Understanding how to plan the future generation fleet with renewables

Energy Transition is not possible without the role of Solar Thermal Electricity, neither in Spain nor in Sunbelt countries

Common understanding and the big question mark

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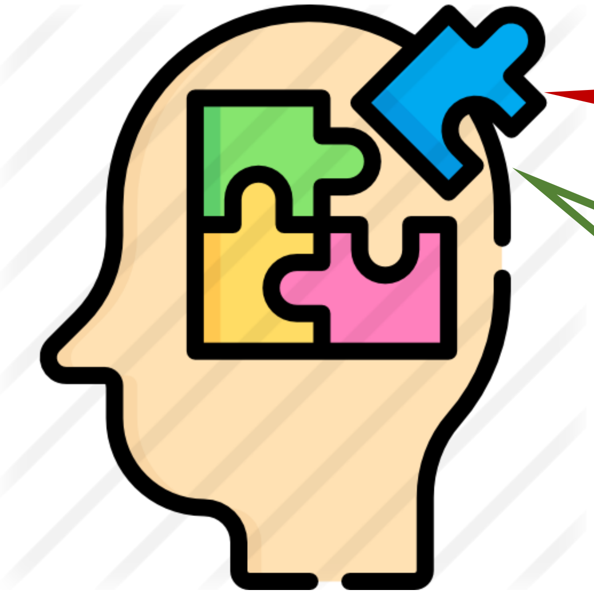
- ✓ Decarbonization of human activities is the main and urgent challenge that we face today
- ✓ Electricity is the easiest energy vector to be decarbonized, as renewable technologies are currently cheaper than fossil fuel plants
- ✓ Therefore "Electrification" of final uses – particularly transport and climatization – along with increase of energy efficiency is a clear trend
- ✓ **The large majority of new capacity to be added** – as result of demand increase and/or decommissioning of conventional plants – **will be Renewable**
- ✓ **BUT**, non dispatchable renewables (PV / Wind) can't meet the demand at any time. They would require fossil backup and their deployment is clearly limited by curtailments and market rules

Missing piece?

Is there any solution envisaged to avoid the need of fossil backup?

Schools of thought
regarding the missing piece for non dispatchable renewables

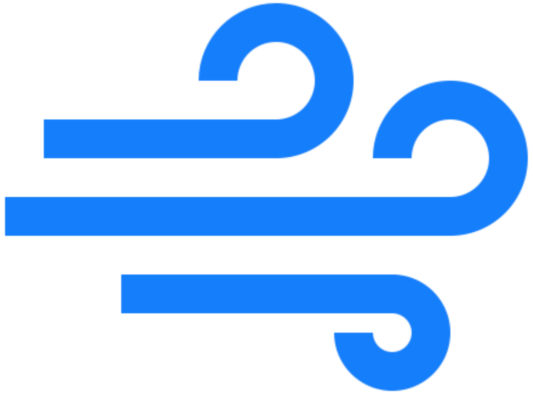


Hey, come on! gas is not that bad, emissions are much lower than from coal. Lets Wind and PV growing as much as they can. Gas will indefinitely help

Don’t worry for curtailments from Wind or PV, lets them growth without limits. Batteries in the grid will be very cheap in the future and they will accommodate all possible surplus

Planning a balanced fleet with dispatchable and non dispatchable renewables. Thus, the need of fossil backup will be reduced, curtailments will be lower and there will be no need for grid storage

Renewable resources are so abundant
but technologies to generate electricity are so different



Is the "agnostic" approach based on lowest price the best way to achieve decarbonization goals at a minimum price? …

…

The answer is NOT. Smart planning is the right ANSWER and dispatchable RE technologies with storage are the KEY

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✓ **Understanding the differences among technologies and the dispatch flexibility of some of them**

✓ **Requesting from REs what the electrical system needs - hourly and seasonally - at the minimum cost**

“Blind”* Least cost expansion models (typical agnostic approach) results in:
- Never ending fossil backup and corresponding emissions
- High curtailments
- High hidden system overall costs

Common sense inductive approaches provides:
- Achievement of decarbonization goals
- Higher renewable contribution
- Reduced curtailments

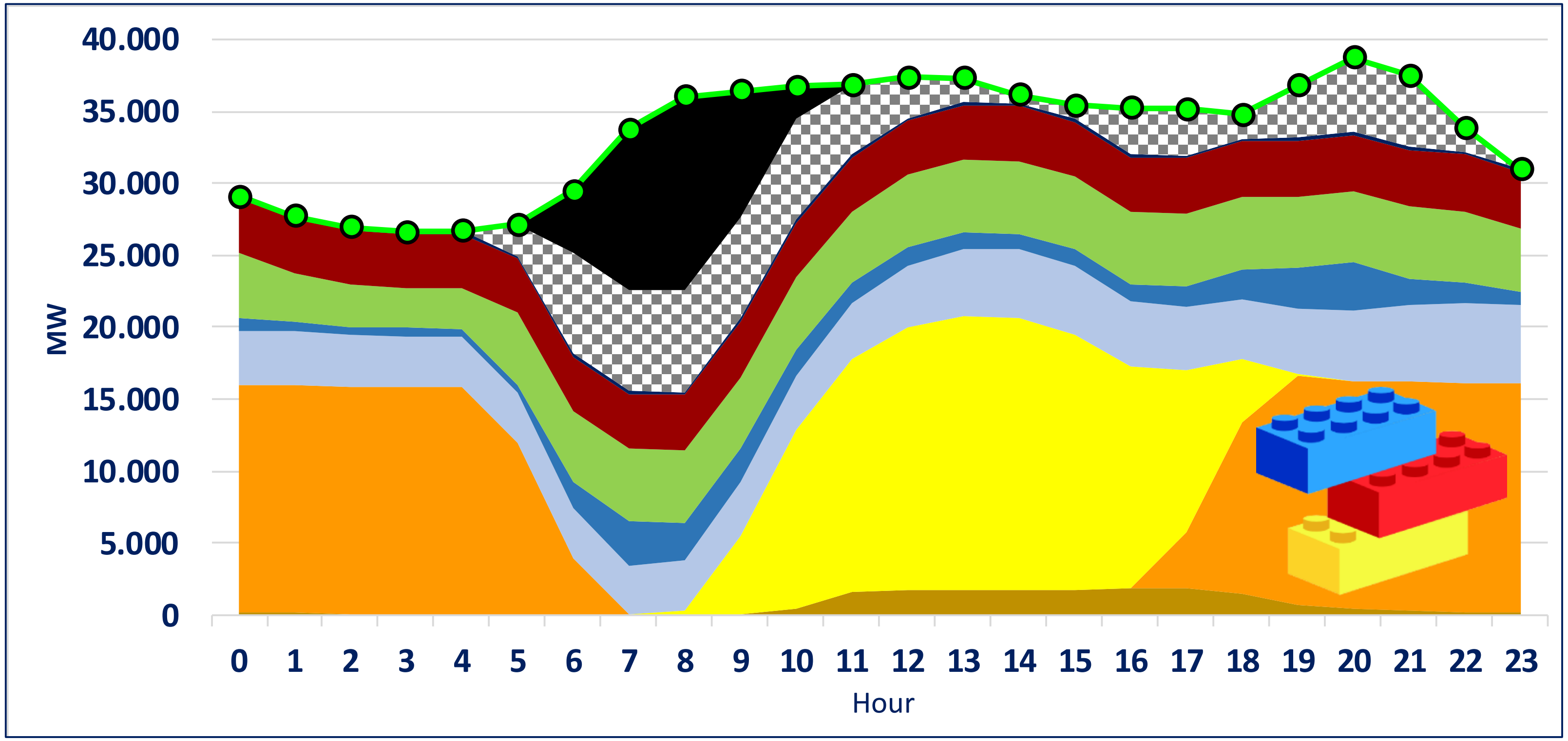
EXAMPLE: Report from “Expert Committee” in Spain. They called “Energy Transition” to keeping the whole nuclear and gas combined cycle fleet by 2030 without reaching the EU goals

EXAMPLE: Protermosolar transition report. No nuclear plants and lower GCC backup power required by 2030, exceeding EU goals at lower system costs

**Least Cost Capacity Expansion models could include* CO_2 *caps, auction prices instead of CAPEX and CSP specific dispatch profile but they don’t usually do. That is why they are levelled as “blind” in this presentation*

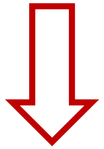
The "fundamentals" of electricity planning

- ❑ **Meeting the demand at any time is about programming the dispatch of available and feasible generation units**



- ❑ **The goal of planning should be:**
  1. To achieve a carbon-free generation system
  2. To ensure quality of supply and grid stability
  3. At an affordable cost

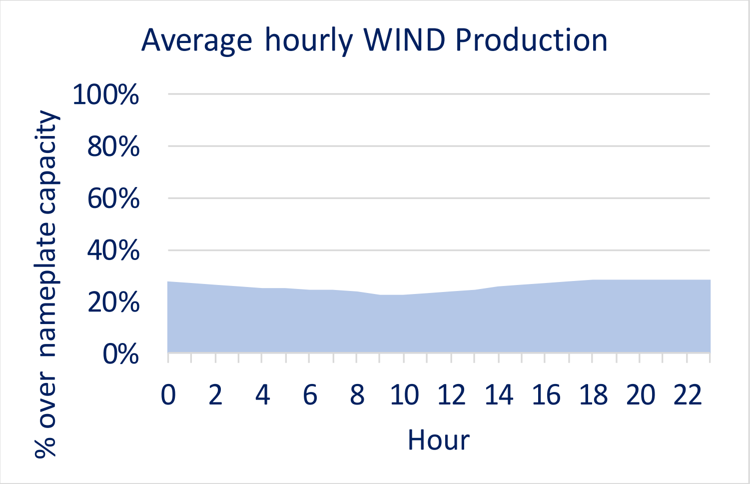
Right approach

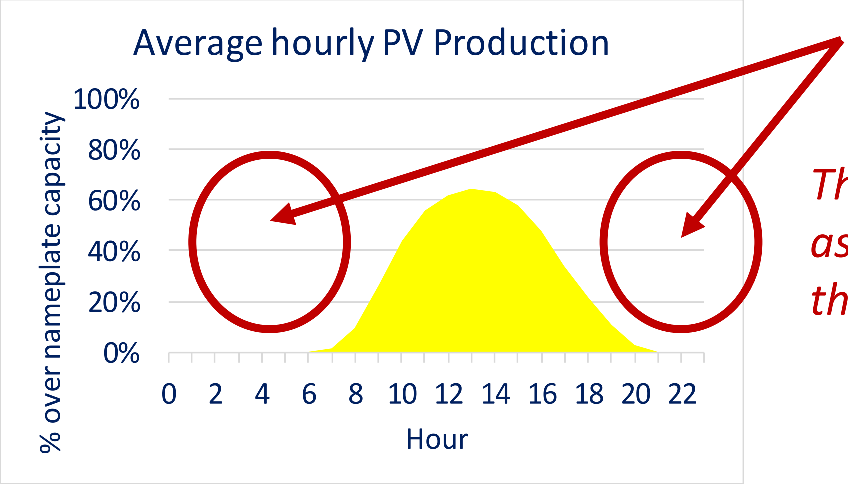


"Blind" Least Cost Expansion models do the other way around

No possible energy transition in the electrical sector without STE/CSP plants

Typical yearly generation profiles of the most deployed renewable technologies



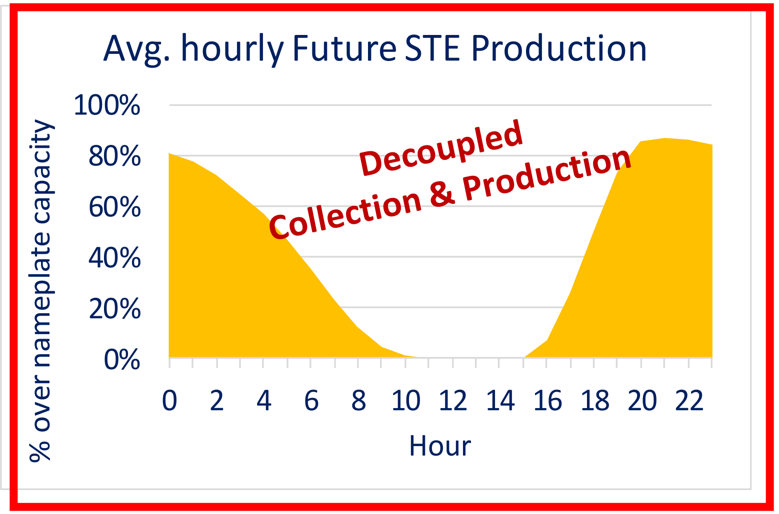


Average hourly production on a long historical series

Which technology could fill up these gaps?

There are no utility scale 12 h batteries as of today. The experts don't expect them on the next decade

What is the missing piece?



