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Cycling in Tandem: The Economics of Battery Co-Location in Poland

Public Report

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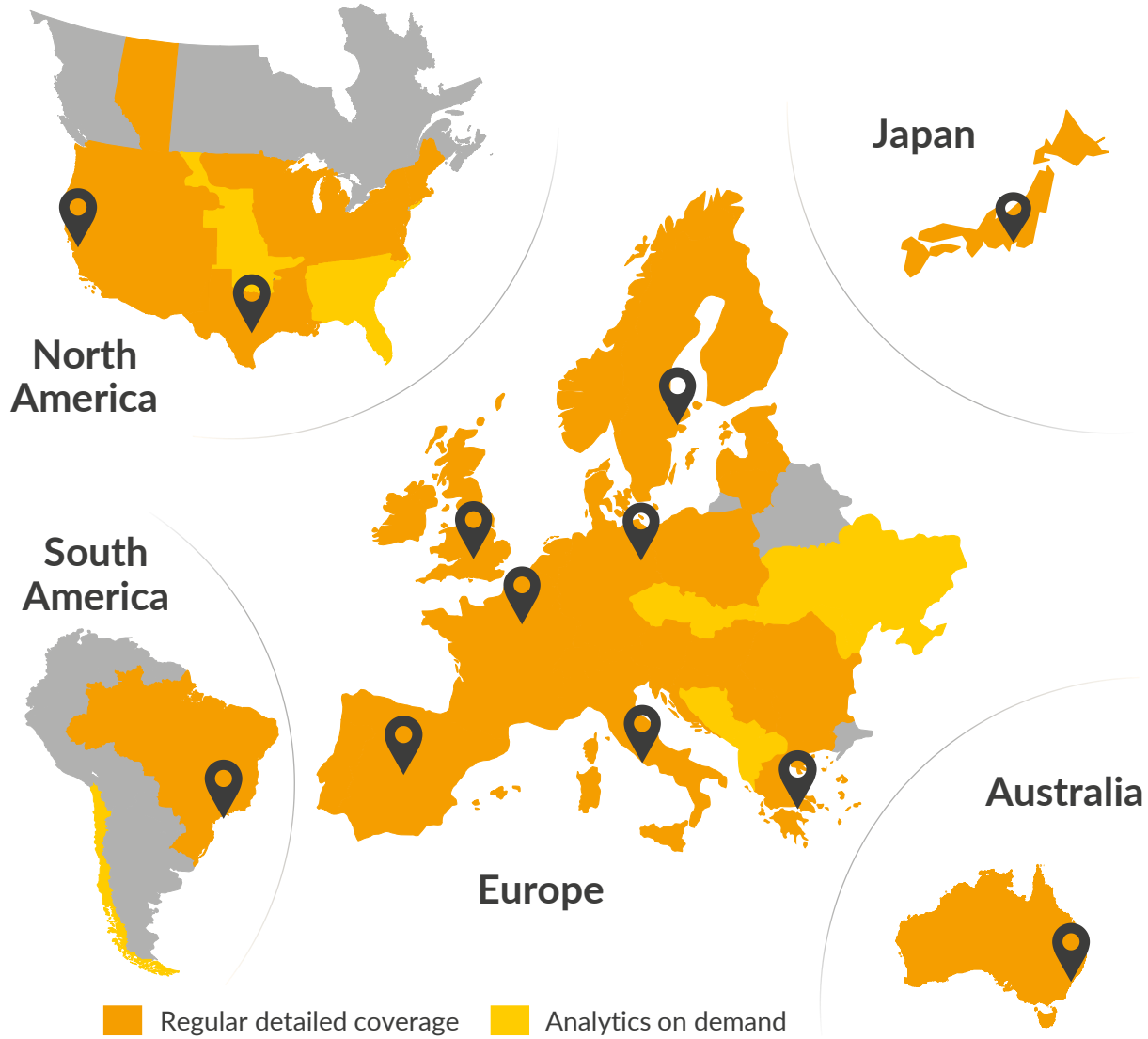

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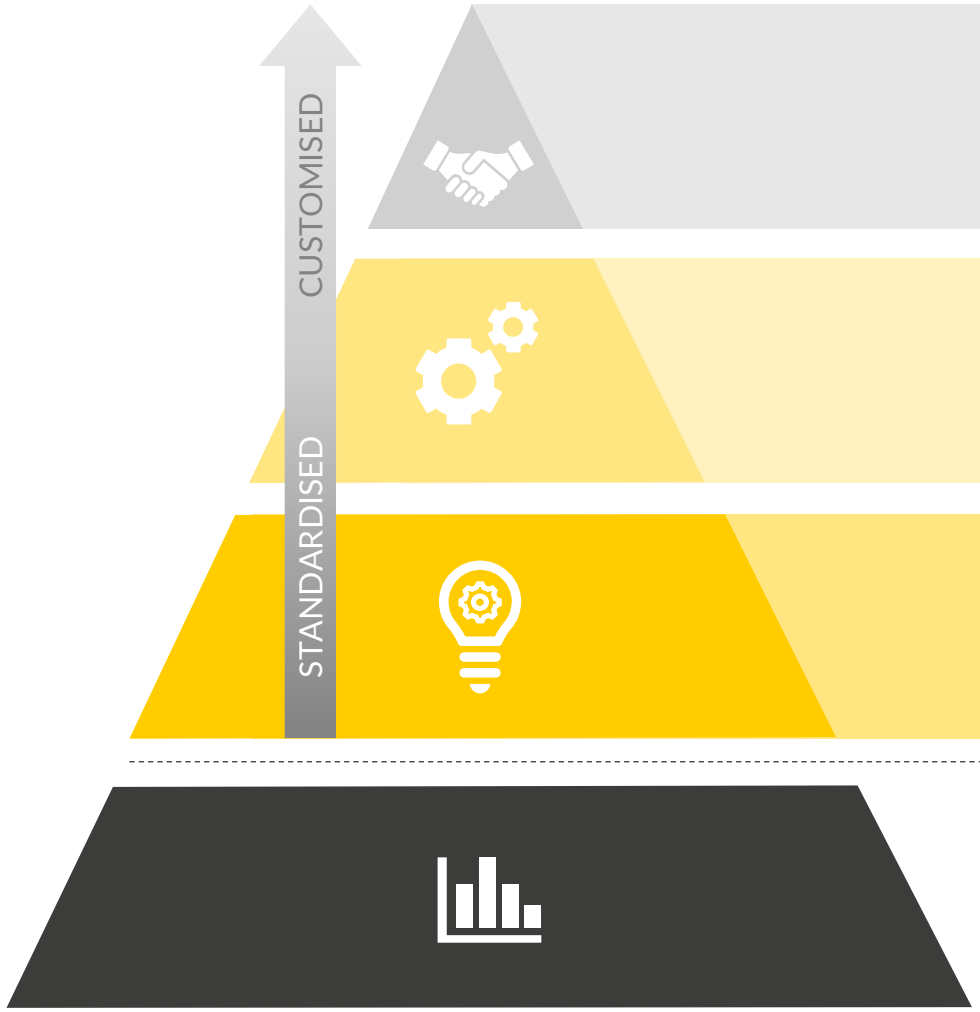

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We work with a very broad range of clients … their constant challenge keeps us up on our toes and ensures our independence

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> *"With its capabilities, intellect and with its credibility Aurora plays an essential role bringing the dialogue [in the global energy transition] to a different plane"*
>
> **Ben van Beurden, CEO, Shell**

> *"Aurora analysis and the provision of reliance was crucial for our debt funding. Their ability to explain market logics and revenue streams was vital for this successful financing."*
>
> **Jeremy Taylor, Director, Green Frog Power**

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Source: Aurora Energy Research

Agenda

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I. Introduction to co-location and the regulatory environment

II. The standalone business case

III. Investing in co-location

IV. Closing remarks

The planned liberalisation of Poland's balancing market has led to a boom in interest in new battery investments

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Timeline of Polish Balancing Market reform

2018

2018
- Start of work on BM reform
- Introduction of Demand Side Response (DSR) dedicated ancillary services

Jan 2019
- BM price caps lifted

Jun 2020
- Polish Implementation Plan accepted by the European Commission

Jan 2021
- First phase of BM reform go-live
- Capacity Market go-live

Jul 2022
- Second phase of the BM reform and EU integration in Poland derogated to 2023-2024

