THE VALUE OF SOLAR THERMAL ELECTRICITY

COST VS. VALUE APPROACH

Image: 55 MW Bokpoort solar plant, carried out by SENER, ACCIONA, TSK and Crowie. Photo courtesy of SENER

EUROPEAN SOLAR THERMAL ELECTRICITY ASSOCIATION

ESTELA

STELA WORLD

THE VALUE OF SOLAR THERMAL ELECTRICITY

COST VS. VALUE APPROACH

Contents

ABOUT ESTELA

ESTELA, the European Solar Thermal Electricity Association, is a non-profit association created in 2007. ESTELA represents members from the industry and research institutions, active along the whole STE value chain. Joining hands with national associations – Protermosolar (Spain), ANEST (Italy), Deutsche CSP (Germany) and the SER-CSP (France), ESTELA is devoted to promoting solar thermal electricity not only in Europe, but also in MENA region and worldwide. To act widely, ESTELA with AUSTELA and SASTELA in 2012 jointly created STELA World. Today, ESTELA is the largest industry association in the world promoting the solar thermal electricity sector.

ABOUT SOLAR THERMAL ELECTRICITY

Solar Thermal Electricity (STE), also known as concentrating solar power (CSP), is a renewable energy technology that uses mirrors to concentrate the sun's energy and convert it into high-temperature heat to create steam to drive a turbine that generates electricity. STE is a carbon-free source of electricity that is best suited to areas in the world with strong irradiation: Southern Europe, Northern Africa and the Middle East, South Africa, parts of India, China, Southern USA and Australia.

Image: Palma del Río II ©ACCIONA

Published by:

ESTELA

European Solar Thermal Electricity Association

Rue de l'Industrie 10,
B-1000 Brussels, Belgium
www.estelasolar.org

STELA World

World Solar Thermal Electricity Association

www.stelaworld.org

INTRODUCTION

In 2016 and the years to come, renewable energy sources (RES) seen globally will no doubt increase their penetration into the electric systems in order to reach the goals of COP21 – limiting global temperature increase to 1.5 ºC. In light of this truly historic Paris Agreement endorsed by nearly 200 countries, we urgently need to revise current EU and national RES targets. The currently defined EU's 2030 climate and energy goals, e.g., a 40% emission reductions by 2030 compared to the 1990 level, simply will not get us there, even with a 27% RES target share for the final energy consumption. Only a stronger emissions target in line with the rapid decarbonisation of the energy sector and a higher share of renewable in the final energy consumption will make this goal achievable.

Regarding the total capacity installed in the EU by 2015, 141.6 GW was in wind and 95.4 GW in PV, accounting for 26% of the EU power mix. Good news is that wind accounted for a total of 12.8 GW, 44% of all new installed capacity in the EU, becoming number one in Europe among all energy sources. Solar PV came second with 8.5 GW, accounting for 29%, while coal took the third place with 4.7 GW (16%). Both wind and PV accounted for 73% of new energy installed capacity in 2015, overtaking the conventional power sources, such as fuel oil and coal for which more capacity is decommissioned than installed. This is an important milestone: today's mix of energy use is at its turning point shifting from conventional fuel sources to renewable energy sources.

However, the transition from the old energy model, particularly in the electricity generation mix, cannot be simply left to the market forces when the intrinsic value of the different technologies is not fairly remunerated. A system approach is needed to value a flexible technology like STE based on its global "value", instead of a simple "cost" of generation. Otherwise, significant drawbacks in both technical and economic terms are likely to arise.

Our recent joint report with Greenpeace and SolarPACES on STE's Global Outlook 2016[1] indicates that STE is the key to achieve a 100% renewable share by 2050 in a wise mix with other renewables. It also estimates that the potential for STE to meet global electricity demand is far greater: the analysis based on the Advanced Scenario assumptions shows that STE could provide approximately 4,500 TWh of solar thermal electricity by 2050, delivering up to 12% of the world's electricity needs. In this most optimistic scenario when only Sunbelt countries are considered, STE would save 1.2 billion tonnes of CO_2 annually by 2050. Geographically speaking, although Europe is not the best place for STE plants, it is estimated that STE would deploy up to 35 GW in Europe by 2030 under aggressive deployment policy. To achieve this, the European energy mix should include a certain share of dispatchable renewable generation technologies. Therefore, in regard to STE, contributing a 0.5% share to the EU energy mix, further support and deployment is needed in order to bring the estimated scenarios to life. Right now it is more important than ever to adopt such a system approach.