STE/CSP plants can provide synchronous and absolutely firm supply, with no deviations for the day ahead program from sunset till sun rise next day

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Another mix of electric generation is possible (and desirable) in Spain

Alternative proposal to the Least Cost Capacity Expansion approach

www.protermosolar.com

The Inductive Production Projection model

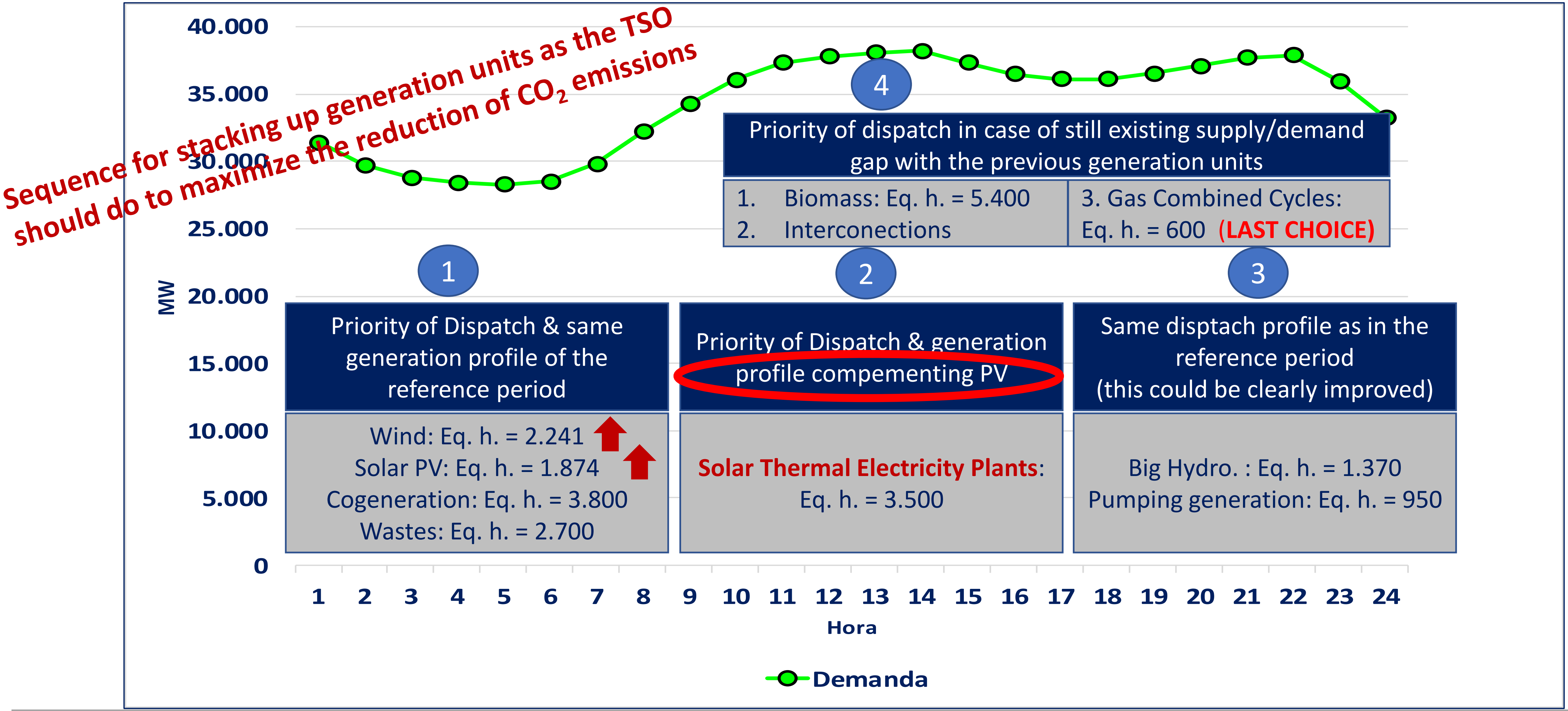
Demand forecast by 2030

Generation data of all technologies in previous years → Proposed fleet in 2030 * → How much backup is required? | What is the generation cost? | What is the emission level?

* The **fleet breakdown in another variable** that can be modified to optimized the answer to each specific goal

The true key point: The smart dispatch sequence

Dispatch sequence in the Protermosolar Transition Report



Current and future CSP dispatch profiles in Spain (and in sunny countries)

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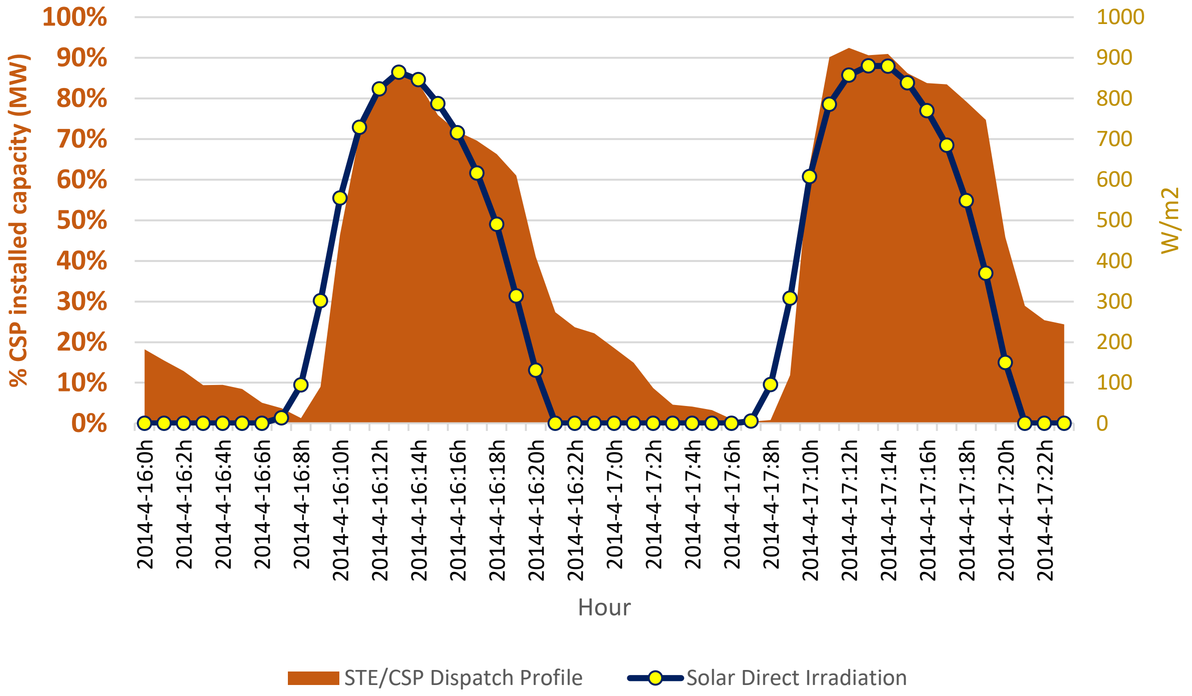
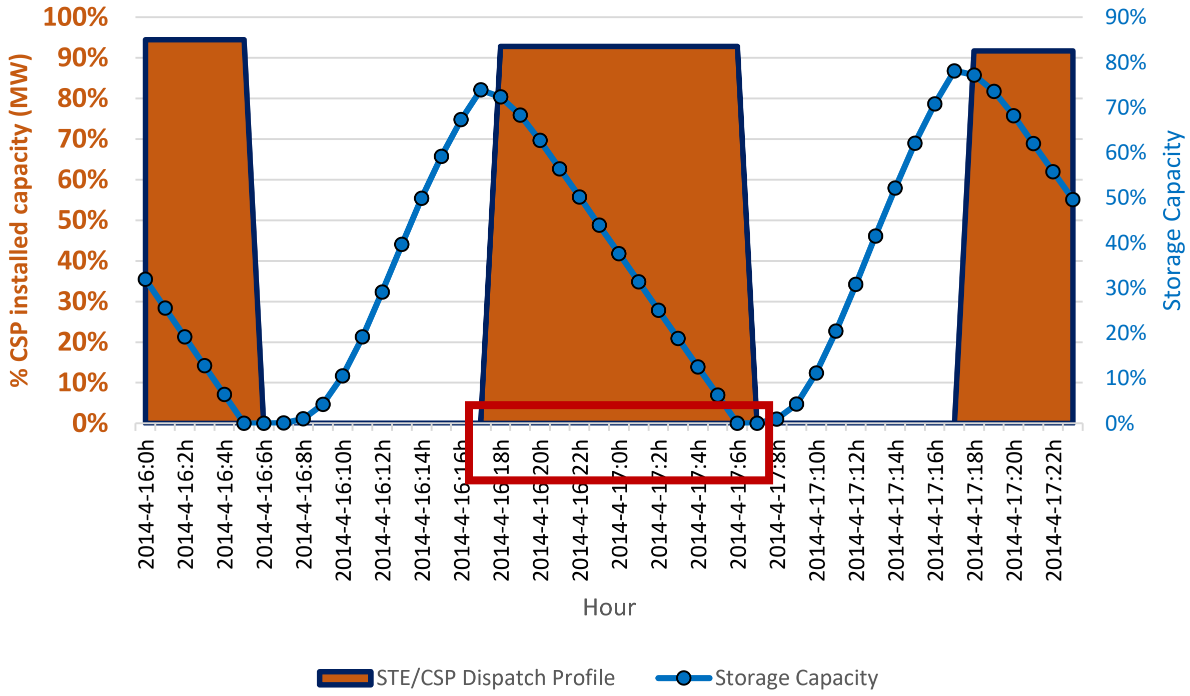
Current STE/CSP fleet dispatch profile - Spring example



Proposed STE/CSP fleet dispatch profile - Spring example



Current fleet consist of 1/3 plants with 7,5 hours of storage and 2/3 without storage

Future CSP plants would be provided with 10 – 12 hours of storage

The Scope

This report is based on projections of real generation data from past years

What if 2030 was like 2014 (2030'14), 2015 (2030'15), 2016(2030'16) or 2017(2030'17) regarding renewable resources, or the average of these (2030'M)?

Optimization criteria

- **Stacking generation units bottom up**
- **Considering the complementarity behaviour of renewable energies**
- **Dispatching STE plants in a complementary way to PV and taking into account the dispatch flexibility of biomass**

Additional degrees of freedom

- **Managing of hydro plants to reduce fossil backup needs**
- **Proactively demand management**
- **Interrupt ability contracts**
- **Further optimization of the renewable mix**

Reflections on the market model

- **The current marginal model will not be sustainable with the increasing penetration of renewables**
- **All new capacity must have fixed remuneration conditions for its regulatory life span**

The report:

Another mix of electric generation is possible (and desirable)

Alternative proposal to the Expert Commission report

Another mix of electric generation is possible (and desirable)

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The natural complementarity of renewables in Spain (Wind / Sun and Water) together with the use of solar thermal with storage from sunset would allow a 2030 scenario*:

- ✓ **Without coal plants**
- ✓ **Without nuclear power plants**
- ✓ **With less support of combined cycles than in the report of the ExpCom (Experts Committee)**
- ✓ **With 85.6% of renewable generation with very few curtailments (82% less than the discharges foreseen by the ExpCom)**
- ✓ **With very reduced emissions (half that provided by the ExpCom)**
- ✓ **Achieving a 34% penetration of renewable energy in the final energy demand**
- ✓ **Fulfilling EU objectives**
- ✓ **And less than 5 c€/kWh generation cost**

That means realizing a **true Energy Transition** with enormous additional benefits for the economy of the country

*Note: The results of this report do not correspond to theoretical simulations, but to the projection made from of generation time data in real years of the mix considered

Summary

	2017 Mix	Expert Committee base case Mix	Protermosolar Mix
Electric power demand	268,5 TWh	296 TWh	296 TWh
Total installed power of the Mix	104,5 GW	147 GW	130 GW
Total Renewable Power	51 GW	106 GW	106 GW
Installed Power Wind	23 GW	31 GW	33 GW
Installed Photovoltaic Power (PV)	4,7 GW	47,15 GW	25 GW
Installed Power Solar Thermal Electricity (STE/CSP)	2,3 GW	2,3 GW	20 GW
Installed Power Other Renewable	0,75 GW	2,55 GW	5 GW
Curtailments		4.600 GWh	830 GWh
Emissions	66.000 kton CO_2 *	12.593 kton CO_2	4.991 kton CO_2
Additional comments	Data from the REE report "The Spanish Electric System - Progress 2017"	It maintains the nuclear and gas fleet and does not reach the EU's objectives. **Can this be called transition?**	Without coal, without nuclear, with less gas support and fulfilling EU objectives **This is an Energy Transition**

* REE takes into account emissions from Other Renewables and from Cogeneration. Both the CoE and Protermosolar do not take into account the emissions of these two sources

