Market Uptake of Solar Thermal Electricity through Cooperation

Model-based Assessment of Concentrated Solar Power in Spain: A Case Study Analysis

16th IAEE European Conference Ljubljana, 27 August 2019

Session 3E: Renewables II - Solar

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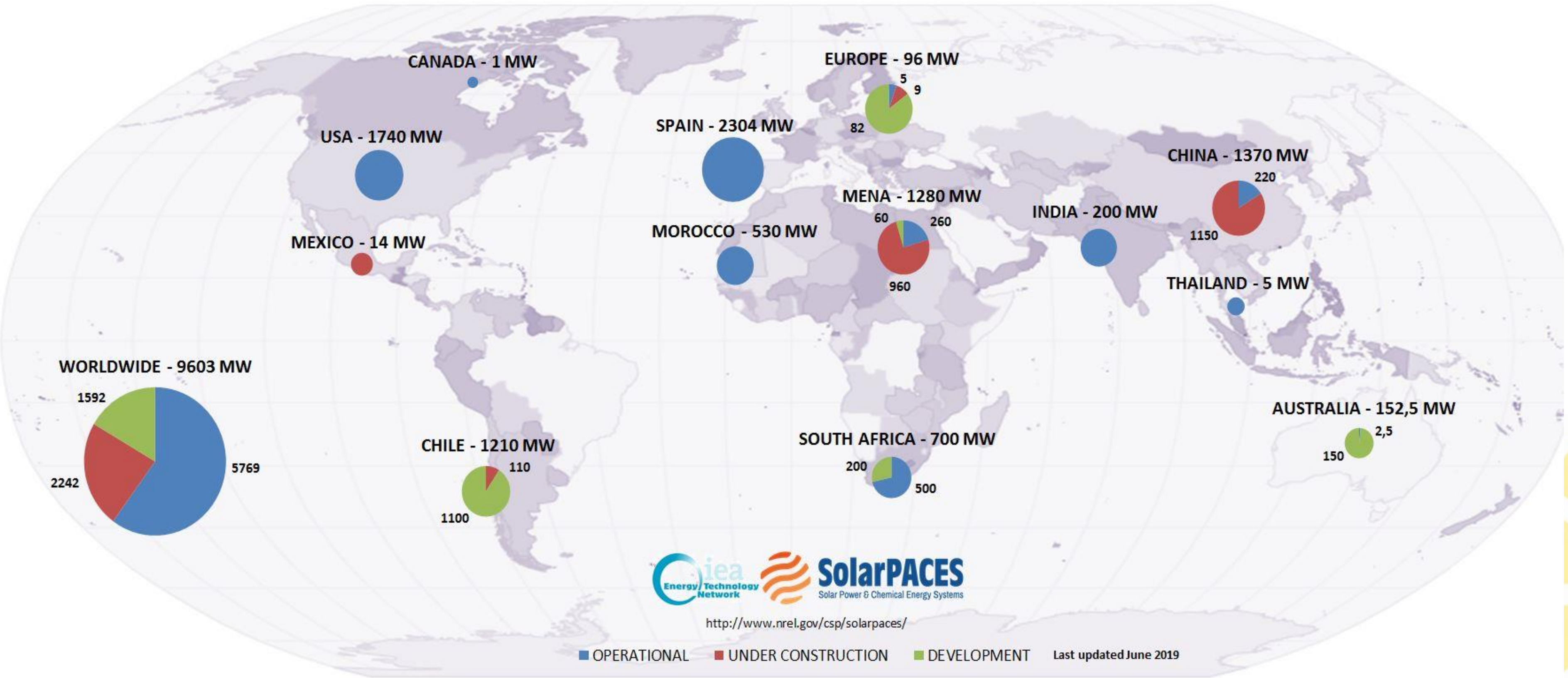
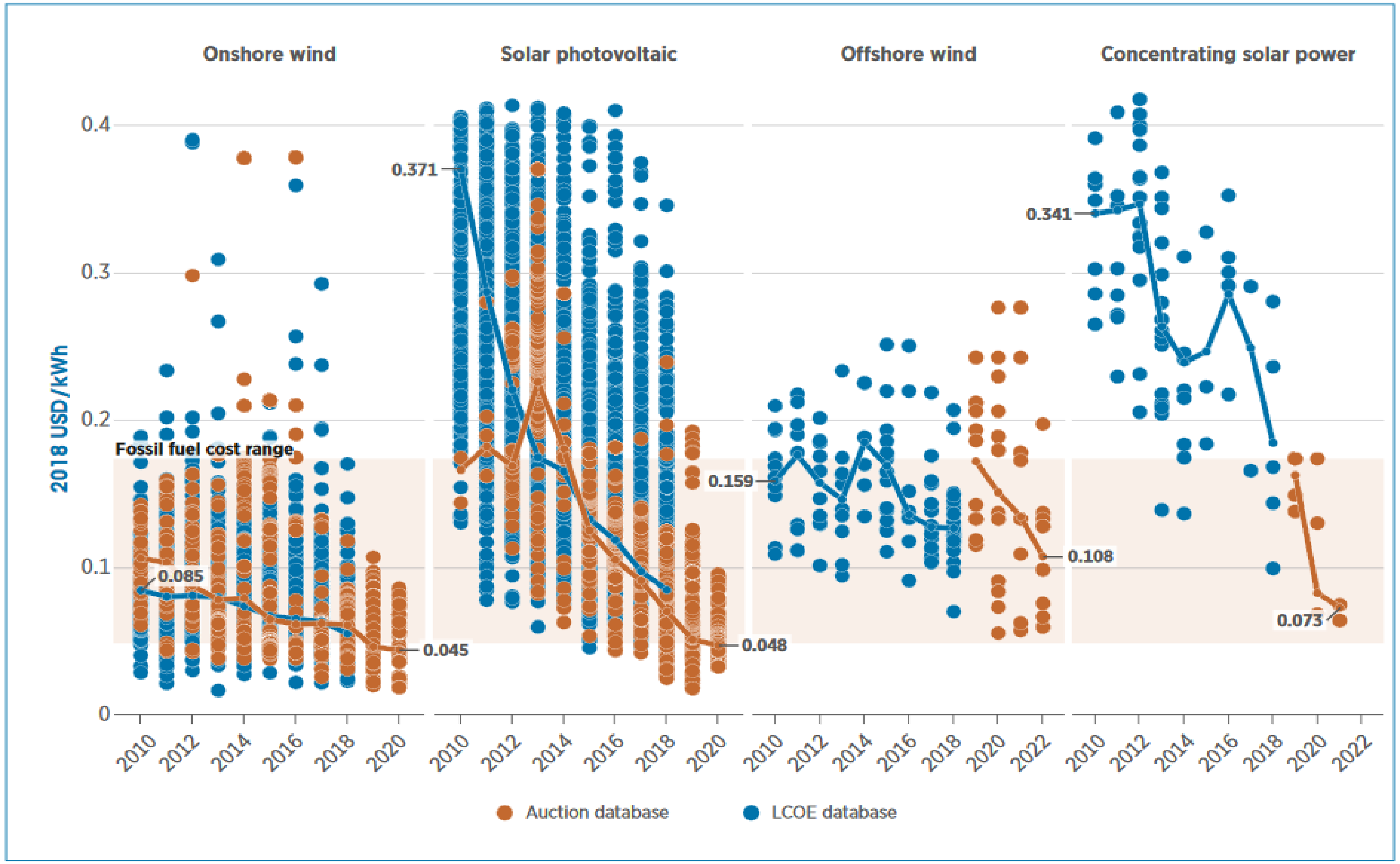
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764626

