and climate goals. In this context, the establishment of a network of interconnected positive energy districts is crucial. Such a network would facilitate the mutual exchange of energy, enhancing overall system efficiency and resilience.

Therefore, it is recommended that the energy demands of industry and transport be addressed within a broader policy framework, at the level of cities or regions. Such an approach aligns with national energy strategies, positioning PEDs not as self-sufficient systems, but as integral components of a larger, interconnected energy landscape capable of supporting national goals. Rather than treating PEDs as isolated entities, they should be understood as part of a broader, integrated approach to sustainable urban development. Viewing them solely as quick fixes risks turning the concept into a mirage, diverting attention from systemic, long-term solutions.

Alborg East of the Future - PED as a strategy that supports the achievement of regional, national, and global goals

By analyzing the presented solutions for the energy scenarios of Aalborg East as PED, it becomes clear that there is not one clear unambiguous solution. As shown in the previous section, achieving a certain type of PED at any cost can result in the creation of new problems, disguised under the pretense of solving CO_2 emissions. In this regard, PEDs, instead of being seen as a concept that can enable significant change, become a hindrance.

Accordingly, the authors of this report believe that districts like Aalborg East should be integral parts of a comprehensive whole, which will allow for the feasible and clear achievement of climate and energy goals at the city and regional levels, in alignment with national and global objectives, without compromising security of supply, network congestion, and unnecessary additional costs of the energy transition.

For all the reasons mentioned, Aalborg East is envisioned in the future as a sustainable part of the city, with the maximum utilization of locally available RES and the application of new technologies to meet and regulate future energy demands. Aalborg East could become a place where thermal storage, heat pumps, waste heat from industry, energy produced from waste incineration, local wind, and PV panels are utilized. The production of e-fuels and hydrogen to meet the future energy demands of industry and transport should be localized wherever physically possible, most justified, and most feasible in the country. Meeting the energy needs of energy-intensive sectors should be a unique goal toward which the entire country strives. In this regard, it is not necessary to insist on achieving the PED concept, especially in districts that include additional sectors besides households, such as Aalborg East.

The energy transition should be designed to solve existing problems without causing new ones, and therefore, the maximum realistically available capacity of locally available renewable energy sources should be used in every part of the country.

The steps that need to be taken to make Aalborg East a new, sustainable version of PED are shown in Figure 6.