However, this will unlikely happen without governmental support schemes. Current policies show that market will only be triggered by low costs and/or self-consumption strategies – mostly at distribution level and in many cases without consideration of the abundancy of the respective resource across Europe and the world.

Time has come to raise our look on energy policy a bit beyond LCOEs[2] and its resulting deployment plans based on pure cost-based auctions. This metric may remain for academic purposes, but it is not supportive to a far-reaching energy policy-making that leading to system planning decisions and support schemes. The value of flexibility enabling a responsive behaviour of plants according to the demand, capacity availability, grid stability, energy security, local economic impacts including effects on job creation, impact on trade balance, etc., are not addressed in a "LCOE approach". The current almost-addictive reference to the lowest generation cost does not build on the essential distinction between 'value' and 'cost' related to the various renewable technologies.

The guiding principle to date should no longer be "how much a generated kWh" in a given plant will cost in terms of CAPEX/OPEX over its 20-to-25-year lifetime (which is for STE plants systematically underestimated as the effective lifetime reaches 40 years). Instead, the value added to the system by this kWh should be the core term. This value can be expressed both in operational terms (time-of-day effective operation hours, impact on spinning capacity reserve contribution to ancillary services, induced generation curtailment, etc.) and in terms of added capacity (investments avoided to cover demand in all timeframes on top of the investment of the new plant itself). However, technologies like STE that deliver such added value cannot yet do it at large neither in Europe, nor worldwide – because neither were these plants designed for it, nor does the electricity market design offer a specific segment where RES generation technologies can compete for firm deliveries on demand.

1 *Solar Thermal Electricity: Global Outlook 2016, Greenpeace, ESTELA, SolarPACES, 2016*

2 *LCOE: levelized cost of electricity*

COST VS. VALUE APPROACH

The Current Level of Cost Comparison with Onshore Wind and PV

Onshore wind and PV have reached already competitive cost levels, at about 6 c€/kWh on average, with 400 GW of onshore wind and 200 GW of PV installed worldwide. With only 5 GW installed capacity, STE has reached now the cost at 14 c€/kWh at relatively good sunny places. When both wind and PV technologies had a power installed equivalent to the 5 GW of STE as of today, their prices were much higher than the current one of STE. The cost of STE could be close to the same price levels of wind and PV if STE's installed capacity was multiplied by 80 (wind) or 40 (PV) in order to compare at the same level of installed capacity. Therefore, the potential for cost reduction of STE technology that could be achieved is large, at the given corresponding market volume.

So the current price gap between STE plants and Wind or PV plants can be partly reduced only when the value-to-the-system is considered. The still remaining gap would be automatically compensated by the growth of the STE market, i.e., based on maturity. STE would not even need to reach the same level of current wind or PV installed capacity, even 10 times less than what they have archived will be enough to demonstrate the full competitiveness of STE power plants.

Last but not least, aren't we comparing apples to pears when comparing STE and PV plants?

The ratio of Cost/kW is definitely not the right indicator. Comparisons must be made at least in terms of investment for the same yearly production. But even the ratio of Cost/kWh produced is not the suitable indicator either.

When considering the electricity generation costs in a power system in its full dimension, what matters is not only the project cost of a given project to a system, but the hidden benefits brought to a system by such a given project: this is the "value".

However, many aspects are usually disregarded when calculating the power generation costs, for example, lifetime of components, degradation of performance, impact of temperature on performance, losses in charging and discharging batteries, pumping stations, etc.