2019: 9.6 GW installed capacity of Concentrated Solar Power (CSP) globally



- **CSP** as one (still rarely used) renewable electricity technology for a decarbonized energy future
- **Strongly growing** industry (esp. China and MENA region)

Steepest learning curve of renewables



Source: IRENA: Renewable Power Generation Costs in 2018 (2018)

- The Levelized Cost of Electricity (LCOE) for projects and global weighted average values for CSP, solar PV, onshore and offshore wind, 2010–2022
- LCOE of CSP still higher than wind and solar PV
- BUT: **Steepest learning curve** and cost reduction
- **Competitiveness** with offshore wind expected for upcoming **5 years**

MUSTEC project in brief

- **M**arket **U**ptake of **S**olar **T**hermal **E**lectricity through **C**ooperation: project started in October 2017 and is funded by the EU Horizon 2020 program
- A dedicated, comprehensive and multi-disciplinary analysis of **past, present and future concentrated solar power (CSP) cooperation opportunities** with a constant engagement and consultation with policy makers and market participants

Cooperation mechanisms ⟷ CSP

- Projects in Southern Europe capable of supplying renewable electricity on demand to Central and Northern European countries
- Industry developments building on concrete CSP case studies

Technology concept of CSP

Technological concept:

- Reflection of solar direct normal irradiation (DNI) onto a receiver (tower, linear Fresnel, parabolic through, or dish system)
- Heat transfer fluid (HTF)
- Heat engine
- Generator
- Optional: thermal storage

+ **renewable** and d**ispatchable** electricity technology
+ highly attractive for **future energy systems (flexibility)**

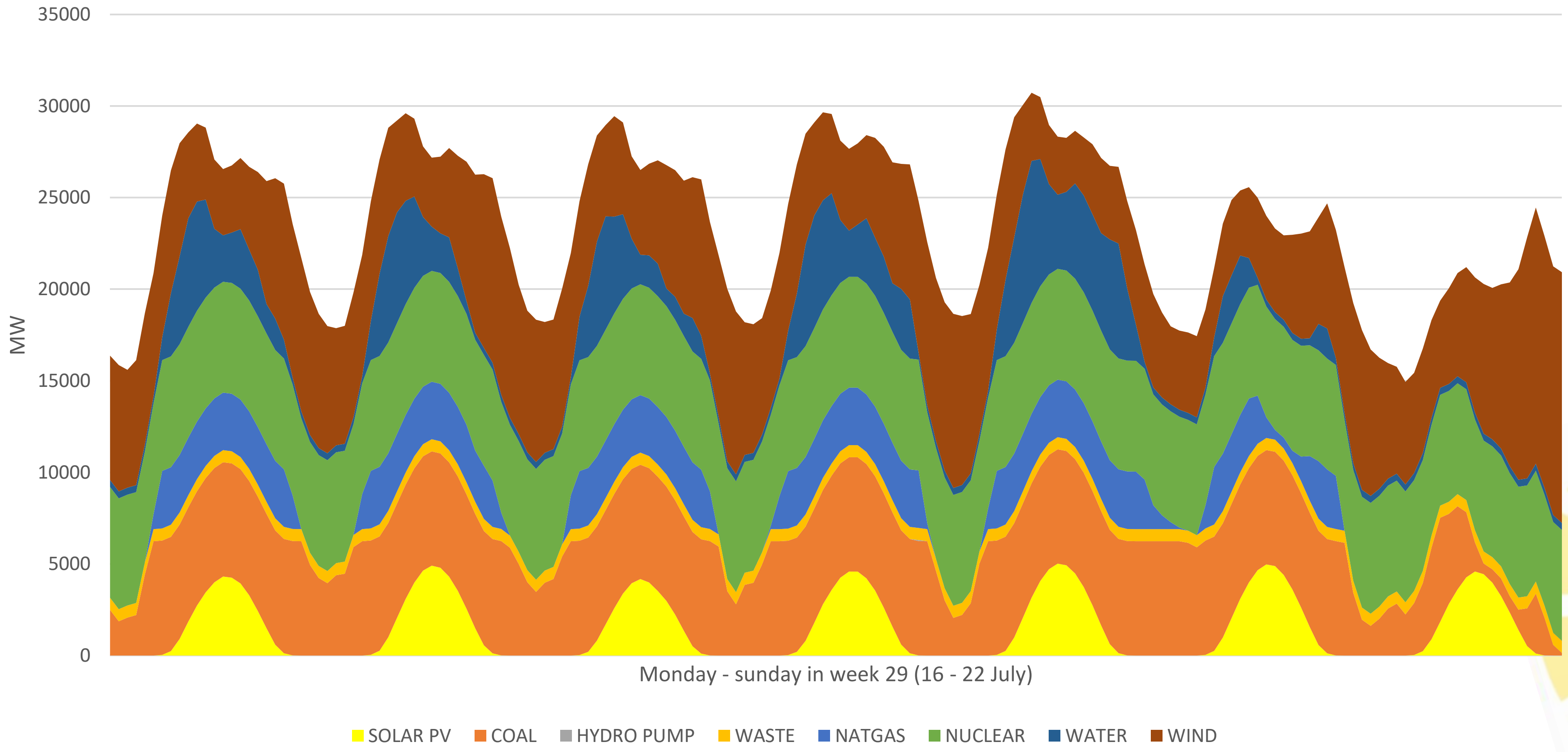
Case study – 200 MW CSP parabolic through