Oct 2022
- BM bid caps implemented

Sep 2023
- URE [2] approves new BM operating terms outlining second-phase reform

Q1-Q2 2024
- Planned TERRE go-live in Poland

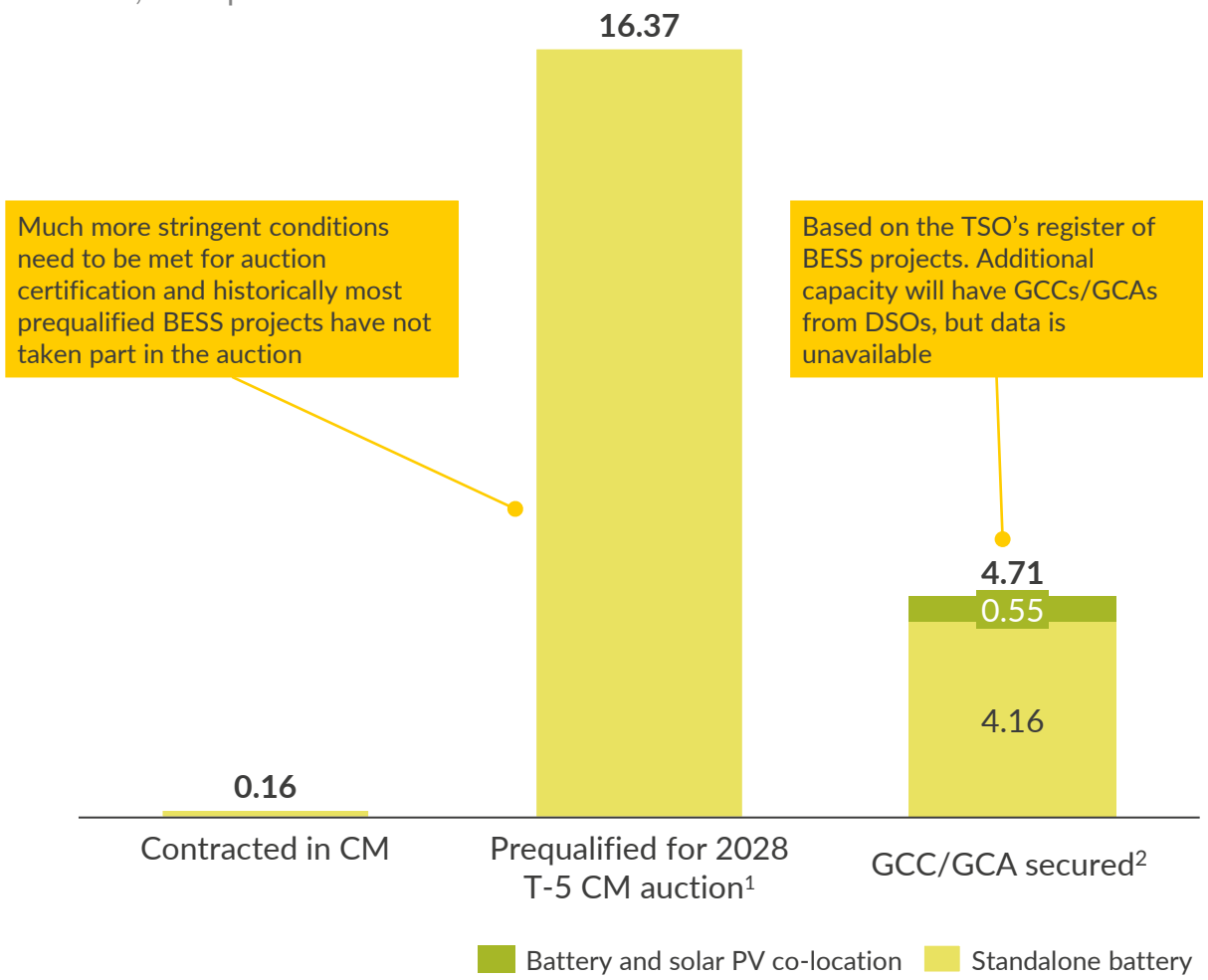
June 2024
- Planned go-live for second phase of BM reform

2024

Jul 2024
- International Grid Control Cooperation (IGCC)-wide deadline for PICASSO and MARI go-live

Polish battery project pipeline

GW, nameplate



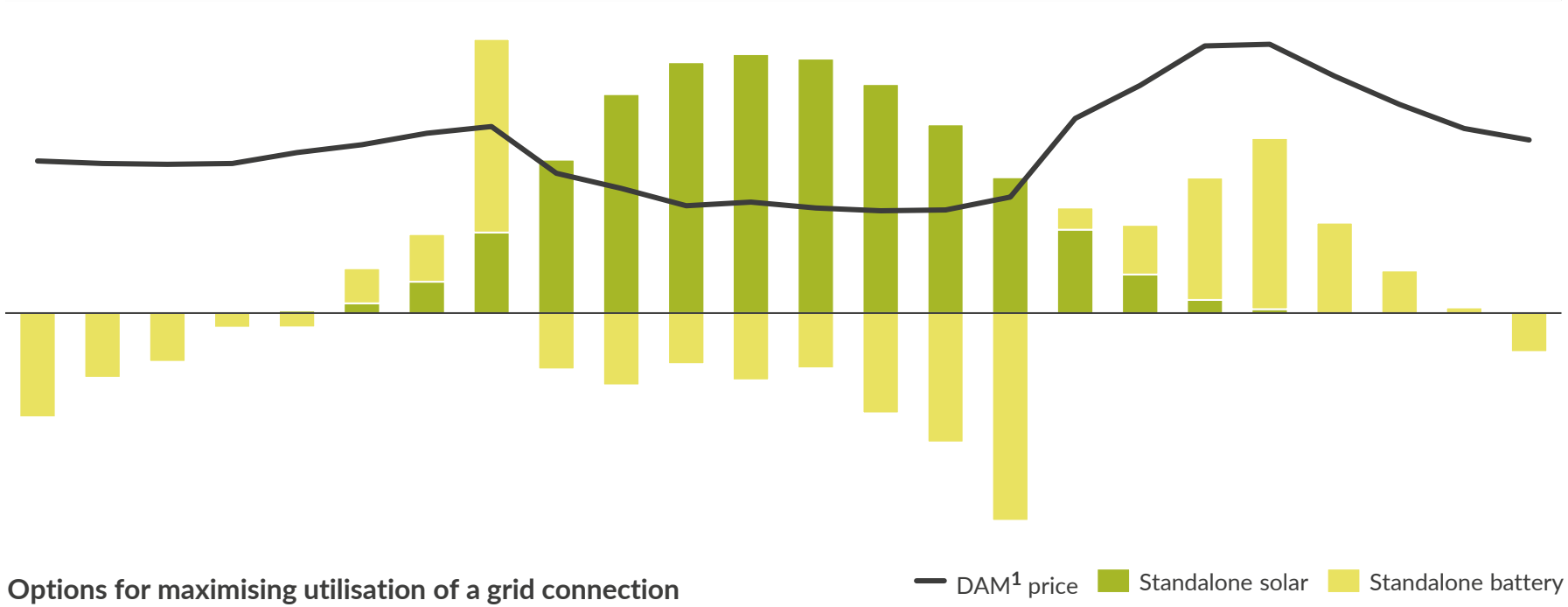
1) Planned units without existing CM contracts for 2028 2) Grid Connection Conditions/Grid Connection Agreements as published by TSO 2) Energy Regulator's Office

Sources: Aurora Energy Research, PSE

Co-locating batteries with solar offers a promising option for maximising the potential of limited grid connection capacities

Average hourly dispatch of a standalone asset in 2030
MWh

Average hourly price in Day-Ahead Market in 2030
zł/MWh, real 2022



Options for maximising utilisation of a grid connection

1- Oversizing standalone solar
2- AC-coupled co-location
3- DC-coupled co-location
4- Innovative solar technologies
5- Co-located solar and wind

Today's focus

November subscriber Group Meeting

- **Co-location can improve the utilisation of grid connection capacity** by combining assets which typically generate at different hours
- Solar PV and battery storage are particularly well-suited to co-location and will be the focus of today's session
  - The effect of cannibalisation means that solar generates in the hours of the day in which prices are lowest
  - Batteries aim to capture daily arbitrage opportunities, charging in the cheap hours of solar production and discharging in evening peaks
  - The two technologies have a very complementary production profile which aids co-location

1) Day-Ahead Market

Sources: Aurora Energy Research

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Different configurations of battery-solar PV co-location exist, both with benefits and trade-offs compared to standalone assets

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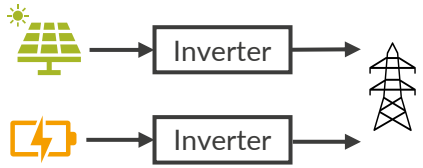
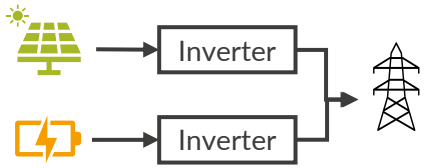
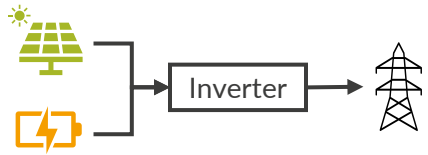
	Assets not coupled	Solar PV AC-coupled	Solar PV DC-coupled
	Assets are on the same site, but are metered and managed individually	Solar and battery require separate inverters to connect to the grid	Solar and battery share a single inverter connected to the grid
			