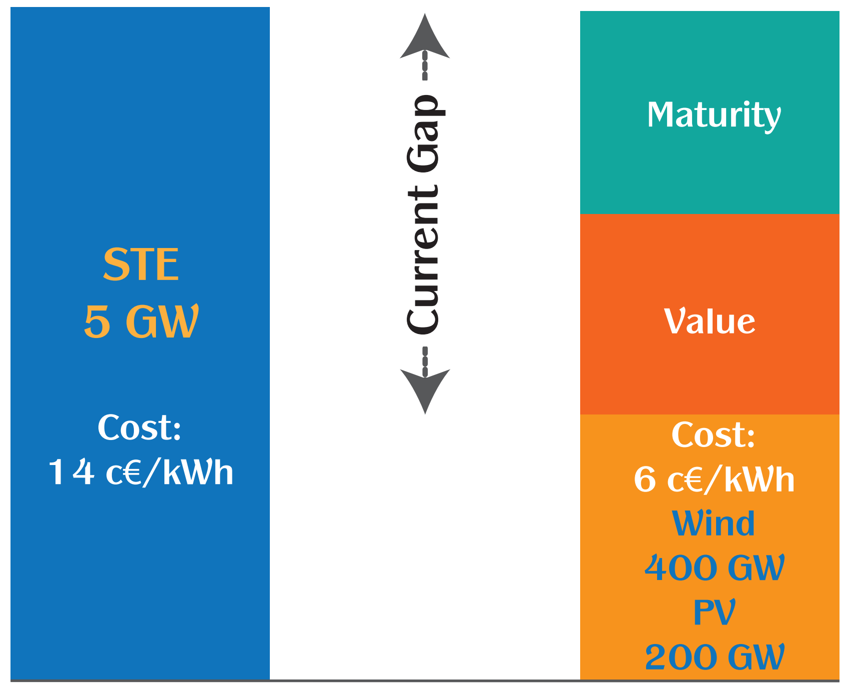


Figure 1: Current cost gap between STE and wind & PV

The Value of Solar Thermal Power

As electricity cannot be stored in the grid, power generation must be necessarily equal to or following the demand curve of consumption. Flexibility in the system can be achieved in various ways: storage of surplus energy, demand-side management, interconnection with neighbouring systems and dispatchability of the generation units.

Any new power plant in the system provides services at a given cost.

Since intermittent renewable plants usually are not able to provide firmness of supply, the increased cost for integrating intermittent renewable generation sources into grid operation is primarily the costs for additional conventional power needed as back-up.

Furthermore, the interconnection costs are the costs for any transmission infrastructure and operational measures by TSOs needed to inject the intermittent renewable energy into the high-voltage grids. Such operational measures include capacity allocation on transmission lines and any re-dispatching measures depending on whether a plant can provide ancillary services (e.g., regulation, spinning/non-spinning reserves, and fast ramping up or down) or not.

Finally, more benefits can also arise, such as impacting costs due to the location of the plant that can reduce the need for new infrastructure, impact transmission congestion or be made available to a utility facility using any surplus capacity for its auxiliary services.

The two-fold types of value for a new generation unit can be summarized as follows:

Operational value represents the avoided costs of conventional generation at their respective dispatching times along with related ancillary services costs, such as operating reserve requirements. Savings on emission costs are also accounted. Apart from this, another potential value is firm capacity.

Capacity value reflects the ability to avoid the costs of building new conventional generation in response to growing energy demands or plant retirements.

But the above mentioned costs are only one of the parameters to be valued ahead of any decision to invest in renewable technologies.

The difference in "added-value to the system" of the various technologies depends certainly on the country considered and the ease for its assessment in the respective country's electrical system. Dispatchable technologies will be highly valued in countries that need to double their installed capacities in the next decade. Nevertheless, some industrialized countries which can show today important back-up capacity might be concerned since an increasing number of old nuclear or coal plants will need to be decommissioned.

An interesting study on this regard has been carried out by NREL not only presenting the different values between a new PV plant and a STE one with storage in the short term, but also demonstrating how this difference changes depending on the progressively increasing penetration share of renewable technologies in their generation mix.

Currently California has a 33% Renewable Portfolio Standard (RPS) for 2020, which means 33% of retail electricity sales must come from eligible renewable energy resources. The Californian authorities stated that a share of 40% renewables is achievable in the near future at reasonable cost. In this study, NREL has compared the relative value of PV and STE (with storage) under a 40% RPS scenario.

The main conclusion is that with a 33%-penetration of renewable energy in California, it is economically equivalent to pay 5 US$ cents/kWh to a new PV plant and 10 US$ cents/kWh to a STE plant with storage. Moreover, this difference increases along with the share of renewable energy. The results of the study clearly show that STE with storage has a higher marginal operational value than PV and that the relative value may increase slightly with increased PV penetration. As shown in Figure 2, the operational value in reduced generational costs for PV in a 33% RPS case is 31.9 US$/MWh and for STE is 46.6 US$/MWh; while in a 40% RPS case, the operational value is 29.8 US$/MWh for PV and 46.2 US$/MWh for STE. A significant portion of STE value appears to be derived from its ability to provide firm system capacity.