- **200 MW_{el}** CSP plant with an **11 hours storage** system in Spain
- The full Spanish electricity system is modelled, as well as exports and imports
- Reference **year 2018**
- All generating capacities are exogenous input parameters

- Optimization of the **hourly power plant dispatch**
- Sensitivity analyses: variations in storage size, solar multiple, natural gas and CO_2 price, and shares of non-dispatchable renewable electricity generation (wind and solar PV) in the electricity system

- (Open source) energy system model Balmorel

Spanish generation mix in 2018



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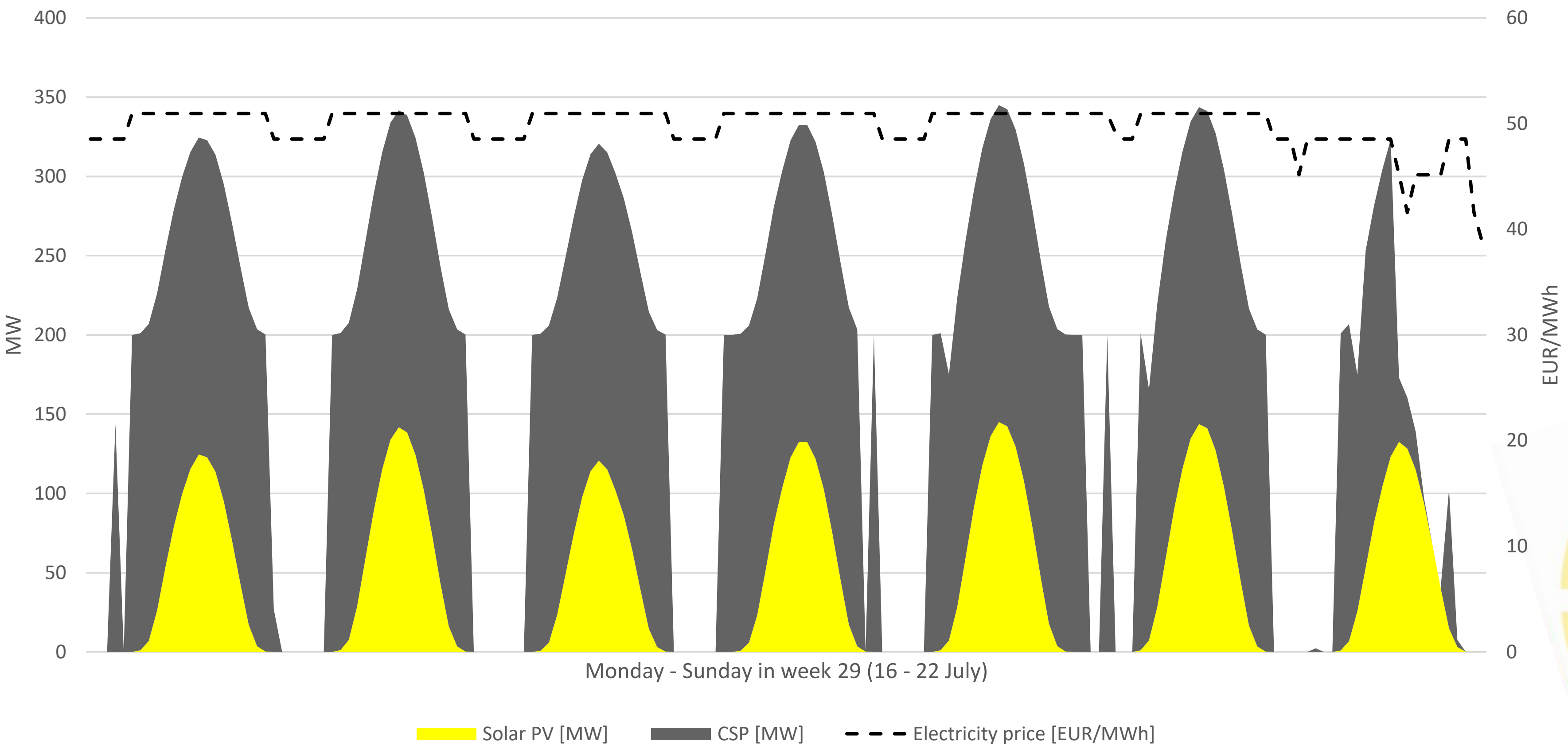
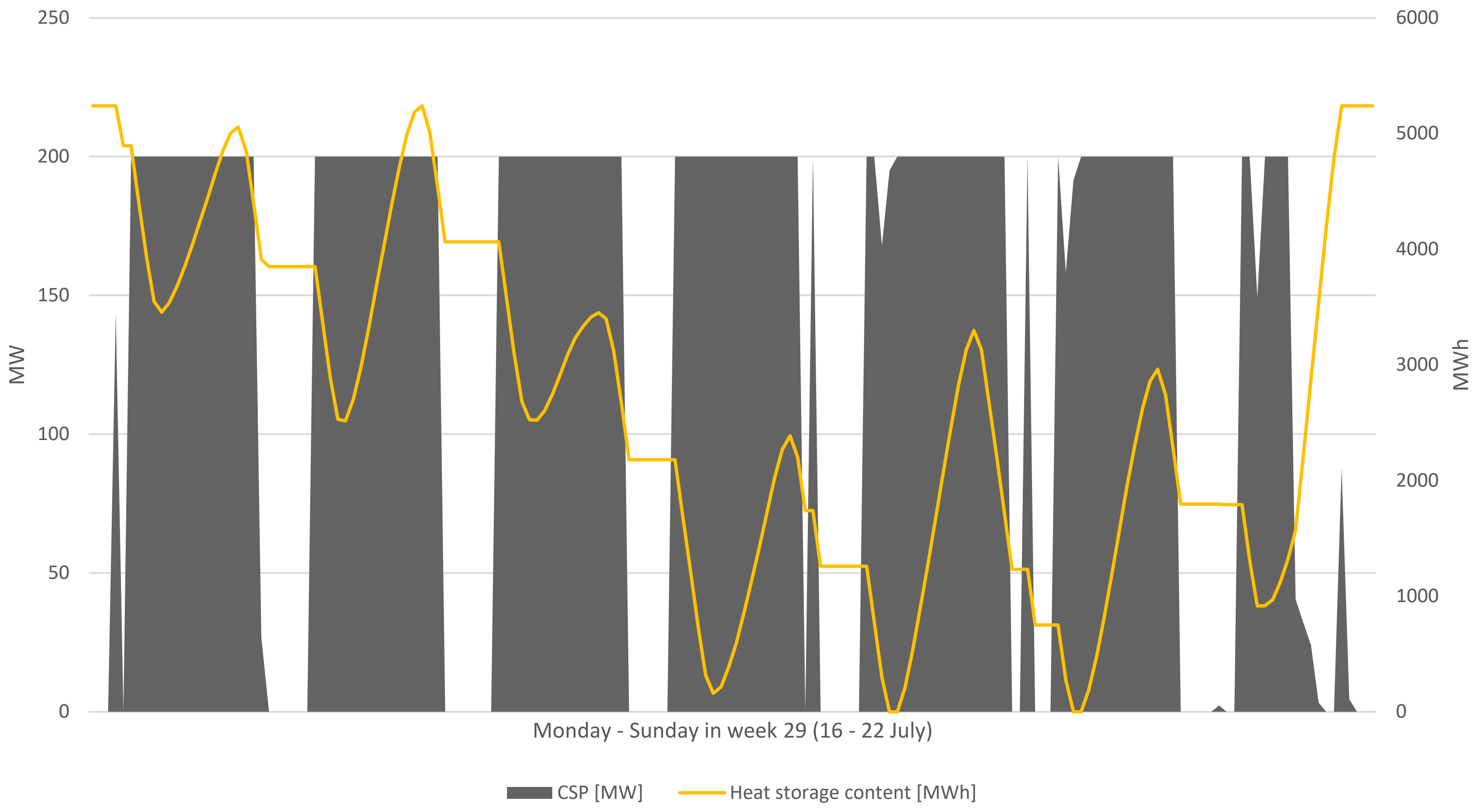
Generation profile: 200 MW CSP and 200 MW PV