Costs *CAPEX & OPEX*	Minimal cost savings	Cost savings on development, balance of system, and OPEX	Further savings due to shared inverter
Asset oversizing *Oversize renewables asset relative to grid connection*	Spilled power cannot be captured	Free charging from spilled power depends on inverter sizing	Solar can be over-sized and battery is able to capture spilled power
Battery dispatch *Charging/discharging profile of the battery asset*	No impact	If oversized, storage output restricted by renewable generation	
Regulatory complexity *Consistency of asset configuration with Polish regulation*	Regulatory obstacles to asset oversizing removed by cable pooling legislation	Regulatory obstacles to asset oversizing removed by cable pooling legislation	Current regulatory environment does not allow for DC co-location

Business case impact relative to standalone asset

Full benefit | Partial benefit | Neutral impact | Some negative impact | Negative impact

Sources: Aurora Energy Research

Cable pooling legislation will allow co-located assets to exceed their grid connection capacity without additional administrative burden

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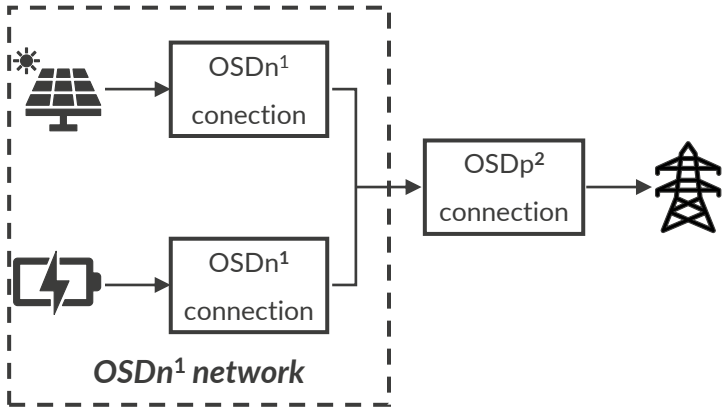
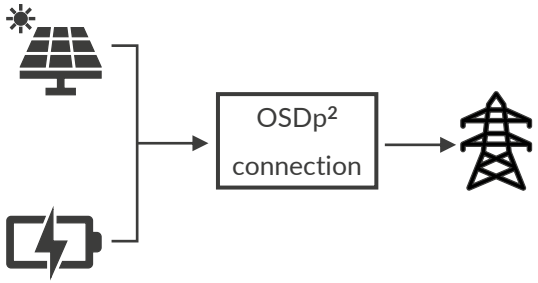
1 Until now, under-scaling a grid connection could only be done by establishing an *OSDn*[1]…



2 … however, regulatory changes introducing cable pooling will greatly simplify the process…



Additions to a new RES Act amendment will enable cable pooling under certain conditions:

1. New permissions will not be needed to add additional RES installations to the existing grid connection infrastructure or Grid Connection Agreement of a separate RES assets
2. Battery storage is considered a RES installation in this context
3. If the total capacity of connected RES assets exceeds that of the grid connection agreement, a device limiting the power dispatched into the grid must be added
4. The additional RES installation cannot benefit from support schemes covering the original asset

This will remove the large administrative burden of establishing an OSDn[1] which previously existed when adding batteries to existing RES installations, or those still under development

3 … and have now been finalised and passed into Polish law.

Nov 2022 — **Charter for the Effective Transformation of the Distribution Sector** is published, recommending legislation to enable cable pooling

Jul 2023 — **Senate adds legislation to enable cable pooling** to an amendment to the RES Act with governmental support

Aug 2023 — **Sejm passes the RES Act amendment** including the addition of cable pooling

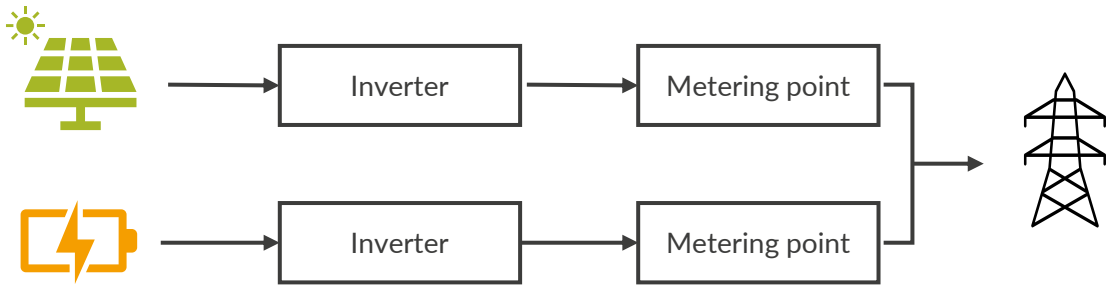
Aug 2023 — **RES Act amendment has been signed into law by the president**

1) Distribution System Operator without a direct connection to the transmission system 2) Distribution System Operator with a direct connection to the transmission system

Sources: Aurora Energy Research, Ministry of Climate and Environment, Chancellery of the President

Current legislation prohibits DC-coupled co-location but makes a full set of markets available to AC-coupled assets

Co-located assets are required to have separate metering points in order to independently charge from and discharge into the grid



Metering requirements mean only AC-coupled co-location is possible

- Market regulations mean that co-located assets need to be separately metered to participate
- Metering takes place after the inverter, as it must be applied to an AC current and after inverter losses have taken place
- It is therefore not possible to separately meter DC-coupled assets
- Separate metering results from grid tariffs being applied to battery losses, which could not otherwise be measured

Co-located assets participate in markets as independent entities, opening three revenue streams which we consider in our analysis

Wholesale markets

- Separately metered co-located assets participate as independent entities in the day-ahead and intraday markets
- A battery without separate metering would not be permitted to charge from the grid over the wholesale market

Balancing and Frequency Control markets

- Separately metered units are treated as independent entities
- The battery retains the status of a battery storage installation and can participate in the aFRR energy and capacity markets and the FCR capacity market

Capacity Market

- Separately metered units are treated as separate entities
- A battery retains its high derating factor, while the lower solar or onshore wind derating factor is applied only to the renewable installation. They must meet their capacity obligations separately

A co-located renewable asset could participate independently in the standard CfD auction for solar and onshore wind assets, but our analysis focuses on the case of fully merchant co-located battery and solar PV

Sources: Aurora Energy Research, URE, Ministry of Climate and Environment, PSE

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Standalone solar IRRs are at almost 9% in 2026, on the verge of enabling investments with a fully merchant business model

