ADVANCED ENERGY STORAGE CONFERENCE 2024

PART 1

TAASTRUP

NOVEMBER 28, 2024

DANISH TECHNOLOGICAL INSTITUTE

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Ministry of Higher Education and Science Denmark

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TABLE OF CONTENTS

ADVANCED ENERGY STORAGE CONFERENCE 2024

Keynote: The role of energy storage technologies in the energy system - today and in the future

Peter Sorknæs, Aalborg University

THE ROLE OF ENERGY STORAGE TECHNOLOGIES IN THE ENERGY SYSTEM - TODAY AND IN THE FUTURE

Peter Sorknæs

Department of Sustainability and Planning, Aalborg University, Denmark

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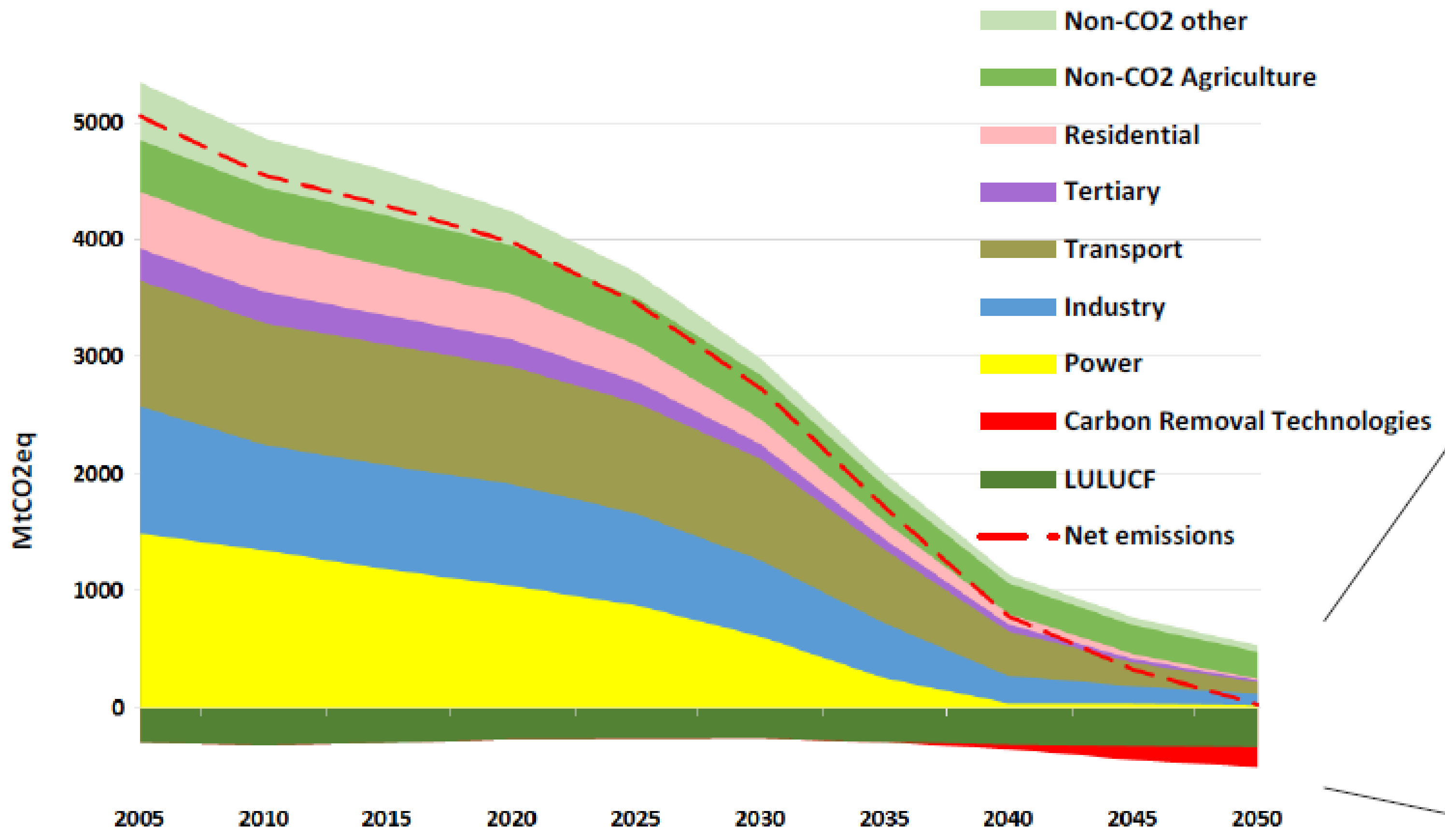
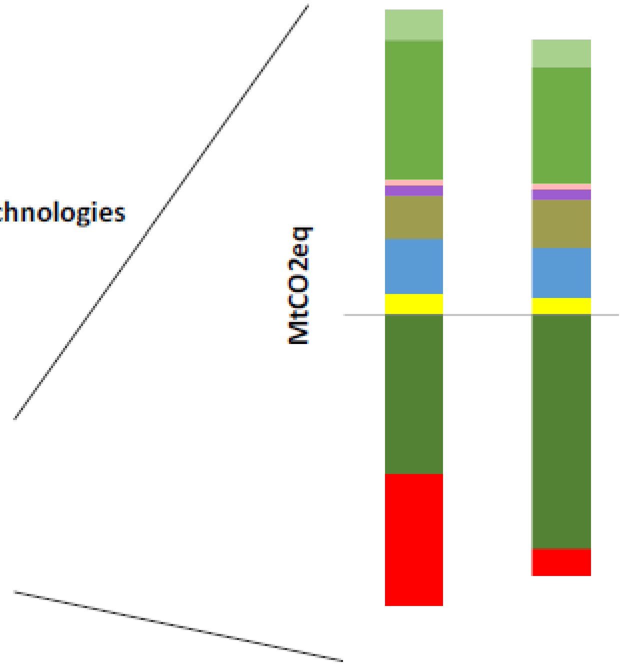
Climate Neutral

A Clean Planet for all

A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy

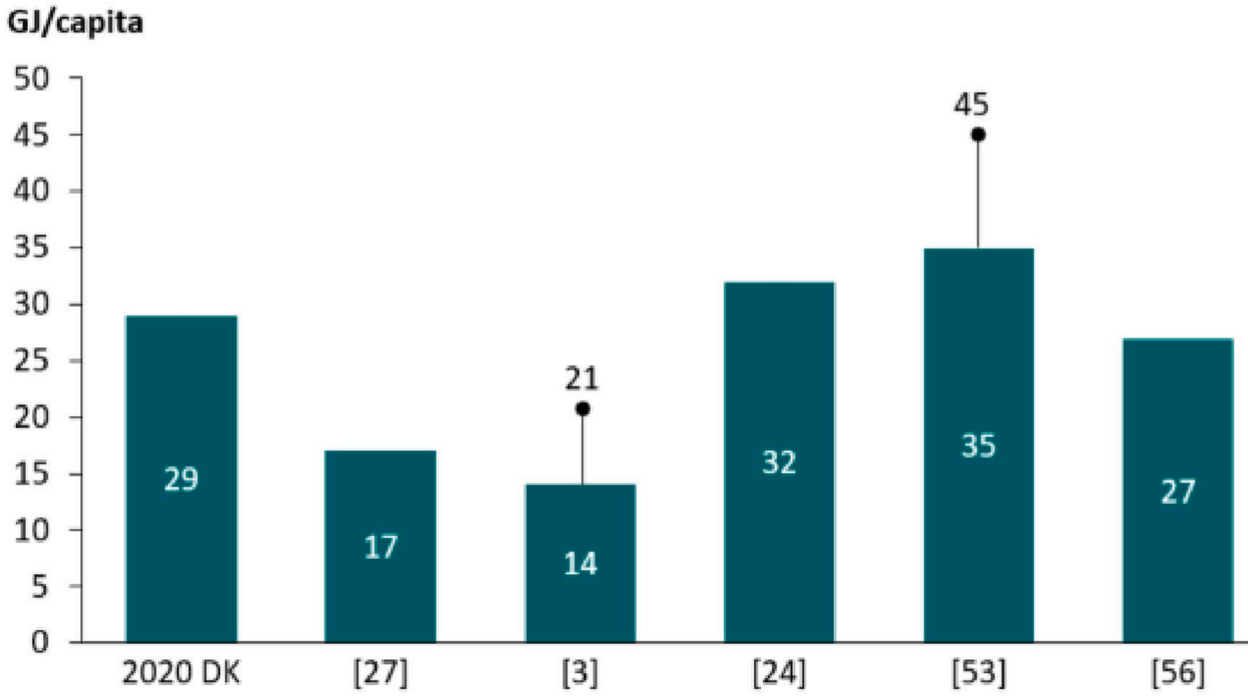


Different zero GHG pathways lead to different levels of remaining emissions and absorption of GHG emissions



Sustainable biomass usage for energy purposes

- The limits for how much biomass globally can be used sustainably for energy purposes are still being debated
- Future amount of sustainable biomass is estimated to be somewhere between 100 and 300 EJ/year, equal to 10–30 GJ/capita annually in a scenario with 10 billion global inhabitants.
- Non-biomass renewables needed in the transition (e.g. wind power and PV)



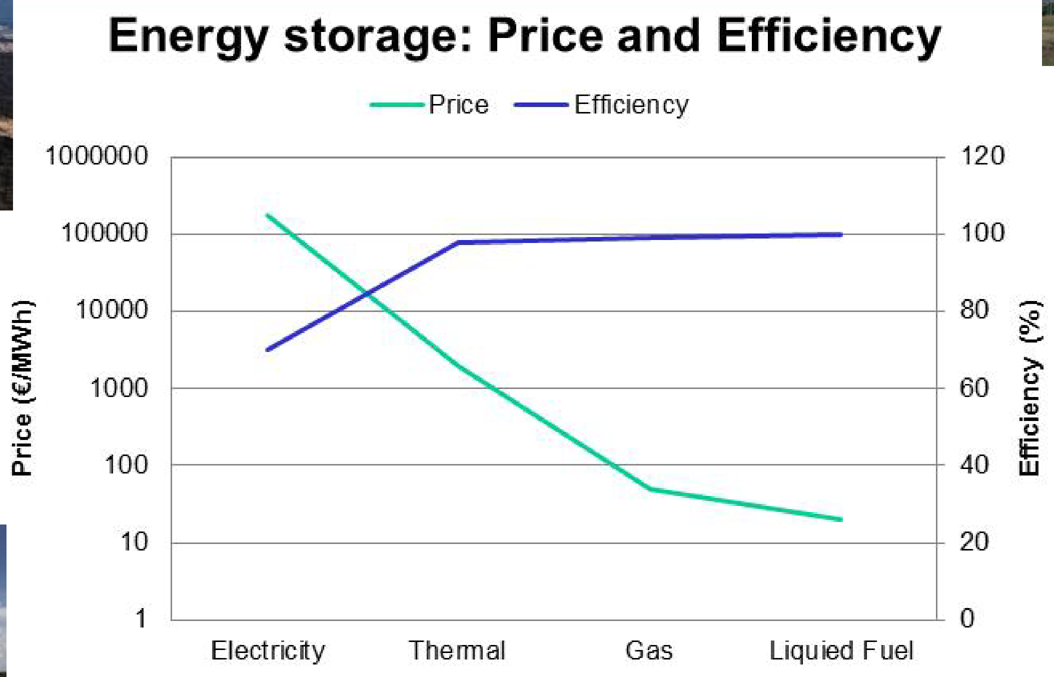
Comparison of different estimates of biomass per person. Black dots represent range reported in the specific studies.

Source: Lund, H., Skov, I. R., Thellufsen, J. Z., Sorknæs, P., Korberg, A. D., Chang, M., Mathiesen, B. V, Kany, M. S. (2022). Renewable Energy. https://doi.org/10.1016/j.renene.2022.06.026

Energy Storage

Pump Hydro Storage
175 €/kWh
(Source: Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits. Electric Power Research Institute, 2010)

Thermal Storage
1-4 €/kWh
(Source: Danish Technology Catalogue, 2012)



Oil Tank
0.02 €/kWh
(Source: Dahl KH, Oil tanking Copenhagen A/S, 2013: Oil Storage Tank. 2013)

Natural Gas Underground Storage
0.05 €/kWh
(Source: Current State Of and Issues Concerning Underground Natural Gas Storage. Federal Energy Regulatory Commission, 2004)

Source: Lund, H., Østergaard, P. A., Connolly, D., Ridjan, I., Mathiesen, B. V., Hvelplund, F., … Sorknæs, P. (2016). Energy Storage and Smart Energy Systems. Doi.org, 11(0). http://doi.org/10.5278/ijsepm.2016.11.2

Smart energy systems

Smart Electricity Grids

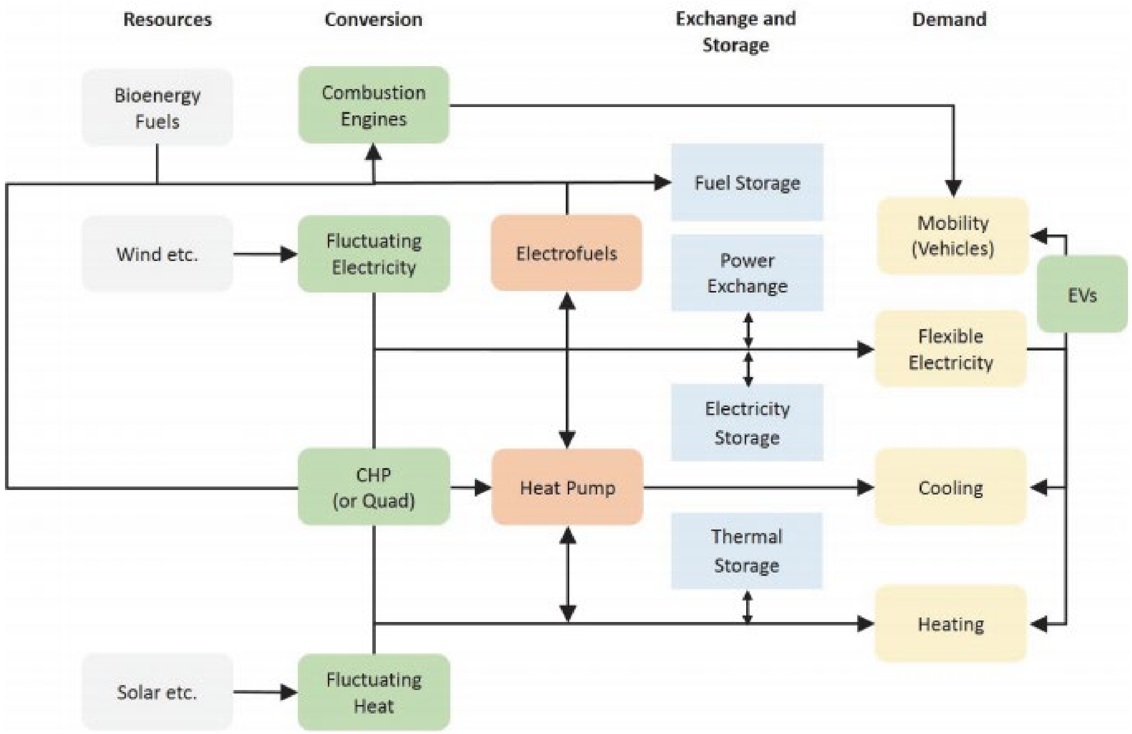
Connecting flexible electricity demands, heat pumps and electric vehicle to the variable renewable resources such as wind and solar power.

Smart Thermal Grids (District Heating and Cooling)

Connecting the electricity and heating sectors, thermal storage to be utilised for creating additional flexibility and heat losses in the energy system to be recycled.

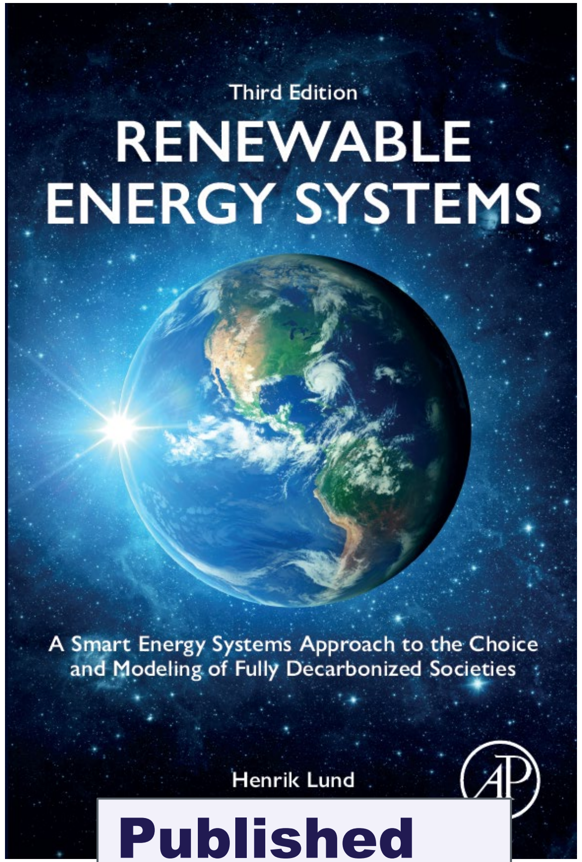
Smart Gas Grids

Connecting the electricity, heating, and transport sectors, enabling gas storage to be utilised for creating additional flexibility. If the gas is refined to a liquid fuel, then liquid fuel storages can also be utilised.