Installed power. Comparison Scenarios Commission of Experts vs Protermosolar

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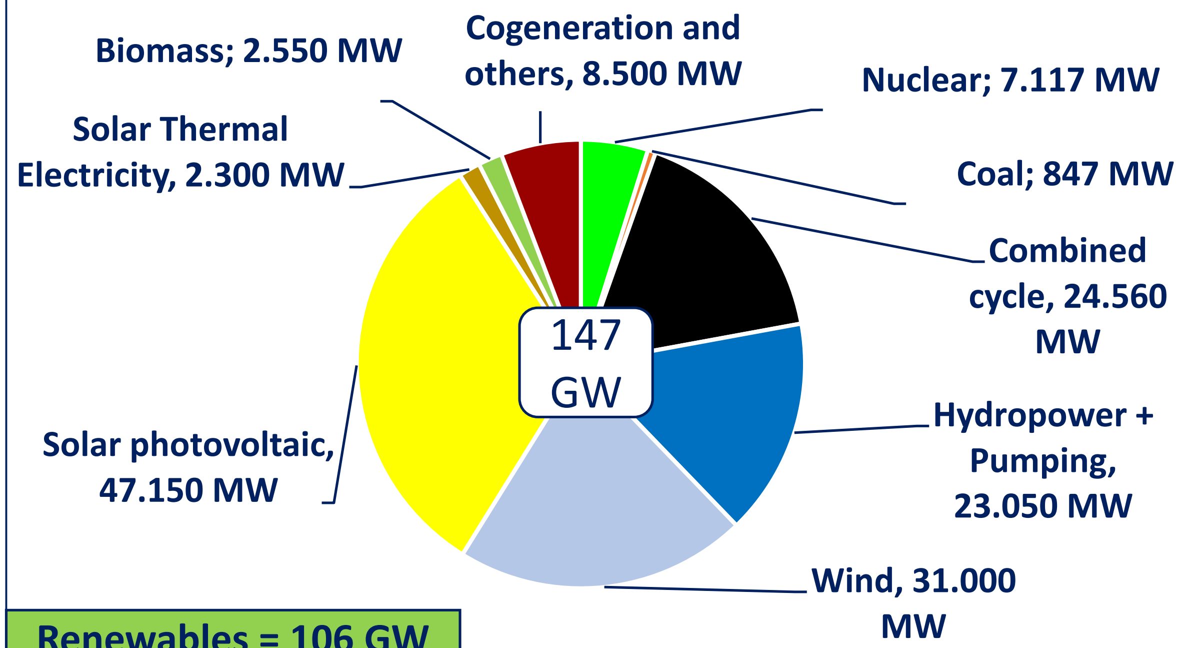
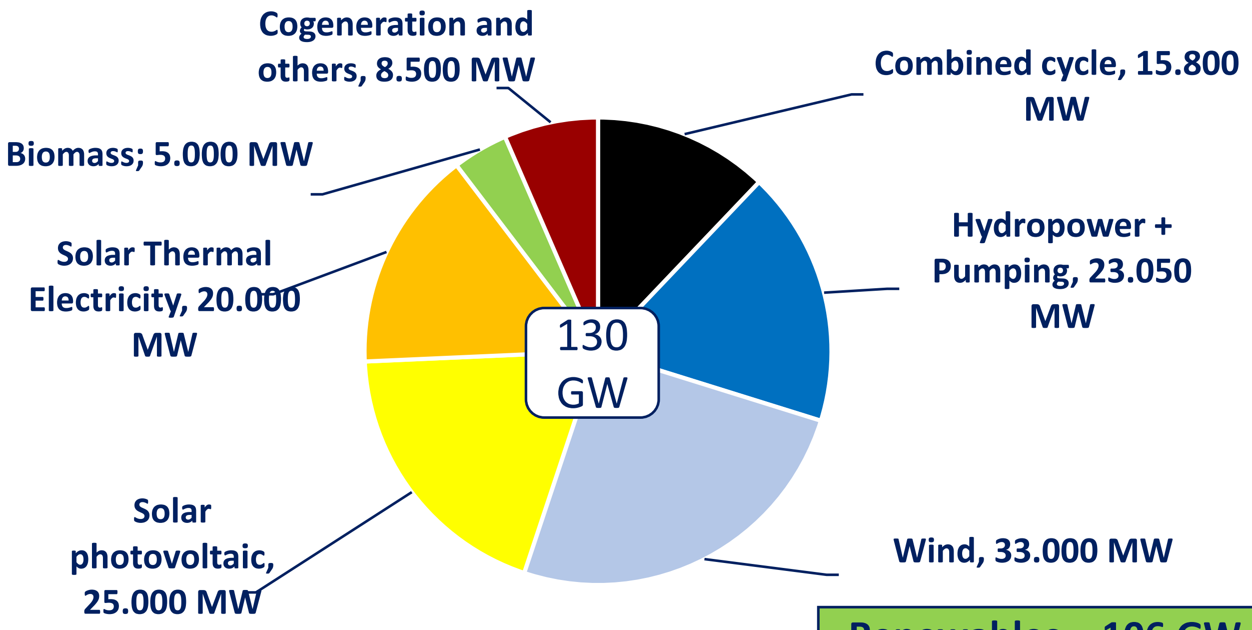
MIX Commission of Experts



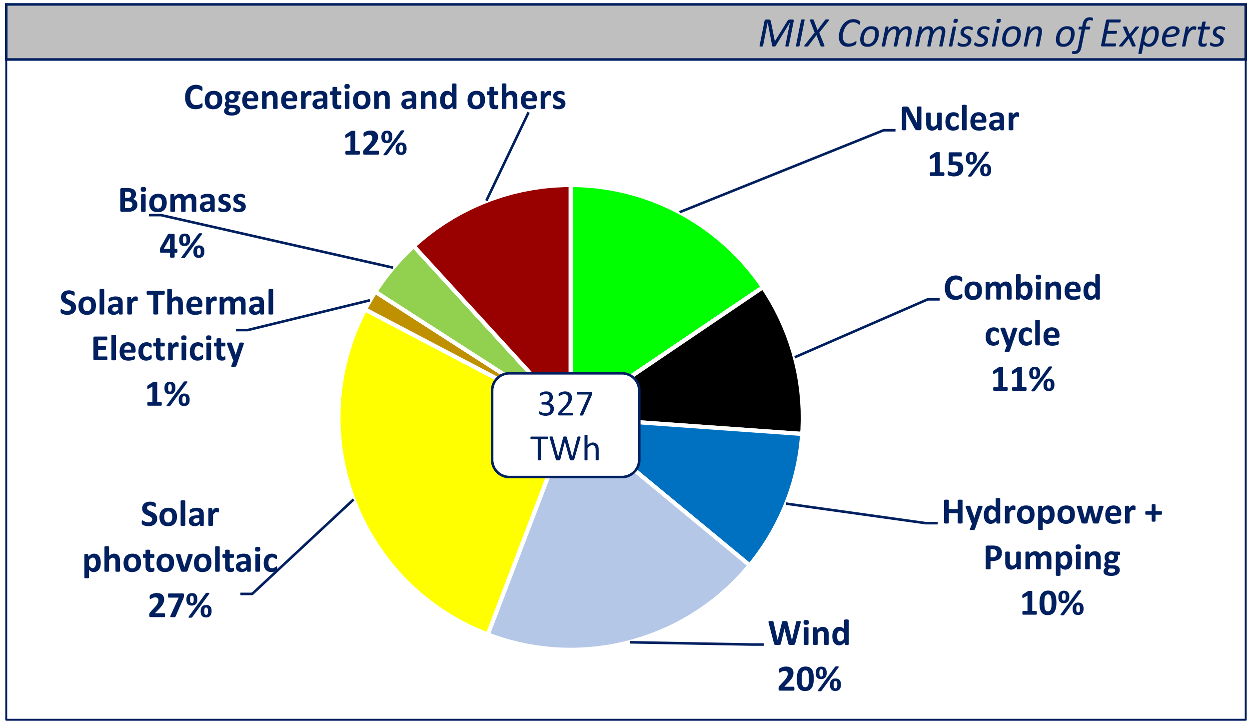
Renewables = 106 GW

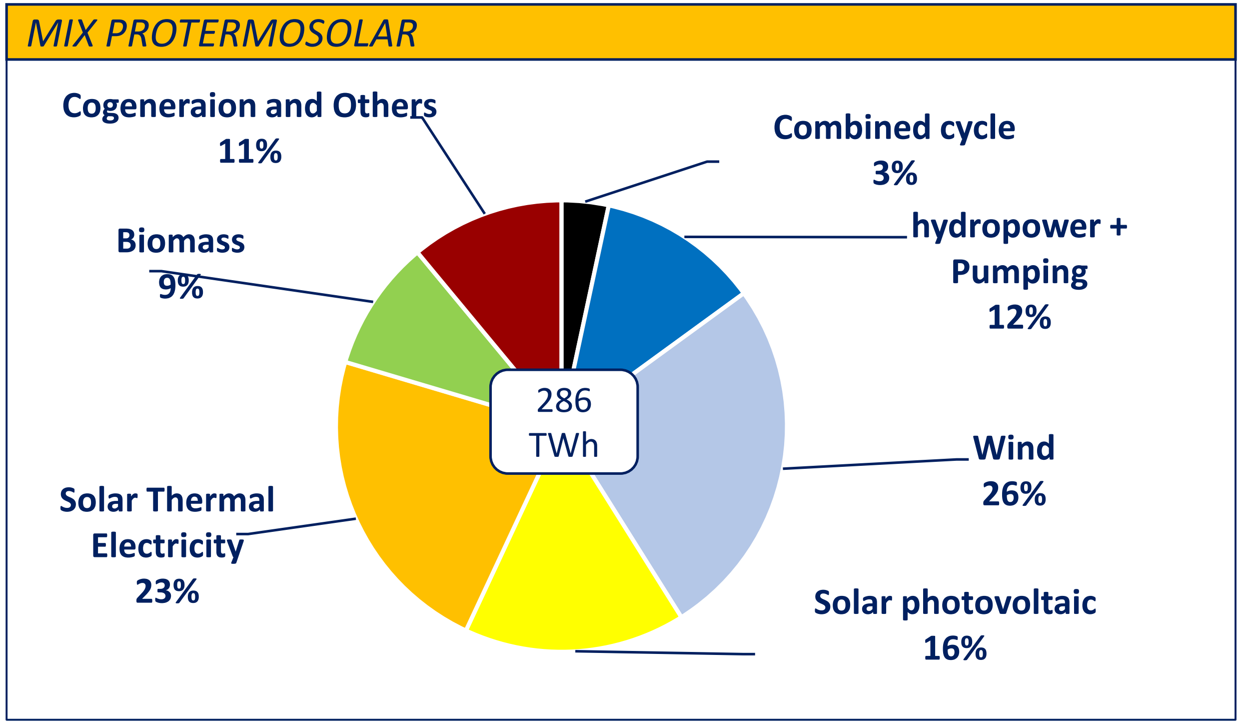
MIX PROTERMOSOLAR



Renewables = 106 GW

Generation Mix. Comparative Scenarios Committee of Experts vs Protermosolar



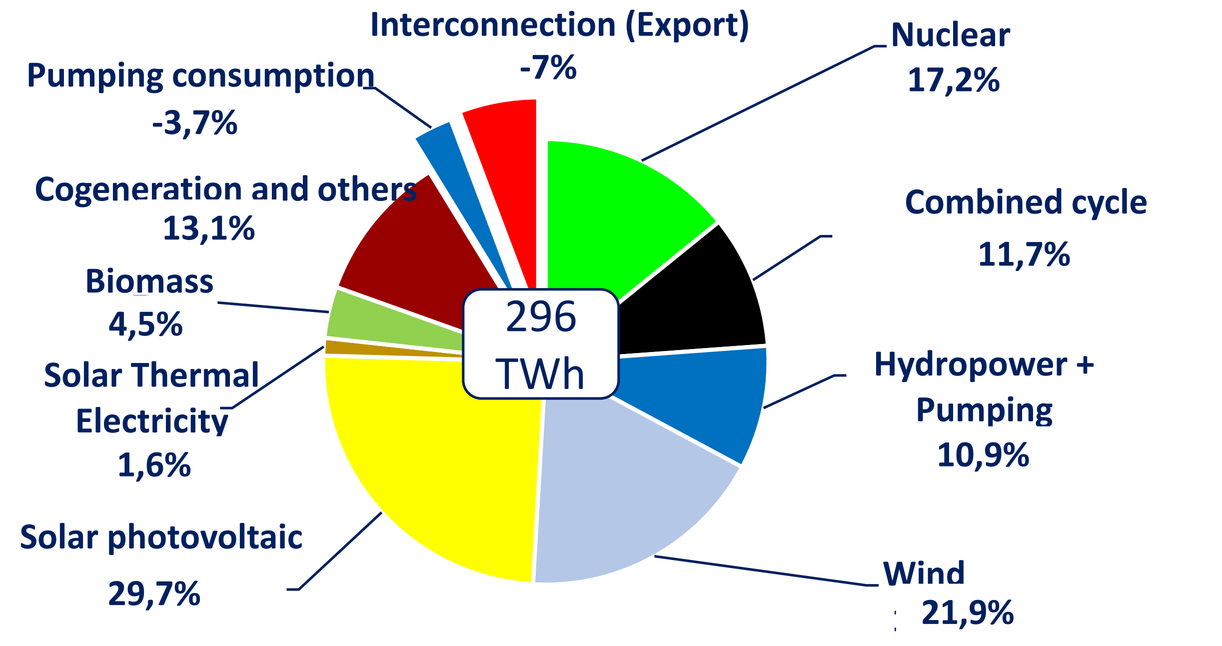


In the proposed mix by Protermosolar:

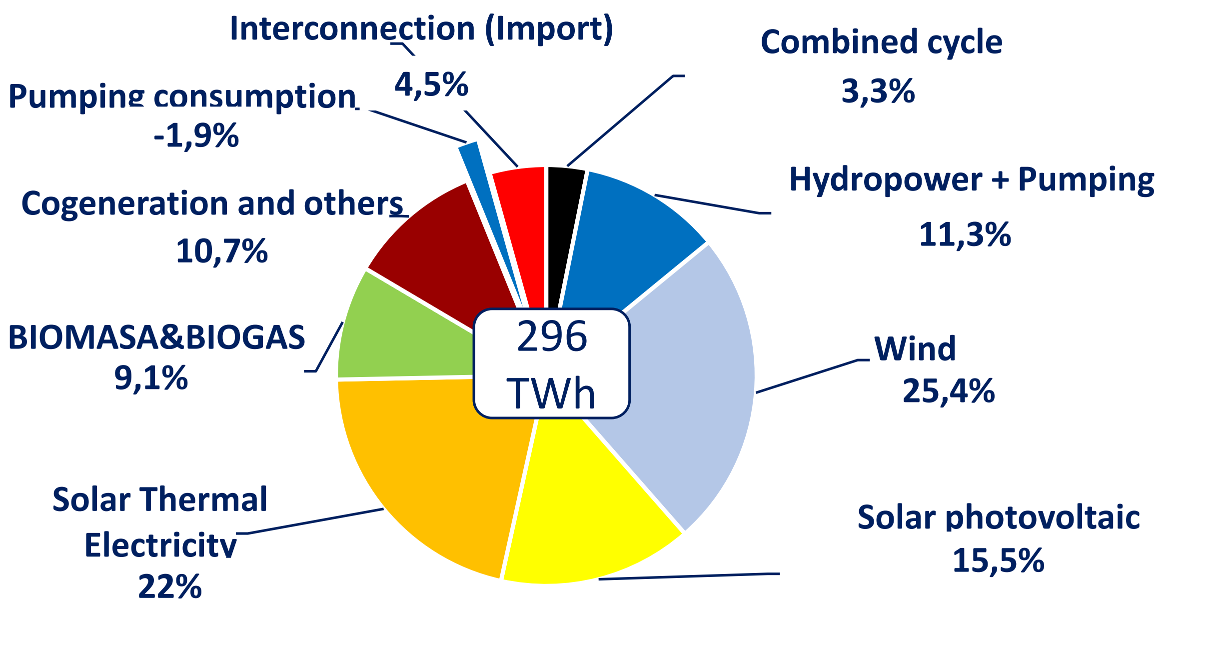
- ✓ 85.6% of electricity generation comes from renewable sources compared to 62.1% of the ExpCom
- ✓ Combined cycles would only contribute 3.4% to the generation mix
- ✓ Carbon and nuclear would phase out of the generation system
- ✓ The balance of interconnections would be a 4.5% import, since it would be more economical to import electricity than to have combined cycles working at a very high cost. The mix proposed by the ExpCom generates much more energy than curtailed or exported at the balance price.