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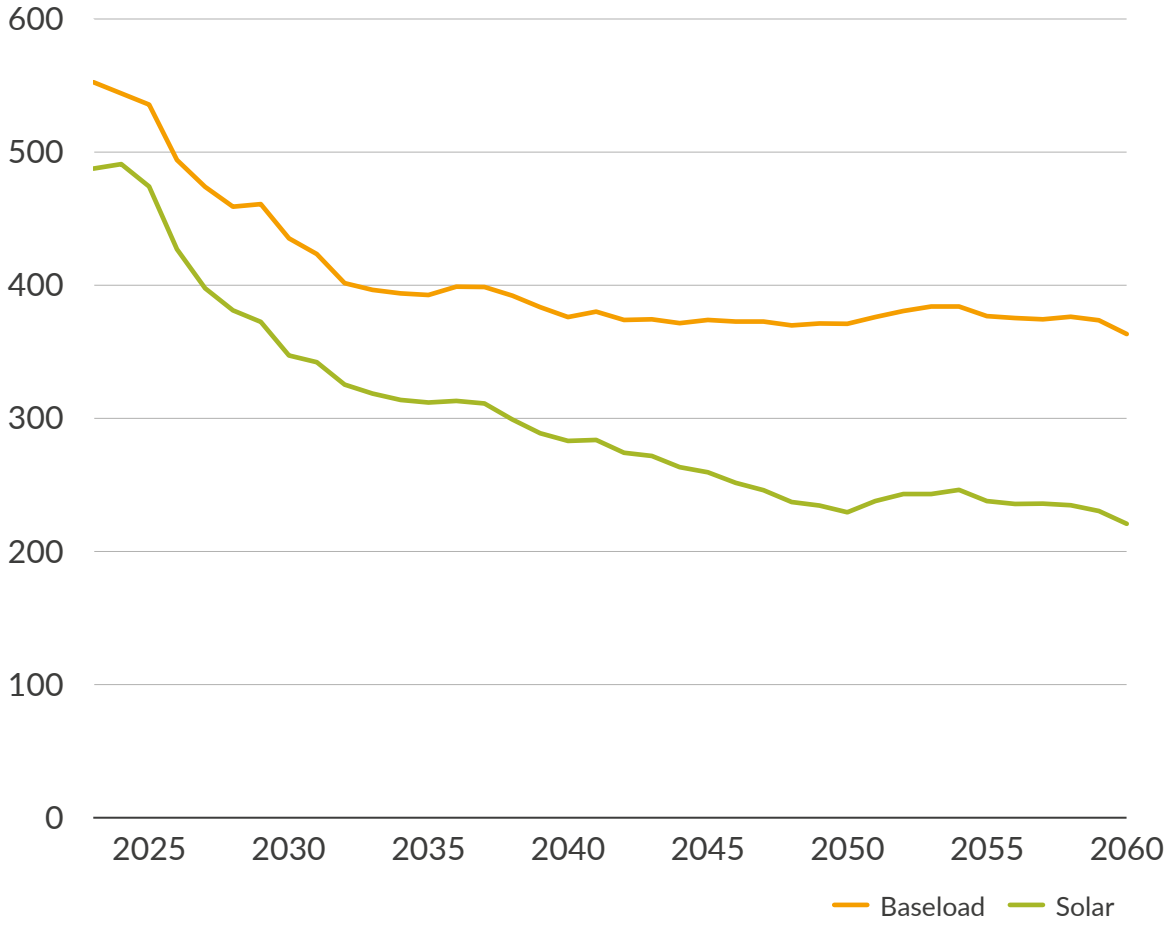
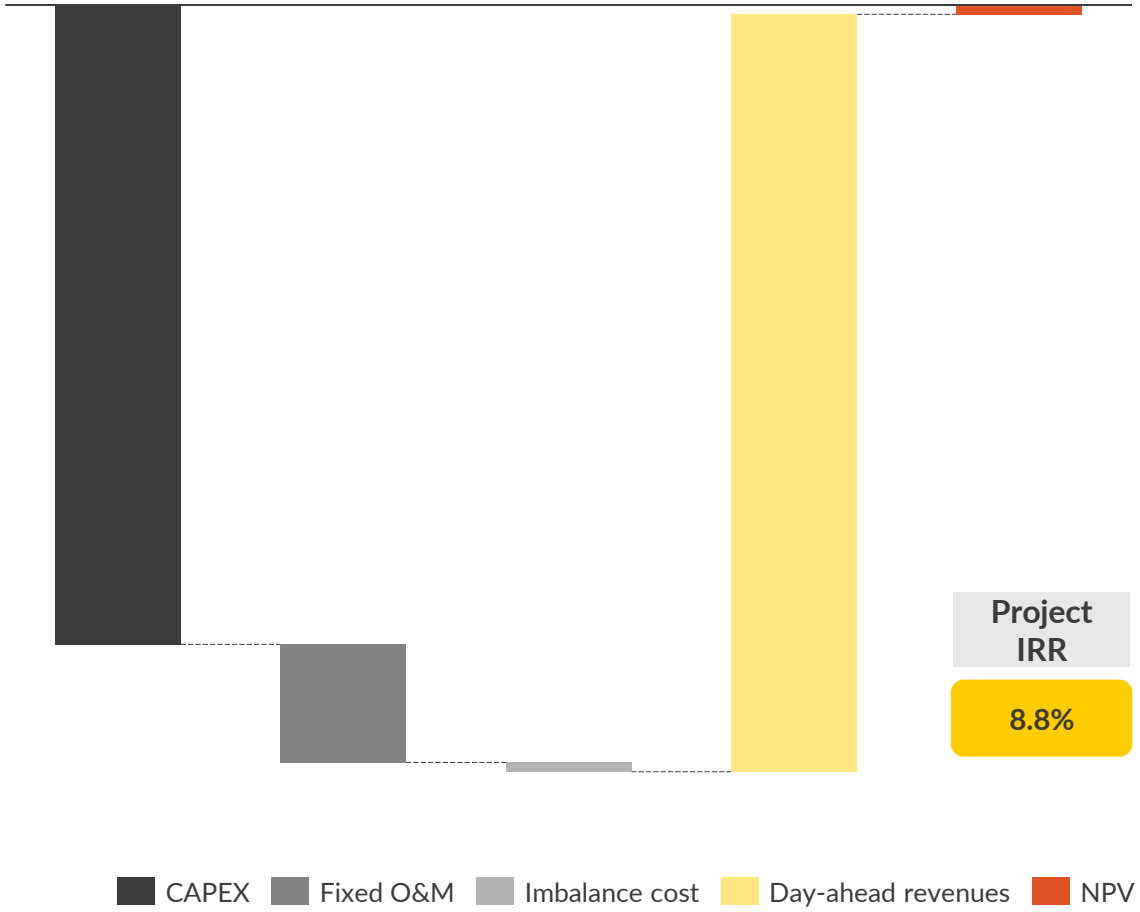
Baseload and Renewables Capture Prices[1,2]
zł/MWh, real 2022



Economics for new-build solar entering 2026 in Aurora Central[3]
Net Present Value[4] zł/kW, real 2022



1) Uncurtailed capture price 2) Based on Aurora's July Power and Renewables Market Forecast Central scenario 3) For a monofacial south-facing solar asset with a 1:1 ratio of capacity to grid connection capacity 4) Net Present Value with assumed cost of capital of 9% for costs and wholesale market revenues

Sources: Aurora Energy Research

Batteries optimise dispatch between markets to maximise revenues; Aurora's dispatch model simulates this process with imperfect foresight

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Flexibility markets and battery parameters[1]

- Day-Ahead prices
- Intraday prices
- FCR prices
- aFRR prices for capacity and energy[2]
- Degradation, cycling rates, duration, efficiency

Imperfect foresight battery dispatch model

1 Optimisation process for day-ahead markets

- Optimisation of markets that take place day-ahead (Day-Ahead, FCR, and aFRR capacity markets)
- We assume perfect foresight of one day for day-ahead markets and limited foresight into same-day markets (Intraday and aFRR energy)
- The model solves for actions in these markets simultaneously

2 Dispatch based on real-time knowledge

- Battery gains insight into aFRR energy and Intraday markets in real time
- Based on results of stage 1, battery charges or discharges if within-day market prices are more attractive than planned actions
- Model accounts for upcoming commitments

Results

- Renewable curtailment
- Battery dispatch
- Revenues per market
- NPV and IRR

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✉ **natalia.mazurowska@auroraer.com**

1) Preliminarily, all prices have hourly time granularity. 2) Batteries only need to consider the automatic Frequency Restoration Reserve (aFRR) when participating in the FRR market, due to the market makeup. For more information see here.

Source: Aurora Energy Research

2-hour batteries commissioned in 2026 can achieve IRRs of 15%, but are dependent on capturing high revenues before markets saturate