Two Smart Energy Systems Theses:

1. One cannot find the best solutions for affordable and reliable transitions of the energy system into a carbon neutral society solely within each subsector of the energy system. One must approach the transition in a holistic and cross-sectoral smart energy system perspective in order to be able to identify the best solution for the overall energy system and for society as a whole.
2. Subsector studies (no matter if they concern the role of a specific technology or the role of a region or country) should aim at identifying the role to play in an overall transition of the whole system, rather than aim at decarbonizing the sub-sector on its own



Published March 2024

IDA’s Climate Response: Danish energy system in a European context

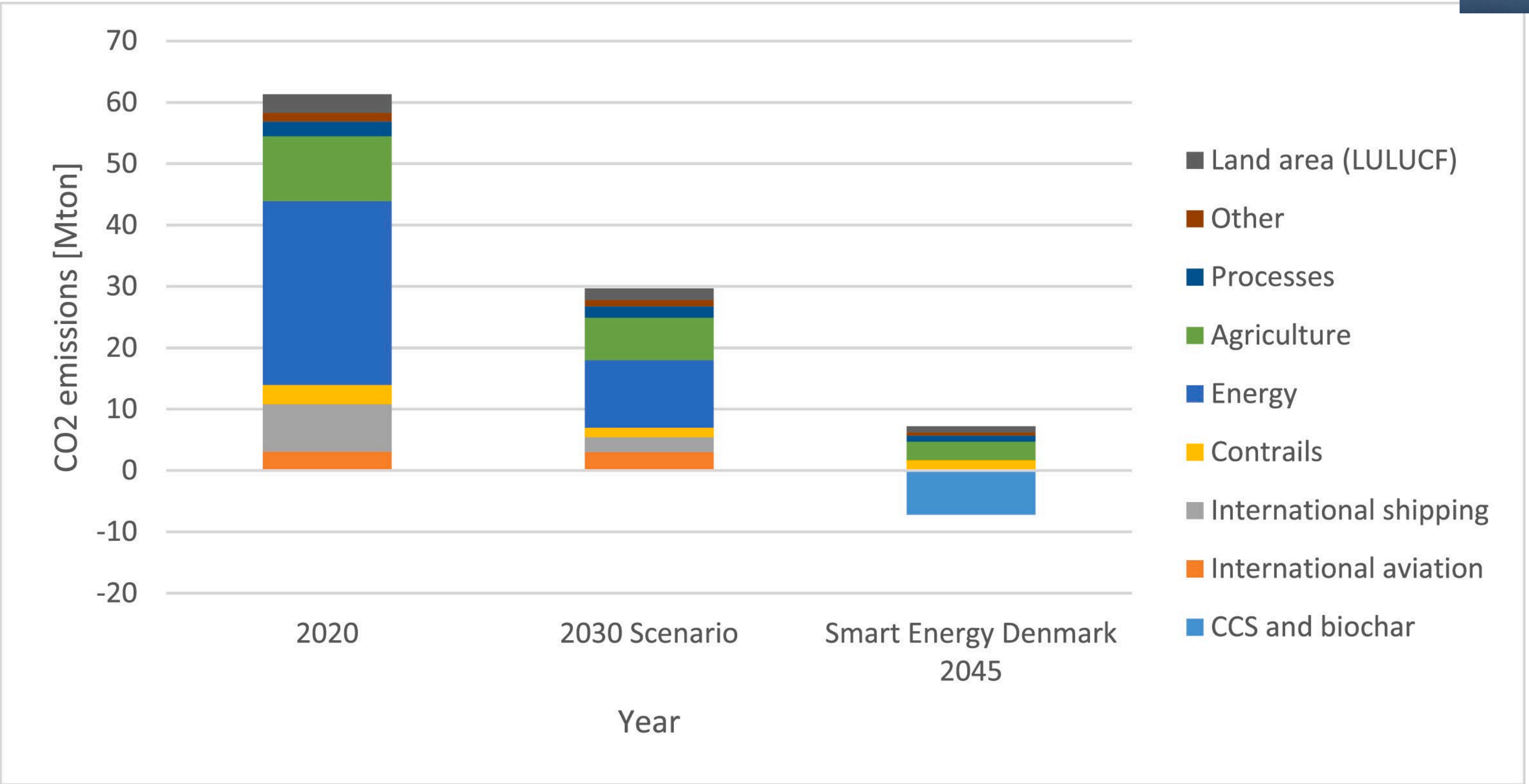
Denmark should fulfill its objective of renewable energy and CO_2-reductions in a way, so it fits well into a context in which the rest of Europe - and the world - will do the same.

Therefore:

- Denmark should include the Danish share of ***international aviation and shipping*** even though it is not included yet in the UN way of calculating the Danish CO_2 emissions.
- Denmark should not exceed our share of ***sustainable use of biomass*** in the world.
- Denmark should make our contribution in terms of ***flexibility and reserve capacity*** to integrate wind and solar into the ***European electricity supply***.

Source: Lund, H., Thellufsen, J. Z., Sorknæs, P., Mathiesen, B. V., Chang, M., Madsen, P. T., Kany, M. S., & Skov, I. R. (2022). Smart energy Denmark. A consistent and detailed strategy for a fully decarbonized society. Renewable and Sustainable Energy Reviews, 168, 112777. https://doi.org/10.1016/J.RSER.2022.112777

Danish CO_2 emissions



Source: Lund, H., Thellufsen, J. Z., Sorknæs, P., Mathiesen, B. V., Chang, M., Madsen, P. T., Kany, M. S., & Skov, I. R. (2022). Smart energy Denmark. A consistent and detailed strategy for a fully decarbonized society. Renewable and Sustainable Energy Reviews, 168, 112777. https://doi.org/10.1016/J.RSER.2022.112777

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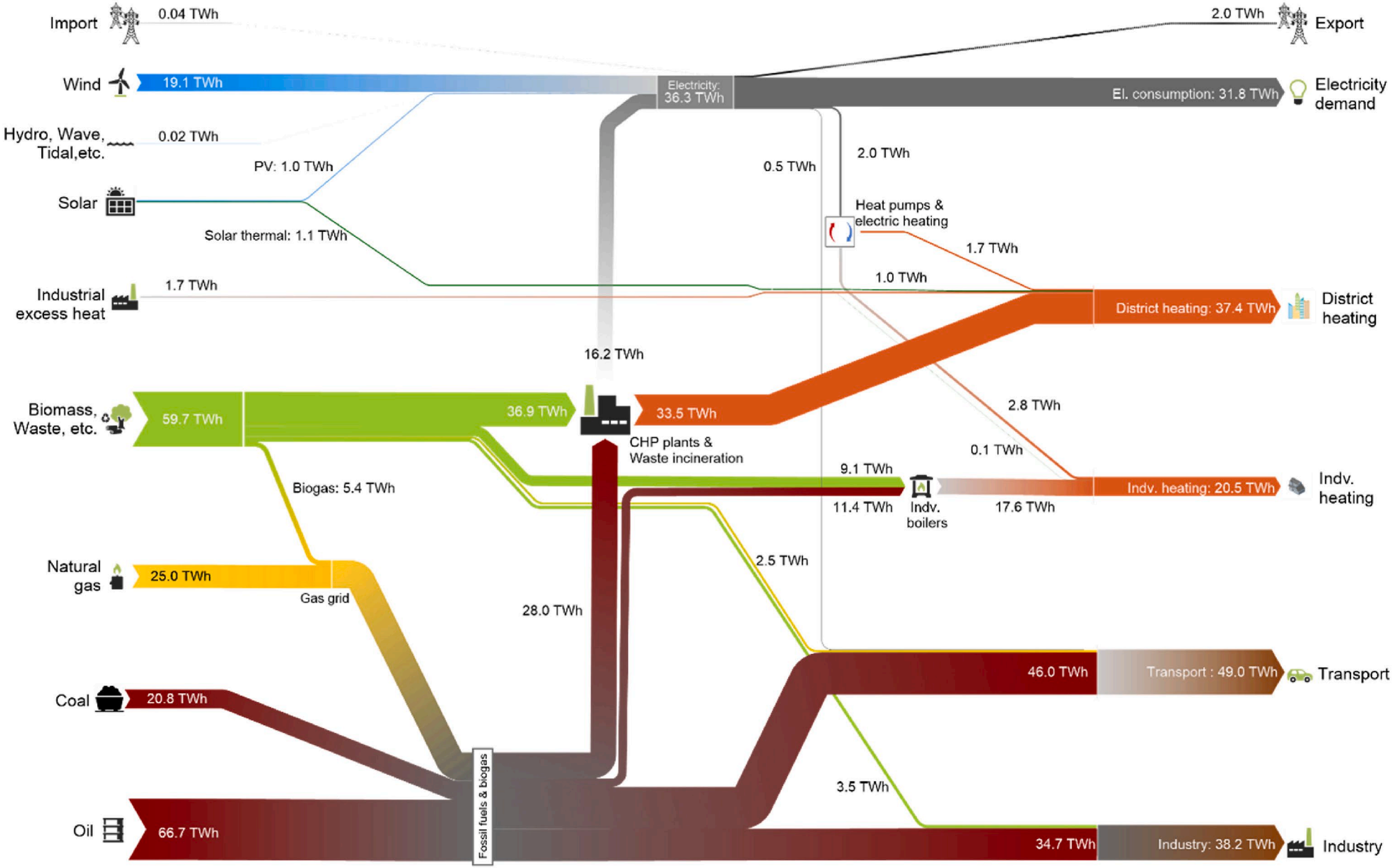
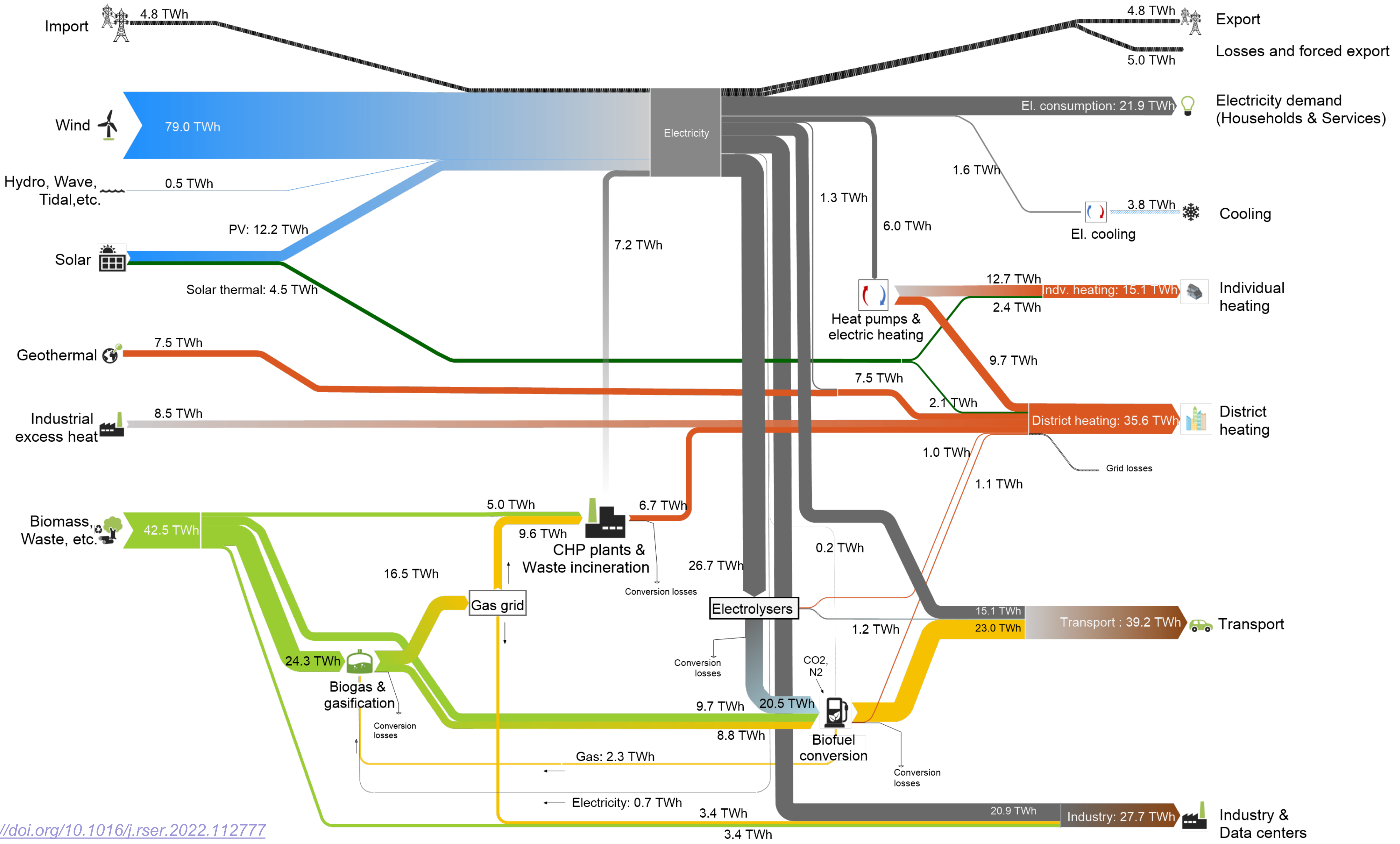
Danish energy system in 2020



Source: https://doi.org/10.1016/j.rser.2022.112777

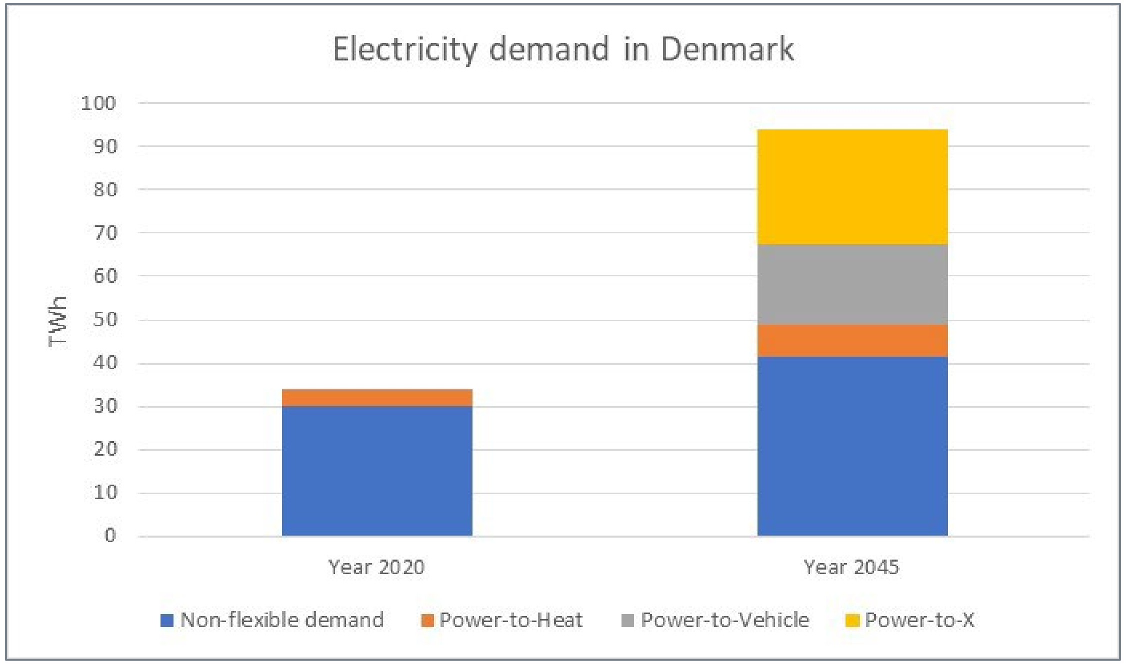
IDA's Climate Response 2045



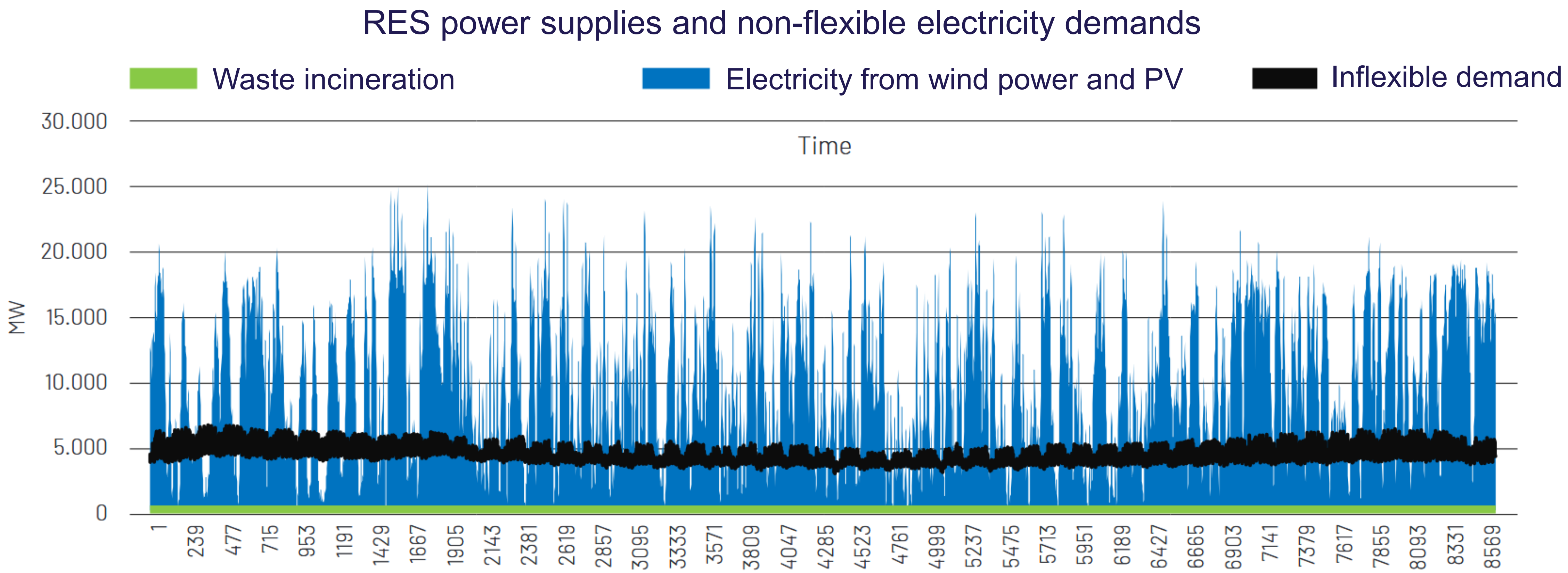
Source: https://doi.org/10.1016/j.rser.2022.112777

Essential changes in the future electricity demand

- The ”classical” non-flexible electricity demand increases by new flexible demands for:
  - Electric Vehicles
  - Power-to-Heat (heat pumps and electrical boilers)
  - Electrolysis and Power-to-X