Value Component	33% Renewables		40% Renewables	
	STE with Storage Value (USD/MWh)	*PV Value (USD/MWh)*	*STE with Storage Value (USD/MWh)*	*PV Value (USD/MWh)*
Operational	46.6	31.9	46.2	29.8
Capacity	47.9-60.8	15.2-26.3	49.8-63.1	2.4-17.6
Total	94.6-107	47.1-58.2	96.0-109	32.2-47.4

Figure 2: Estimating the Value of Utility-Scale Solar Technologies in California under a 40% Renewable Portfolio Standard, NREL/TP-6A20-61695, Jorgenson, J., P. Denholm and M. Mehos, 2014 May.

The current power market design rules are being revised in many countries, particularly in the EU. In this context, "flexibility products" could be defined with the system operators for different kinds of services where the value of dispatchability would be reflected.

In case a future market design would fall short of changing its rationale compared to the current one, it will be up to regulators and system planners to duly assess the value rather than just using the pure marginal cost approach, so as to make the energy model transition sustainable, efficient and also affordable.

The technologies that deliver this added value, such as STE plants, cannot yet do it at large neither in Europe, nor worldwide. The reason for that is common sense: neither were these plants designed for it, nor does the electricity market design offer a specific segment where RES generation technologies can compete for firm deliveries on demand.

Last but not least, due to their respective low market volume, flexible RES technologies have already achieved a substantial, but slower cost reduction curve compared to non-flexible RES technologies.

The conclusion in DNV-GL's CSP optimization report carried out for the California Energy Commission states clearly that STE coupled with thermal energy storage can improve both economics and technical performance of the system:

- Less fossil fuels used for shifting solar power to high-value evening hours
- Significant system cost savings for system control and load-following
- Less variability in power system
- Hedging against solar forecast errors

STE plants can cover a wide range of needs:

- Peaker: with 2-3 hrs of storage – designed to quickly provide power (or decrease power) to the grid as needed to balance the intermittency of PV and wind
- Intermediate: with 5-8 hrs of storage – designed to provide power in the early morning and evening as well as during some periods of the day
- Baseload: with 10-17 hrs of storage – designed to provide power 24 h/day

The following figure 3 shows the example of Solana plant in Arizona and how it can meet various system operator needs.

This plant contributes to the supply of the demand during the long summer peak while in winter electricity can be dispatched during the early morning and evening peaks. This example clearly shows that value for the system is far beyond the generation cost.