Demand Mix. Comparative Scenarios Commission of Experts vs Protermosolar

MIX Commission of Experts



MIX PROTERMOSOLAR



- In the mix proposed by Protermosolar, the demand coverage for renewable sources is 83%, compared to 69% of the ExpCom
- Both generation mix correspond to a demand of 296 TWh. (The hydraulicity of the mix of Protermosolar (hydropower + pumping) shown in this graph takes into account the average of the last 4 years = 33.5 TWh, a value very close to the 32 TWh of the scenario of average hydraulicity taken into account in the base case by the ExpCom
- The saturation of interconnection considered for 2030 in the scenario proposed by Protermosolar is 7 GW, both import and export, which can be considered as more conservative compared to the sum of capacity with France, Portugal and Morocco taken by ExpCom

Main indicators of the generation mix proposed by Protermosolar

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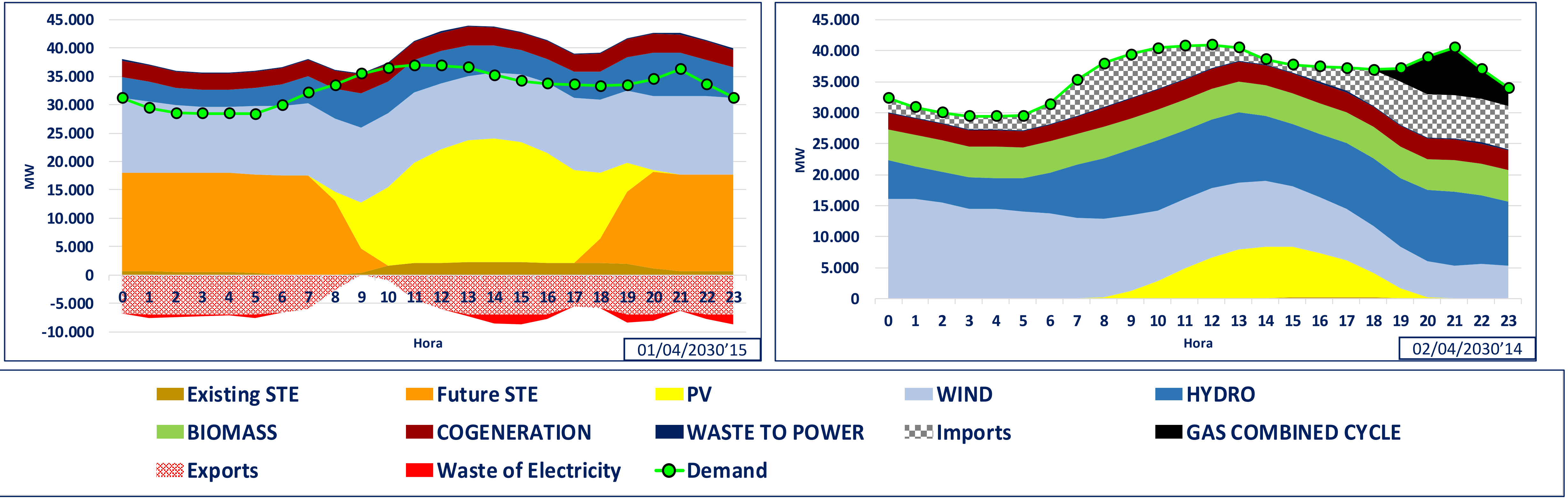
		Mix 2030 ' xx = extrapolation to 2030 of the year XX				
	CdE values	2030'M	2030'17	2030'16	2030'15	2030'14
Backup Power Cycles (GW)	24,6	15,8	15,8	15,7	15,7	14,2
Number of equivalent hours in combined cycles	1.413	615	598	734	701	478
Generation of combined Cycles (GWh)	34.702	9.700	9.430	11.565	11.015	6.792
% Renewable/Generation	62%	85,6%	84,5%	85,0%	85,3%	87,6%
Generation cost(€/MWh)	52	48,8	49,97	48,67	49,16	47,45
Kton CO_2 Mix	12.593	4.990,9	4.890	5.639	5.513	3.921
Accumulated curtailments (GWh)	-4.616	-833,3	-289	-1.488	-723	-834

In the mix proposed by Protermosolar (2030'M):

- ✓ It takes 8.8 GW less than backup power
- ✓ The generation with combined cycles is 72% lower than that proposed by the ExpCom
- ✓ The RES participation in demand coverage is 85.6%
- ✓ The cost of the generation mix would be less than the ExpCom. Average cost hypothesis of operating facilities in 2030 (c €/kWh): wind = 4; PV = 3.5; Solar thermal = 5.5; Biomass = 6; Cycles = 7.4, cogeneration = 7; Hydraulic = 2; Turb. pumping = 2.5; import = 6; Export = 4. The incentives to the renewables already installed would be financed independently.
- ✓ CO2 emissions would fall by 60%
- ✓ The curtailments would be 82% lower than those estimated by the CdE (which, in addition, we believe have been underestimated)

Comparison of days with/without sun in spring

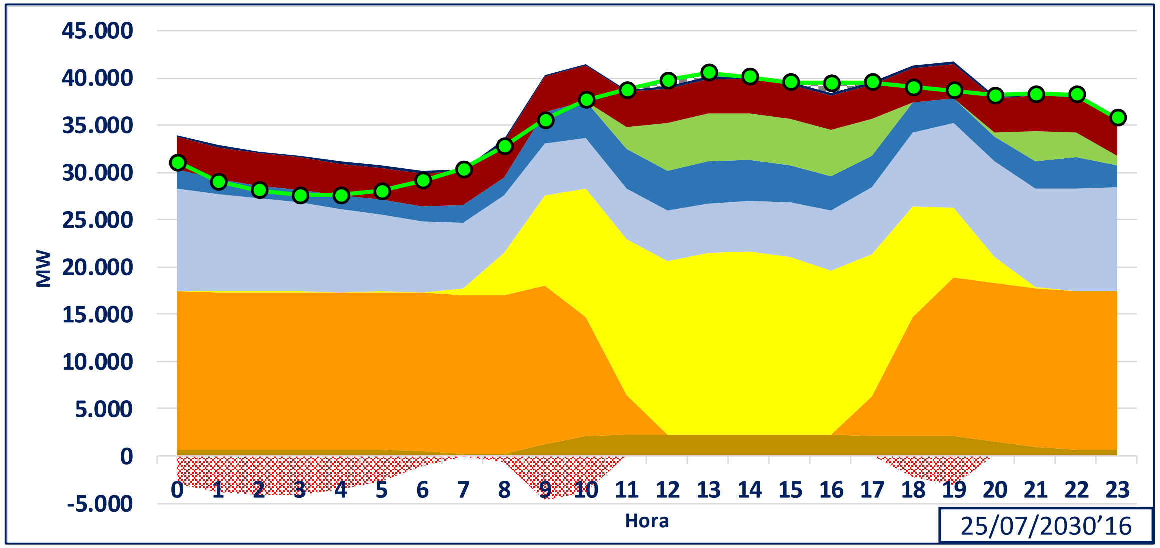
Examples of actual days projected at 2030

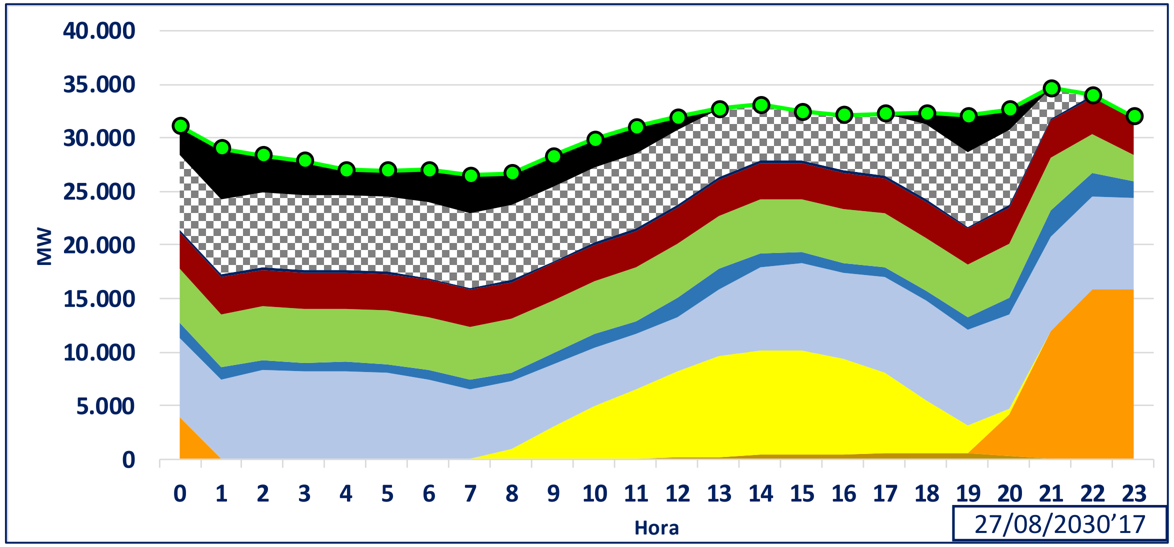


- In this example of a sunny day in spring, the daily profile would be fully export oriented and with some curtailments given the abundance of renewable resource. Biomass would not operate on that day. Taking the real generation of hydropower into account leads to this export situation, but a future, optimised management of hydropower would have kept this resource since it can reduce the need for backup in other future days and eliminate curtailments.
- On a spring day with a low solar resource, but with a high wind resource, the demand would be covered thanks to the generation of biomass, cogeneration and imports. The need for combined cycle generation is reduced to the late-night peak.

Comparison of days with/without sun in summer

Examples of actual days projected at 2030



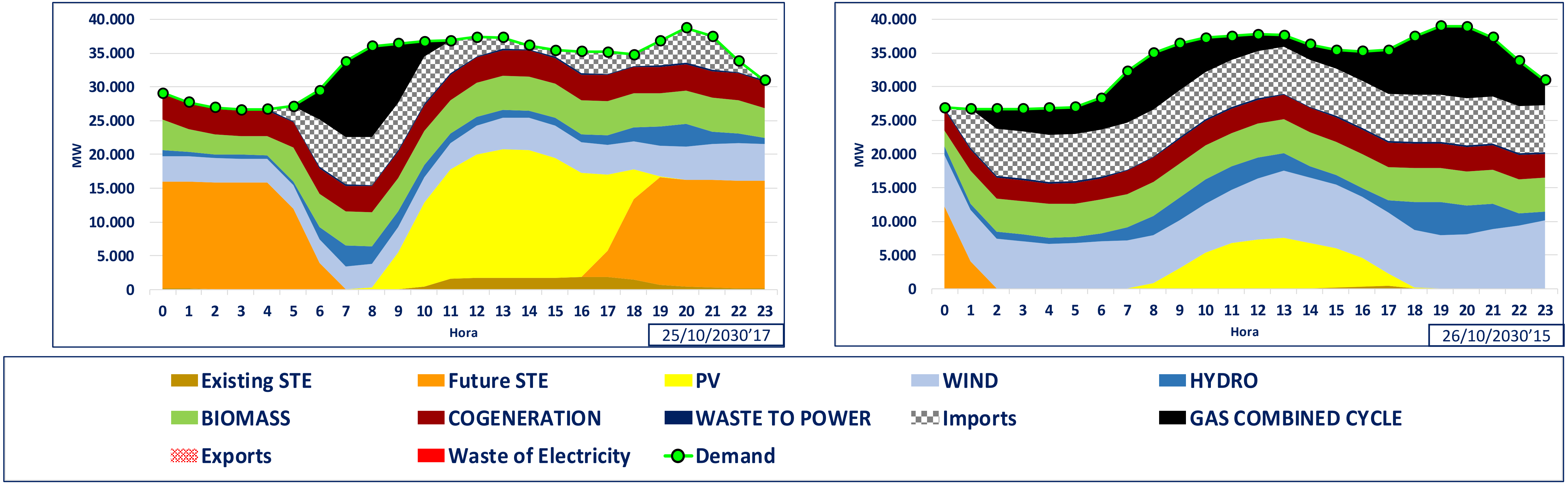


Existing STE | Future STE | PV | WIND | HYDRO
BIOMASS | COGENERATION | WASTE TO POWER | Imports | GAS COMBINED CYCLE
Exports | Waste of Electricity | Demand

- On a sunny summer day, solar thermal and photovoltaic plant cover a large part of the demand. Given the abundance of the solar resource and the overlap that would necessarily be produced during some hours between PV and solar thermal, there would be opportunities for exports. Also in this case, a better management of hydropower retaining the resource would reduce this export need as well as a support in future days. Biomass would have to operate in central hours of the day to adjust the generation to demand. The combined cycles would not be necessary on that day.
- On days of low solar resource associated with low wind resource, there would be a need for biomass to operate at nominal load practically all the day and to take advantage of imports. On that day it would be necessary to operate a part of the backup for combined cycles during a good part of the day. In this example there was no good solar resource the day before (a quite seldom situation during summer with two days in a row without solar thermal generation) without possible contribution of the solar thermal plants during the night.