PV and wind will cover 5-10% of the ”classical” non-flexible electricity demand



In the shown example only 7% is not met by wind power, PV or waste incineration

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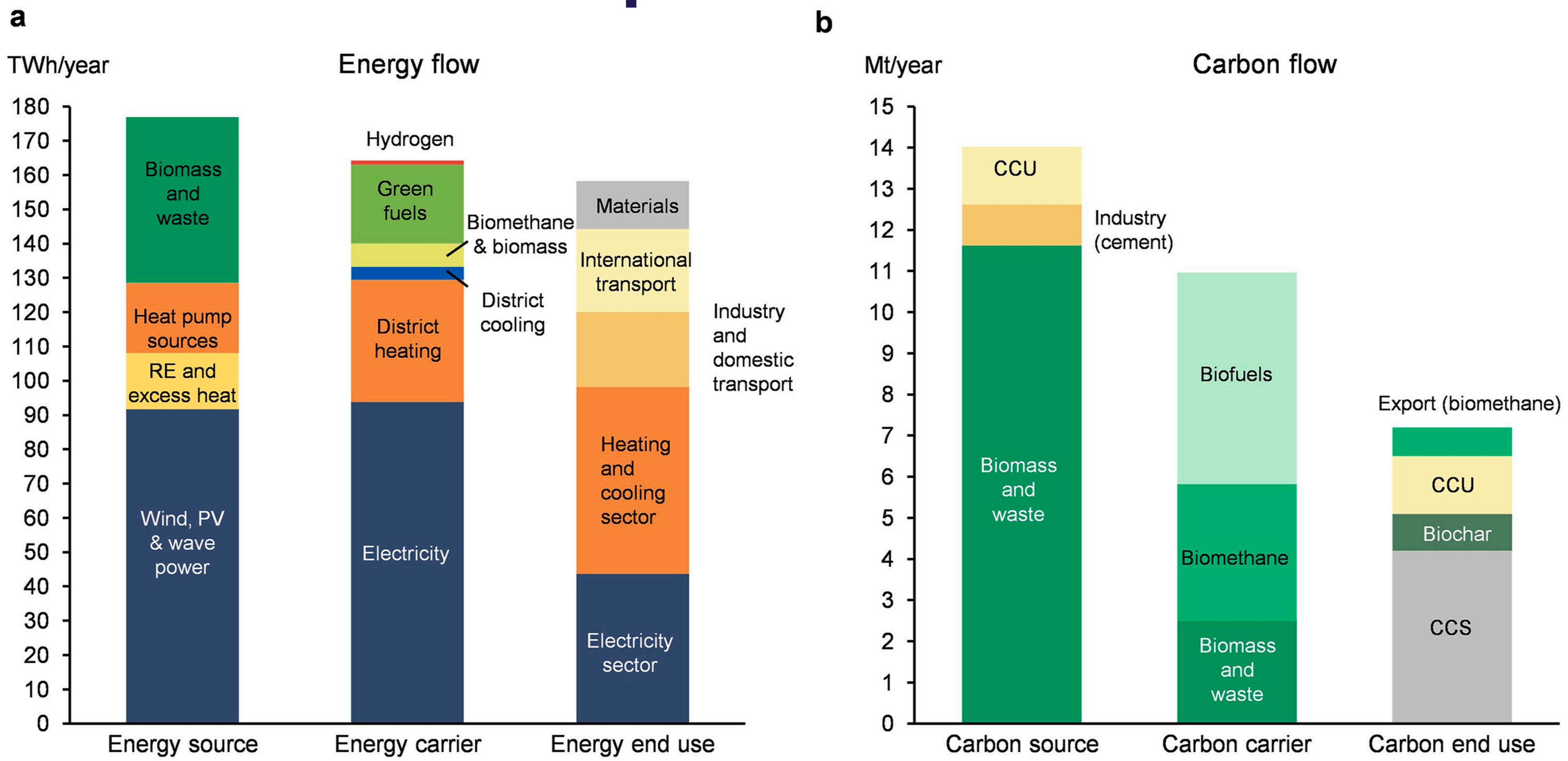
https://vbn.aau.dk/ws/portalfiles/portal/534311584/Fakta_om_atomkraft_V2_FINAL.pdf

Energy and Carbon Flows of the IDA's Climate Response 2045 scenario



Source: *Lund, H., Østergaard, P. A., Yuan, M., Sorknæs, P., & Thellufsen, J. Z. (2025). Energy balancing and storage in climate-neutral smart energy systems. Renewable and Sustainable Energy Reviews, 209, 115141. https://doi.org/10.1016/J.RSER.2024.115141*

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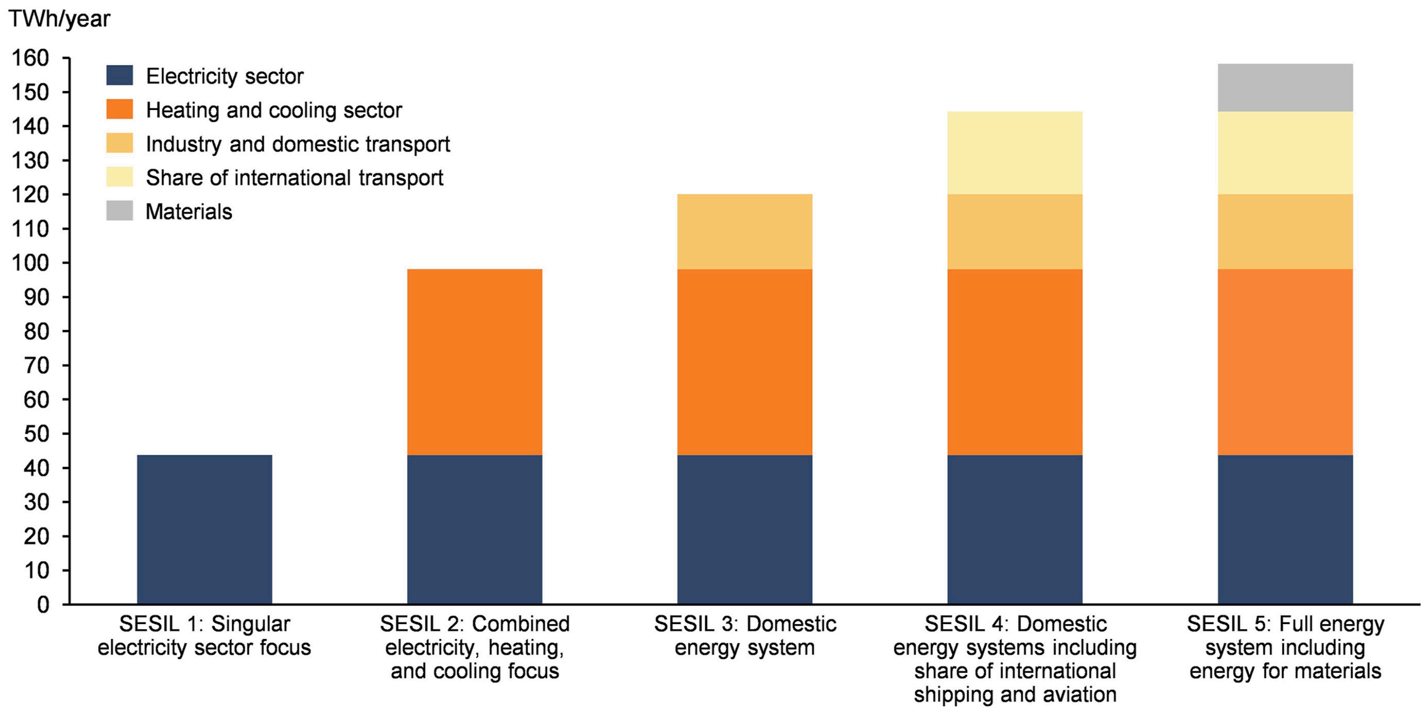
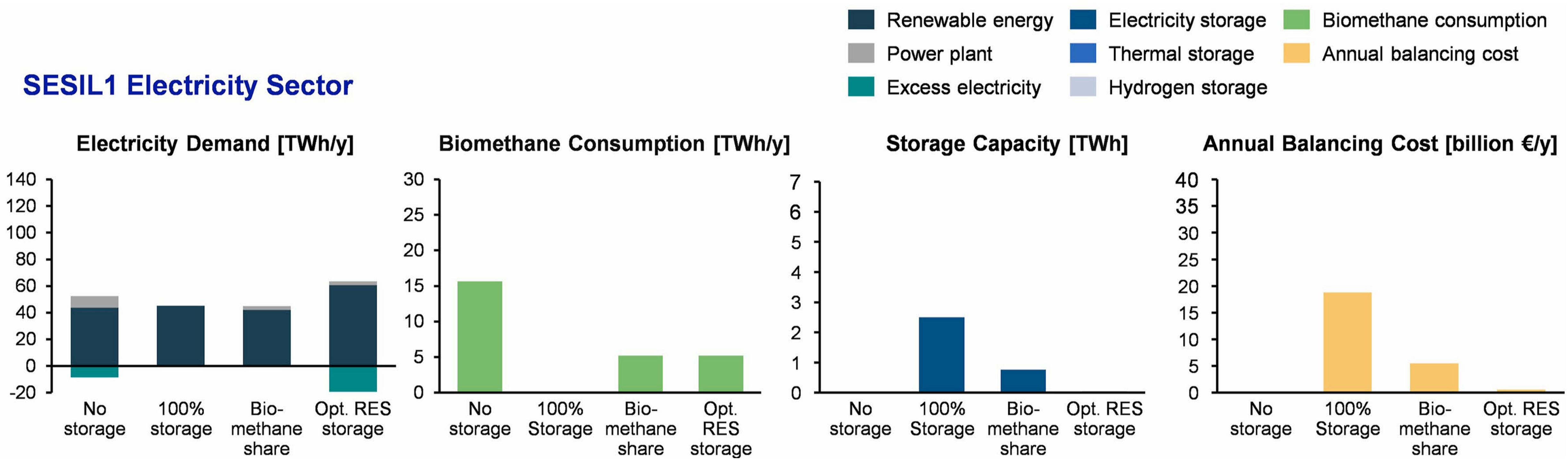
System Integration levels (SESIL)



- *SESIL 1: Singular electricity sector focus.* The classical electricity demand with electricity storage as the only option.
- *SESIL 2: Combined electricity, heating, and cooling focus.* Thermal storage as an additional option.
- *SESIL 3: Domestic energy system*. Industrial and domestic transport demands. Smart charging or even V2G.
- *SESIL 4: Domestic energy systems including the share of international shipping and aviation.* Significant increase in Power-to-X technologies to provide liquid green fuels. Gaseous and liquid green fuel storage.
- *SESIL 5: Full Energy System including energy for materials.*

Source: Lund, H., Østergaard, P. A., Yuan, M., Sorknæs, P., & Thellufsen, J. Z. (2025). Energy balancing and storage in climate-neutral smart energy systems. Renewable and Sustainable Energy Reviews, 209, 115141. https://doi.org/10.1016/J.RSER.2024.115141

Electricity balancing and least-cost storage solutions in SESIL1



Source: Lund, H., Østergaard, P. A., Yuan, M., Sorknæs, P., & Thellufsen, J. Z. (2025). Energy balancing and storage in climate-neutral smart energy systems. Renewable and Sustainable Energy Reviews, 209, 115141. https://doi.org/10.1016/J.RSER.2024.115141

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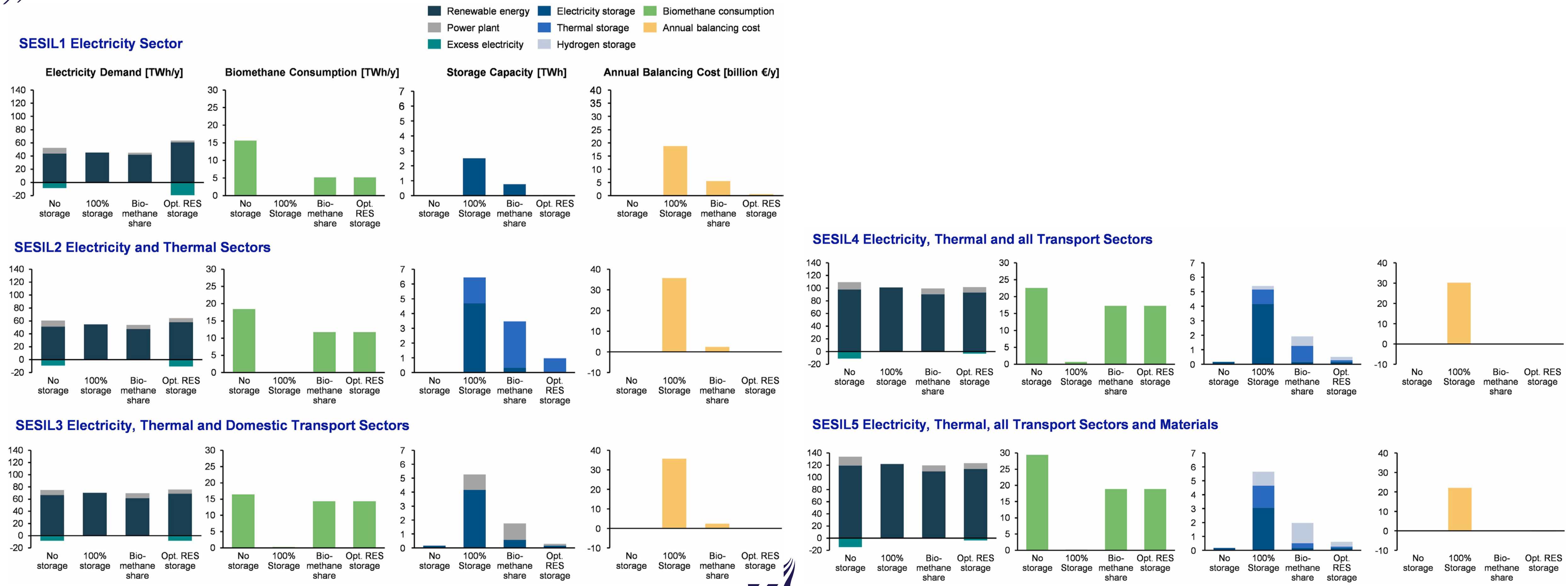
Electricity balancing and least-cost storage solutions in each of the five SESILs



Source: Lund, H., Østergaard, P. A., Yuan, M., Sorknæs, P., & Thellufsen, J. Z. (2025). Energy balancing and storage in climate-neutral smart energy systems. Renewable and Sustainable Energy Reviews, 209, 115141. https://doi.org/10.1016/J.RSER.2024.115141

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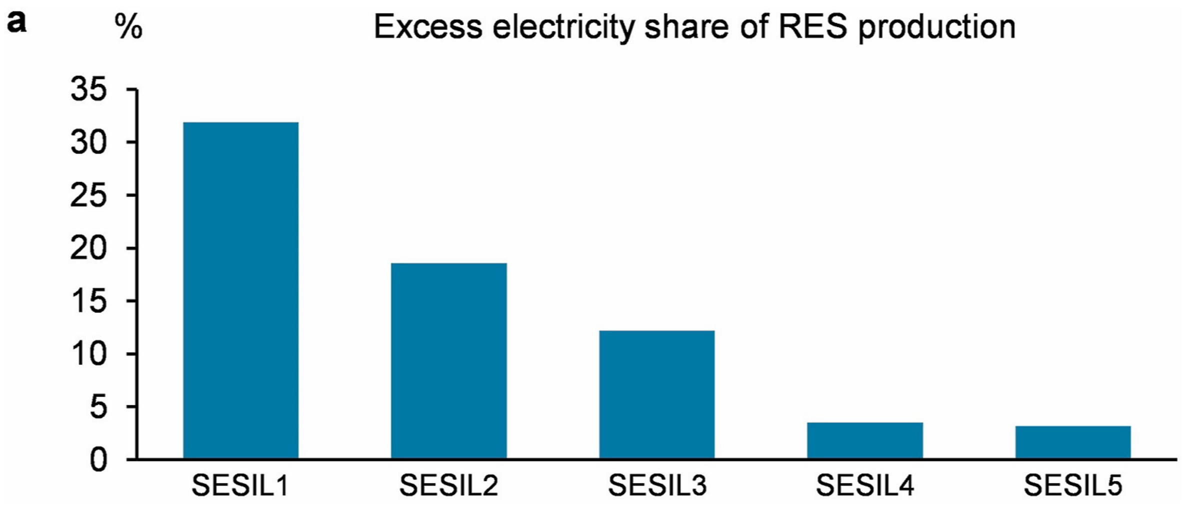
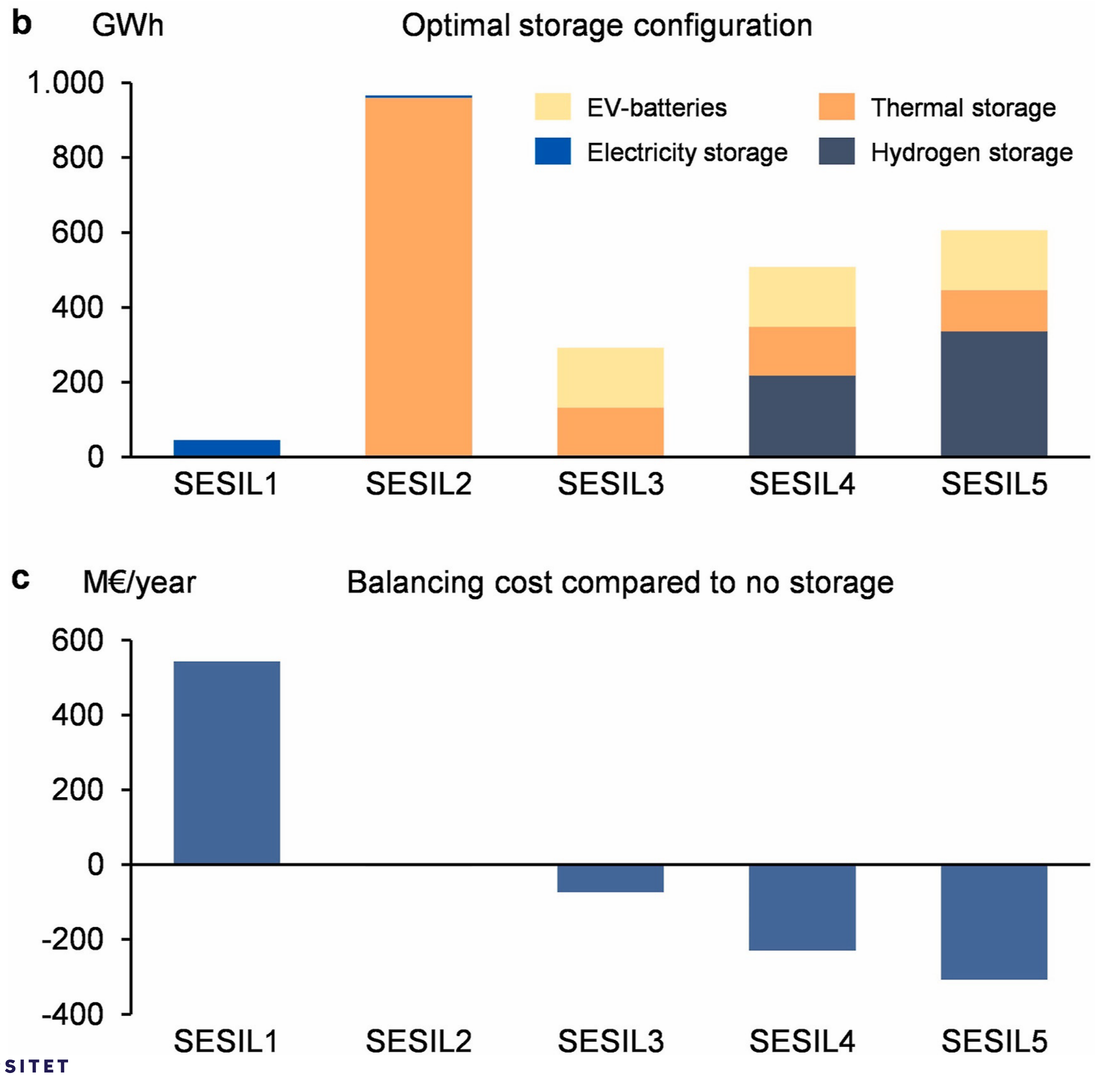
Comparison of least-cost balancing and storage solutions