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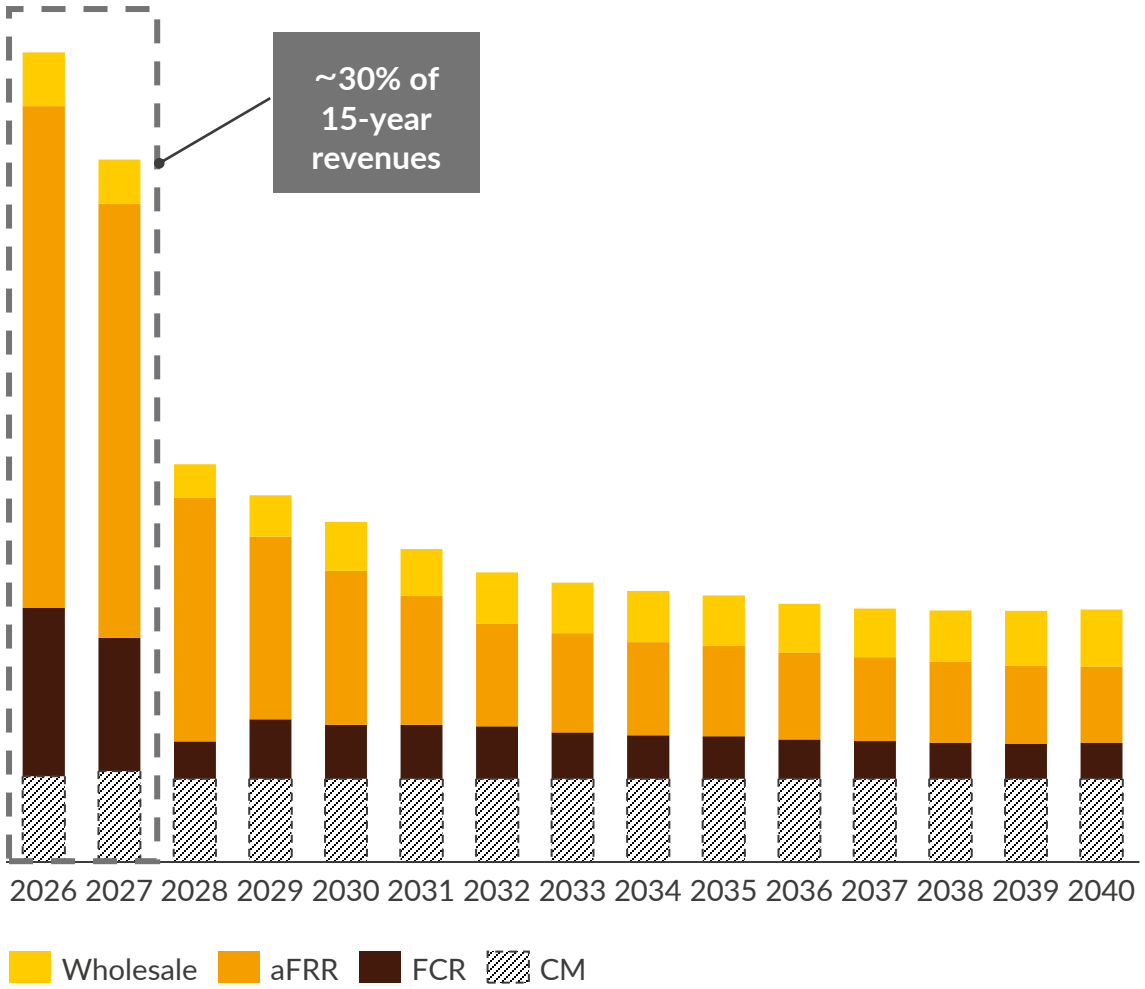
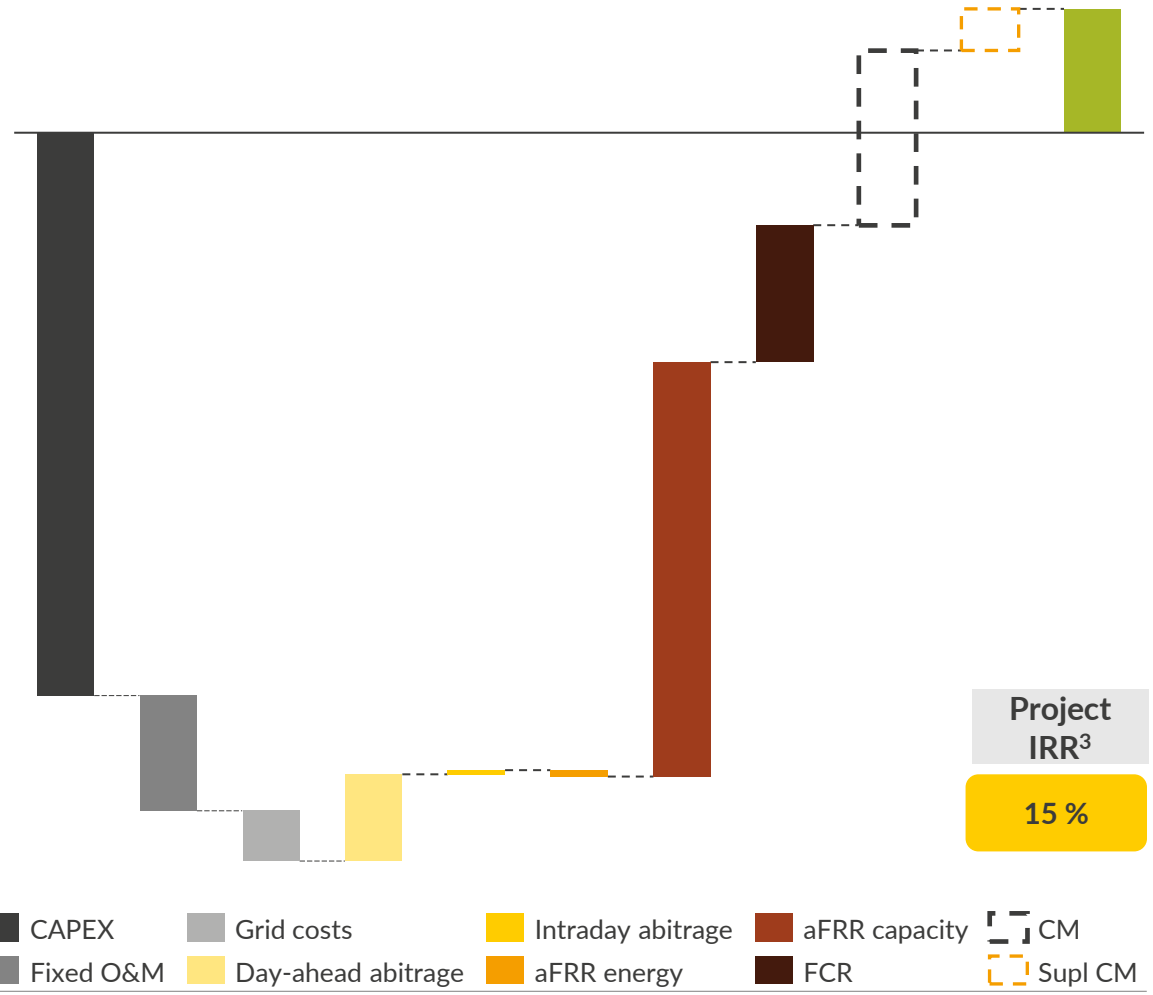
Annual revenues breakdown for assets[1] deployed in 2026
zł/kW/year, real 2022



Economics for **new-build battery entering 2026 in Aurora Central[1]**
Net Present Value[2] zł/kW, real 2022



1) 2h batteries are presented, characterised by an average daily cycling target of 1.5 cycles, over a total 15 years battery lifetime. 2) NPV calculated based on discount rate of 11% for all revenue streams except the Capacity Market, which is discounted at 6% and 9% for main and supplementary auctions, respectively. Costs are discounted at 9%. 3) IRR in real terms, pre-tax

Sources: Aurora Energy Research

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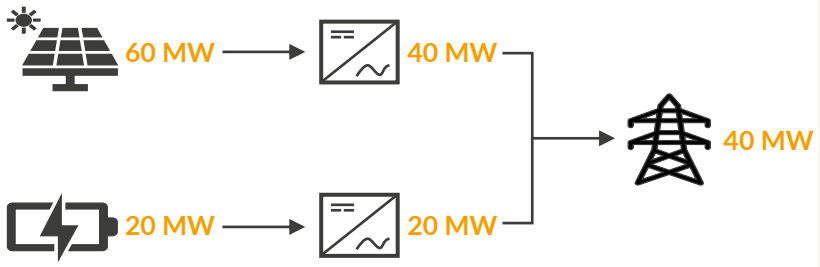
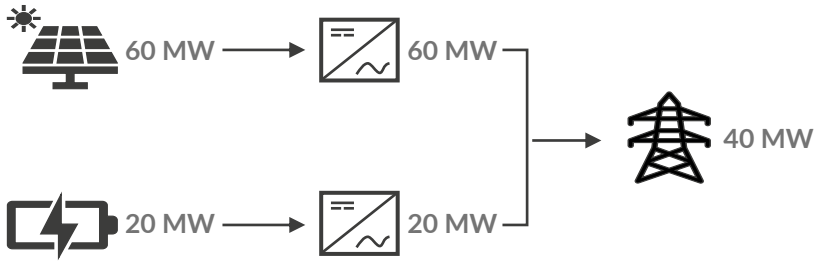
Typical AC co-location setups will not be able to capture spilled generation and face constraints to optimal asset dispatch