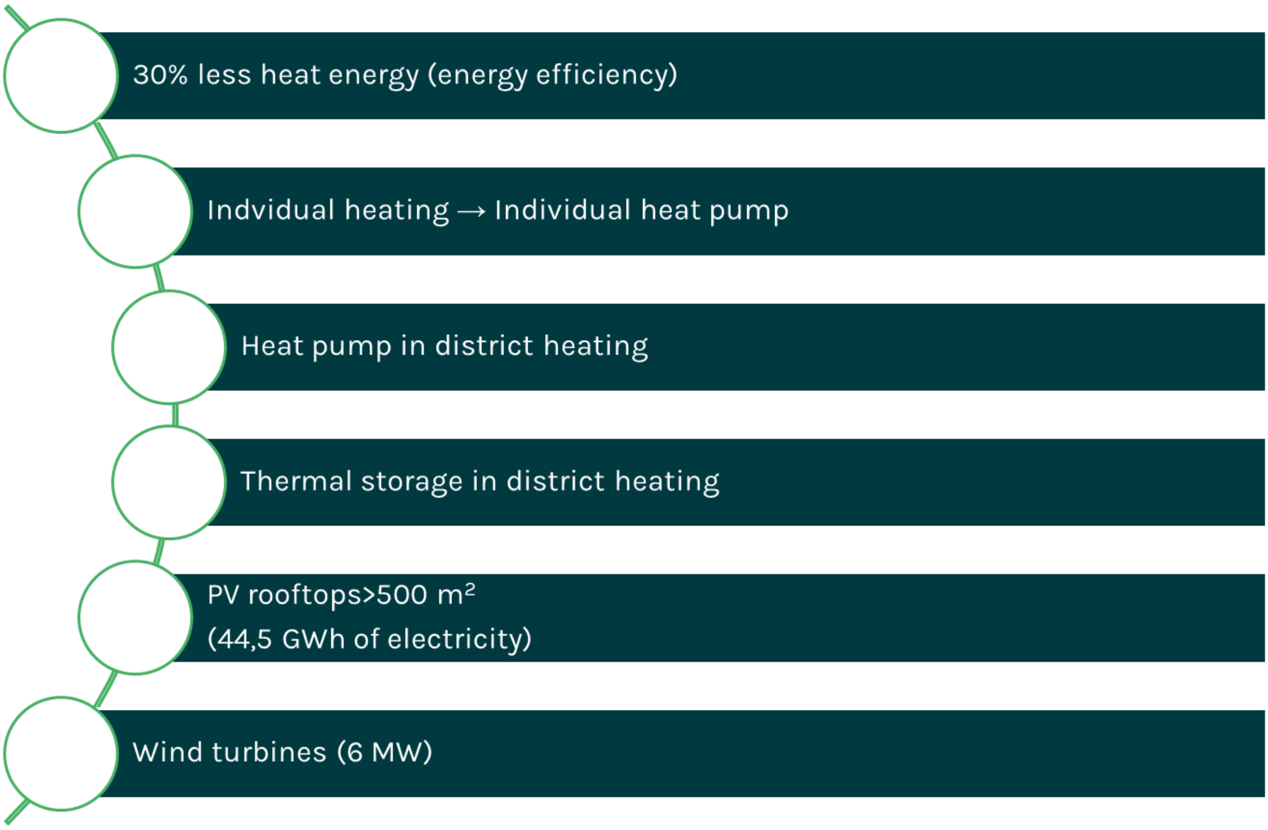


Figure 6. Steps towards future PED of Aalborg East

If the IDA 45 national scenario is taken into consideration and its energy demand is fairly allocated to the analyzed district, it becomes evident that Aalborg East can only contribute to meeting a part of the future energy demand. Specifically, 23% share of produced energy in the total required energy for the district's climate neutrality, as can be seen from Figure 7 showing the energy flows of Aalborg East's future energy system.

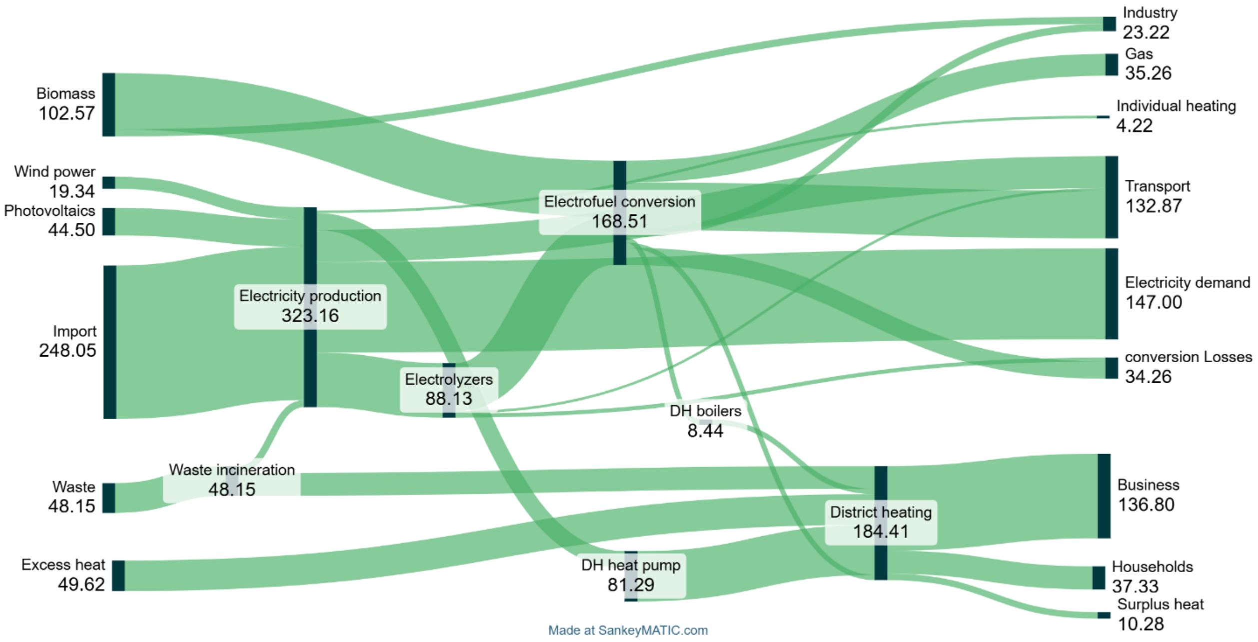


Figure 7. Energy flow of proposed future scenario of Aalborg East

PED in a life cycle systems perspective

From a systems perspective, the Positive Energy District concept entails marked risks for suboptimization. Drawing a circle around a PED on the map creates an inside and an outside, which always will determine what is counted and what is not counted. The basic objectives of the PED in terms of energy positivity, decarbonization, local resilience, etc., may therefore potentially lead to sub-optimal solutions, which need to be assessed and potentially counterbalanced. Important parts of this is covered in *Energy Requirements of the Future Energy System - General Principles* on page 8, where the focus is that the PED should be designed to function in a full energy system perspective. This approach ensures that e.g. carbon neutrality is not pursued by installing power generation technology inside the PED-circle, if the same investment is better placed 'outside'. Therefore, the proposed improved PED definition focuses on the PED as an area that locally contributes to achieving the aims of the low carbon society with a focus on the energy systems. The implication of this is that the criteria for a well performing system *is not* to be carbon neutral, but to have a production and consumption balance leading to net emissions being as low as possible.