Comparison of days with/without sun in autumn

Examples of actual days projected at 2030



- On a sunny autumn day, the solar thermal works until late into the following night, although the decrease of solar thermal generation coincides with the absence of the photovoltaic, which implies that the combined cycles are required to cover the demand from 5:00 to 10:00 in the morning.
- On a autumn day with low solar resource, the biomass operates at nominal load all day, imports saturate throughout practically 24h and finally the combined cycles work to cover the demand; their contribution is higher when photovoltaic plants works at very low load does not contribute. Neither the wind nor the hydropower have been able to operate at high load due to the scarcity of resources.

Comparison of days with/without sun in winter

Examples of actual days projected at 2030

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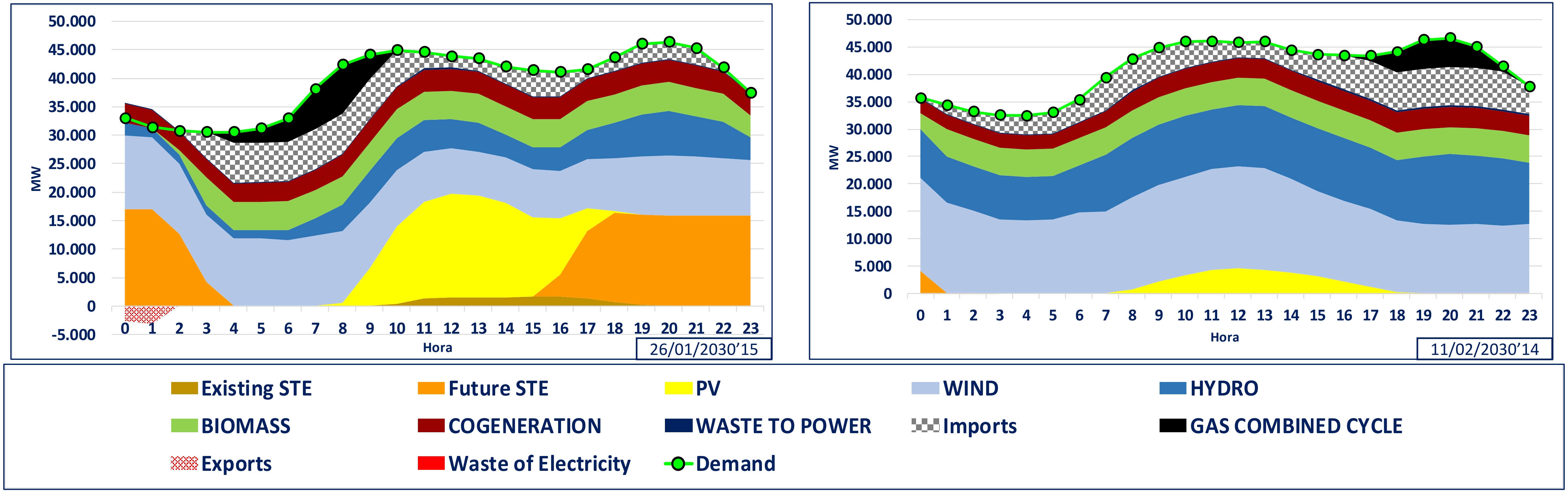
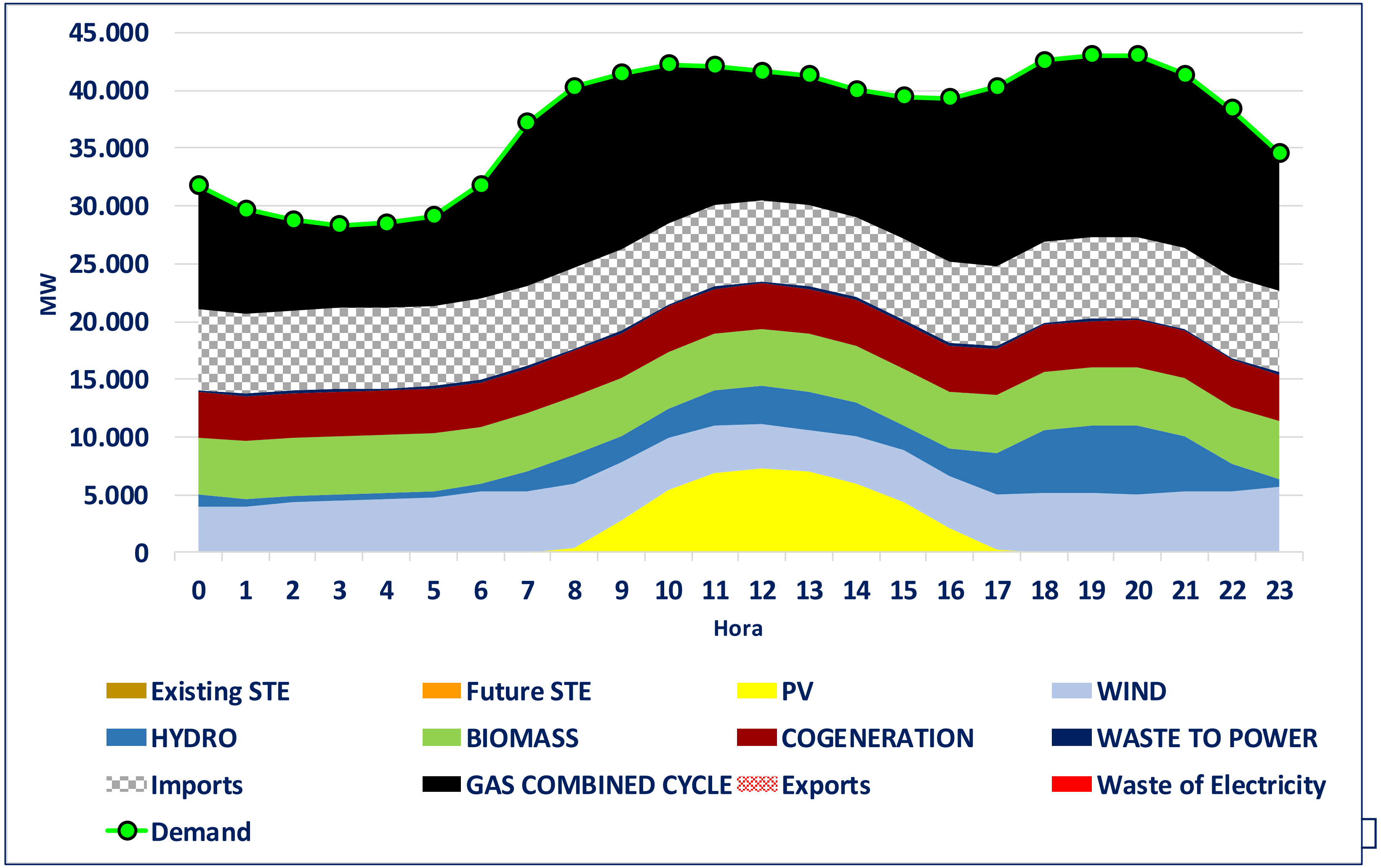


- On sunny days, the solar thermal and photovoltaic complement each other in such a way that on a sunny day of winter they could act as base load from 10 a.m. until 1 pm. At night, in absence of photovoltaic generation and with empty tanks of the solar thermal plants, a high import would be necessary. The cycles would enter to cover the peak of the morning and from this moment, the biomass would enter at nominal load and the import would regulate its load to adapt to the demand not covered.
- On the sunny days of winter, the greatest presence of wind and hydraulic resources, associated with periods of low pressures, would cover much of the demand. Biomass, in the absence of sun, would operate at nominal load, thus reducing the need for combined cycles, which would, however, be necessary in the peak of the afternoon.

System response on the worst day of the year

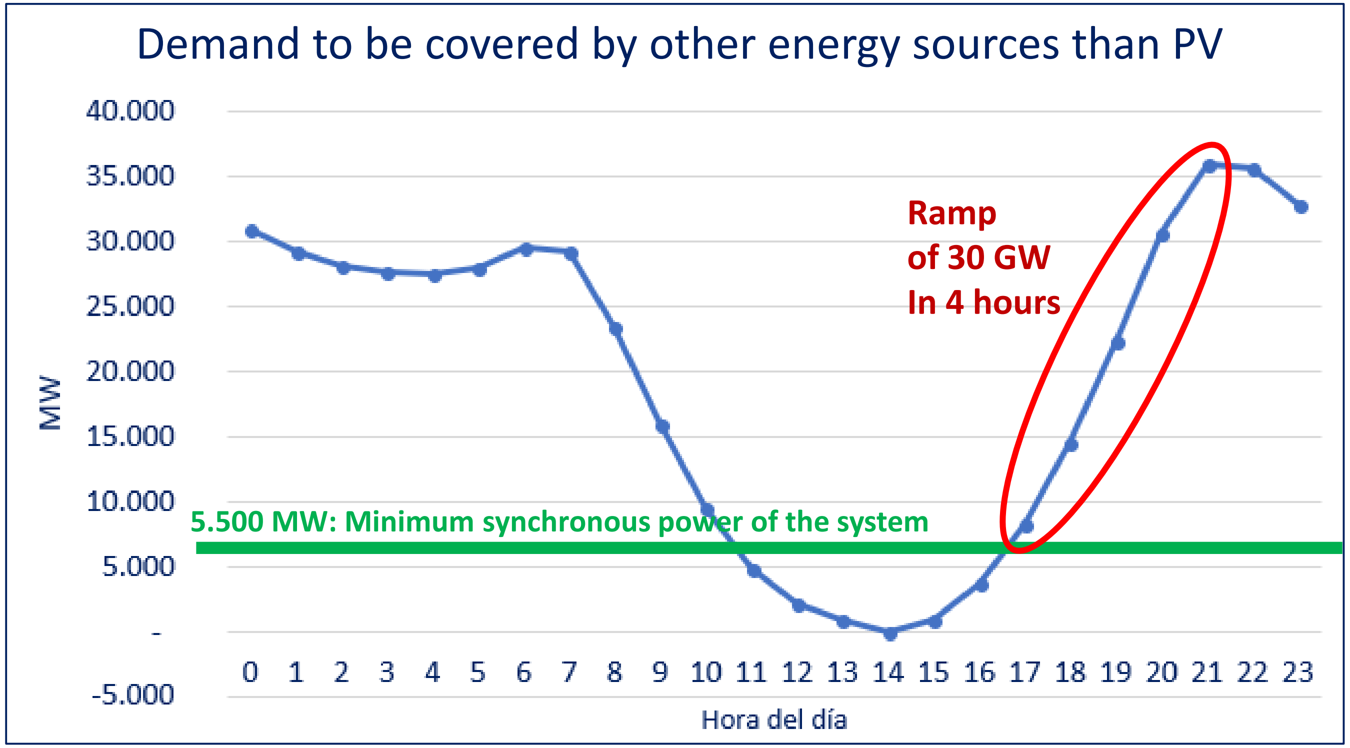
The most unfavourable day of the 4 years analyzed is the equivalent of November 28, 2017 projected into 203. The solar resource was very low, so less that the solar thermal plants could not collect any energy during the day, neither the photovoltaic could hardly generate. There was little wind, and scarce hydraulic resource. For these reasons biomass operates at full load all the day, imports saturating interconnections and combined cycles work all day.

The peak of the afternoon, with the hydropower generating as in 2017 would result in a peak for combined cycles of 19.8 GW, although, a smarter management of the hydraulic resource of that day would allow to lower that peak to 15.8 GW, the peak hour highest of the 4 years



Technical economic problems derived from the mix of the promoted by the Experts Committee – A technical and financial "no-go"

Example of Sunny day Tuesday, June 7, 2017 projected to 2030:



A non-viable technical and financial approach

- Intermittent technologies lose a substantial part of their value for the system as their penetration increases. So eventually the corresponding investments will come to a hold and funding would become anyway extremely challenging.
- The curtailments in case of 80 GW of intermittent generation would be very high (higher than those considered by the ExpCom)
- There would be no backup capacity for the 47 GW of PV installed on sunny days at sunset time (duck curve)
- Much fossil/nuclear backup capacity would still be needed – which does not appear to be the best way forward towards a decarbonised and waste-free generation!