AC co-location with inverter capped at grid connection capacity

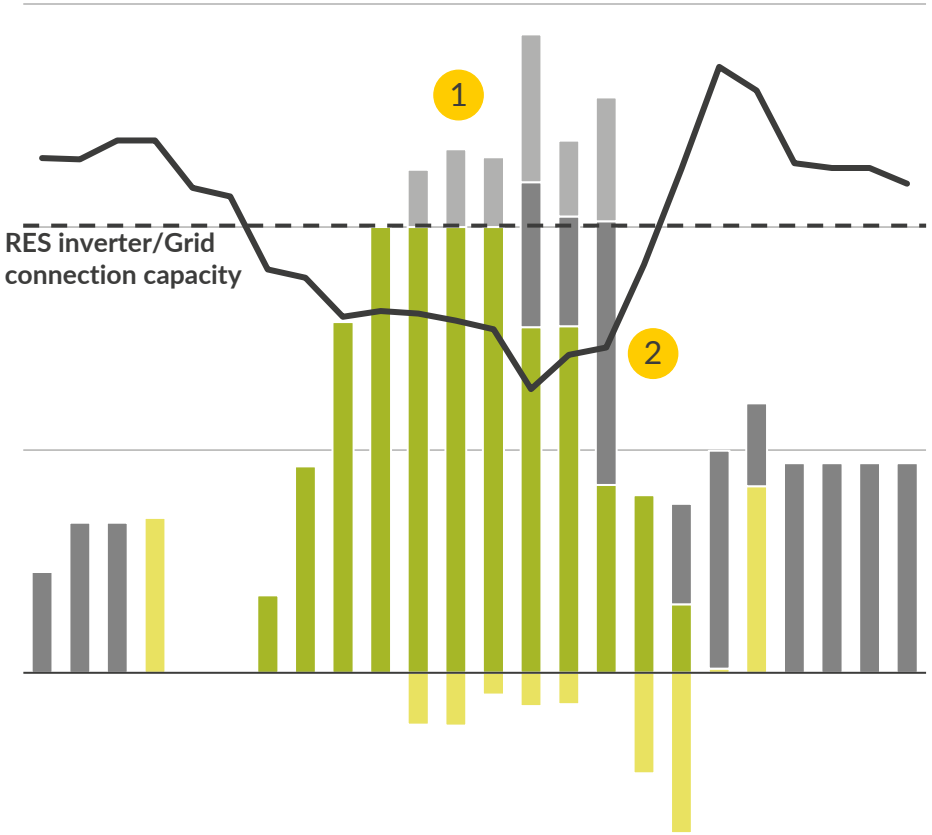


AC co-location with inverter matched to solar capacity



Hourly dispatch[1]
MWh

Day-ahead market price
zł/MWh, real 2022



1) Example day in 2035 2) Reservation of battery capacity in the FCR and aFRR up capacity markets

Sources: Aurora Energy Research

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AC co-location with inverter capped at connection capacity

- A typical AC co-located setup sees the renewable inverter capacity equal to the export capacity of the grid connection, even if the renewable asset has a larger capacity
- Such a setup has both inverter (1)- and grid (2)-capacity related constraints on dispatch

1. Where solar production exceeds the inverter capacity, the battery is not able to charge for free from the spilled generation. Instead, the solar asset must curtail while the battery pays to charge from the grid
2. In some hours, FCR and aFRR capacity revenues are more attractive than the DAM. Solar is then curtailed to allow the battery to participate in these markets

Adding a co-located 2-hour battery can boost the IRR for an existing standalone solar PV project by up to 23%

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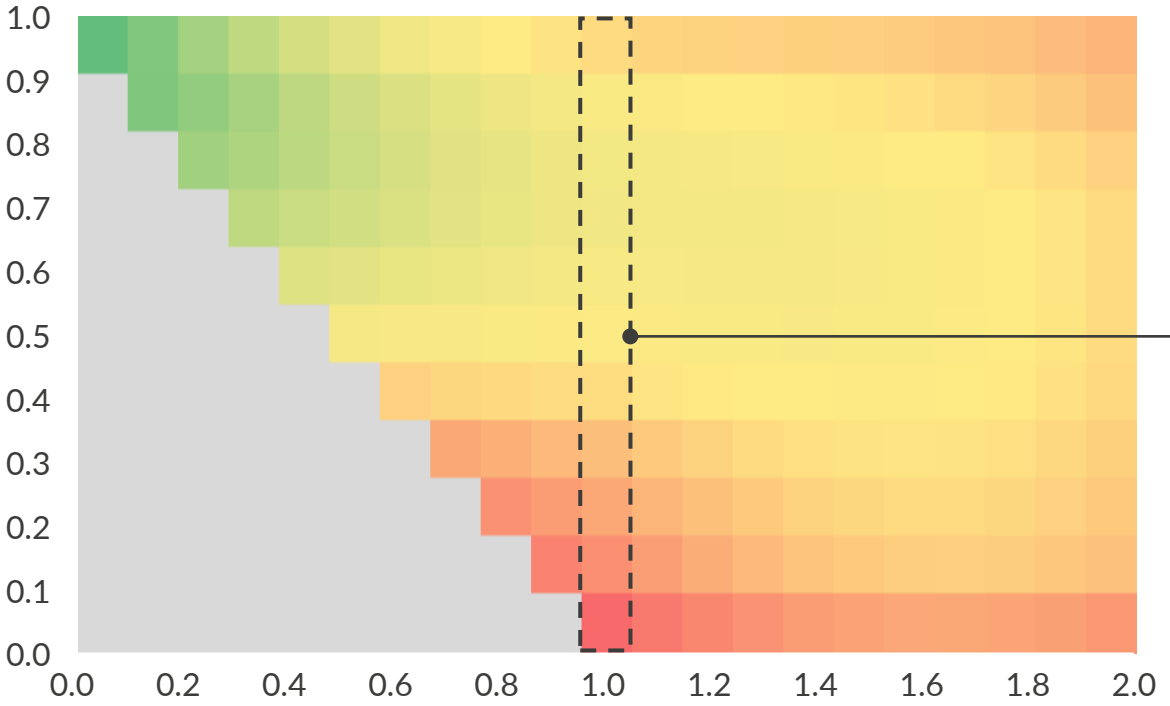
1 kW solar PV (relative to 1 kW grid connection) and 2h battery[1], 2026 entry

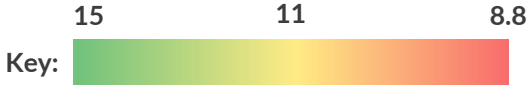
Battery sizing
kW, relative to 1kW grid connection

IRR[2] of RES and battery
%



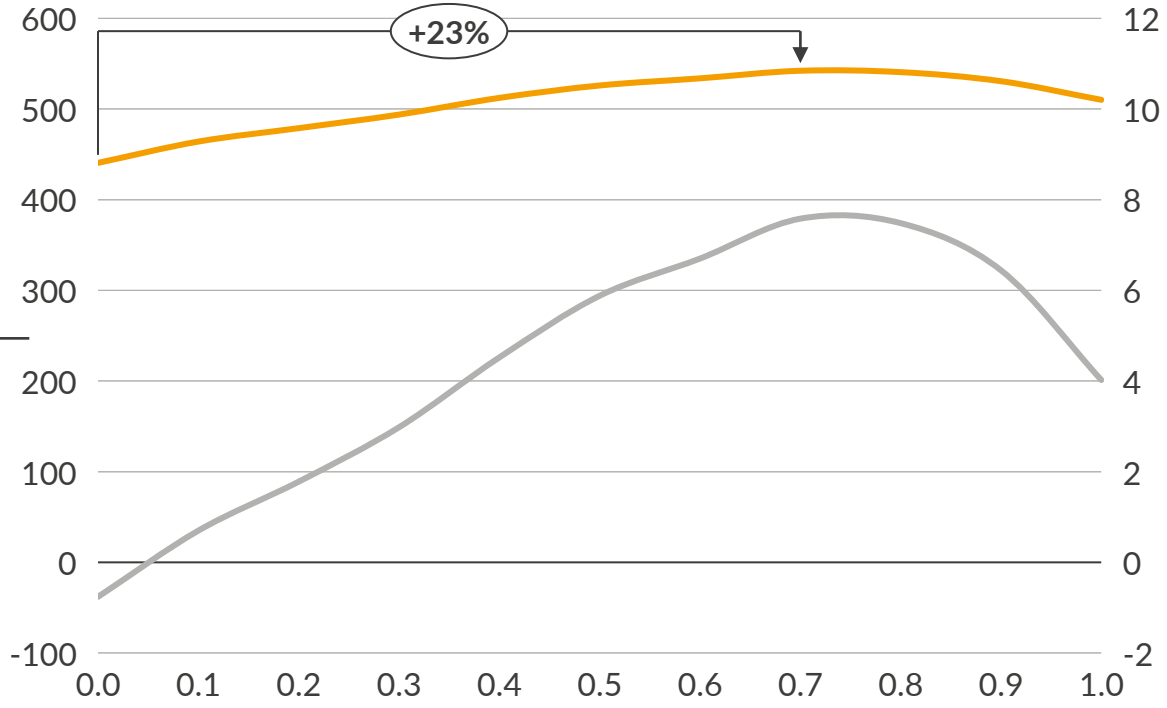
DC solar PV sizing
kW, relative to 1kW grid connection

IRR[1] of RES and battery, %



IRR[2] solar RES and battery
%

NPV[3] solar PV and battery asset
kPLN/kW grid connection capacity (real 2022)



Battery sizing
kW, relative to 1kW grid connection

IRR NPV

1) Assuming 30 year lifetime for renewable asset, and 15 years for the battery. Assumes 2-year supplementary and 13-year main auction capacity market contract from year of entry. 2) IRRs shown pre-tax and do not consider any financial costs 3) Net Present Value based on assumed WACC of 9% for solar revenues and all costs, 6% for main auction capacity market contracts, 9% for supplementary auction capacity market contracts and 11% for all other battery revenues