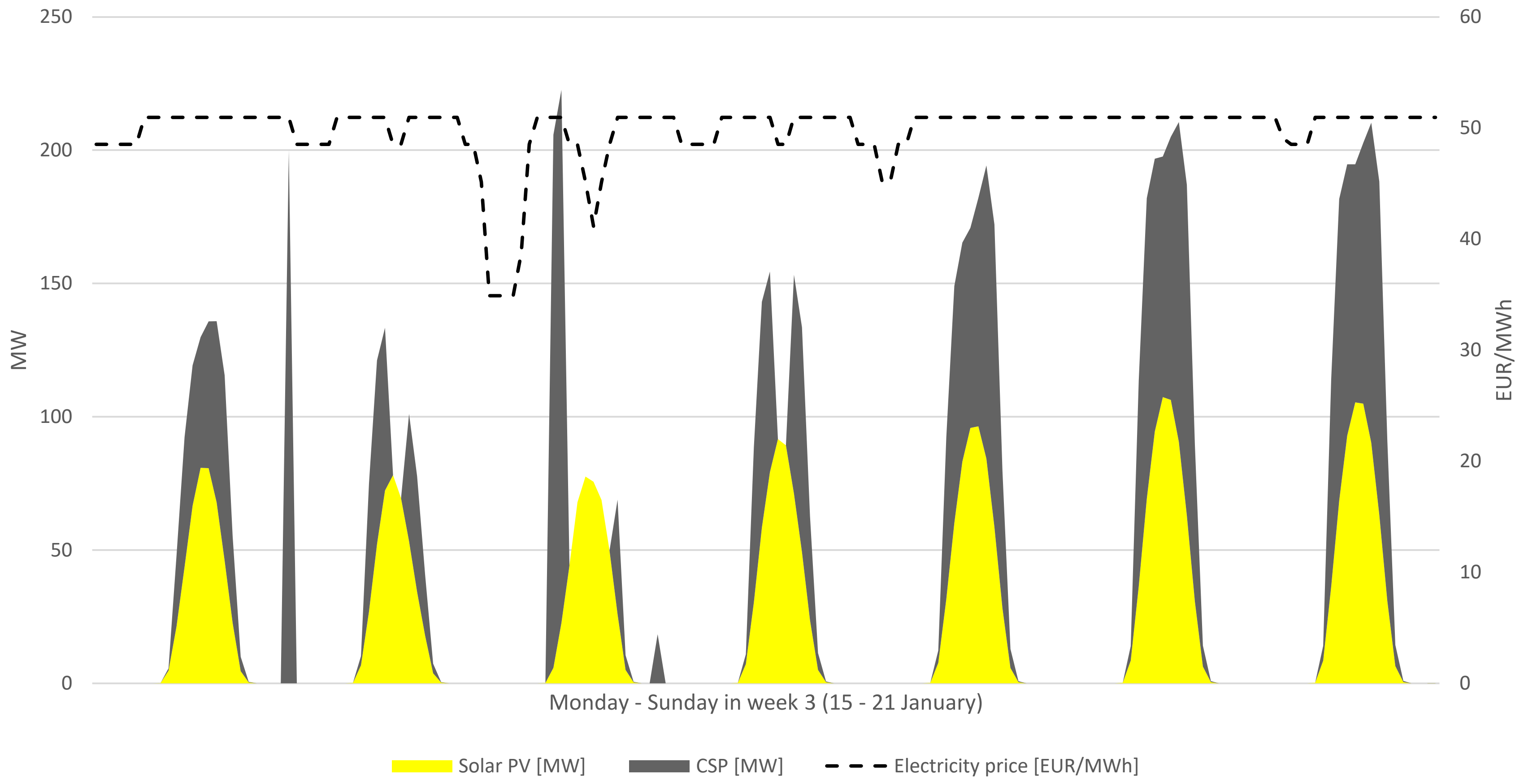
- CSP **produces during the day** because of the higher electricity price than during the night
- Compared to PV: Additional generation in the **morning and evening hours** of the day
- Storage is used to shift generation during the day not to the night