A key challenge in PED's will, in specific cases, be finding the best use of resources that may serve several purposes. This implies to understand the climate impacts of not only the energy system, but also of connected non-energy systems, which in practice is best handled by applying a targeted lifecycle thinking and assessment approach to becoming able of handling these classes of resources. We recommend a system-oriented method developed for assessing sustainable business models focusing at the use of consequential system understanding [24]. In this context it is essential to follow the recommendations of the European Commission regarding the use of consequential modelling as being the relevant method for decision support [25,26].

The most important class to consider is constituted by biogenic resources, which in different forms may feed into both energy production, as well as food/feed and non-food products. An example of this is the use of side streams from breweries. Spent grains can both be used as feedstock for biogas production, as feed for animals, or even potentially as feedstock for a bioprocess producing protein valorized food for humans. The two latter uses of the feedstock will have the best performance seen from a life cycle perspective, but within the PED circle, using the feedstock for biogas production would constitute a (suboptimal) positive contribution to energy production in the PED.

Economic benefits of PED implementation

The transformation of Aalborg Ø into a virtual Positive Energy District (PED) presents a groundbreaking opportunity to be a leader in developing sustainable urban energy. By harnessing renewable resources, the district can achieve a stable and abundant supply of affordable green energy while contributing surplus electricity to the other districts. Both the development and operation of a virtual PED unlock a variety of business opportunities, which Aalborg Ø, supported by Aalborg Municipality, should actively pursue. The sooner a virtual PED would become a reality, the greater the potential benefits, especially due to first-mover advantages.

Aalborg Ø is well-positioned to attract and cultivate new green businesses. Large data centres, which require a reliable and cost-efficient electricity supply, would be natural candidates for establishment within or near the district. Additionally, businesses focused on surplus energy utilization - whether repurposing excess heat or redistributing electricity - can play a key role in PED development. Service providers specializing in marketing and expanding the PED concept can further strengthen Aalborg Ø's position as a pioneer in energy innovation.

The PED framework also fosters technological advancement, including battery technology, smart grids, and energy management systems. Smart grids integrate sensors, automation, and two-way communication, allowing for real-time energy consumption adjustments. Existing and new businesses within Aalborg Ø, in collaboration with researchers at Aalborg University, can contribute to ongoing innovations in energy efficiency, creating new opportunities for investment and economic growth.

Energy surplus itself would emerge as a distinct economic activity, attracting electricity trading companies and contributing to municipal and state tax revenues. Meanwhile, Aalborg East's possible success as a PED could also strengthen its appeal for green tourism and international partnerships. Its position as a model district would also encourage collaboration with other PEDs in Denmark and abroad, driving both technological exchange and green investments.

Looking ahead, Aalborg Ø would be more than just a completed PED; it could become an evolving centre for energy innovation. Its continuous development ensures ever-increasing energy production, efficiency improvements, and new business opportunities. By maintaining a long-term vision for sustainability, Aalborg Ø could become a frontrunner in the global transition to clean energy.

Conclusion

The Aalborg East case study underscores the necessity of adopting a flexible, system-oriented approach to PED implementation. The comparative analysis of different scenarios demonstrates that the virtual PED offers the highest operational efficiency, primarily due to its capacity to incorporate RES beyond the district's geographical limits. This approach reduces dependency on localized photovoltaic infrastructure, optimizes energy flows, and minimizes both import and export imbalances.

When integrating high-demand sectors such as industry and transport, the virtual model proves to be most viable, whereas the dynamic model is applicable when excluding industrial loads and focusing on residential, service, and public sectors. Additionally, scenarios restricted to household consumption could be realized while fulfilling the criteria of all three PED typologies: virtual, dynamic, or autonomous.

The result affirms that PEDs should not be operationalized or understood as insular entities. Instead, the strategic value lies in their integration within broader, interconnected urban energy systems, contributing to enhanced grid flexibility, resilience, and alignment with overarching decarbonization policies. Rigid self-sufficiency targets may inadvertently introduce inefficiencies or counterproductive outcomes.

Therefore, it is imperative that PED frameworks maintain definitional flexibility, ensuring coherence with national and supranational sustainability agendas. Sectoral demands, particularly due to industrial activity and the required mobility, are best addressed through comprehensive urban or regional strategies, positioning PEDs as functional components within a larger, coordinated energy transition. Overemphasis on isolated PED performance risks undermining long-term systemic objectives in favor of short-term, superficial gains.

Therefore, this report emphasizes that PEDs must function as cohesive elements within a larger framework. This approach ensures the realistic and efficient achievement of climate and energy goals at both city and regional levels, aligned with national and global targets—while safeguarding supply stability, avoiding network congestion, and preventing unnecessary additional costs throughout the energy transition process.

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