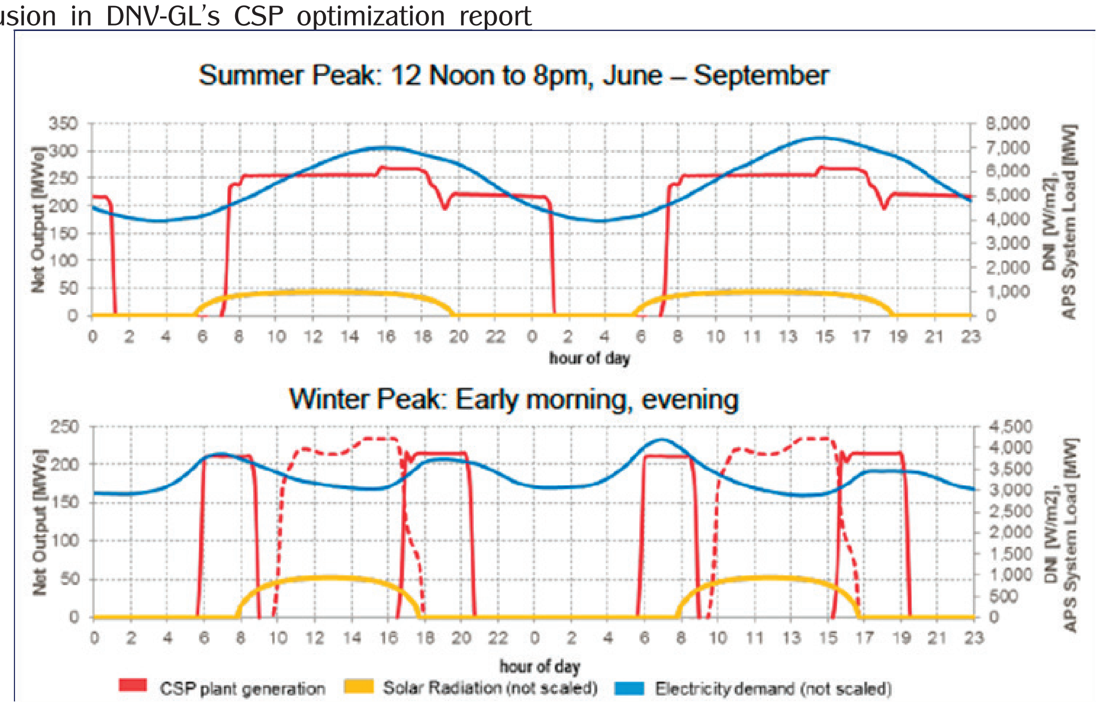


Figure 3: STE Flexibility: Dispatching Power when Most Needed. Source: Abengoa Solar

Firmness of Supply is a Step Beyond Dispatchability

From a system perspective, STE offers a significant advantage over PV and wind – dispatchability due to its build-in thermal storage capabilities. As previously mentioned, a significant portion of STE value appears to be derived from its ability to provide high reliable system capacity.

But STE plants could be designed in such a way that they not only follow the demand in sunny or partly cloudy days, but also provide firm supply combining its storage system with smart hybridization solutions.

Strengthening firmness to the power generated from STE plants can be achieved by hybridizing with biomass, biogas or natural gas.

In the past, all hybrid systems – no matter whether they were based on biomass or gas – were designed in a way that the auxiliary heater was built parallel to the solar field, heating the HTF to the same temperature as if the solar field was in operation, in order to cope with cloud passing or absence of solar irradiation. The main drawback is that the gas is burned at a very inefficient conversion rate.

To date more efficient systems have been conceived. For instance, installing a relatively inexpensive open cycle gas turbine where the exhaust energy is recovered in the same thermal storage system of the STE plant, as if the energy were coming from the solar field, will provide similar conversion efficiency to a combined cycle and a much more flexible operation of the complete installation. This concept is under development in the Hysol T&I project[3], funded by the European Commission through the FP7 programme. This R&D project aims at demonstrating a Solar Hybrid Plant is the best way to get firmness, using at least 80% of renewable resources.

Plants that guarantee firm supply of electricity on demand can be "the solution" for certain needs. For example, regions in a country where supply over long distances implying high losses or require the enhancement of the grid stability.

3 http://www.hysolproject.eu/

STE Enabling a Higher Penetration of Intermittent RES Technologies

STE enables to integrate more intermittent renewable sources:

- Since a high penetration of intermittent wind and solar requires flexible power to respond to the intermittency;
- Due to a reduced simultaneity of the solar resource availability and the demand – because when PV increases, peak demand shifts to the evening, creating steep "ramps" requiring flexible power to respond to;
- Conventional flexible power emits carbon and criteria pollutants, and are expensive and inefficient;
- Flexibility provided by STE helps maintain grid system reliability.

Thus, dispatching STE at the evening peak to complement PV plants will increase significantly the operational and capacity value of hybrid STE/PV plants.

Sometimes the co-location of different plant types happens "by chance" (as a result of non-simultaneous investment decisions), like the case of Andasol plants and wind parks in the Guadix area in Spain (STE and wind) or the Solucar complex in Seville (STE and PV). Regarding the Andasol case, STE plants and wind parks were co-located on the same site so that the electrical infrastructures show higher utilization factors along the year, compared to having STE plants or wind parks alone. The variability of the wind park supply on such sites can easily be compensated by the STE plant, thanks to its storage system.

But hybrid STE and PV plants can also be built "on purpose", such as the Atacama plant, currently under construction, in Chile. A 110 MW STE plant with 17.5 hours of storage can provide the required baseload to the mining sector in the northern part of Chile and a 100 MW PV plant, built at the same place, makes use of the same transformer sub-station, so as to reduce the cost of the generated electricity.

As mentioned in the recent IEA technology roadmap[4], STE is able to provide firm and dispatchable electricity at the request of power grid operators, especially during the demand peaks in the late afternoon, in the evening or early morning; while PV generation is at its best in the middle of the day. Both technologies appear hence as ultimately complementary. The value of STE will increase as PV deploys further in order to be able to shave mid-day peaks and beef-up evening and early morning peaks.