Source: Lund, H., Østergaard, P. A., Yuan, M., Sorknæs, P., & Thellufsen, J. Z. (2025). Energy balancing and storage in climate-neutral smart energy systems. Renewable and Sustainable Energy Reviews, 209, 115141. https://doi.org/10.1016/J.RSER.2024.115141

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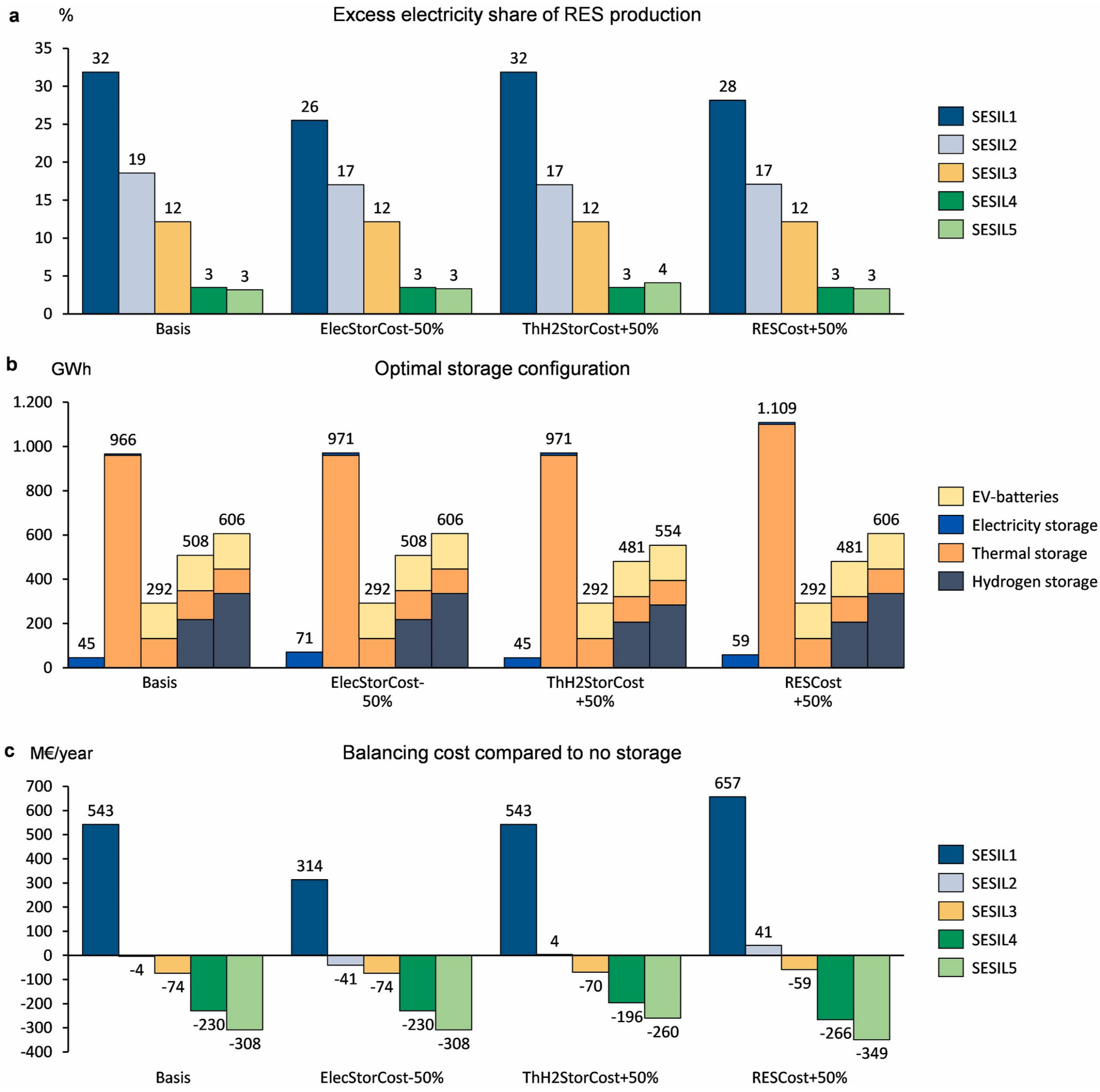
What if different costs?

- Three variations tested:
  - a 50% reduction in the cost of electricity storage
  - a 50% increase in the costs of thermal and hydrogen storage
  - a 25% increase in the costs of solar PV as well as onshore and offshore wind power
- Conclusion, these do not change the overall pattern shown with the base cost assumption.

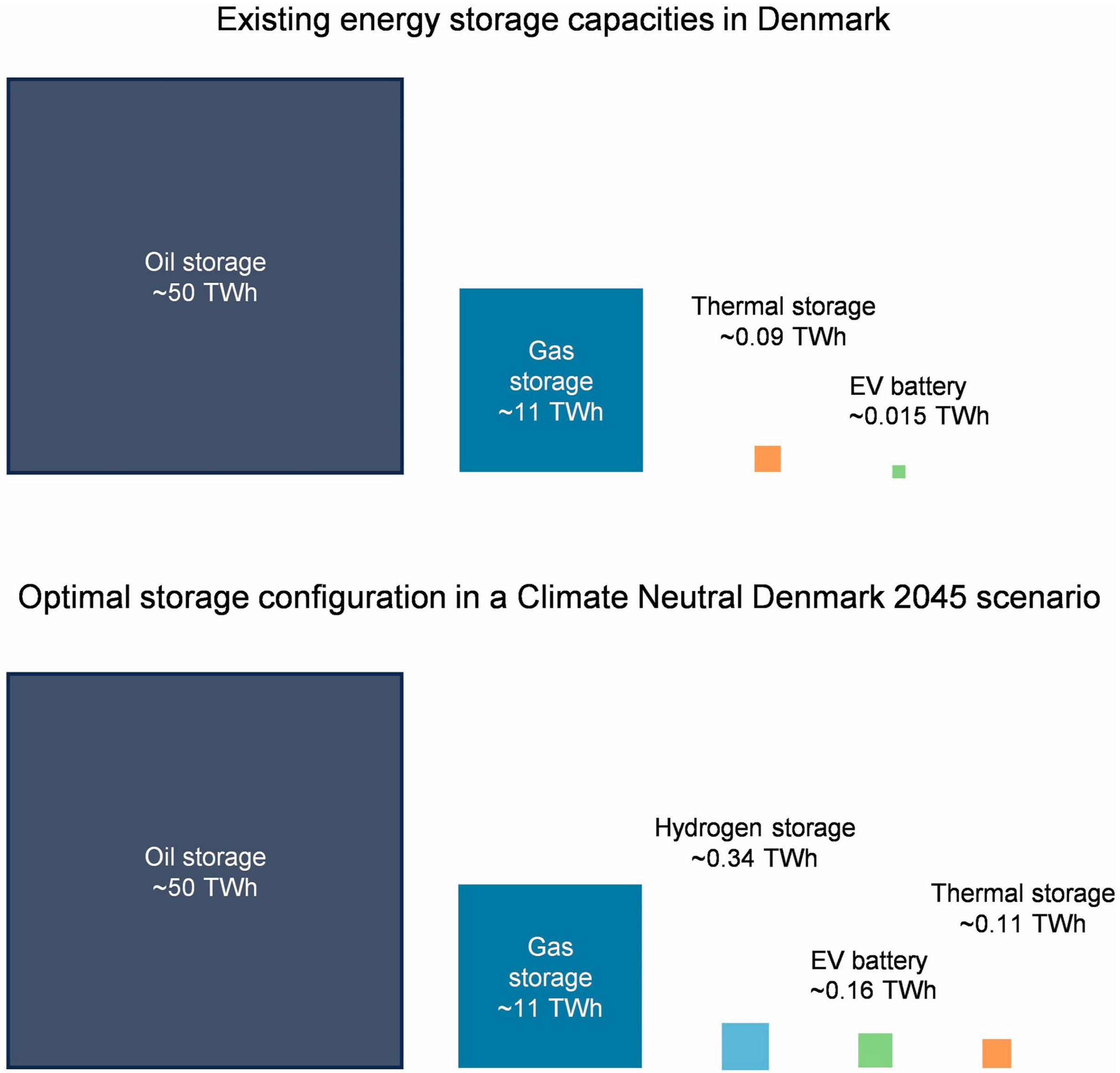


Source: Lund, H., Østergaard, P. A., Yuan, M., Sorknæs, P., & Thellufsen, J. Z. (2025). Energy balancing and storage in climate-neutral smart energy systems. Renewable and Sustainable Energy Reviews, 209, 115141. https://doi.org/10.1016/J.RSER.2024.115141

The need for storage in a climate-neutral Denmark

- Based on the SESIL analyses this is how we find energy storages in Denmark could look in 2045 as compared to current levels.

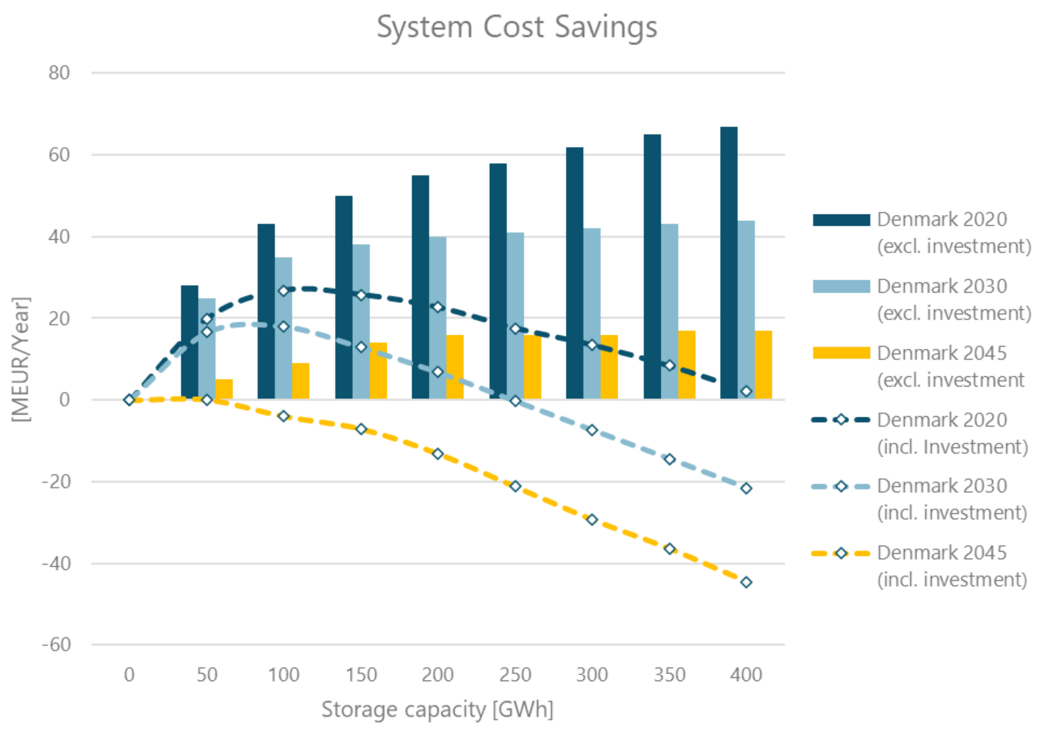
- The work focus on hourly energy system balancing and does not identify needs in relation to in-hour balancing, nor in the transition towards 2045.



Source: Lund, H., Østergaard, P. A., Yuan, M., Sorknæs, P., & Thellufsen, J. Z. (2025). Energy balancing and storage in climate-neutral smart energy systems. Renewable and Sustainable Energy Reviews, 209, 115141. https://doi.org/10.1016/J.RSER.2024.115141

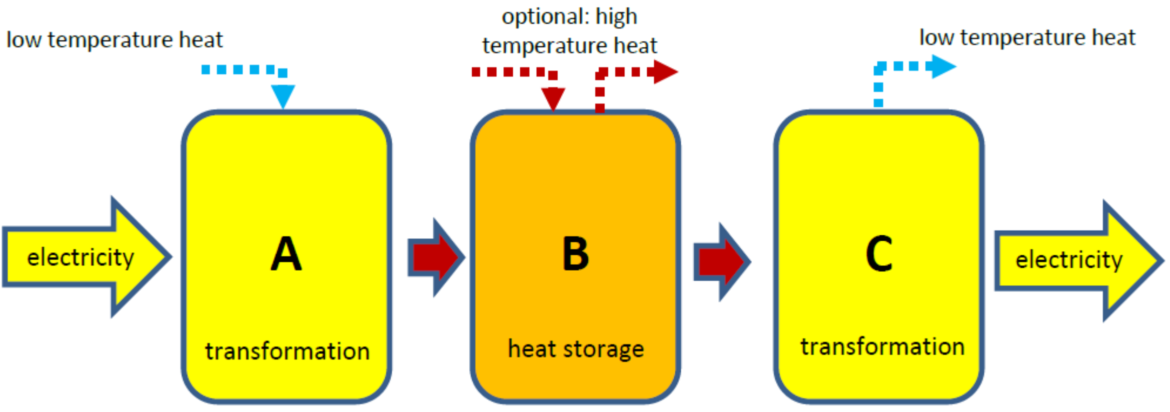
Future role of district heating storages

- Offers fuel savings, variable cost savings and reduced curtailment of renewable electricity sources in the energy system.
- The role of district heating storages evolves with the energy system transition.
  - Initially, they primarily reduce fuel consumption and associated costs.
  - In a fully decarbonized future with extensive renewable integration, the primary benefit shifts toward reducing curtailment losses and enhancing grid stability.
- District heating storages remain economically viable in the current and near-term transition. However, the investment costs do not make up for the variable cost savings in a fully decarbonized 2045 scenario at low energy prices.
- An adequate system-wide storage capacity for Denmark is estimated to be between 100-200 GWh, approximately double the current capacity. Beyond this range, additional capacity yields diminishing returns.
- They offer similar benefits to electrical storage but at a significantly lower investment cost, highlighting its importance as a flexible, cost-effective component of both current and future smart energy systems.

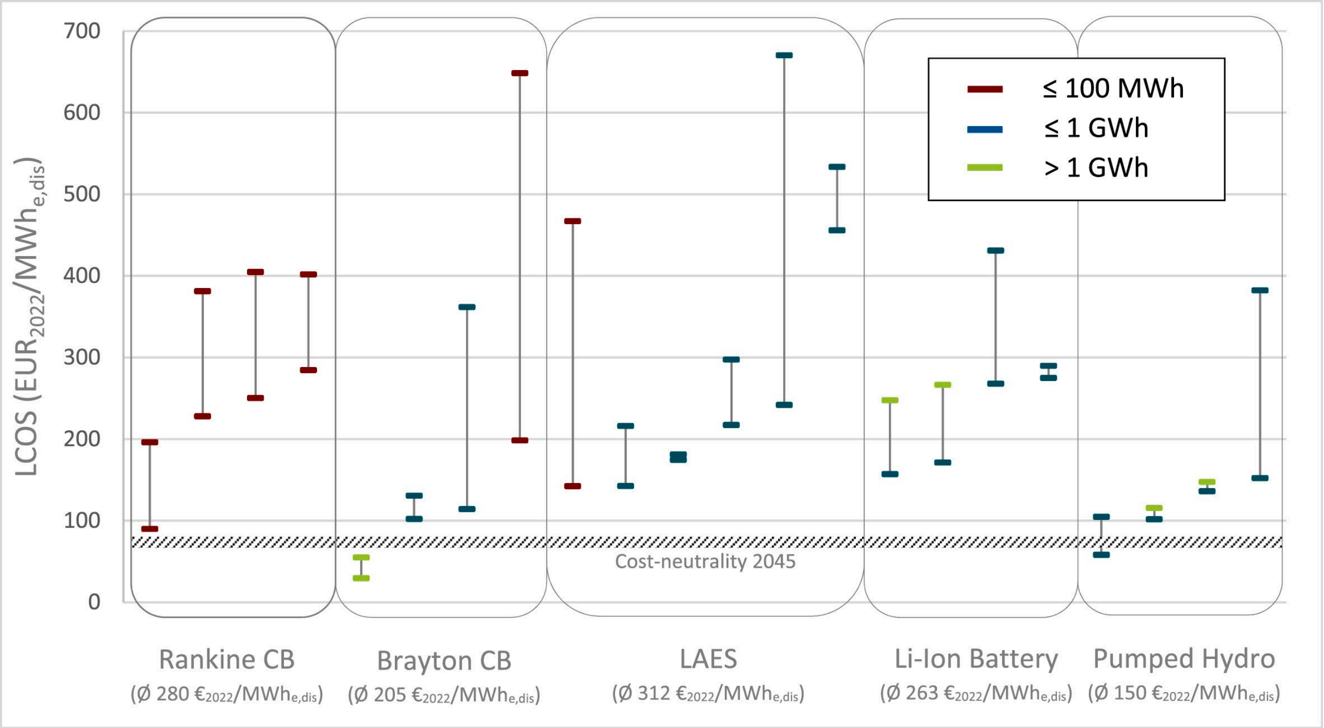


Source: Kjær Christensen, T. B., Lund, H., & Sorknæs, P. (2024). The Role of Thermal Energy Storages in Future Smart Energy Systems. Energy, 133948. https://doi.org/10.1016/J.ENERGY.2024.133948

Carnot batteries could provide cheaper (though less efficient) storage options



Though relatively few yearly cycles are expected (up to around 32)



LCOS of different Carnot battery types as well as established storage technologies including the corresponding storage capacity ranges.