Verification of the condition of synchronous generation level (in the 35.060 h of the 4 years analysed)

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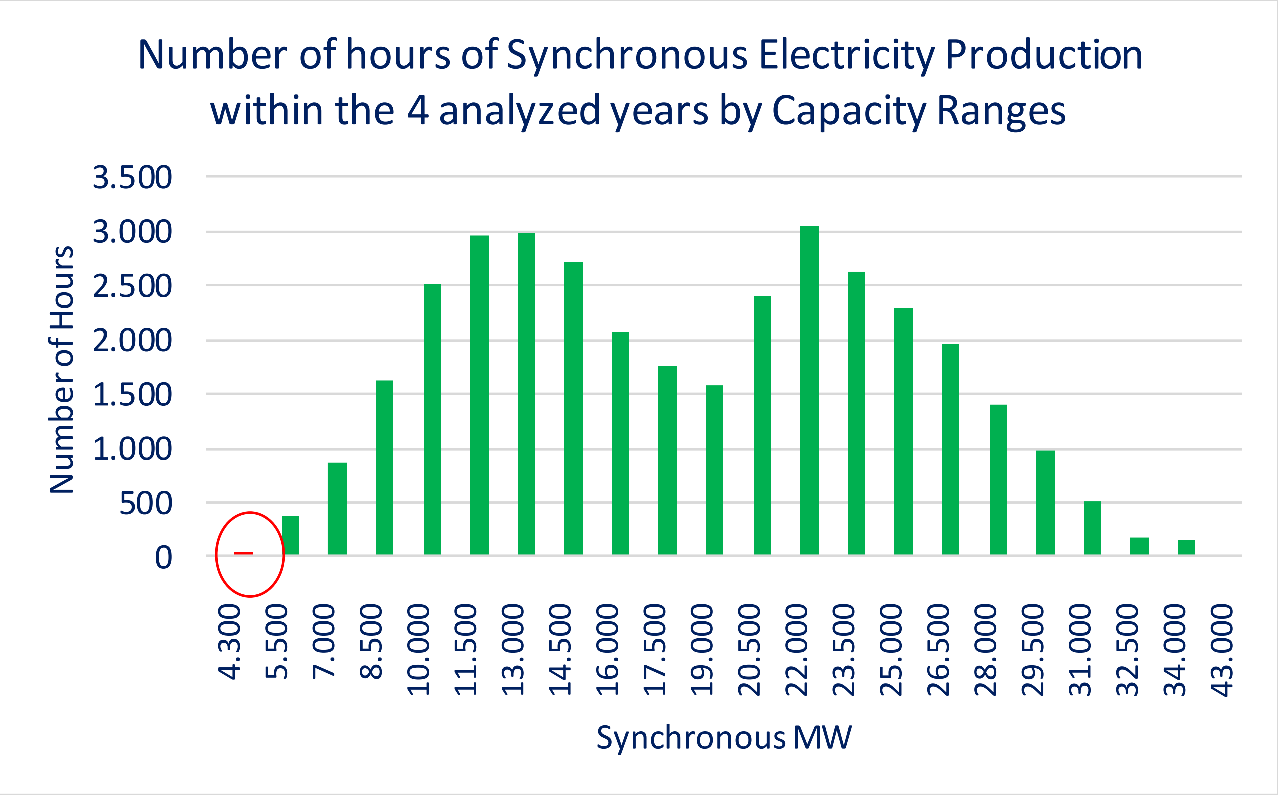
The solar thermal power plants, thanks to their synchronous generator with great mechanical inertia, contribute to:

- Primary Reserve
- Secondary and tertiary bands
- Reactive power
- Not increasing the need for spinning reserve
- Contribution to short circuit power

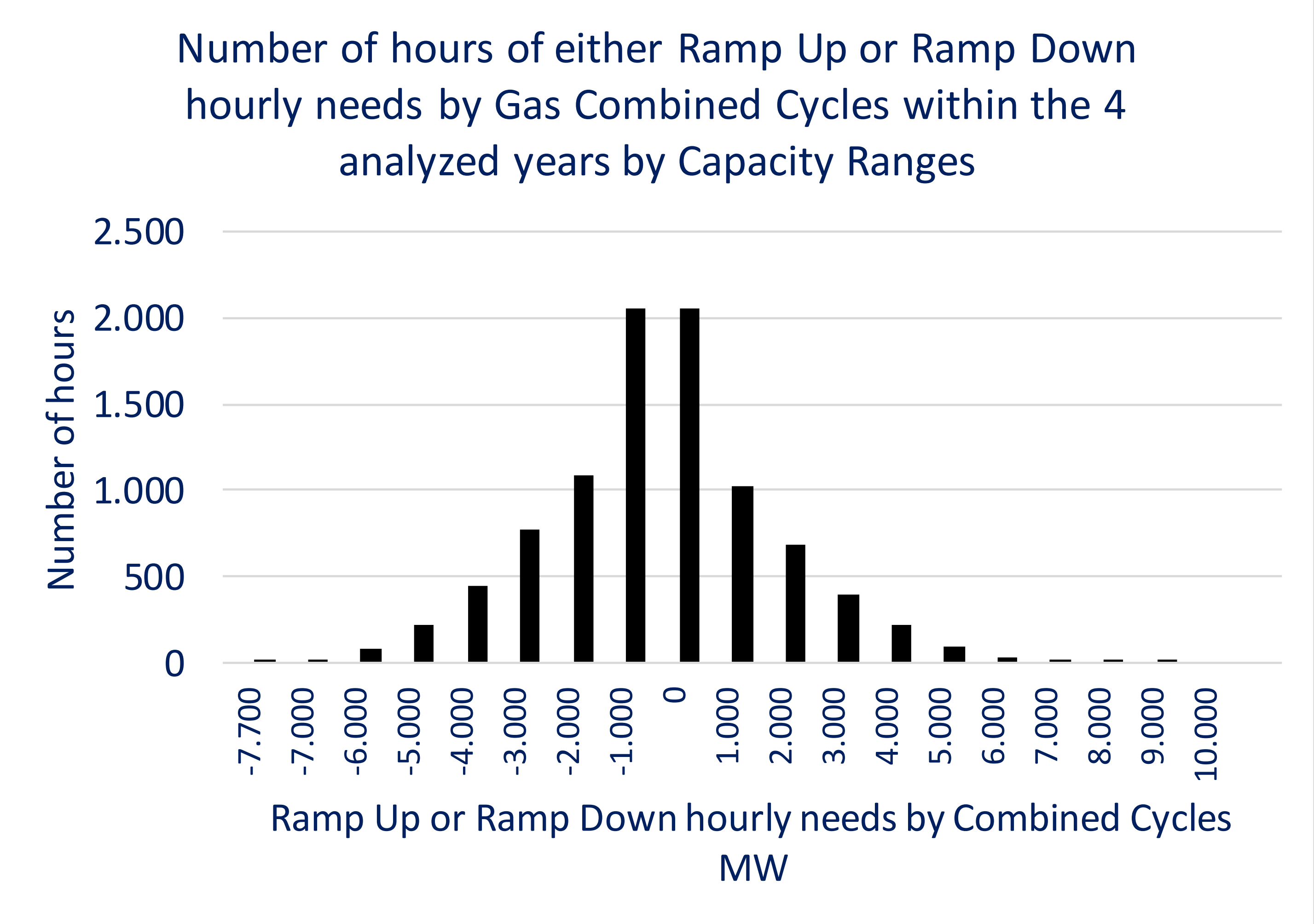


✓ Minimum connected synchronous power demanded by REE is 5500 MW, which nearly fully complies (except in 51 hours) with the mix proposed by Protermosolar

✓ If that minimum rises to double (11000 MW), it would be necessary to incorporate 8.3 TWh of cycles in the 4 years, which would give an average of 2.1 TWh/year, which would represent a 0.6% of the demand

✓ In no case it would be necessary to increase the proposed total backup power of 16 GW

Backup needs with combined cycles



Hourly Ramp needs by Gas Combined Cycles	% of hours over the 4 years analyzed 20 (14-17) '
< 1.000 MW	44,7%
<2.000 MW	67,6%
<5.000 MW	97,3%
< -5.000 & > 5.000	2,7%

Solution for upward-ramps > 5000 MW:
Add 46,000 MWh/year of cycles/year.(Δ 0.5%)

Solution for downward-ramps :
Export or discharges (0.004% demand)

No unsolvable ramps appear in the time interval analysis. A “10-min timeframe" analysis would even soften the ramps.

Management Needs of Biomass Plants

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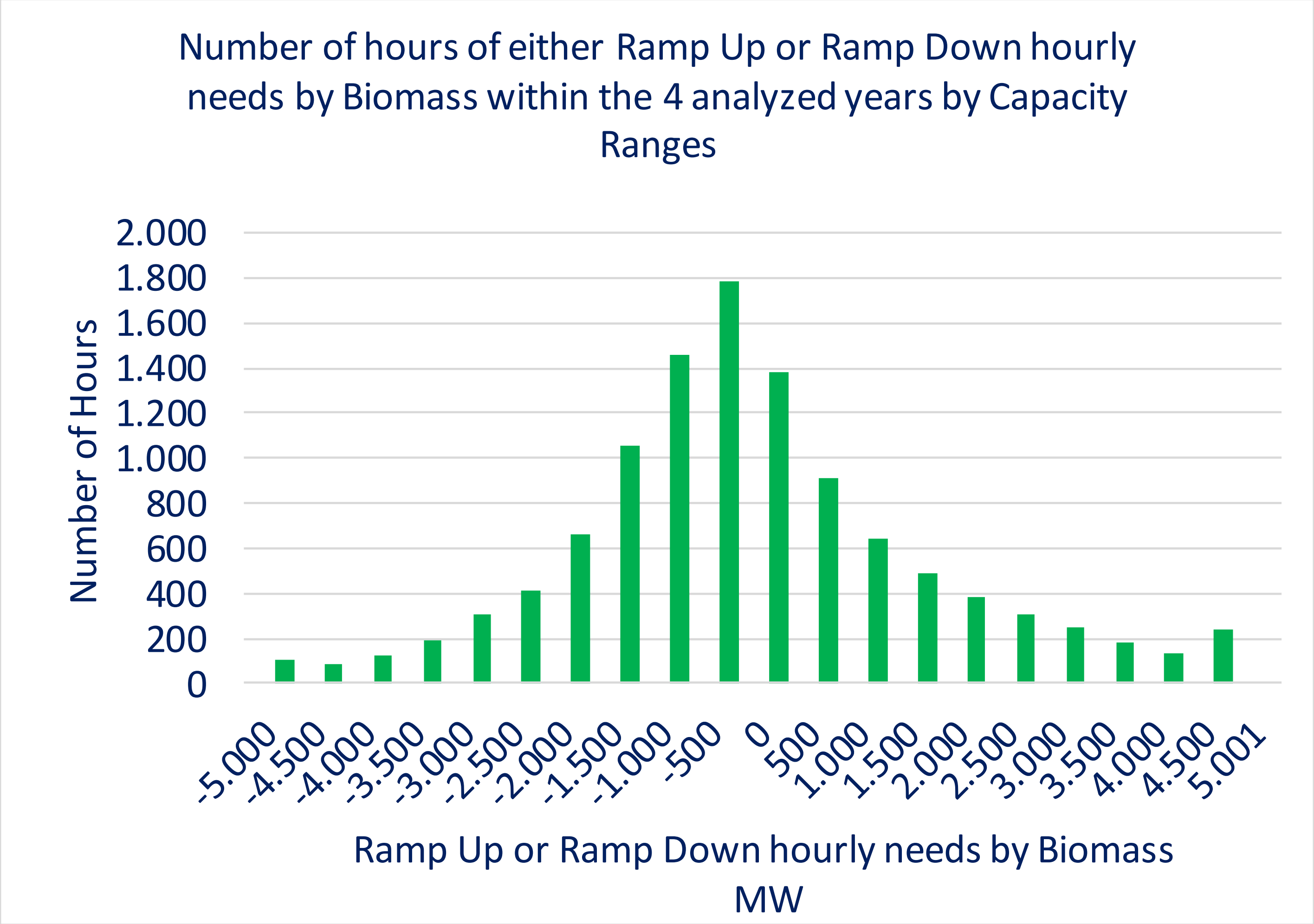


Hourly Ramp needs by Biomass	% of hours over the 4 years analysed 20(14-17)’
< 500 MW	28,5%
< 2.000 MW	75,5%
≤ 5.000 MW	100%

Biomass plants can withstand ramps of 100% of their nominal power (5,000 MW) within 1h. This means the ramps identified would not be a technical problem

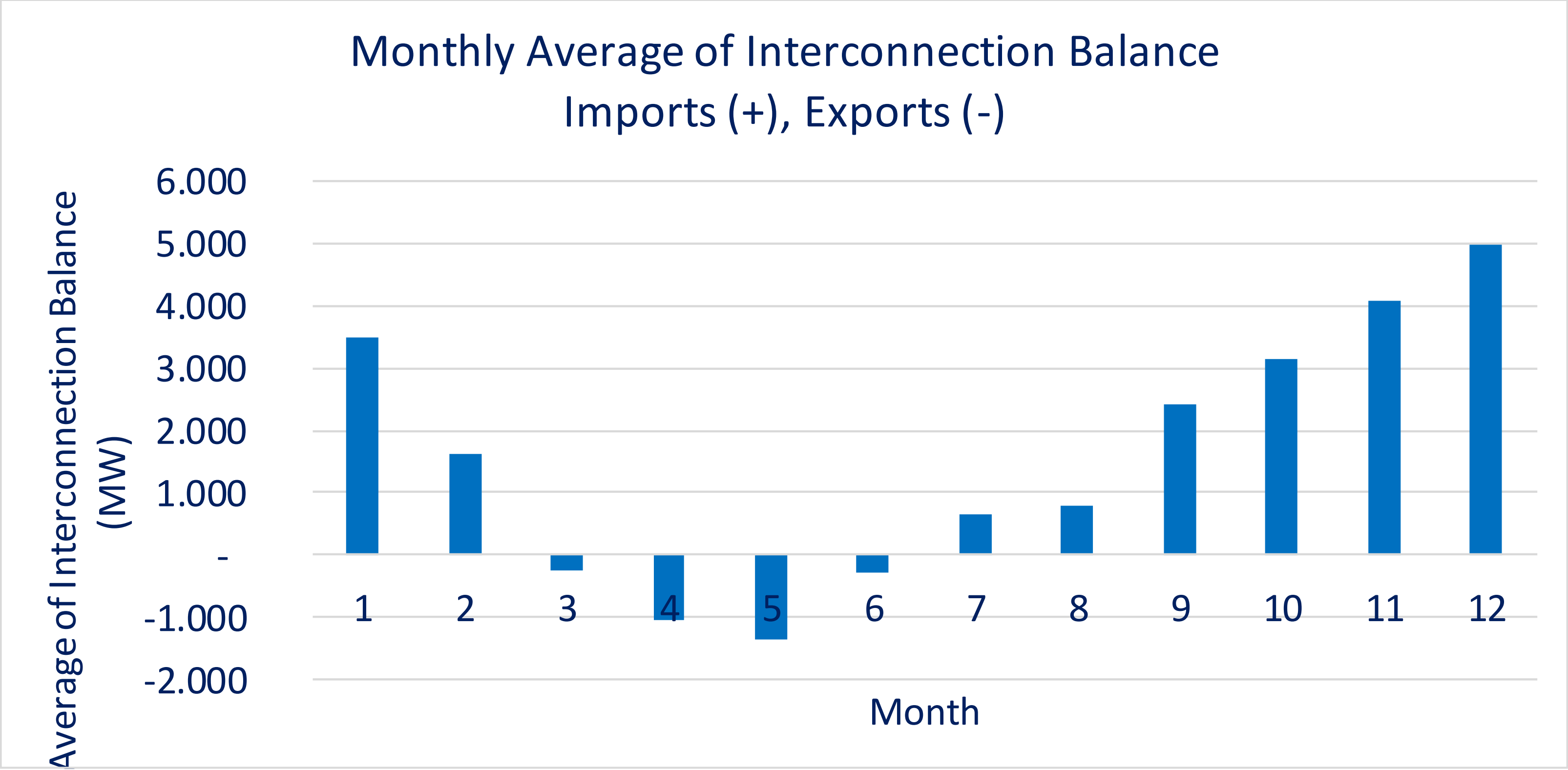
No unsolvable ramps appear in the time interval analysis. A “10-min timeframe" analysis would even soften the ramps.