4 Technology Roadmap: Solar Thermal Electricity, IEA, 2014

Image: Andasol plants (150 MW) and wind parks (200 MW) in the province of Granada, Spain ©ACS Cobra

Image: 10 MW STE plant co-located with 1 MW PV in the Solucar complex, Seville, Spain ©Abengoa Solar

Maturity

The current power market in Europe is driven mostly by costs, and in many cases without considering the abundancy of the local resources. Onshore wind and PV may already have reached competitive cost levels on good sites, at about 6c€/kWh, with 400 GW of onshore wind and 200 GW of PV installed worldwide.

The question arises as whether it is still worth continuing to support STE technology due to its slightly higher costs than wind and PV. However, when we look at the cost of a technology, we should also consider its historic cost and its maturity.

When looking back at the deployment of onshore wind and PV that started more than 30 years ago, it appears that from the 1980s to the early 2000s, the average capital costs for wind energy projects declined markedly. In the U.S., capital costs were approximately 65% below costs from the early 1980s[5].

In other words, it took onshore wind energy more than 30 years to bring the cost down to the current level. Also for PV, it took also more than 35 years for its costs to come down to the level to date.

For onshore wind and PV, it has been a continuous evolution since then, with an exponential acceleration in the last decade. While STE started to be commercially deployed in the late 80's in California – SEGS plants, but it did not deploy further at the early 90's with an installed power of only 450 MW. The new STE era began its construction only since 2006. The cost at that time was around 30 c€/kWh and only ten years later it has decreased by half.

Taking into account the facts and figures from the past years and the expected trends, costs are expected to decline as shown in figure 5. These curves correspond to the best estimates of the STE industrial companies within ESTELA and they are fully consistent with the "harmonized" costs – discounting all the differences with a standard project without public aids – of all parabolic troughs plants built in the past in the U.S., Spain, India, Morocco, and South Africa, at their respective construction time. The cost reduction curve refers to the year in which the plant starts its construction.

This cost reduction trend necessarily requires a minimum volume of projects, which has been estimated at cumulative 30 GW by 2025, although some promoters are more optimistic in getting quicker cost reductions. The first threshold of 10-12 €/kWh will be achieved through lower cost solar collectors and construction practices; while 8-10 €/kWh will be the result of reaching higher temperature system and mass production. Central receiver plants can certainly help in this process.

Interestingly, the forecasts of the U.S. Department of Energy's SunShot Initiative are even much more aggressive. Their goal is to bring the cost of solar thermal electricity down to 6 US$ cents/kWh by 2020 not only based on the impact of technological development on the cost of components, but also on reductions in other called "soft" costs, such as permitting, EPC and financing.

Below are three recent examples showing how fast the STE costs were reduced in terms of maturity and financial support in the last 2 years.

- **Morocco:** the PPAs of the two recently awarded STE plants in Morocco Noor 2 & 3 (200 MW PT & 150 MW T) were 15% lower than the previous one of Noor 1 awarded 2 years ago.
- **Chile**: a 110 MW STE plant, with 17.5 hours of storage, partly hybridized with PV, was recently selected in Chile with a PPA of $110/MWh, in competition with all other generation technologies including Gas Combined Cycle.
- **South Africa**: the tariff for the current "Expedited Round" in South Africa is close to 20% less than the previous one for Round 3 established 18 months ago.

These trends would result even clearer when comparing the current PPAs with the FiT in Spain in 2010 or with the Round 1 in South Africa that reveals cost reductions of around 50% over the last 5 years.

When comparing the currently 5 GW installed in solar thermal power plants with the 400 GW in wind or 200 GW in PV, it is obvious that STE technologies have a huge potential for further cost reductions. Moreover, scale factors, new materials, more efficient manufacturing processes and assembly activities on site will certainly contribute to more substantial cost reductions.

In addition, better performing solar field designs, higher temperatures for working fluids and the use of new power blocks with a higher conversion efficiency will further contribute to lowering the costs of solar thermal electricity. The table below lists the current and expected costs of the main systems of a typical solar thermal power plant. In addition to what can be labelled as "soft costs" (including project and site development), permits, engineering, EPC risks and corresponding margins, construction and performance insurance, amount to approximately 25% of the CAPEX.