Source: Sorknæs, P., Thellufsen, J. Z., Knobloch, K., Engelbrecht, K., & Yuan, M. (2023). Economic potentials of carnot batteries in 100% renewable energy systems. Energy, 282, 128837. https://doi.org/10.1016/J.ENERGY.2023.128837

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Keynote: Challenges and prospects of integration of energy storage to the distribution grid

Jacob Ribergaard Vinther, Cerius-Radius

Challenges and prospects of integration of energy storage to the distribution grid

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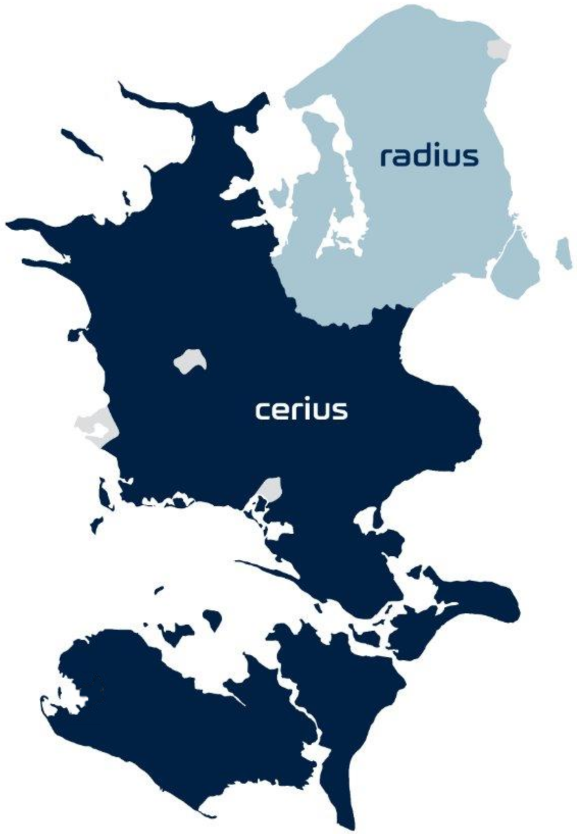
Agenda

- Cerius-Radius the DSOs of most of Eastern Denmark
- The responsibility of the DSO
- The ideal grid connection process
- Pilot project – Flexibility from EVs through an aggregator as a replacement for grid reserve

Cerius-Radius



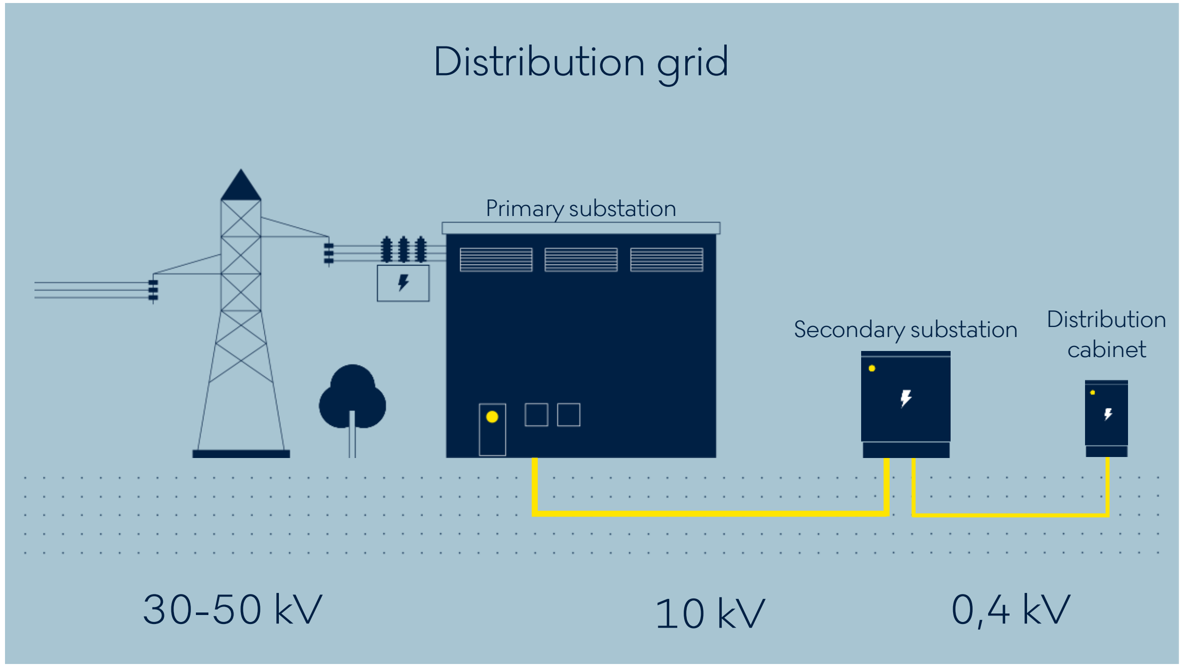
- Cerius and Radius are two of the distributions system operators, operating the electrical distribution grid on Zealand and adjourning island.
- Supplying approximately 1,5 million electricity customers.
- Delivering around 40 % of the electricity delivered at distribution level in Denmark.

Cerius-Radius

Our assets approximately covers:

- 220 primary substations
- 21.000 secondary substations
- 44.000 km cables and overhead lines
- 300.000 distribution cabinets

We used to build one primary substation every four years – now we build four primary substations a year.



The responsibility of the DSO

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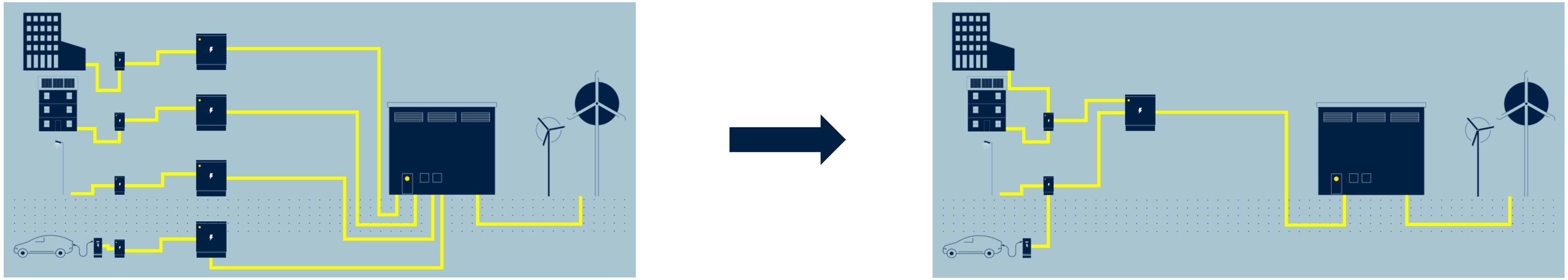
The distribution system operators

- The DSOs are regulated monopolies which means the respective companies are the only companies which can build distribution grids in the granted areas.
- Are required to connect all customers and treat customers equal (technology neutral).

- Collective grids ensure cost-efficient electricity transportation:



Electricity supply lines

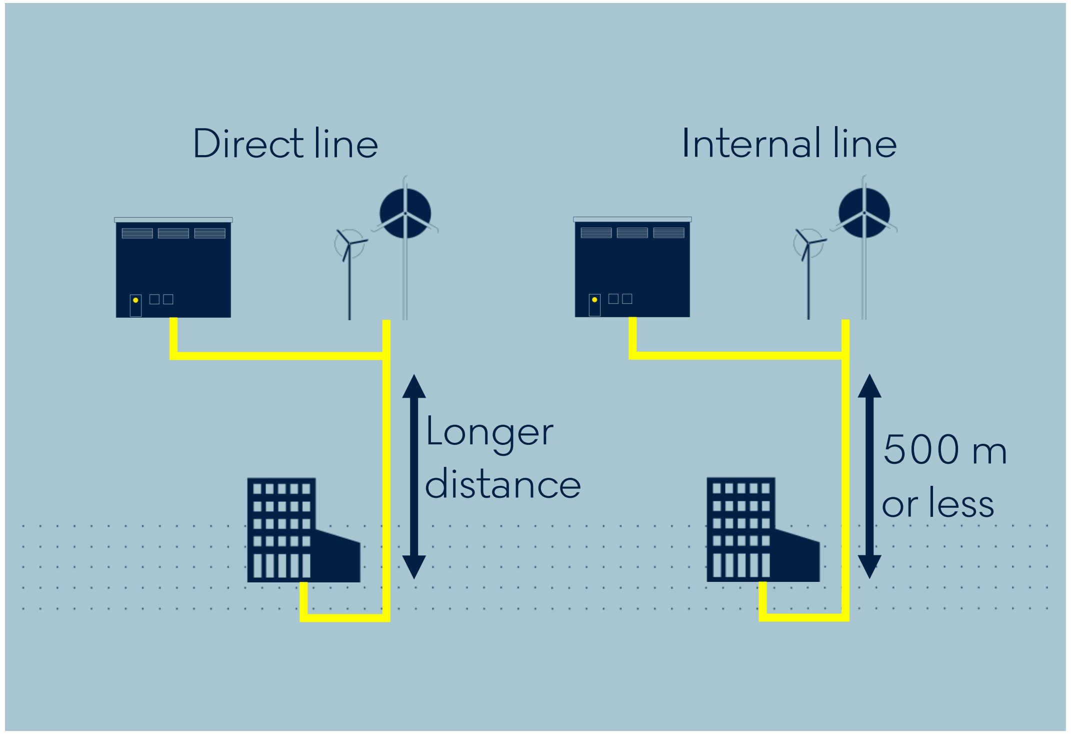
Typically, all consumption and production is directly connected to the distribution or transmission grid.

Exceptions can however be made:

- Direct supply lines (Approved by the DEA)
- Internal supply lines (Approved by the DSO)

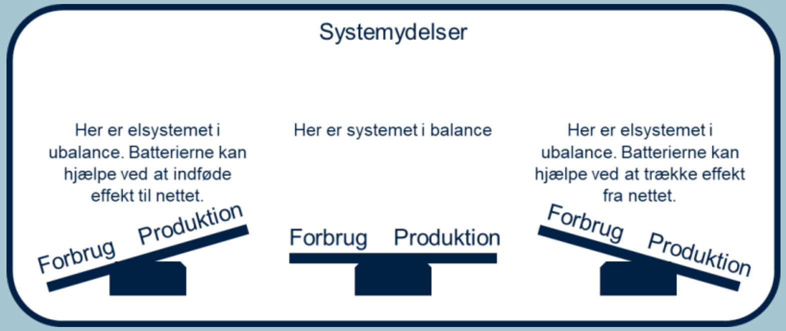
Rules for connecting batteries or other energy storage facilities:

Tilslutning af batterier – Radius (in Danish)

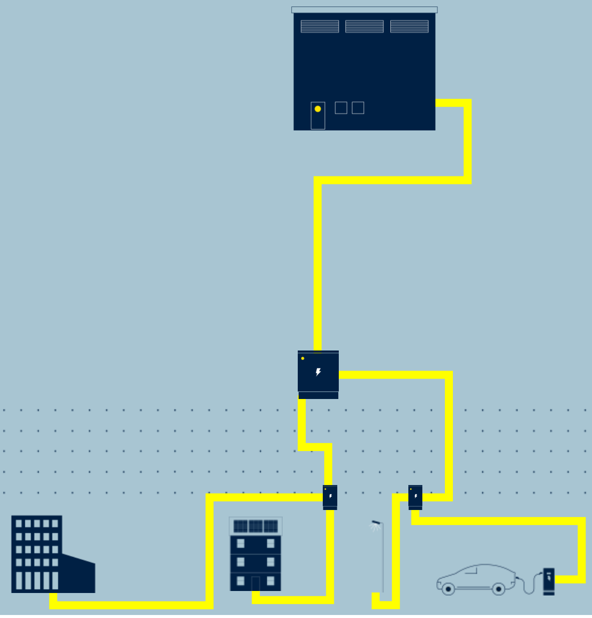


Distribution grid and electricity system

Electricity system

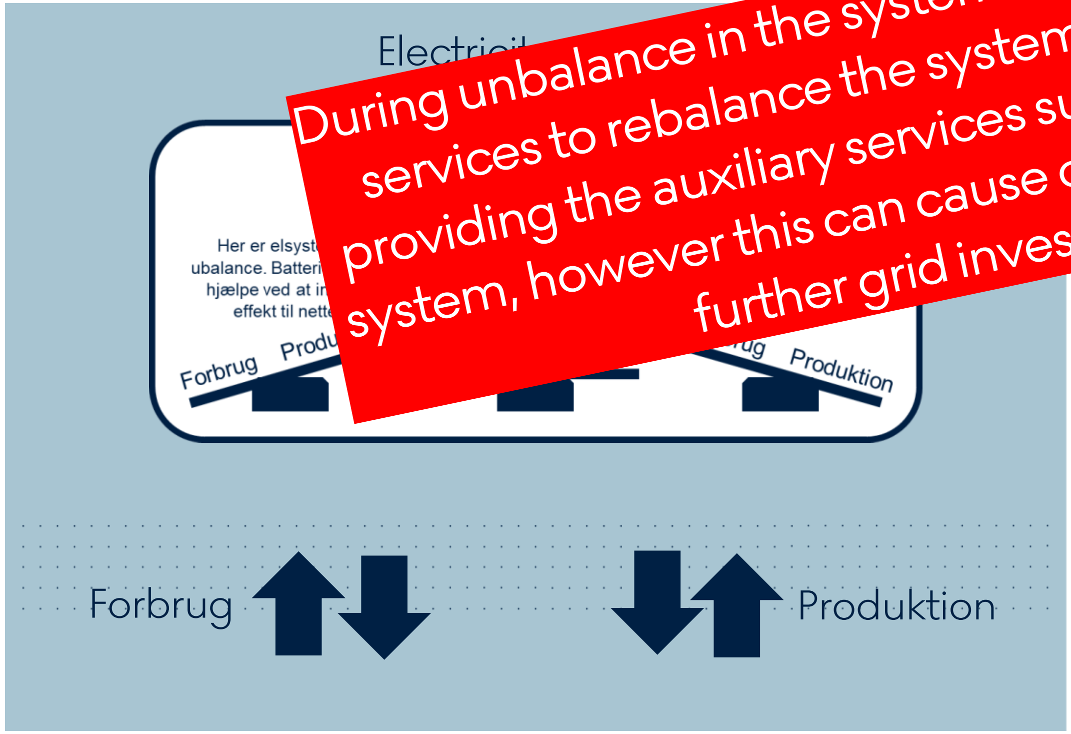


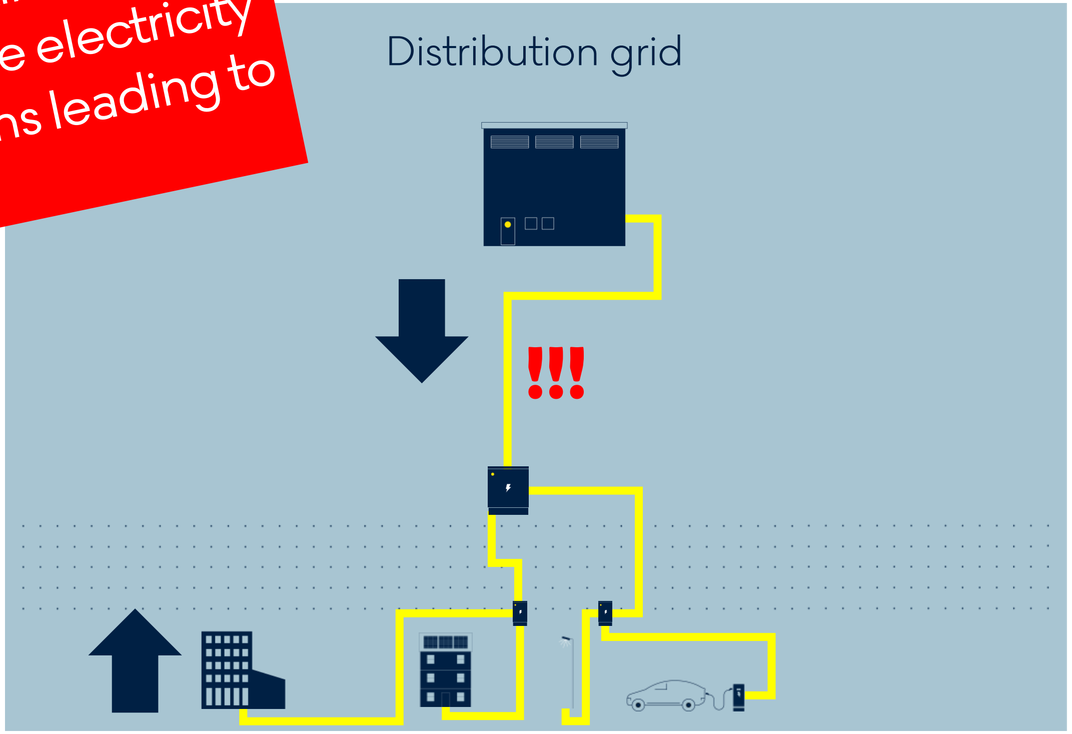
Distribution grid



Distribution grid and electricity system

During unbalance in the system Energinet buys auxiliary services to rebalance the system. The flexible users providing the auxiliary services supports the electricity system, however this can cause congestions leading to further grid investments.