CSP uses storage to operate full load during the day because of higher prices



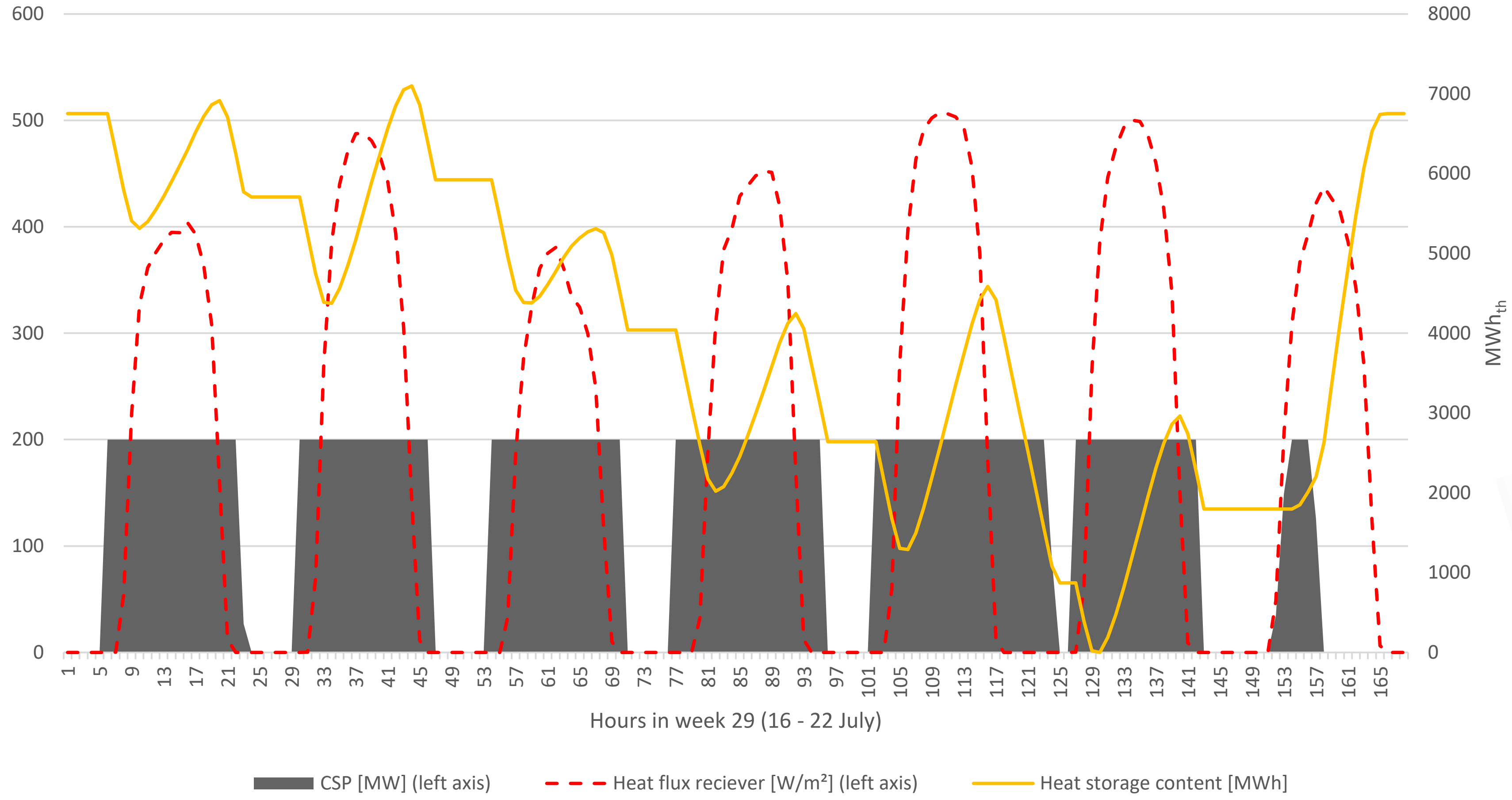
- Thermal storage is charged during the day
- Storage depletes over the course of the week and is recharged full on the weekend when electricity prices are lower

Less CSP generation during winter



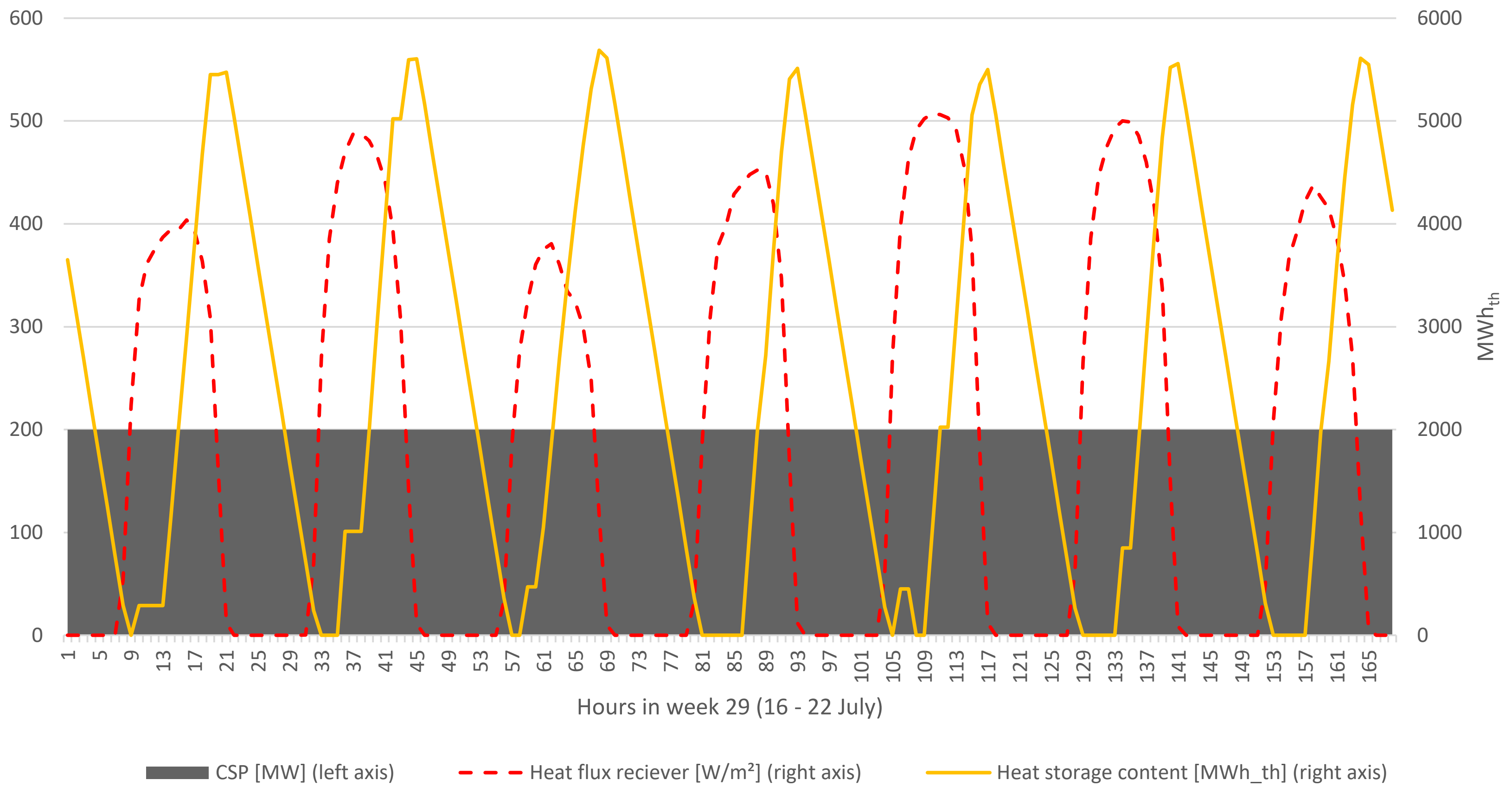
- Less solar irradiation means **less electricity generation during winter**
- Also during winter, CSP produces during the day due to the price signals