Sources: Aurora Energy Research

AC coupled co-location offers CAPEX and OPEX savings of around 5% compared to an uncoupled asset configuration

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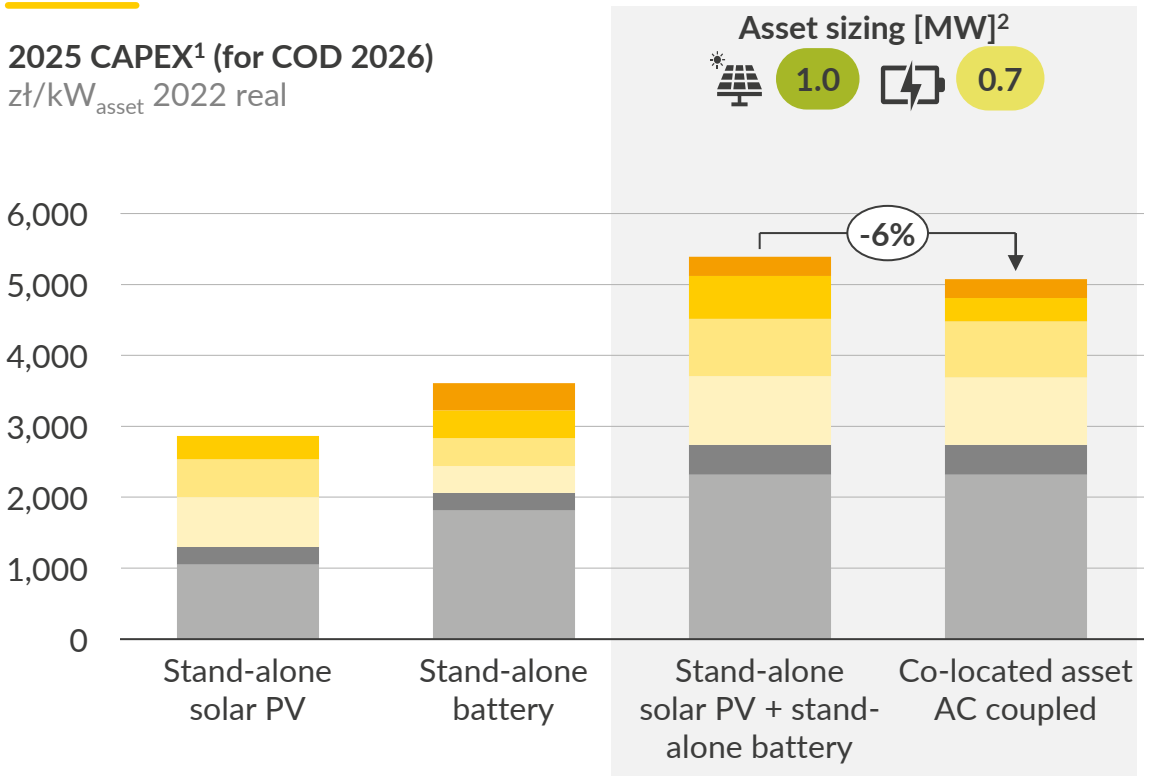
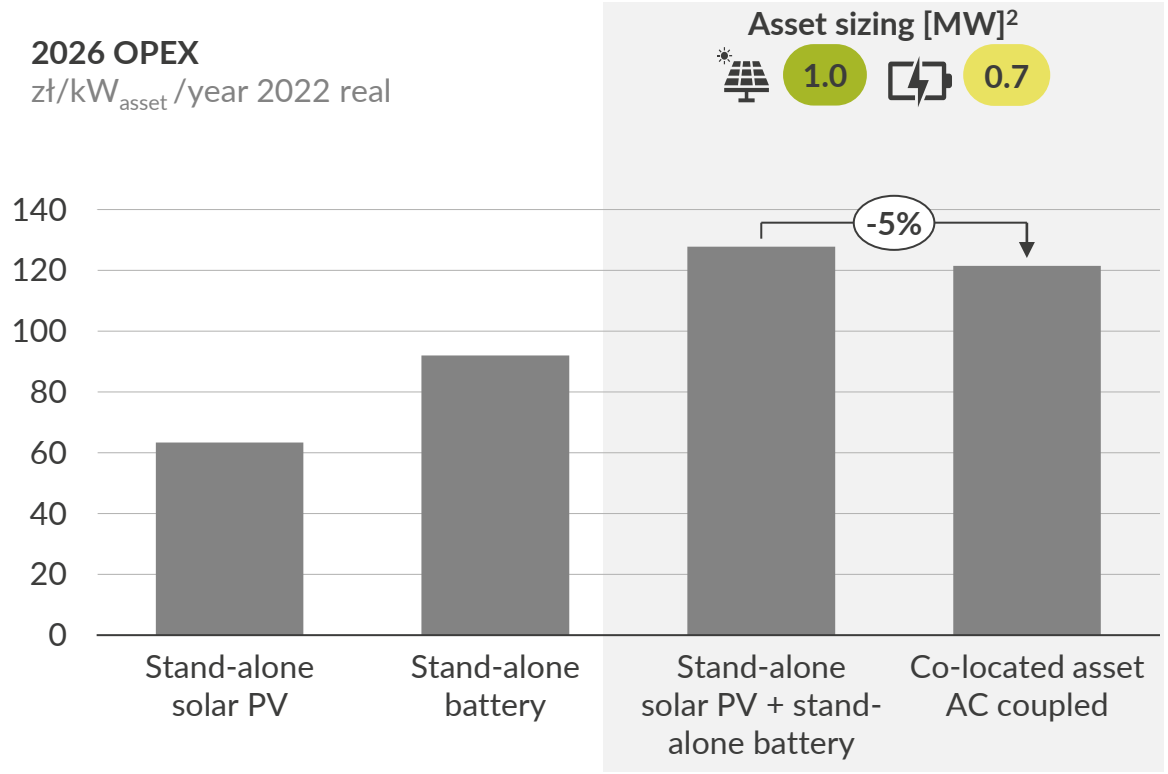
2025 CAPEX[1] (for COD 2026)
zł/kW$_{asset}$ 2022 real



2026 OPEX
zł/kW$_{asset}$ /year 2022 real



- Co-location allows for reduced grid connection costs, as only one connection must be built, and it does not need to match the combined asset capacity
- Moreover, part of the installation and development costs can be saved on since co-located assets built at the same site

- The bulk of the OPEX savings for an AC coupled co-located asset are based on a reduction in operations and maintenance costs
- Self-consumption does not offer savings on grid fees in Poland, as separate metering means the assets are metered individually

EPC soft costs | Installation & development | Inverter
Grid connection | Balance of system | Battery/PV Module

1) For a 2-hour storage duration battery. 2) Results presented are for a co-located asset with a solar:battery:grid size ratio of 1:0.7:1

Sources: Aurora Energy Research

Wholesale markets remain the key revenue stream, supplemented by battery participation in aFRR and FCR capacity markets