The ideal grid connection process

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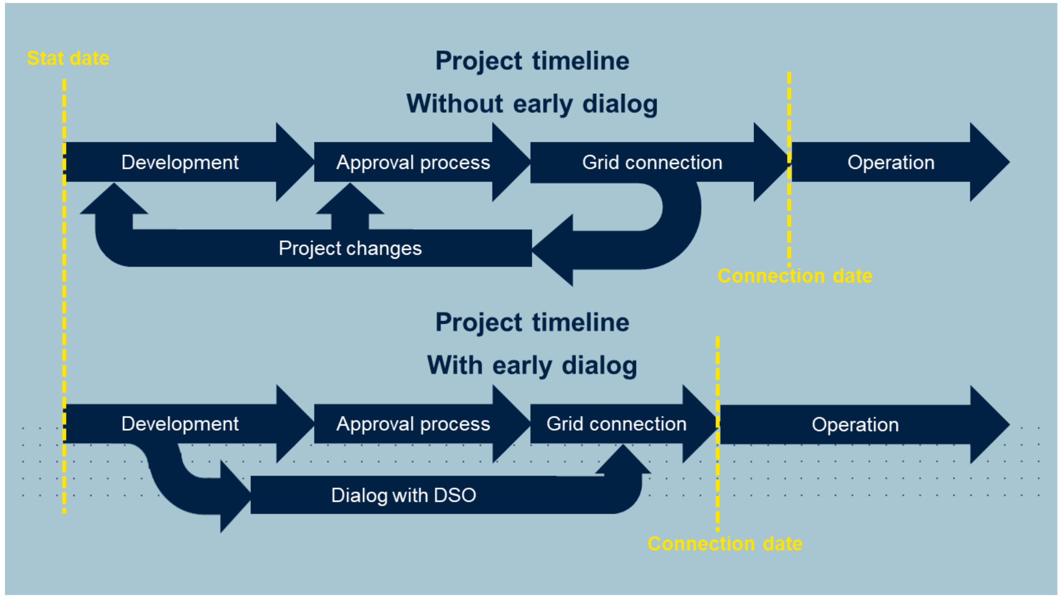
Initiate the dialog early

- **The initiation of an early dialog with Cerius-Radius is key.**
  - Especially for projects for which the location and size aren't fixed.
  - We can provide insight into the state of the local grid based on specific request – so called screenings.

- **We can't reserve grid capacity for projects.**
  - We don't start establishing the connection until a grid connection agreement has been signed.



Project development

Location, size and timeline

- If the location, size and timeline of the project is fixed, you can skip the initial dialog.
- Again, the sooner you fix the location, size and wishes for the timeline, the better.

The grid connection process

Grid connection agreement is signed.

We start assigning internal project owners. As soon as a project owner is free, they are assigned to your project, if you are first in line.

We build the connection, while you ensure that the project is compliant.

Once both your and our assets are built, you can order the meter setup.

You can't connect before a connection agreement has been signed.

After the connection has been made, you might be required to test your facility.

A final notification of operation is granted, when everything is compliant.

The grid connection process
- Your response time affects our process!

1. Grid connection agreement is signed.
2. We start assigning internal project owners. As soon as a project owner is free, they are assigned to your project, if you are first in line.
3. We build the connection, while you ensure that the project is compliant.
4. Once both yours and our assets are built, you can order the meter setup.
5. You can't connect before a connection agreement has been signed.
6. After the connection has been made, you might be required to test your facility.
7. A final notification of operation is granted, when everything is compliant.

Pilot project – Flexibility from EVs through an aggregator as a replacement for grid reserve

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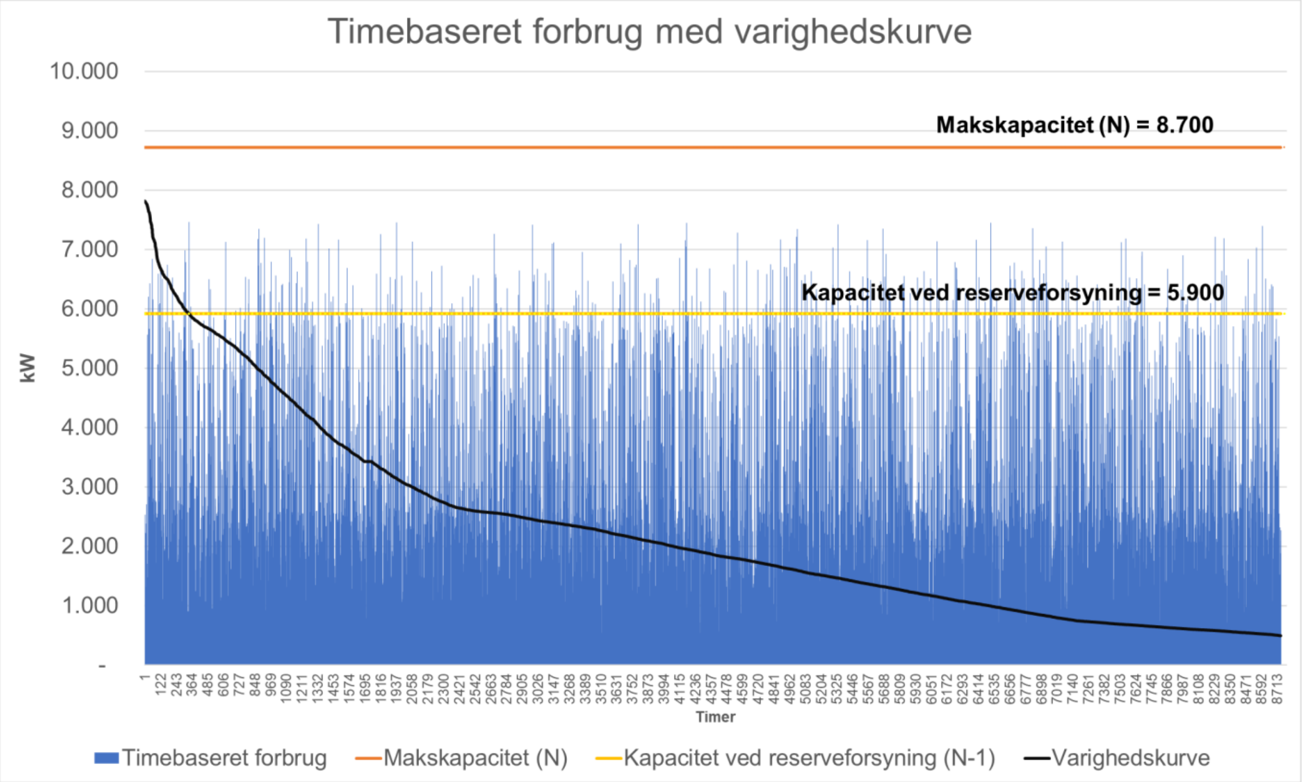
Overload of 10 kV-grid

During faults, a local 10 kV-capacity was exceeded.

- Occurs few hours a year

The project scope was to test if the overload could be solved through flexibility, and if one or more customers could provide reliant and safe flexibility.

The challenge can be solved by expanding the grid capacity or alternatively flexibility of consumers.



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The need for flexibility

Challenges and flexibility need

In different fault scenarios the capacity limit is exceeded.:

- Criteria of dimensioning: 7,3 MW
- Maximum load: 8,1 MW
- Flexibility need: 0,8 MW

The need for flexibility occurs when parts of the grid are faulty or out for planned maintenance.

Faults are relatively rare

Assumptions on duration and occurrence:

Type	Occurrence pr. year	Period pr. disconnection	Limitation period
Fault	0-5 times	5-12 days	Typical during the day and peak hours
Revision	0-3 times	6-48 hours	Typical during the day and peak hours
Safety disconnection	0-5 times	6-72 hours	Typical during the day and peak hours

The need for flexibility

Challenges and flexibility need

In different fault scenarios the cap

- Criteria of dimensioning: 7,3 MV
- Maximum load: 8,1 MW
- Flexibility need: 0,8 MW

The need for flexibility occurs whe
or out for planned maintenance.

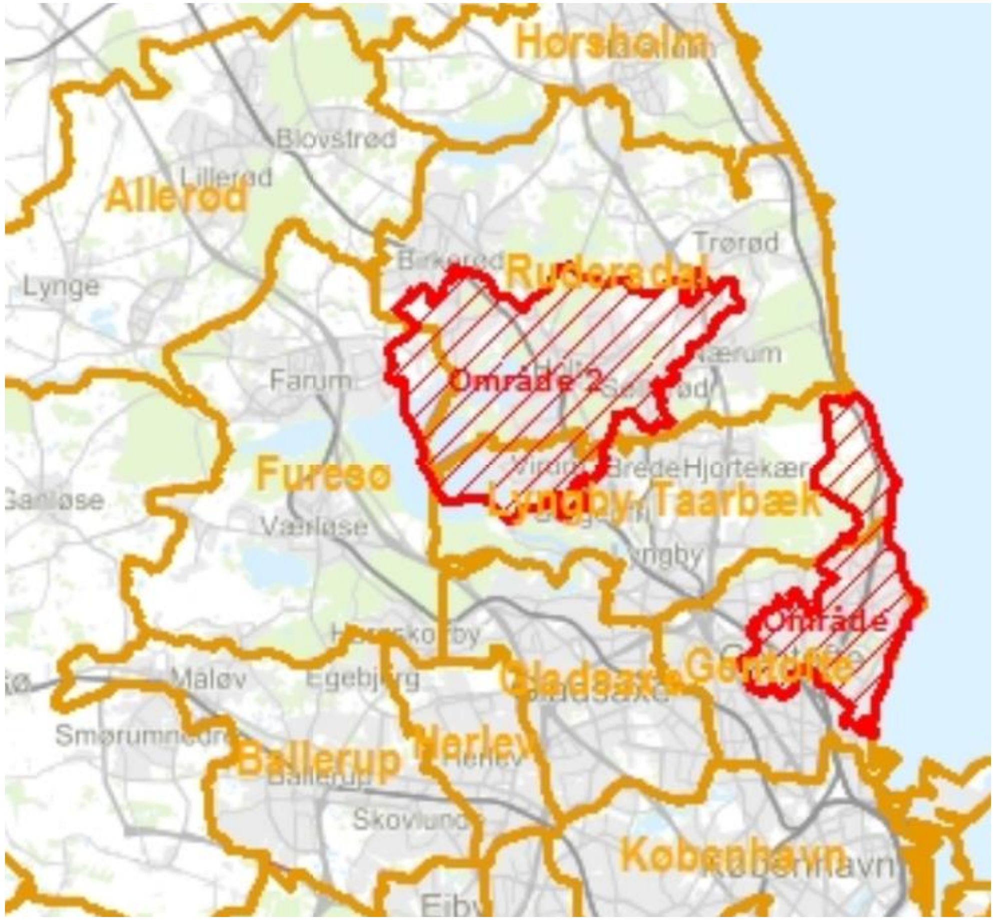
It was agreed that the flexibility delivered should be 0,9 MW downward regulation:

Corresponds to disconnecting 200 EVs charging with 4,5 kW or 80 EVs charging with 11 kW.

occurrence:

		Period pr. disconnection	Limitation period
		5-12 days	Typical during the day and peak hours
		6-48 hours	Typical during the day and peak hours
Safety disconnection	0-5 times	6-72 hours	Typical during the day and peak hours

Simulation in two areas with all of Radius area in backup.



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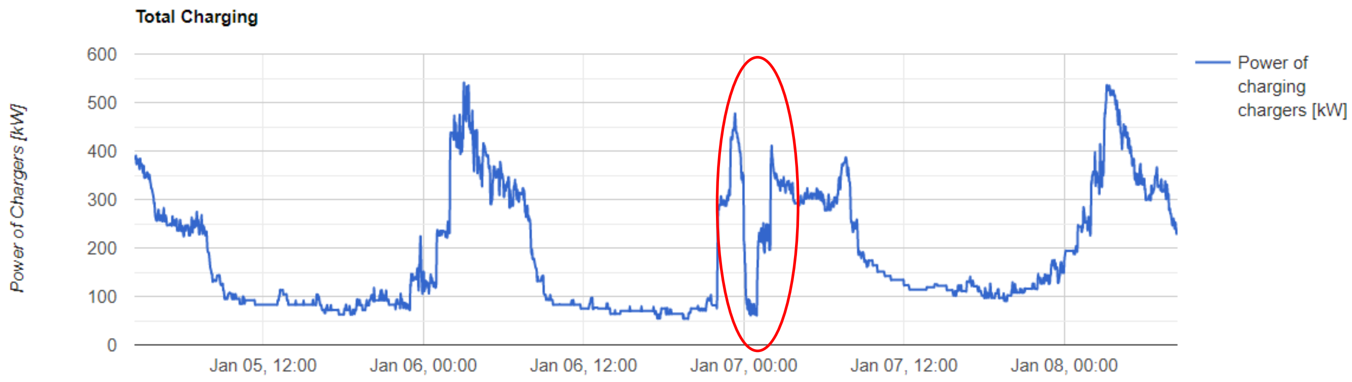
Results

- It is possible to activate flexibility and preform validation.
- Can limit the need for grid investments. However, this I dependent on the duration and number of flexibility providers.
  - The flexibility should be available at any time where a fault can occur.



- The payout for the flexibility service must not exceed the cost of grid investment.
- Payment for the flexibility can come in:
  - Direct payment
  - Lower tariffs
  - Lower connection fee (Limited grid access product)

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Implementation of flexibility

- Customers with flexible production or consumption can provide services to the distributions grid.
- This should be based on long term contracts as day-to-day contracts provide a larger risk.
- Costs must not exceed cost in grid investment.
- The more flexible customers the better.
- Flexibility as an alternative for grid investments relies on a large share of local flexible customers around the bottleneck.

The possibilities are closely linked to the customers needs for distribution grids – Here is flexibility a building brick.

Jacob Ribergaard Vinther
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ADVANCED ENERGY STORAGE CONFERENCE 2024

Advancing the green transition in Port of Hirtshals through energy flexibility and storage: Insights from the EFFORT Project

Mette Dam, Greenport North

greenport north

Advancing the green transition in Port of Hirtshals through energy flexibility and storage

Insights from the EFFORT Project

28th of November by Mette Dam Jensen

and special guest star: Mikkel Bendixen Copeland, TI

1

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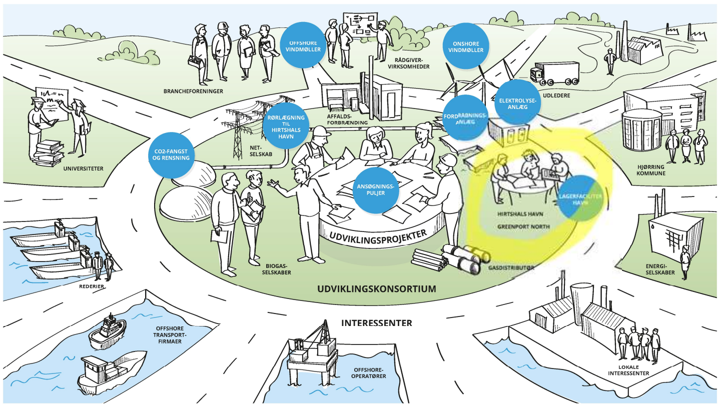
GREENPORT NORTH P/S

- Port of Hirtshals
- Hirtshals Havnefond
- Nord Energi A.m.b.A
- Hjørring Municipality



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GREENPORT NORTH PROJECTS

greenport north

GREENPORT SCANDINAVIA

EFFORT

INNO-CCUS
Carbon capture, utilisation and storage

Minifyrtårnsprojekt
Hirtshals – Greenport North

En del af CO2VISION

Grønn Jyllandskorridor

CONVEY

4

5

BUSINESS OF TODAY

greenport north

SMART ENERGY SYSTEM

”WE ARE FLEXIBLE WHEN AND WHERE WE CAN”

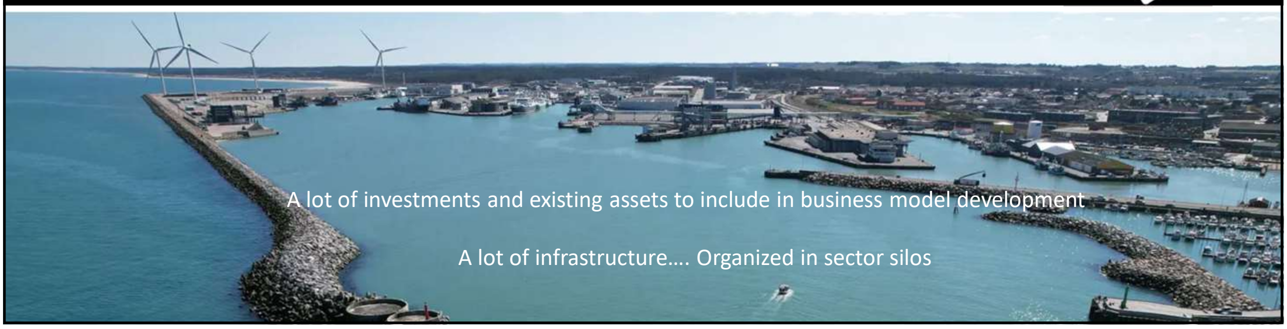
SECTOR COUPLING

”WE USE AND STORE ENERGY BETWEEN SECTORS ”

TARGET: TO ENABLE BUSINESS FOR THE FUTURE

6

100 years of port industrialization



7

WHERE TO START?