Increase of storage size (11 to 17 hrs) doesn't change operational behavior of the CSP



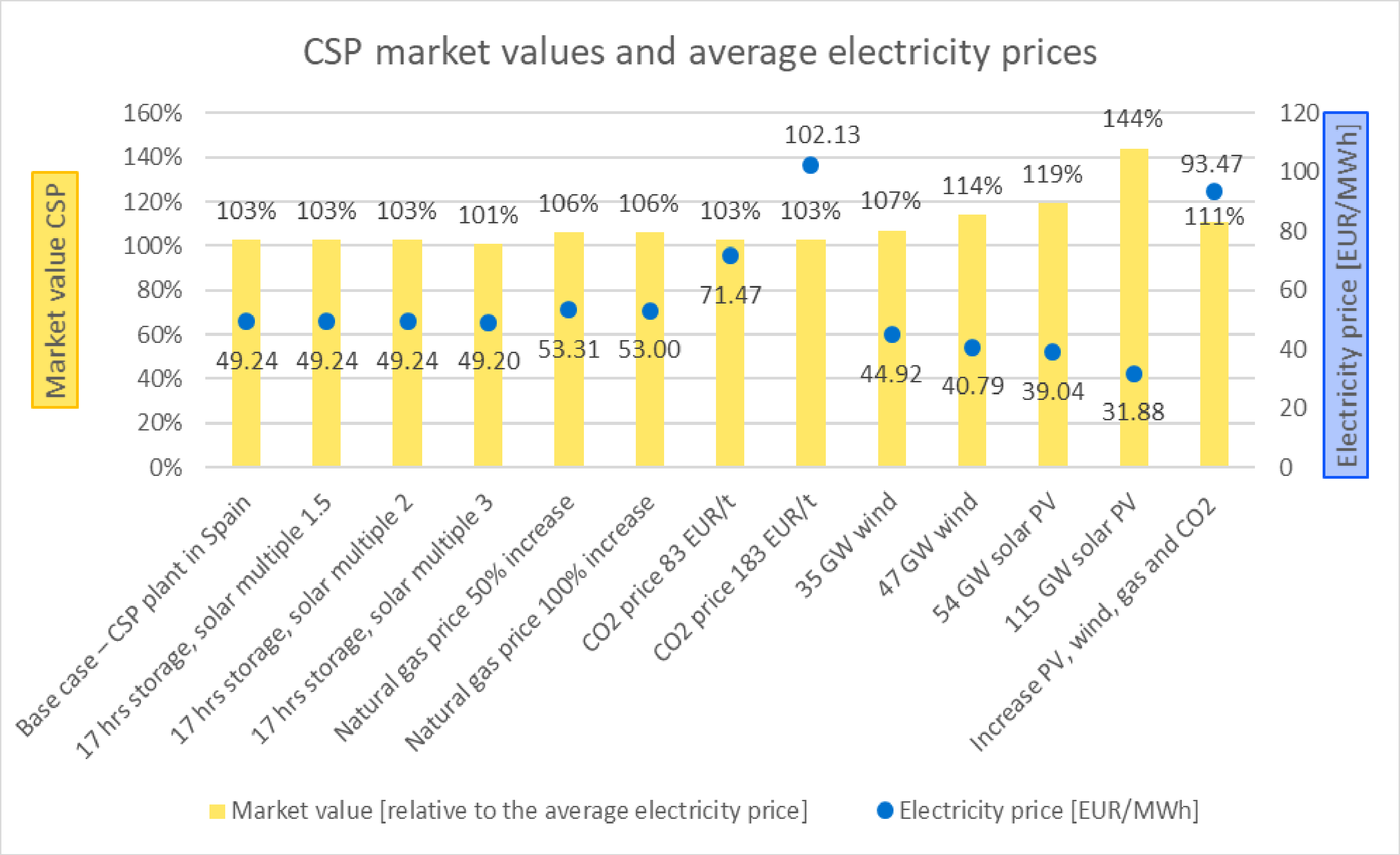
- 17 hours instead of 11 hours storage capacity
- Shift of the generation during the day: 11 hours storage is sufficient

Increase of the solar field size enables continuous base-load operation during summer



- Solar multiple of 3 instead of 1.5
- Solar multiple as measure for the ratio of the size of the thermal power output of the solar field and the thermal power input of the generator (at design point)

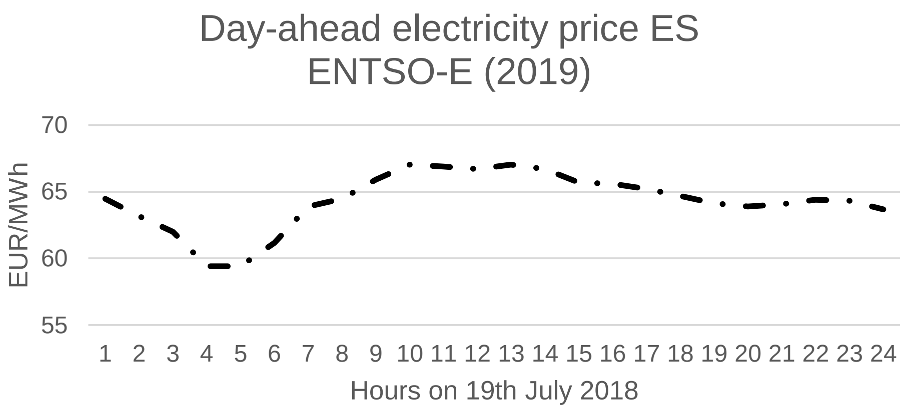
Promising future prospects for CSP



- Increased thermal storage capacity: **does not increase the market value of CSP** significantly because the electricity prices during the day are the highest. However, in combination with an increased solar multiple, the produced electricity and revenues are increased.
- Relative **market value** for the CSP plant is above 100 % in all sensitivity analyses: **highest in the case of a very high PV share** in the electricity system (144%)
- High shares of non-dispatchable generation by PV and wind increase the relative market value of CSP the most. At the same time, **average electricity prices and revenues are the lowest in these sensitivity analyses.**

Main conclusions

- Current (2018) Spanish electricity system: price pattern **doesn't provide incentives** to shift CSP generation to **night**, the most profitable way for a CSP plant is to sell its electricity production during the day (**shifts to morning and evening hours**)
- BUT: CSP is capable of **reacting very flexible to price signals**!
- Use of a storage system: highly dependent on the electricity price dynamics of a market, i.e. the **correlation** between **solar radiation and peak price levels**.