5 NREL, The Past and Future Cost of Wind Energy, E. Lantz, M. Hand & R. Wiser, 2012

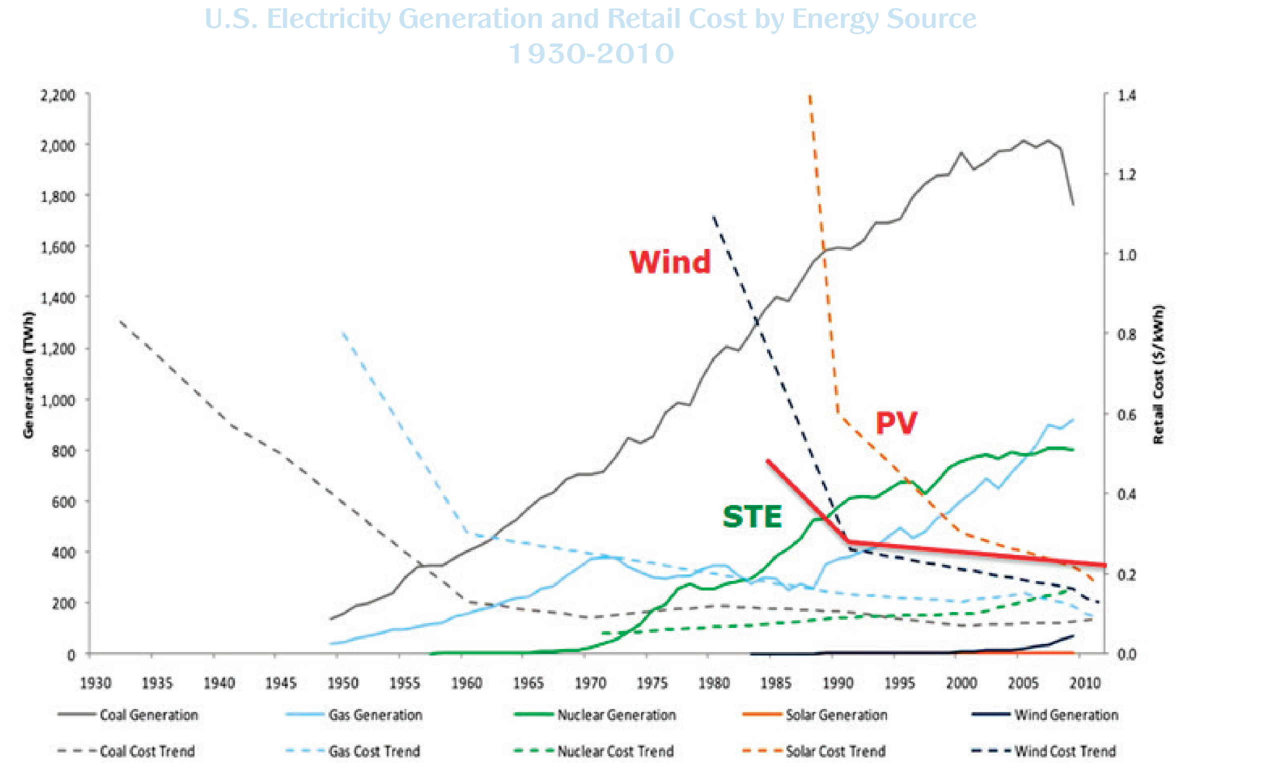


Figure 4: Electricity Generation and Retain Cost by Energy Source in the U.S. between 1930 and 2010. Source: EIA, MIT, American Energy Independence; NREL; Cooper; Hudson estimates