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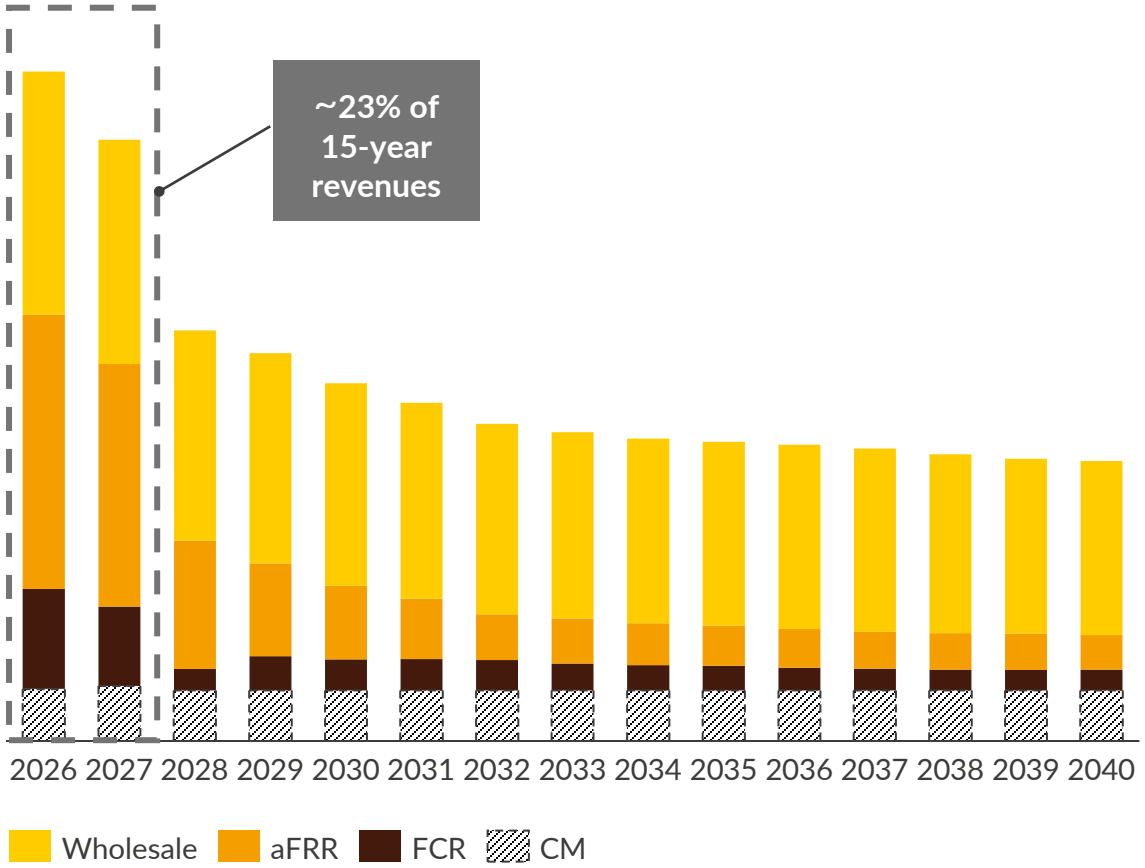
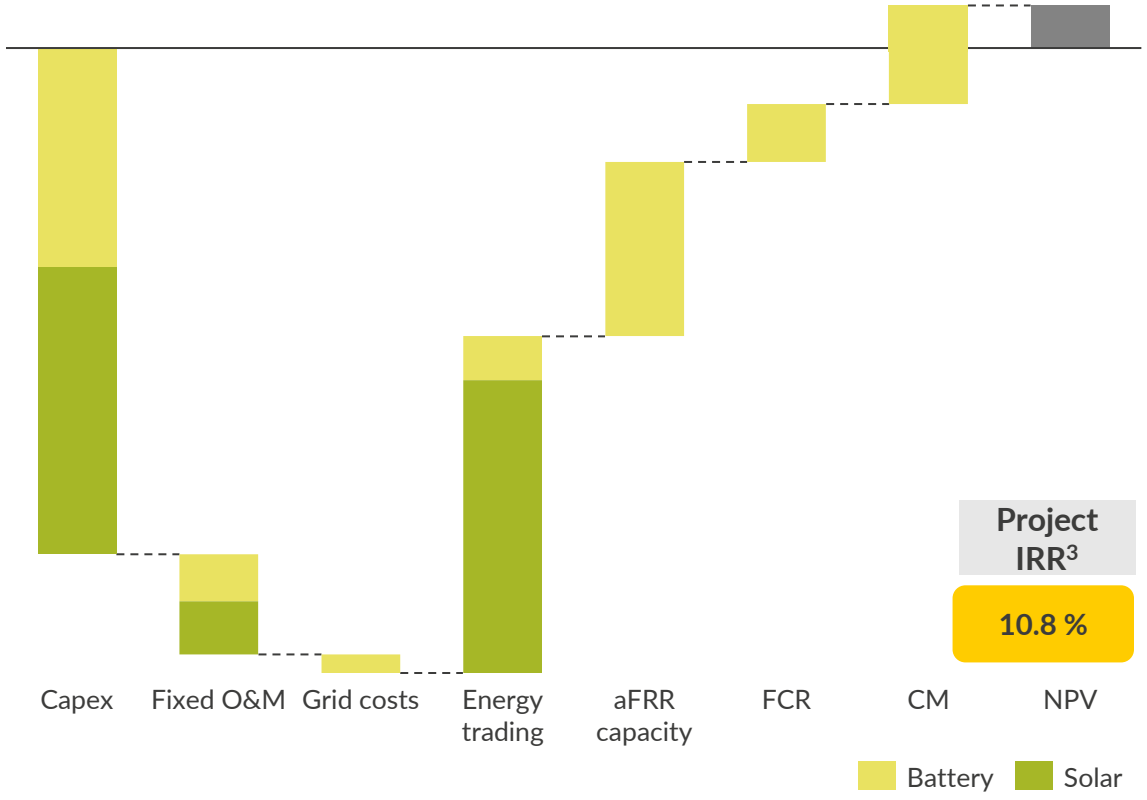
Solar PV and 2h battery, AC-coupled, 2026 entry

Annual revenues breakdown for assets[1] deployed in 2026
zł/kW/year (real 2022)



Net Present Value of RES and battery
zł/kW (real 2022)

Co-location configuration
1 | 0.7 | 1.0



1) 2h batteries are presented, characterised by an average daily cycling target of 1.5 cycles, over a total 15 years battery lifetime. 2) NPV calculated based on discount rate of 11% for all revenue streams except the Capacity Market, which is discounted at 6% and 9% for main and supplementary auctions, respectively. Costs are discounted at 9%. 3) IRR in real terms, pre-tax

Sources: Aurora Energy Research

Agenda

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I. Introduction to co-location and the regulatory environment

II. The standalone business case

III. Investing in co-location

IV. Closing remarks

Key takeaways

1. The grid poses one of the main obstacles to a rapid energy transition in Poland. The **recent passing of legislation to enable cable pooling** means that co-location can be an effective way to maximise limited grid connection capacities.

2. The current requirement to place separate metering points for co-located assets means that only AC-coupled co-location is possible in Poland. Full access to **Wholesale, Balancing and Capacity Markets** is then available.

3. Batteries entering operation by 2026 see very strong returns, **with IRRs reaching 15%.** With aFRR and FCR capacity markets saturating by 2030, the value of standalone battery investments falls.

4. Standalone solar investments **entering the market in 2026 can expect IRRs just under 9%,** placing them on the verge of investability on a fully merchant basis.

5. Adding a co-located battery to a standalone solar project entering in 2026 **can improve its IRR by 23%.** Returns are optimised when 0.7 kW of battery capacity is added per 1 kW of solar and grid connection capacity.

Source: Aurora Energy Research

Access detailed power market analysis and investment case data for batteries with our Polish Flexible Energy Market Add-on Service

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Flexible Energy Market Service

Forecast Reports & Data

Technology and Market Development Reports

- Overview of regulatory framework for batteries
- Revenue stacking models for batteries
- Projections for battery CAPEX and OPEX by delivery year
- Reports and datasets follow the same format with content tailored to specific markets

Forecast Data

- Central case forecast prices provided at hourly granularity until 2050:
  - Wholesale power prices
  - Capacity market prices
  - FCR and aFRR market prices

Investment Cases

Standalone battery

- Multiple investment cases per country or zone including:
  - Arbitrage of wholesale market and balancing market
  - Focused participation in frequency control market (if applicable)
- Annual project margins to 2050; IRR and NPV for multiple entry years

Explore how your business can benefit from our regular forecasts and investment case data from **Natalia Mazurowska, Commercial Associate**

✉ **natalia.mazurowska@auroraer.com**

We are expanding our Subscription Analytics to Slovakia and Czechia—don't miss the chance to join the upcoming market workshops

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Workshop 1
Policy and market overview – Czech and Slovak markets

- **Overview of regulatory and market trends in the Czech and Slovak power markets** with particular focus on decarbonisation and security of supply
- Impacts on future power supply and demand, and how they are reflected in Aurora's modelling
- Discussion of key uncertainties in the Czech and Slovak power markets

17 January

In-person workshop in Prague

Workshop 2
The Czech and Slovak power market until 2060: a sneak preview

- **Fundamental modelling of the Czech and Slovak power markets**, leveraging Aurora's comprehensive experience with modelling other European power markets
- **Discussion of Aurora's preliminary outlook for the Czech and Slovak wholesale markets**, including baseload prices, capacity mix and capture prices for key technologies
- **Opportunity to provide feedback** and exchange views on Aurora's analysis

14 February

In-person workshop in Bratislava

Workshop 3
Aurora's power market outlook for Czechia or Slovakia

- **Presentation of Aurora's full-fledged market outlook** for the Czech or Slovak power market until 2060
- Deep-dives into business opportunities, as well as key risks, for participants in the Czech or Slovak power market

18 April

Virtual workshop and Databook

Regular Market Forecasts & Reports
Czech or Slovak Power & Renewables Forecasts

- **Forecast reports** on the Czech or Slovak power market **and underlying data**, published bi-annually
- Ongoing interaction through workshops and analyst support

Q2 and Q4 updates

Forecast updates & analyst support

Discuss our analysis and then receive regular market updates and business cases!
Reach out to Joanna Marszalkowska to reserve your spot


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