- Systems with a **high share of non-dispatchable** fluctuating renewables lead to the **highest relative market values** for CSP (up to 144% in high-PV systems)
- In a **possible future electricity system representing** these features – combined with expected cost reduction of CSP technology - , CSP could play out its **main operational advantages** – dispatchable, renewable, and CO2-free generation of electricity
- Outlook: Scenario modelling of different policy pathways up to 2050

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Thank you!

Questions? Feedback?

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Appendix

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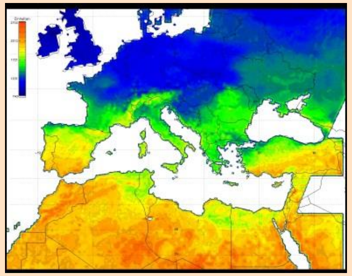
WP8

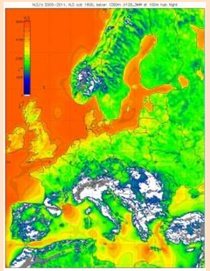
The applied modelling system

- ***Green-X*: analysis of RES investments, RES developments and related impacts** on costs, expenditures and benefits
- ***Balmorel & Enertile*: interplay between supply, storage and demand** in the electricity market.

Solar PV / CSP

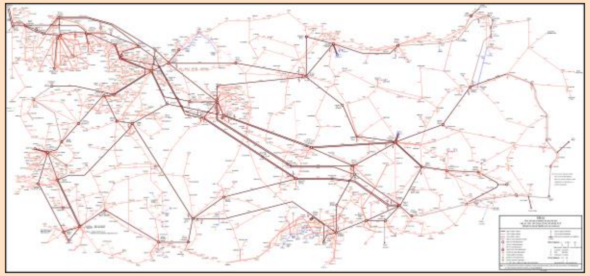


Wind



Locational power plant database

Transmission Grid



- Energy/CO_2-price development
- Default (2010) technology costs
- Energy demand development

Green-X

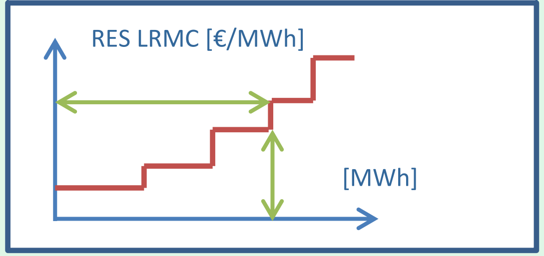
Yearly time resolution (2006 -2050), years modelled: 2010 to 2050

RES policy

Financing conditions

Non-economic barriers

Dynamic cost-potential curves, Policy interaction, Investment decision



RES deployment (electricity, heat, transport)

RES system costs

RES support expenditures

Assessment of benefits (CO_2 & fossil fuel avoidance)

RES investments

ITERATION

- RES deployment
- Dynamic cost development (technological learning)

- Feedback on RES market values
- Feedback on curtailment of RES
- Feedback on electricity prices

Balmorel

Enertile

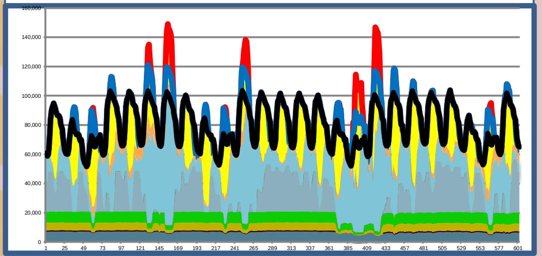
Hourly time resolution (8760h), years modelled: 2020, 2030 & 2050

Demand

Supply

Storage

Common electricity market model



System flexibility impact of enhanced market coupling (heat market)

Power plant dispatch & -commitment

Electricity prices Total system costs

Transmission grid expansion

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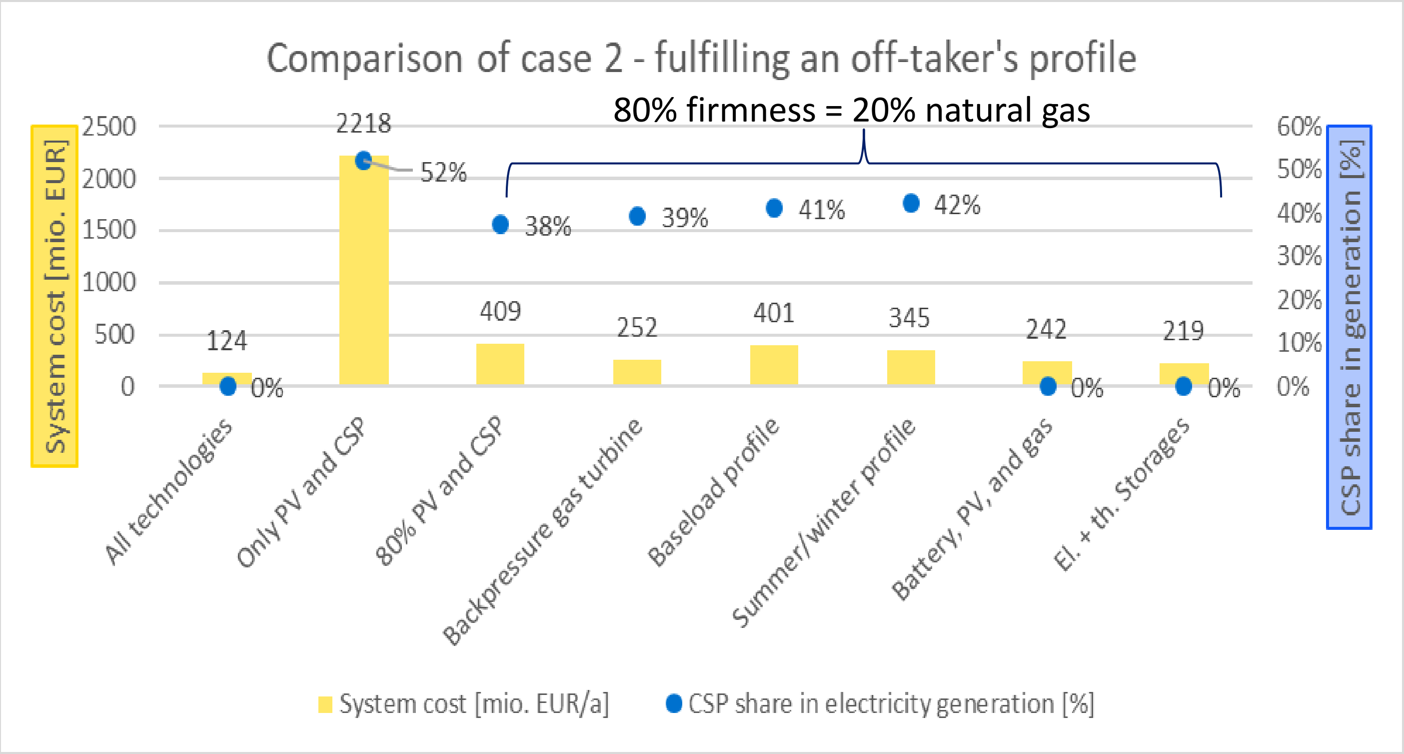
Case study 2 – fulfilling an off-taker’s profile