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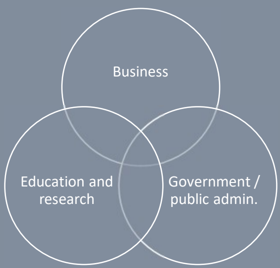
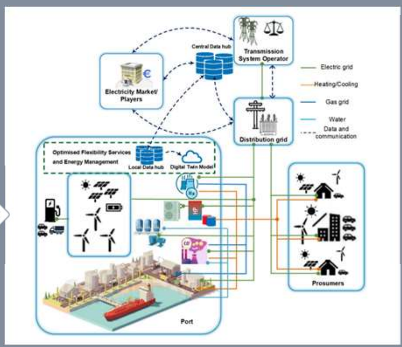


Triple helix model of innovation



Project scoping

ELFORSK

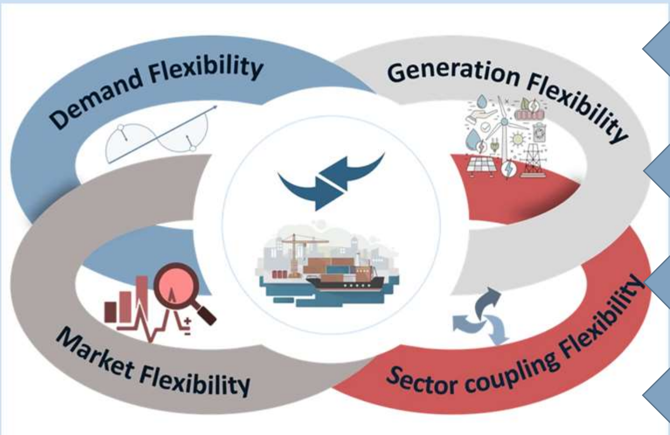
EFFORT

Project execution

8

EFFORT ambition: Electrification and flexibility provision

EFFORT



TIMELINE: JAN 2022 – JAN 2025

BUDGET: APP. 12 MIO. DKK
SPONSORED BY ELFORSK

DATA AND DIGITALIZATION

SCENARIOS, MODELLING, DIGITAL TWIN
REAL TIME ANALYSIS AND CONTROL

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EFFORT project partners

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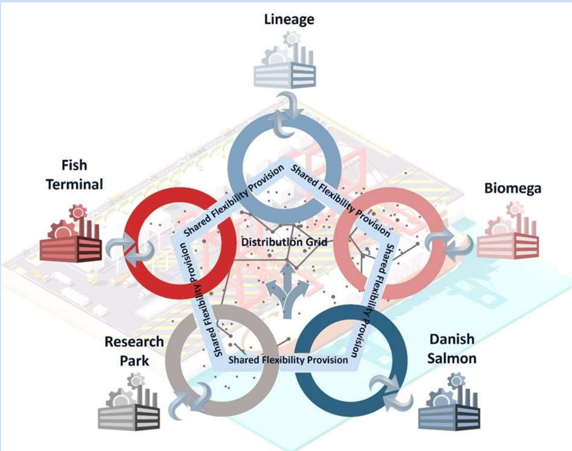
AAU ENERGY AALBORG UNIVERSITY
TEKNOLOGISK INSTITUT
centrica Energy Trading
nord energi
centerdenmark
PORT OF HIRTSHALS HIRTSHALS HAVN
EMD International
PlanEnergi
ELFORSK

The EFFORT project is supported by ELFORSK

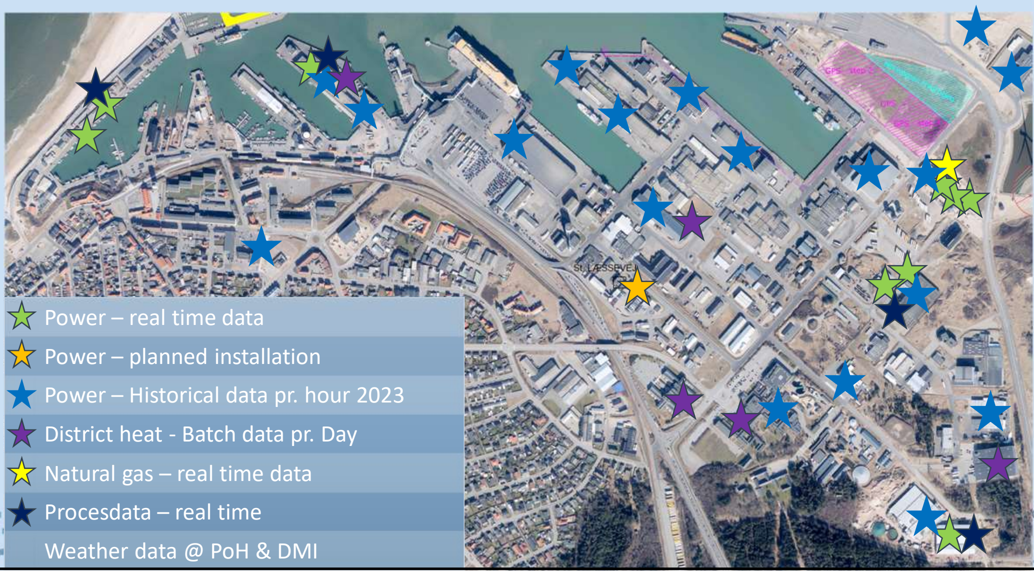
10

EFFORT industrial partners - use case development



11

EFFORT data collection @ Port of Hirtshals

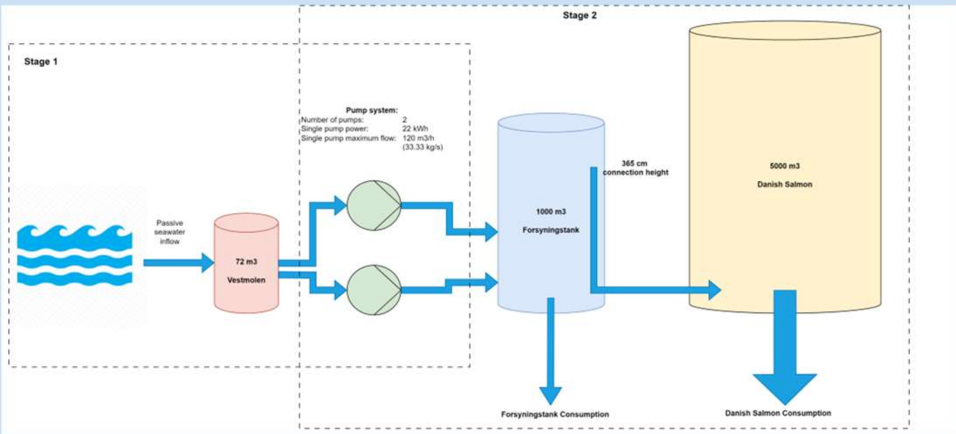


12

The Research Park – a case
”Nordsøen Forskerpark”

13

System overview



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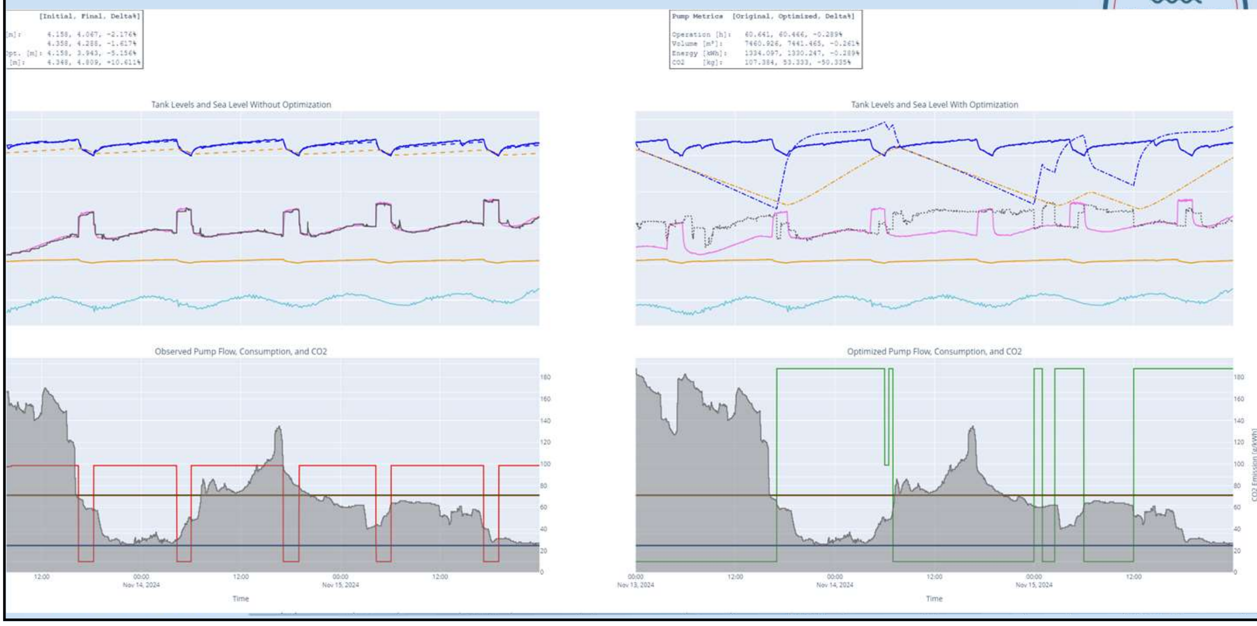
Learnings from data analysis



17

ENERGY STORAGE AND SECTORCOUPLING

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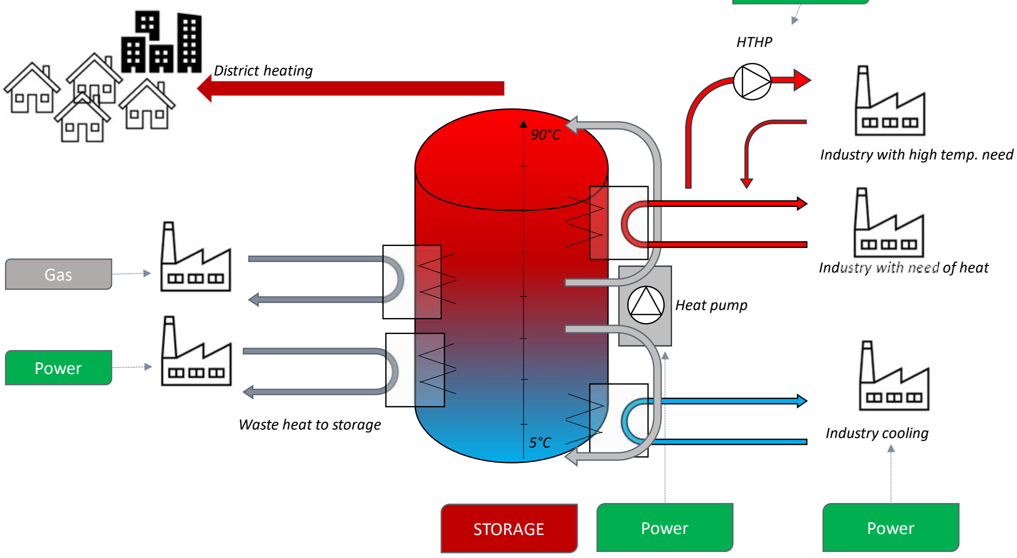

22

WHERE IS THE FIRST STEPPING STONE?

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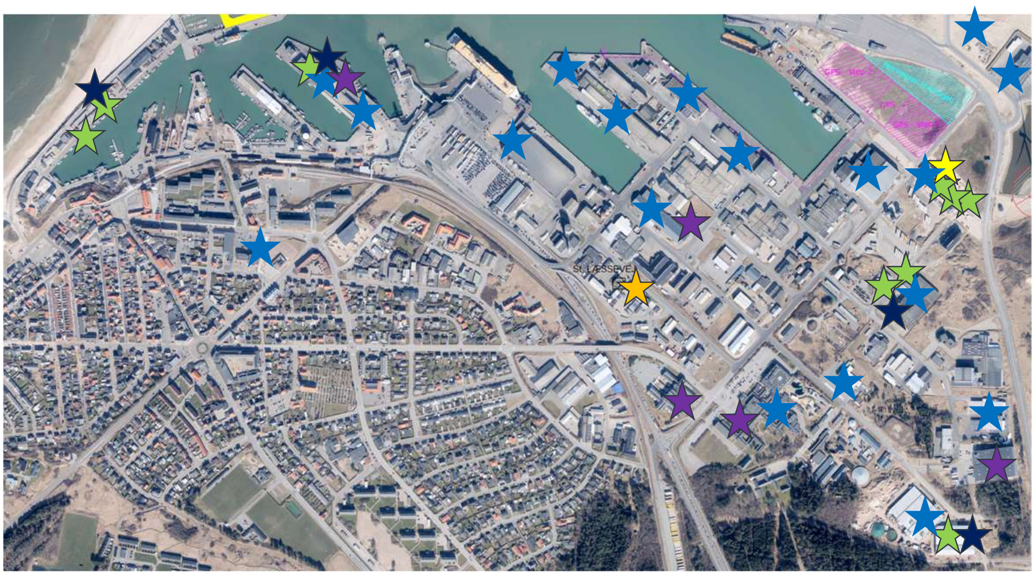

23

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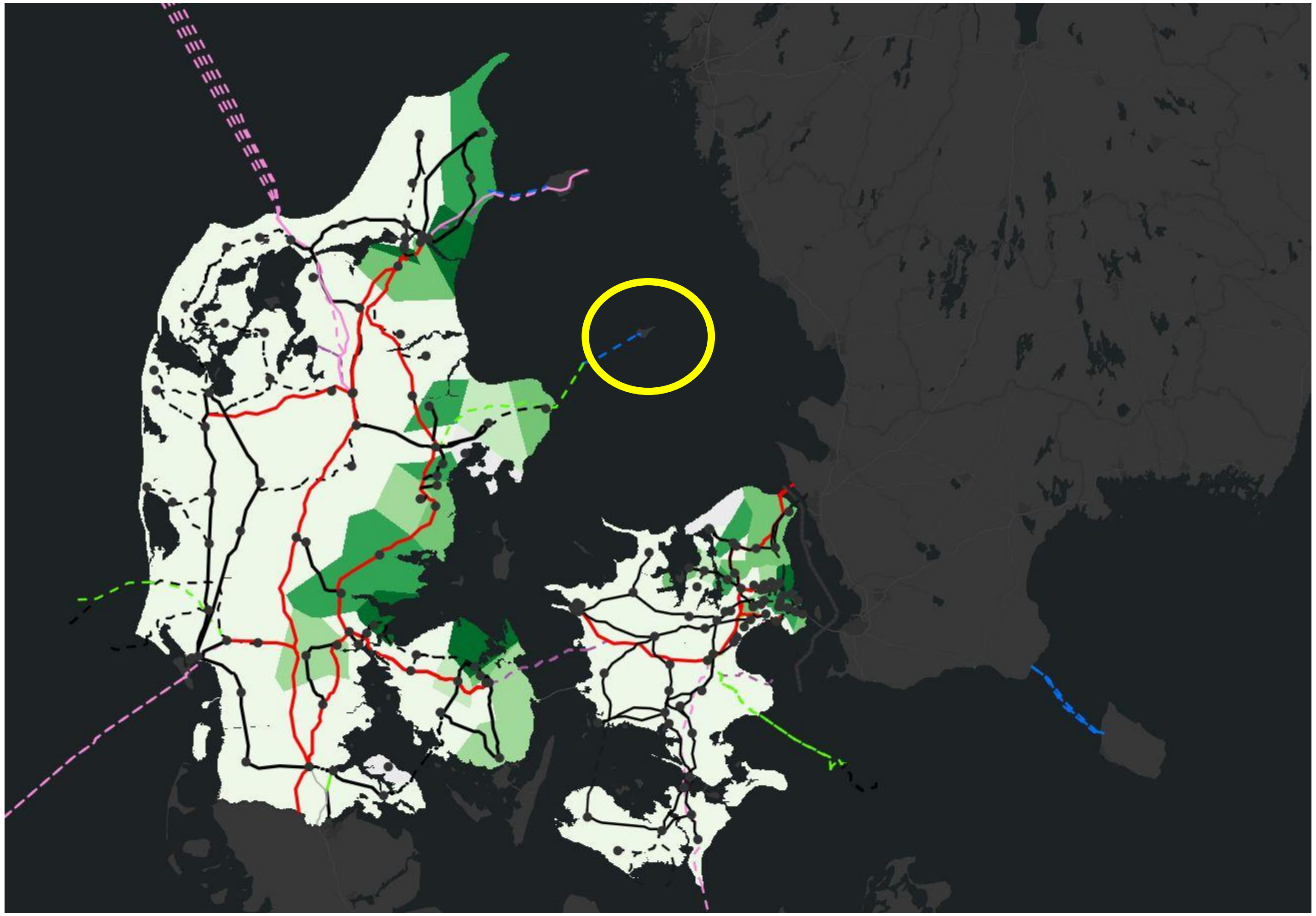
The most isolated island in Northern Europe, Anholt. We want partial self-sufficiency in electricity

Simon Døssing, RF-Anholt ApS

The most isolated island in Northern Europe, Anholt.
We want partial self-sufficiency in electricity

Introduction

- Simon Døssing
- Live on Anholt
- Master Electrician
- Technician, RF Anholt ApS



Anholt

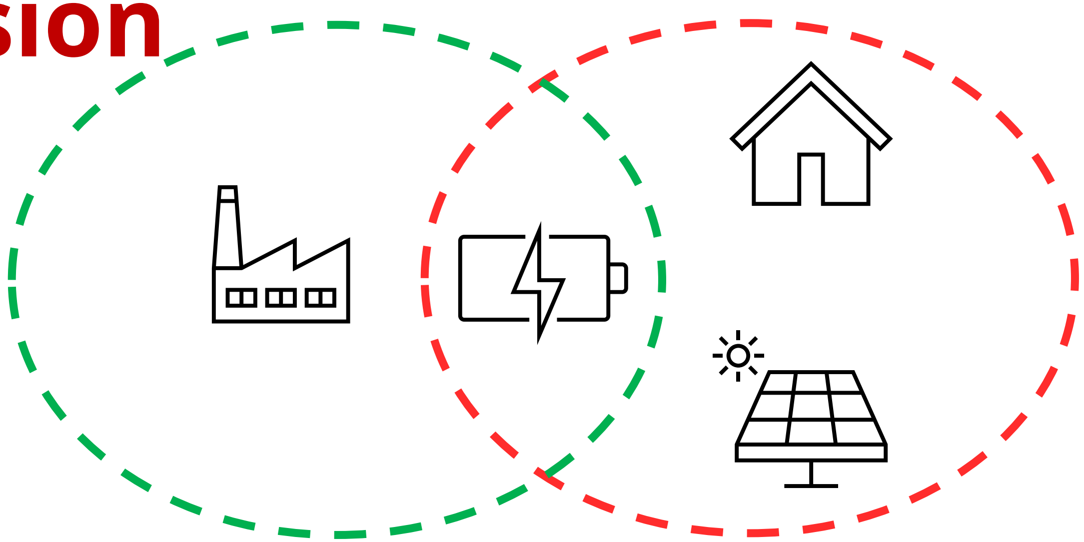
- Inhabitants / consumers
  - Winter – 150 people
  - Summer – 4.000 - 6.000 people
- Isolated from mainland
  - One ferry a day in summer
  - 4 times a week in winter
- Electrical supplied from mainland via windfarm

Who is RF Anholt?