Exchanges through interconnections

The interconnection capacity considered in the study (7,000 MW) would result in an import net 4.5% over the demand.
Interconnections would be saturated (% of hours):

Import:
- Protermosolar = 23,2 %
- CdE: ES-FR = 8,9 % / ES – PT = 0%

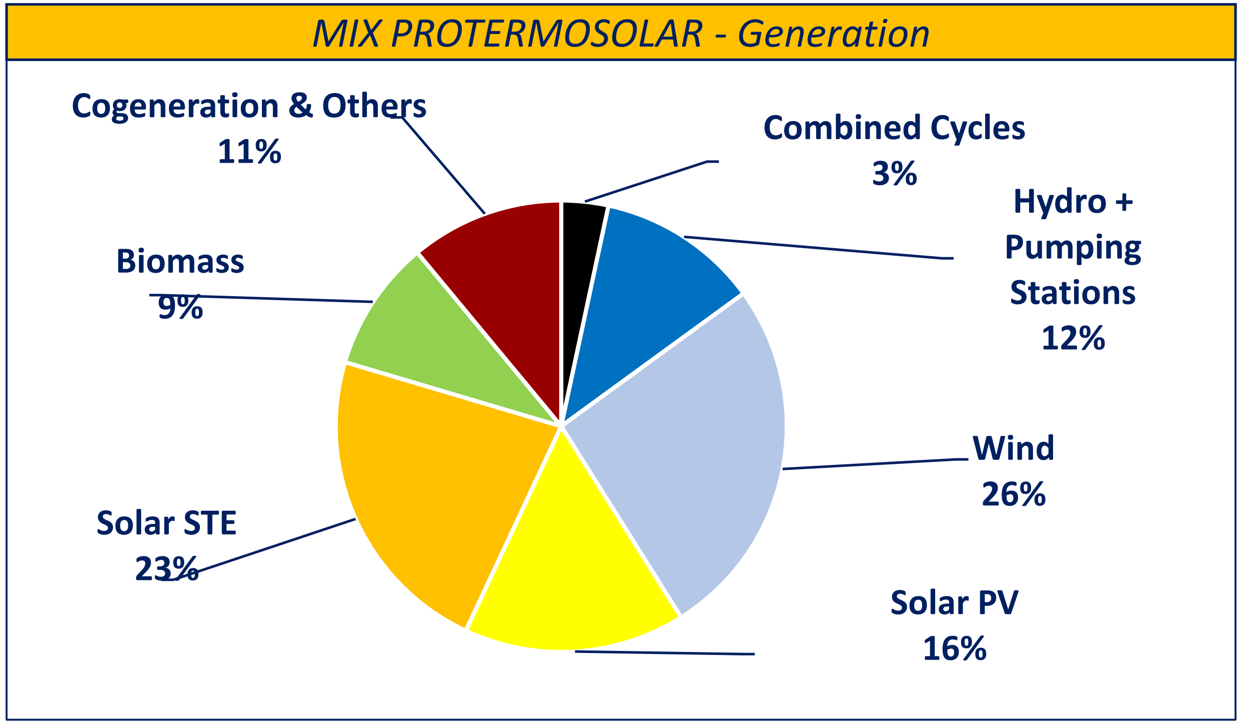
Export:
- Protermosolar = 4,4 %
- CdE: ES-FR = 33,4% / ES-PT = 4%



Spain would be a country with neutral balance from February to August and an importing country from September to January.

Costs of the New Generation Mix

The renewable park would be built over the next decade. A reasonable estimate of the average cost to which the generation of that park would result from successive technology-specific auctions would be:



Energy Source	Generation Costs in 2030 (€/MWh)
Combined cycle(50€/ton CO_2)	74
Hydropower	20
Pumping	25
Wind	40
Solar photovoltaic	35
Solar Thermal Electricity	55
Biomass & Biogas	60
Cogeneration	70
Waste to Power	80
Import	60
Export	40
Total Generation Costs	48.8

To the current renewable park would be endowed with remuneration stability and the incentives would continue to being paid independently to the generation

Sensitivity Analysis of total Generation Cost in 2030

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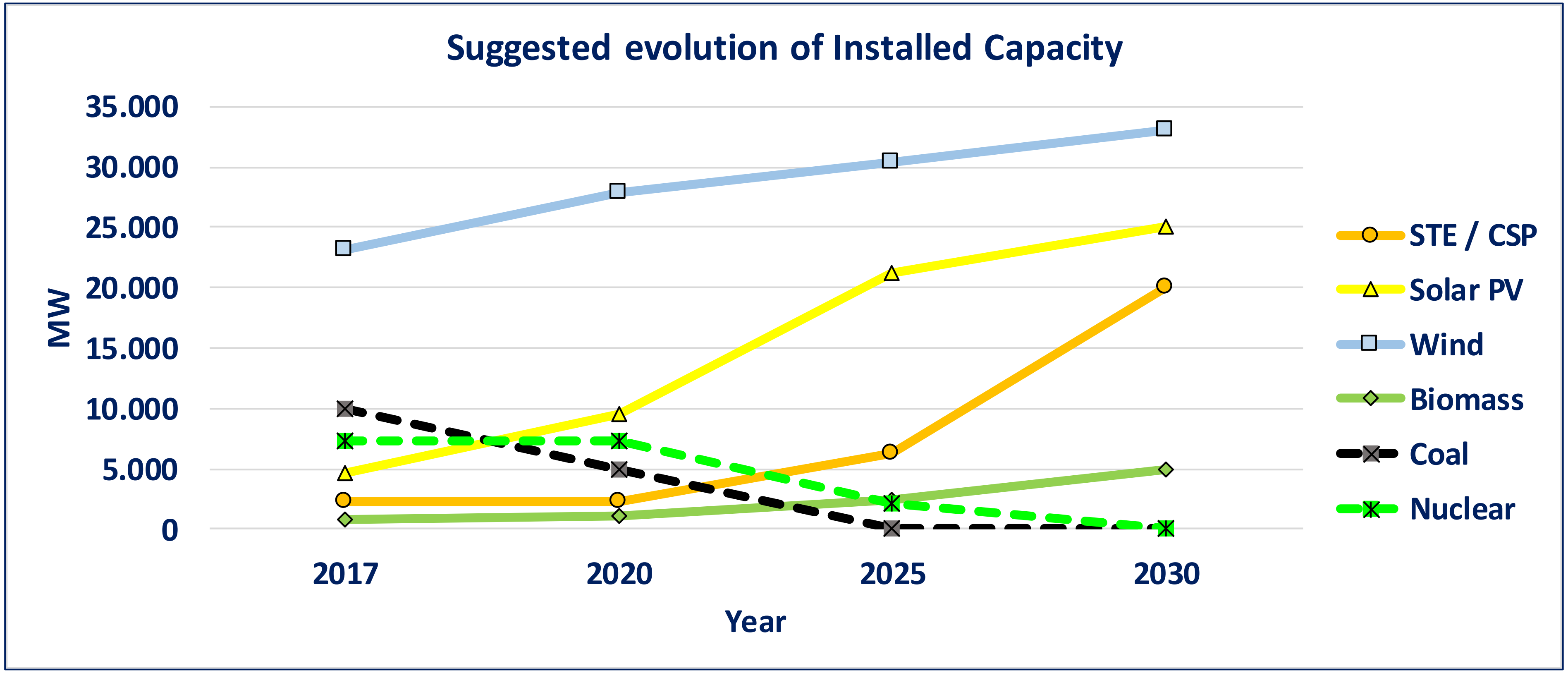
(Table Unit: €/MWh)	2030 Generation Cost	Sensitivity analysis for total Generation Cost at 50€/MWh	Sensitivity analysis for total Generation Cost at 60€/MWh	Sensitivity analysis 1	Sensitivity analysis 2	Sensitivity analysis 3	Sensitivity analysis 4	Sensitivity analysis 5
GCC	**74**	74	74	74	74	74	74	74
Hydro	**20**	20	20	20	20	20	20	20
Hydro Pumping	**25**	25	25	25	25	25	25	25
Wind	**40**	40	40	40	40	37	40	37
Solar PV	**35**	35	35	35	35	32	35	32
Solar STE/CSP	**55**	60,5	106	65	55	55	55	65
Biomass & Biogas	**60**	60	60	60	80	60	60	80
Cogeneration	**70**	70	70	70	70	70	70	70
Non RES Waste	**80**	80	80	80	80	80	80	80
Imports	**60**	60	60	60	60	60	65	65
Exports	**40**	40	40	40	40	40	35	35
Total Generation Costs	**48,8**	**50**	**60**	**51**	**50,6**	**47,6**	**49,3**	**52,1**
Difference (%)	**0%**	**+2,48%**	**+23,02%**	**+4,51%**	**+3,75%**	**-2,51%**	**+1,06**	**+6,80**

What does it need to happen to before 2030? Different Technology needs at different timing



2017 – 2020: Already awarded auctions (PV, Wind & Biomass) + PPAs
2020 – 2025: Linear increase for Wind, High penetration of PV, Small penetration of STE/CSP & Biomass
2025 – 2030: Variable RES capacity will be close to market limits. High penetration of STE/CSP & Biomass

What does it need to happen to before 2030?
Specific Technology auctions and a foreseeable RES planning

PROTERMO SOLAR

	STE / CSP		Solar PV		Wind		Biomass	
	€/MWh	New Inst. Capacity (MW)	€/MWh	New Inst. Capacity (MW)	€/MWh	New Inst. Capacity (MW)	€/MWh	New Inst. Capacity (MW)
2021	75	500	40	2.700	45	514	95	200
2022	72	500	38	2.700	43	514	85	200
2023	70	500	37	2.700	42	514	75	200
2024	67	1.000	35	2.000	41	514	70	300
2025	63	1.500	32	1.500	40	514	65	400
2026	59	2.000	31	1.000	39	514	60	500
2027	54	2.925	30	701	39	514	55	536
2028	51	2.925	29	701	38	514	50	536
2029	48	2.925	28	701	37	514	50	536
2030	47	2.925	27	701	36	514	48	536
Weighted average by Technology in 2025	**67**		**37**		**42**		**75**	
Weighted average by Technology in 2030	**55**		**35**		**40**		**60**	

Additional contributions from solar thermal power plants to the Spanish economy

PROTERMO SOLAR

- **Given its high local content, investments in solar thermal power plants would contribute to:**

✓ Increase of GDP
- Contribution in construction phase of €3.5 million/MW €62 billion (17.7 GW)
- Contribution in phase of operation of €250,000/MW €5 billion (20 GW)
- Tax contributions (companies, VAT, tax, local taxes)
- Employment generation (with consequent decrease of the unemployment benefits)
- Construction phase (1.77 GW/year) = 88,500 jobs/year
- Operation phase (1.77 GW/year) = 1,770 additional direct jobs/year. From 2030 there would be 20,000 permanent jobs

✓ Regional Economic Convergence!!!