- Configuration has to cover a specific **off-taker’s demand profile**
- Down-scaled **closed electricity system** covering 0.2% of the Spanish electricity demand
- The model **optimizes investments and dispatch** to cover the off-taker’s demand in every hour of the year

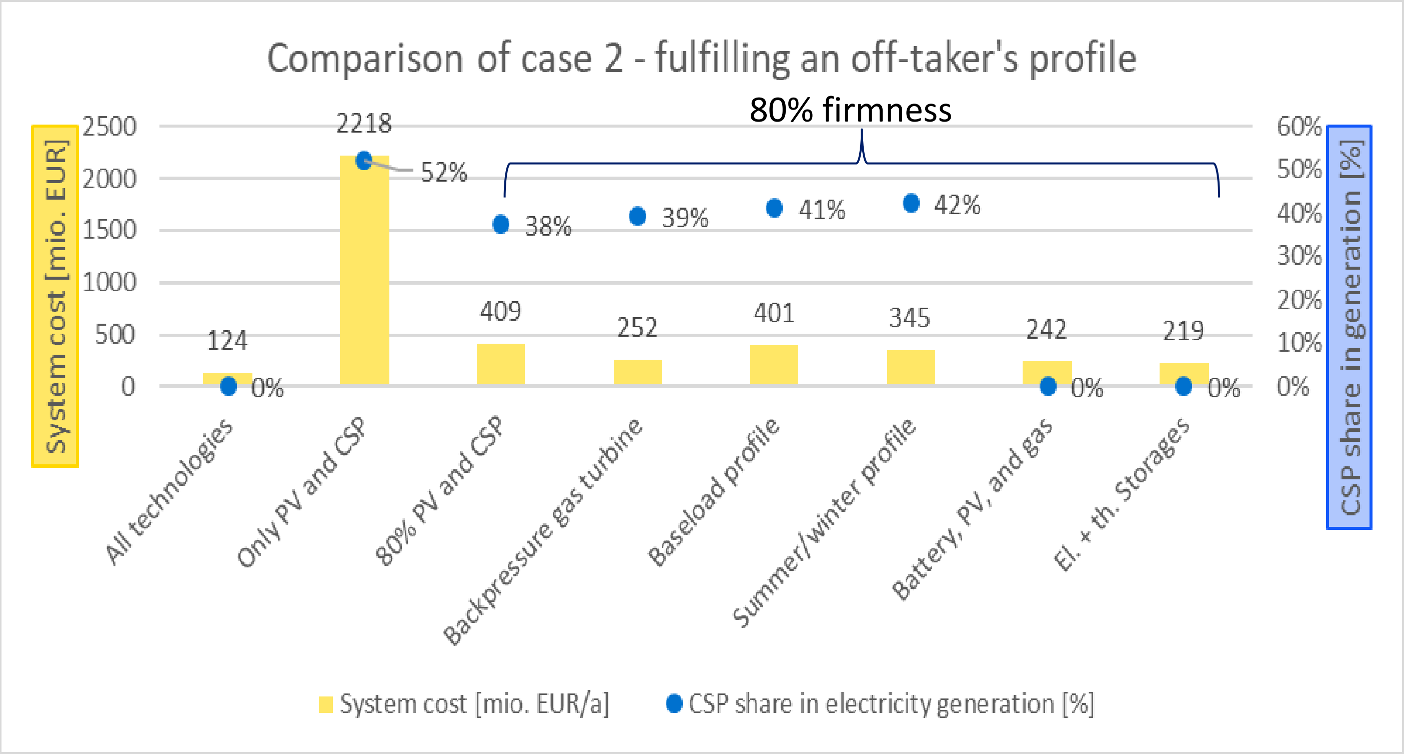
- Sensitivity analyses: configurations of the CSP plant, possible combinations of hybrid technologies (PV and natural gas), grade of firmness of supply, and variations of the off-taker’s demand profile
- Assessment of **batteries vs. thermal storages** to fulfill a given demand profile

Results: Case study 2 – fulfilling an off-taker's profile



- **Cost-optimized** solution under current cost assumptions to fulfil the off-taker's demand profile: condensing **natural gas and PV**
- Fulfilling the same off-taker's profile only with CSP and PV leads **to huge over-capacities** during summer since the low radiation during the winter defines the unit sizes
- **Backpressure** gas turbine (recovering the exhaust heat in the thermal storage) can reduce the system cost significantly (-38%)
- Slightly **higher CSP share** in the case of a baseload and summer/winter profile (41%-42%) compared to the Spanish load profile (38%)

Cases study 2 – fulfilling an off-taker's profile



- Adaptation of profile to **seasonal conditions** (higher production of CSP during the summer) **reduces system cost by 14%** compared to a baseload profile over the whole year
- Generation **evenly shared** between PV and CSP → **complementary** use in order to achieve a continuous, emission-free supply of electricity
- It is more cost-effective to invest in thermal storage systems in combination with **electric boilers** to store **excess renewable generation** than in utility scale battery systems → opportunity for CSP to step into the system

Thermal storages and boilers