- **R**eserve**F**orsyning = Auxiliary Power supply
- Contractor with Public power grid (EnergiNet)
  - In case connection to mainland power grid fails
- New contract proposal out for 2026-2036
  - Power demand changed from 1MW to 1,4MW, n-1
- <u>Upgrade of generator capasity is imminent</u>

- More diesel generators?
- Or Battery and Solar panels?

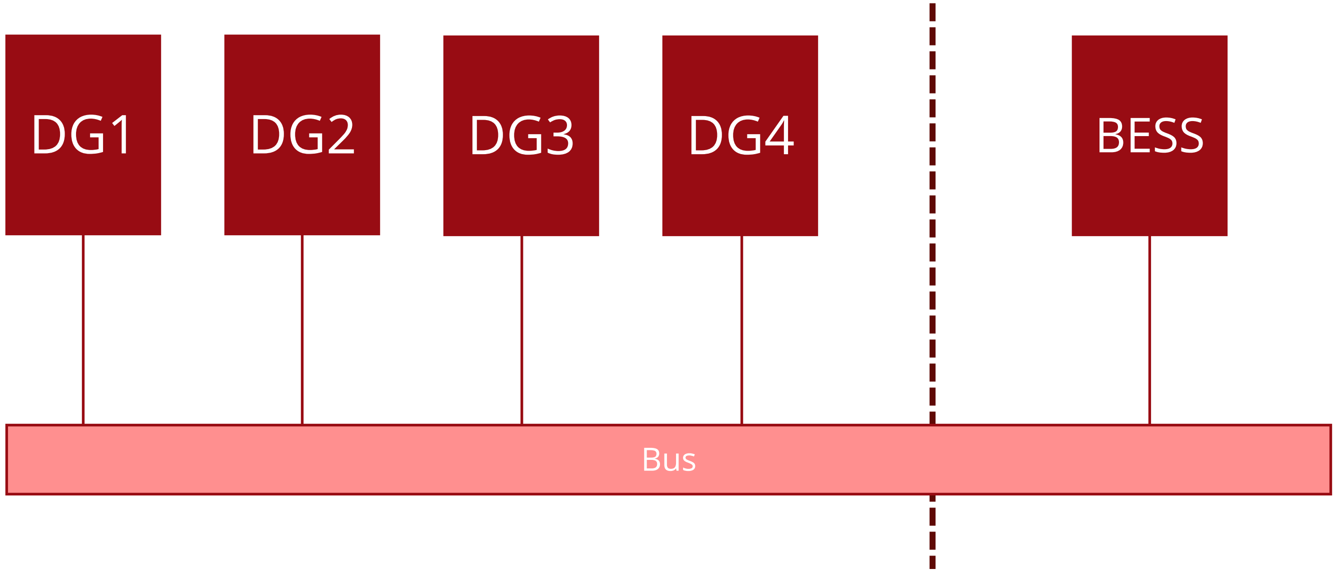
The vision



- Efficient use of RF-Anholt assets
  - Non emergency situation
- Increase in local production
  - Solar power
- Local energy engagement
  - Energy Community
    - Involvement / Ownership
    - Energy cost reduction
    - Prioritized consumers
- Partial diesel independency in case of international conflict

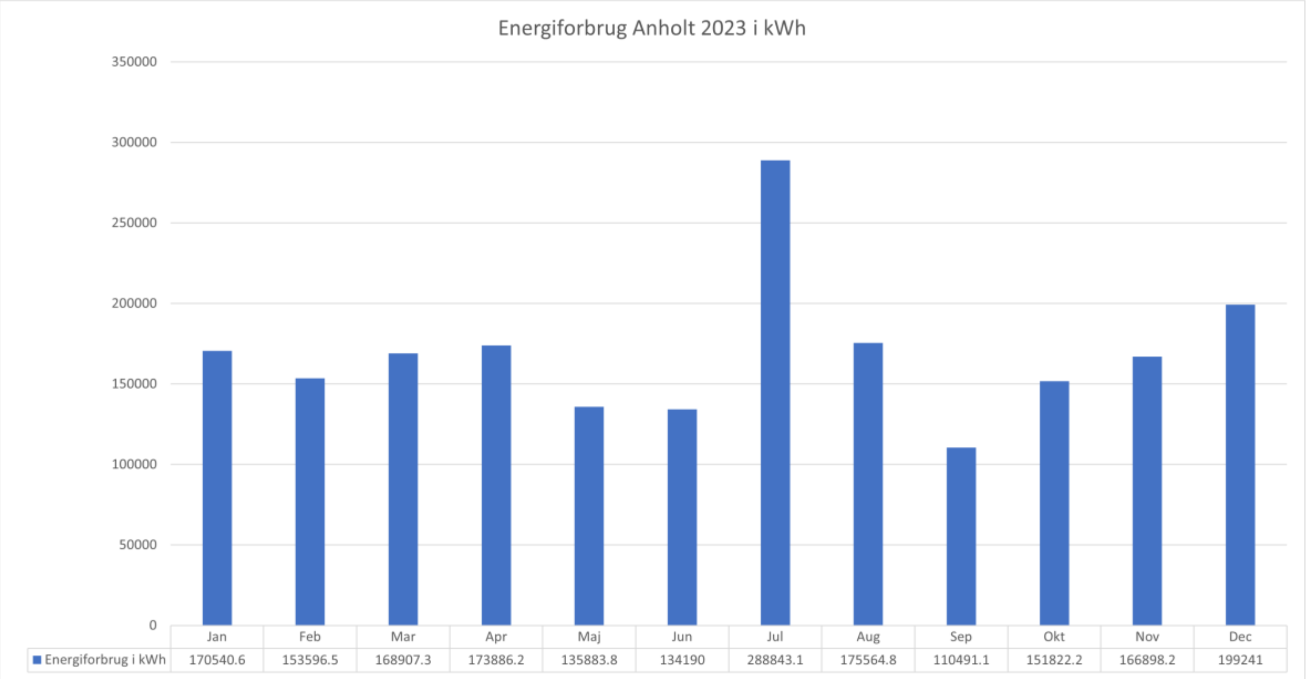
Backup power supply

- Integrating a Battery Energy Storage System (BESS) reconfigures the machine park and adds valuable flexibility. This shift moves away from the traditional, often underutilized, fossil fuel-only system. The BESS allows for dynamic energy management and facilitates better integration of renewable energy sources. It also opens up opportunities to participate in e.g. ancillary service markets, adding value locally and to the electrical system.



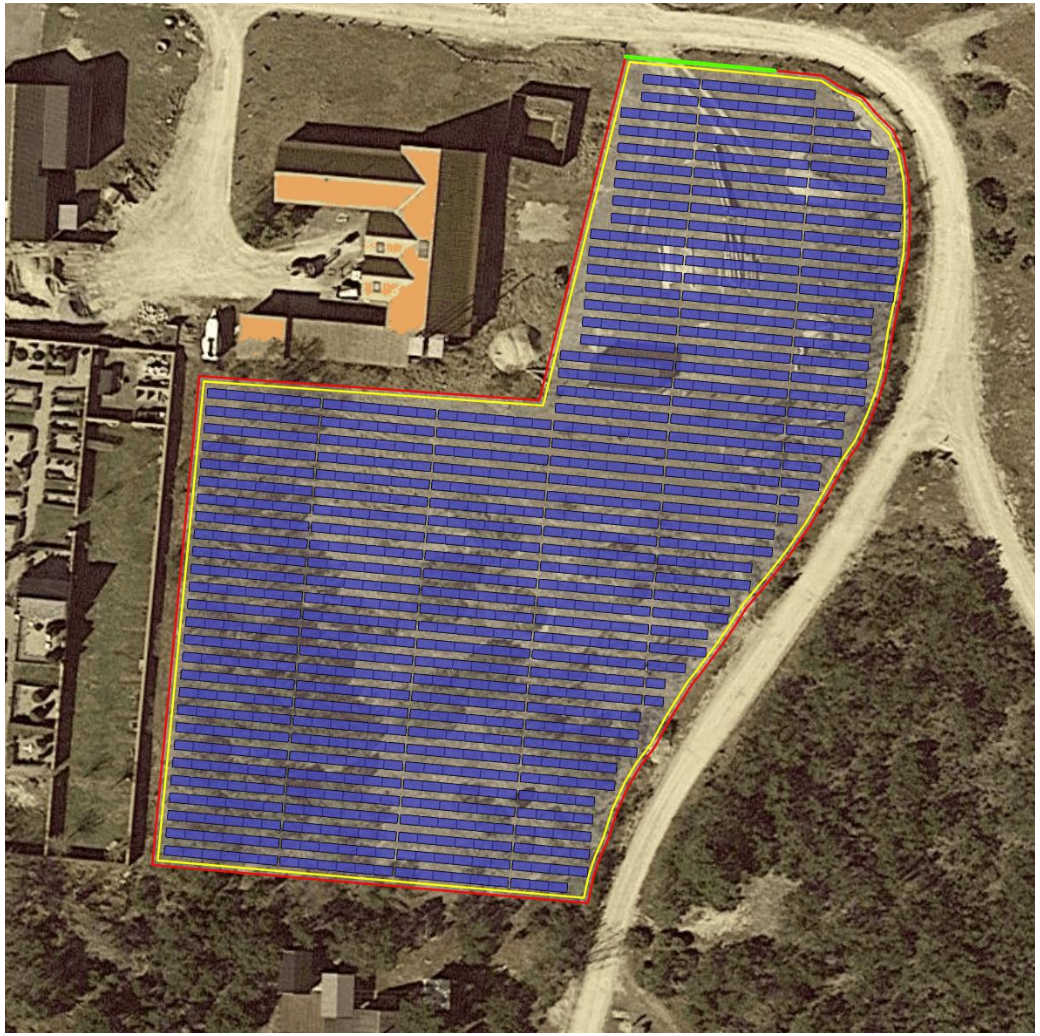
The consumption profile at Anholt

- Anholt's electricity consumption varies throughout the year. Total consumption in 2023 was 2.03 GWh. There is a noticeable increase in consumption during July, likely due to increased tourism. Furthermore, consumption is higher from October to April, presumably due to increased use of electric heating, such as heat pumps. This seasonal variation is important to consider when designing a hybrid energy system intended to cover both regular consumption and serve as a backup power supply.



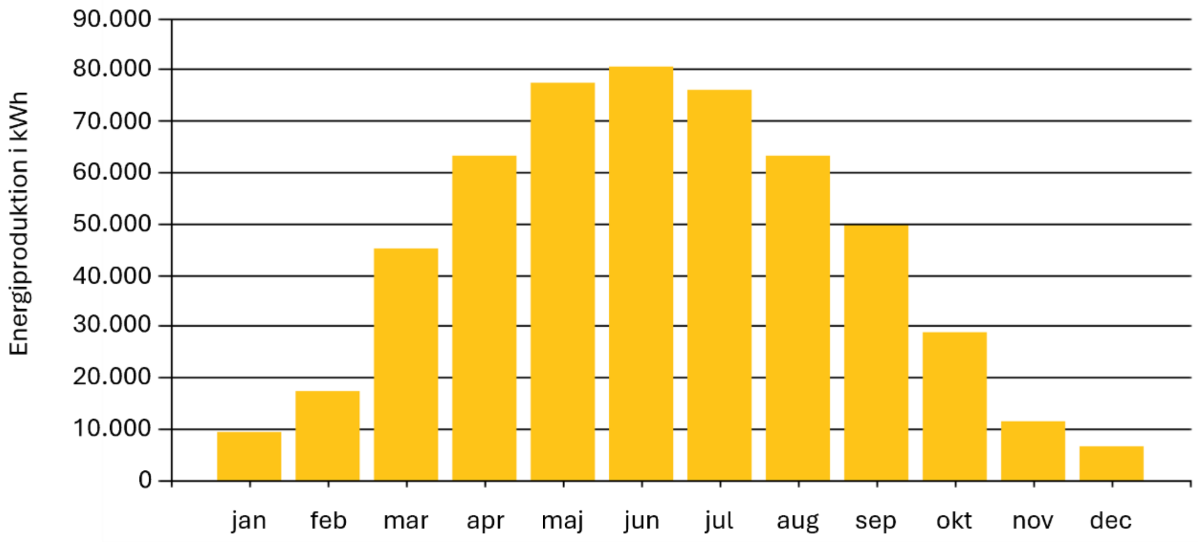
Available area for establishing production

- A possible location for the solar power plant is next to existing power plant, an area of approximately 5,565 square meters.



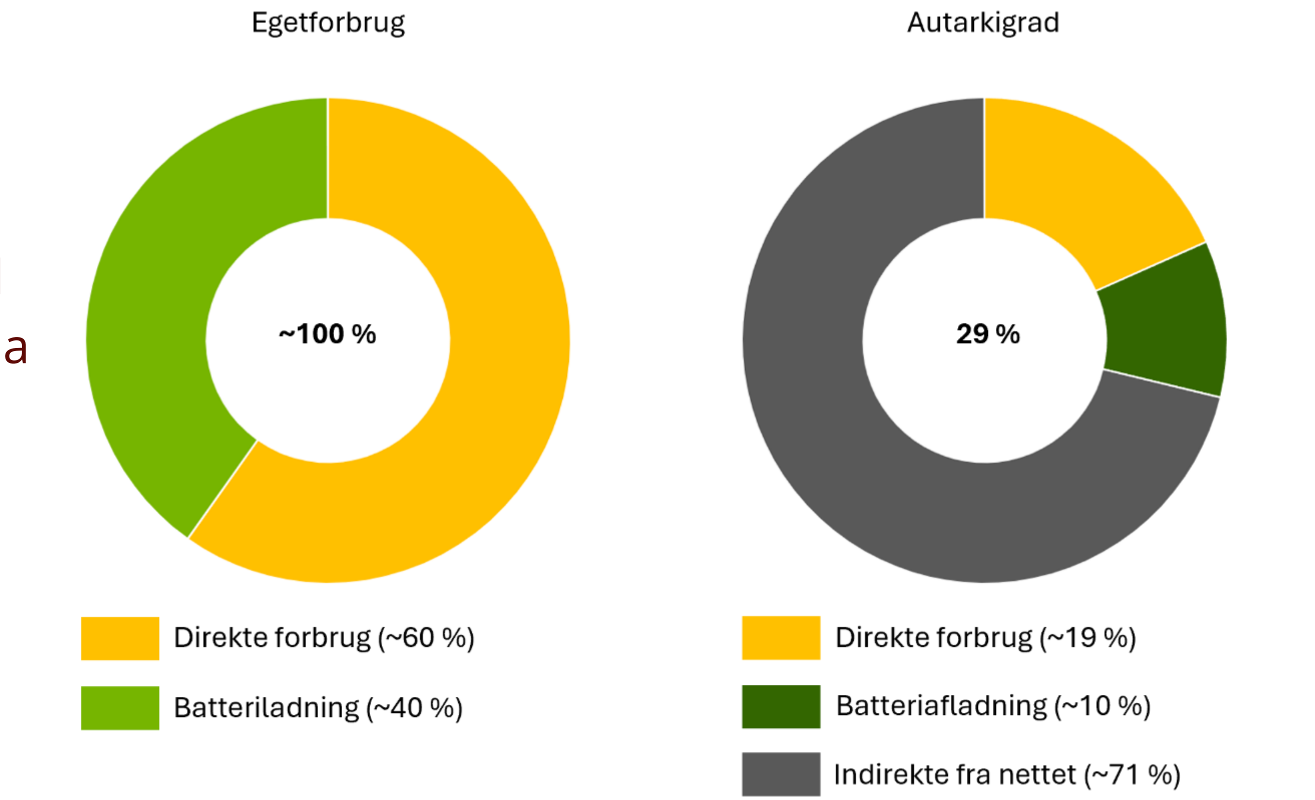
Production and consumption with solar panel installation

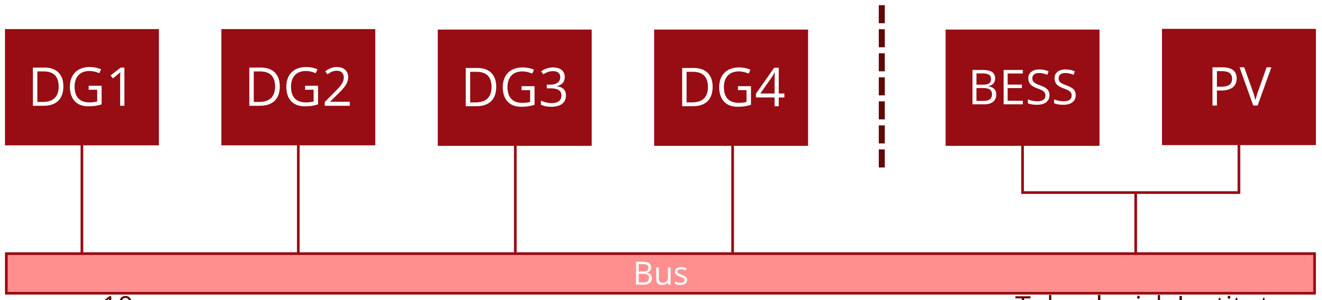
- Anholt's unusual consumption curve indicates a high potential for solar cell utilization, as peak consumption is centered around the summer months, coinciding with maximum solar energy production, and vice-versa.
- Simulations predict an expected annual production of approximately 0,5 MWh, corresponding to 900 kWh/kWp.
- This will reduce CO2 emissions by approximately 283 tons per year.



Backup power supply and production

- By combining local production and storage, nearly all of the solar energy generated on Anholt will be available to both residents and visitors. This multipurpose approach creates a more resilient energy system while simultaneously supporting the green transition.





Now

- This year contract regarding auxiliary power will be negotiated, which might include Battery Energy Storage System
- Area for solar power is in public hearing
- Local meeting to determine support for Energy community.

Thank you

ADVANCED ENERGY STORAGE CONFERENCE 2025

Advanced Energy Storage Conference

See you in 2025 for Advanced Energy Storage 2025

4 December 2025 - Aarhus, Denmark