In addition the solar thermal electricity plants would lead to:

✓ Reduced imports of fuels → improvement of the trade balance
✓ CO_2 Payments Reduction
✓ Keeping Spanish companies with the technological leadership for STE and capturing much of the related business on world markets
✓ Attraction of foreign investments

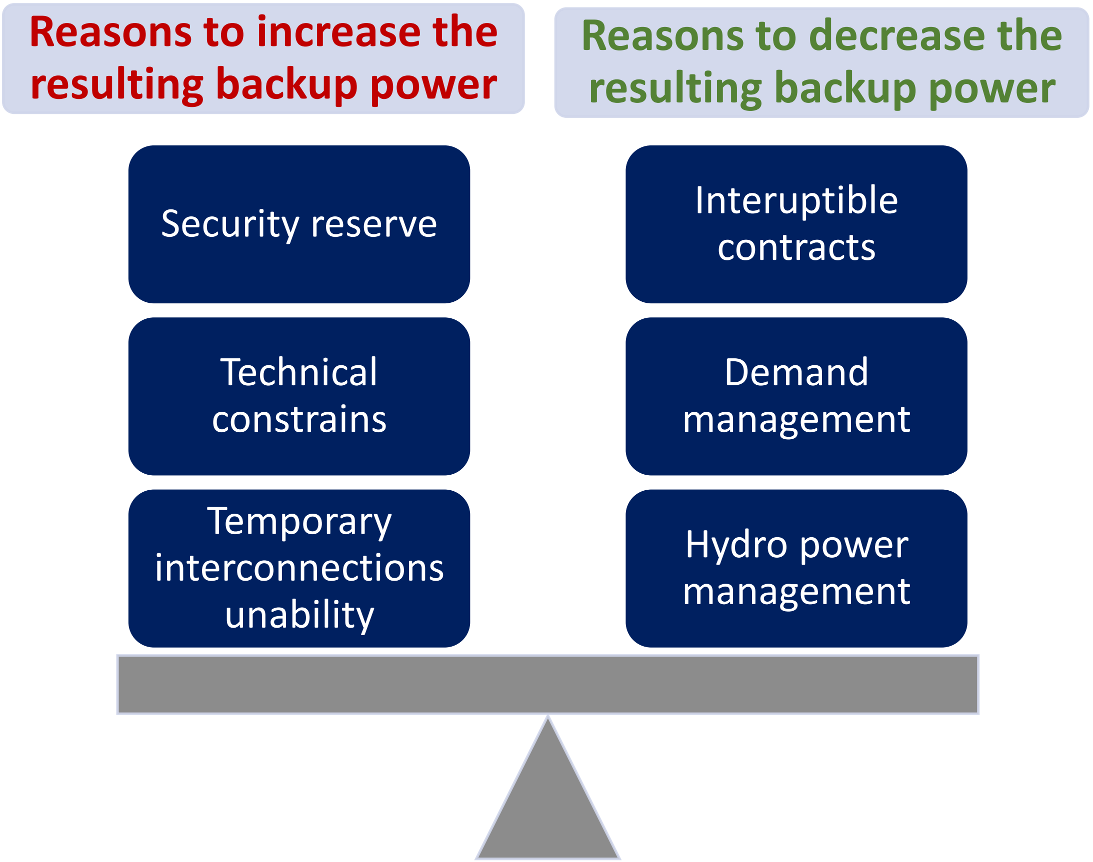
Comments on the resulting gas backup

A thorough analysis at hourly level through the long historical series was done to find out the largest gas backup power required and to check the compliance of the proposed fleet with the system required minimum synchronous level and the feasibility of the required ramps.

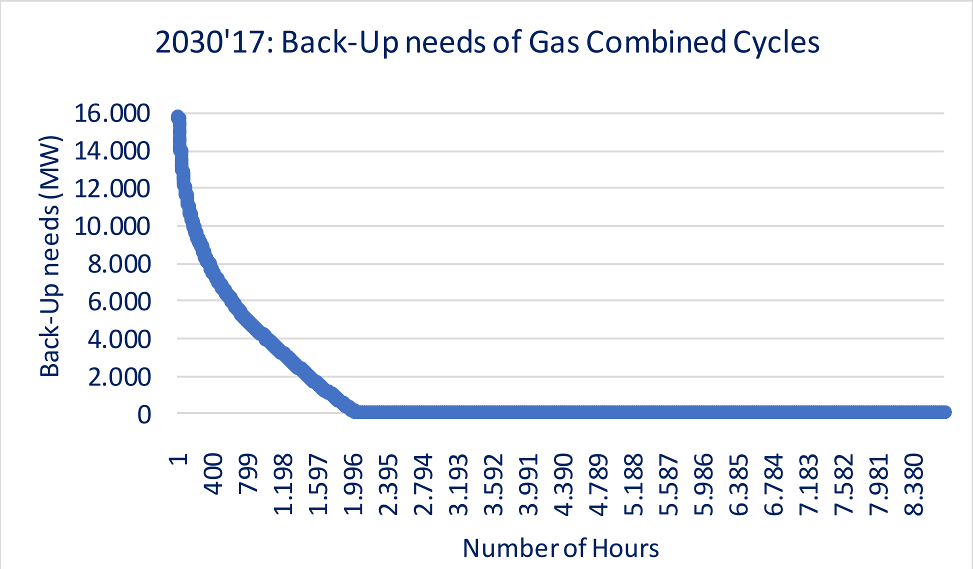
The result was that that the maximum necessary gas combined cycle backup **never went beyond 16 GW**. It does not mean that 16 GW would be the necessary backup.

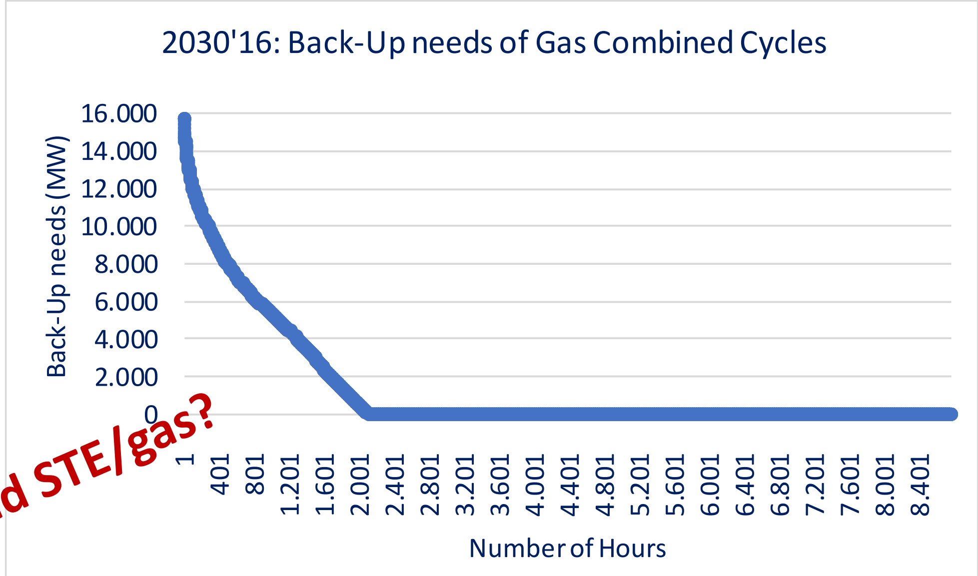
There are reasons to move the balance in either way but what is clear is that there are no reasons to maintain the whole current gas combined cycle fleet of 25 GW even in the case of decommissioning of the complete nuclear fleet.

Technical constraints would happen precisely when there were not many cycles in operation. Therefore it could result on a slightly increase GCC contribution over the year, but not in much additional backup power requirements.

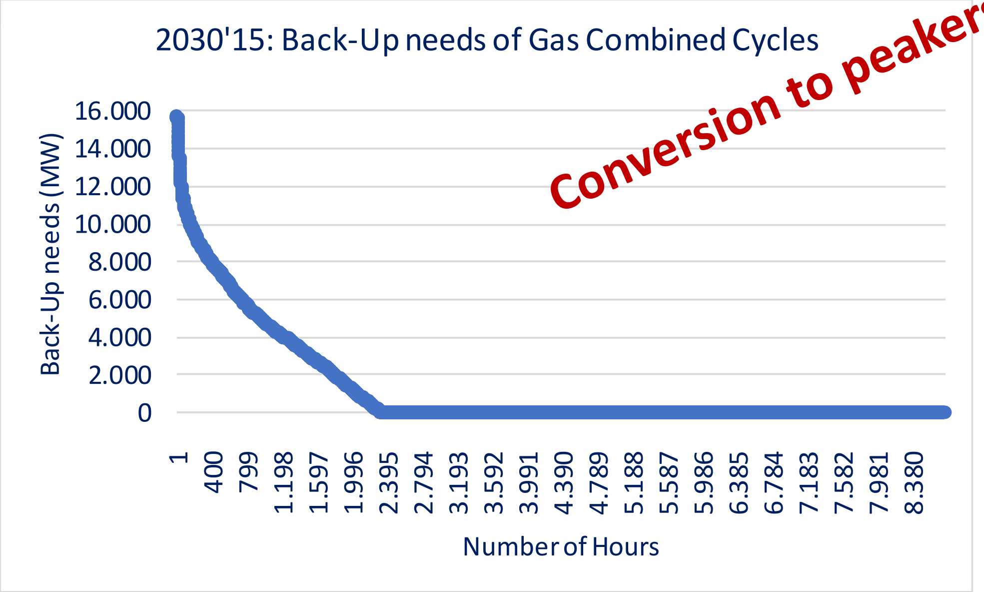


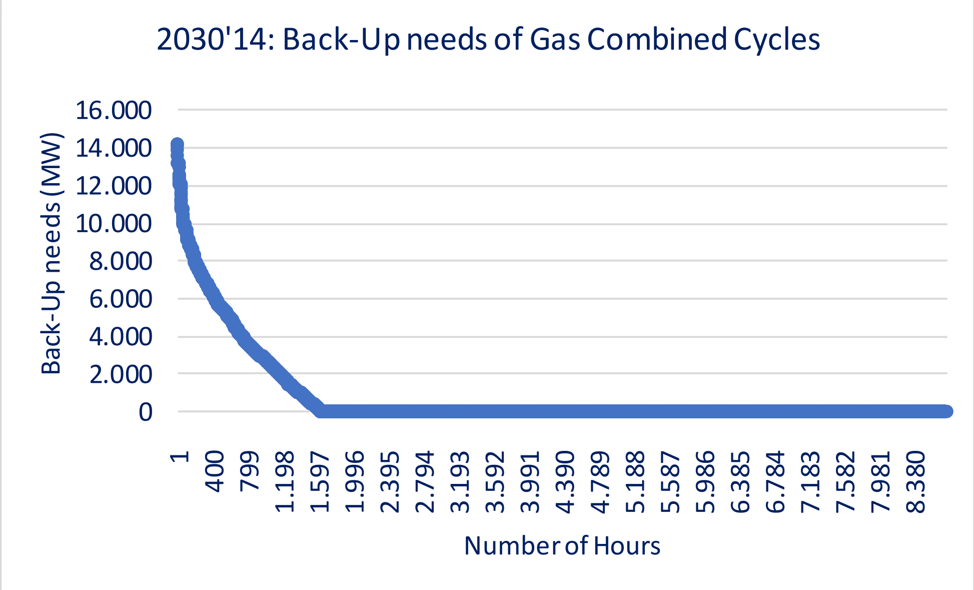
Backup needs with combined cycles





Conversion to peakers or hybrid STE/gas?

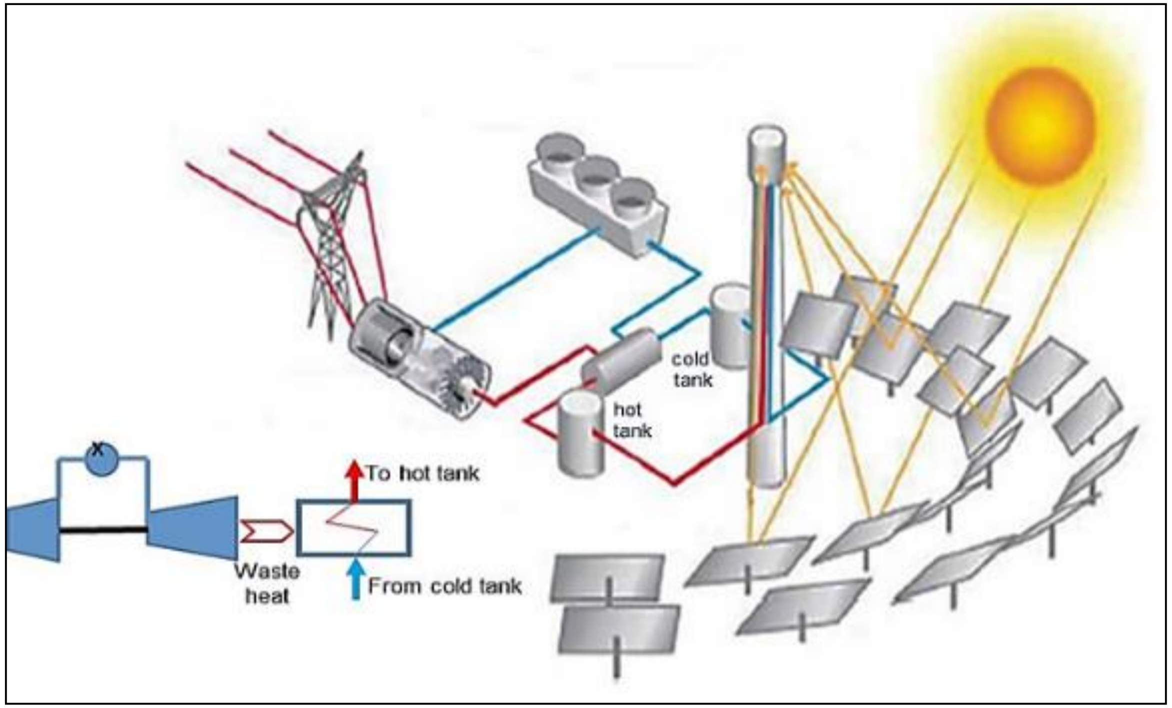




Complementary reflections on the need for backup capacity in gas

Demand and hydropower generation management could further reduce the natural gas back-up needs of this study. The interruption contracts would also reduce this power.

Given the small number of hours of operation that the combined cycles would show, a reconversion or substitution of combined cycles as gas open cycle peaker turbines, installed next to the solar thermal power plants, as a **decoupled Solar-Gas Combined Cycle**. Doing so, exhaust energy is recovered by the storage system of the solar thermal power plants. The plants could offer full firmness of supply. Their load factor will be increased, therefore additional cost reduction of the solar plant could be achieved. The steam turbines will run more hours as if the tanks would have been charged with solar energy



Moreover, the solar thermal power plants could offer their storage capacity – upon minimal additional investments – to reduce wind curtailments in days of high wind and low sunshine, heating the tanks with resistances and operating then the steam turbine as in the solar mode. This mode could be named **Power to Heat**. The overall conversion efficiency will be around 40%, which is close to the Power to Gas concept but much cheaper and easier.

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