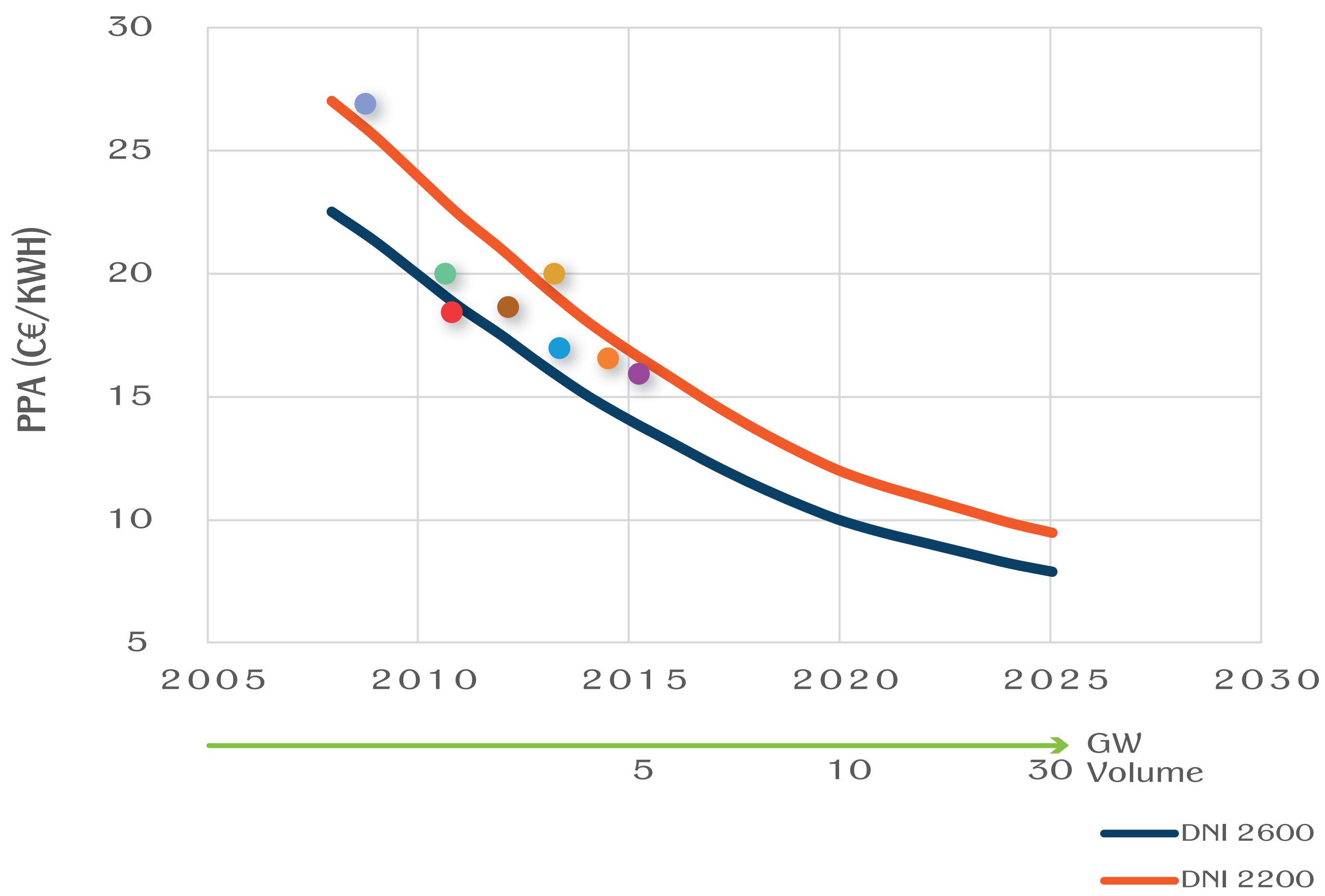


Figure 5: Required value for a 25-year PPA without escalation for a standard 150 MW 5-hour storage STE plant without any kind of financial public support

Drivers for cost reduction in STE

	Today	2025
A) Solar field incl. HTF (€/m²)	160 – 250	100 – 160
B) Thermal Storage (€/kWhth) (for central receiver, costs will be 1/2 of these)	26 – 30	18 – 21
C) PowerBlock (€/kWe)	720 – 765	700 – 790
D) System Efficiency	15% – 17%	18% – 20%

A) Solar Field and receiver sub-systems

1. Collector with larger Aperture (trough)
2. Economically optimized heliostat features, field layout, tower high and receiver geometry
3. Advanced assembly procedure, industrialized assembly, industrial automatization in manufacturing; (sub) supplier standards; standardized design; improved field layout (tower)
4. Higher reflectivity, higher cleanliness
5. Improved durability
6. Improved absorber coatings for receivers
7. Wireless power supply and control (heliostat)
8. Increasing fluids working temperature at receivers
9. Improved O&M procedures

B) Thermal Storage

1. Direct storage concept (HTF = Storage Medium)
2. Higher temperature difference
3. Adapted thermal storage materials
4. Standardized design; sub-supplier design standards
5. Advanced charging and discharging, improved operation strategies in general

C) Power Block

1. Higher cycle efficiency (i.e., by downsizing supercritical steam turbines)
2. Improved hybridization concept
3. Larger power block
4. Standardized design

D) System Efficiency

1. Higher process temperature
2. Lower parasitic consumption (higher temperature through larger aperture and other HTF; at the tower: gravitational pressure loss recovery)
3. Adapted turbine design (for daily start-up)
4. Improved control and O&M strategies/procedures

Importantly, structured financing costs for solar thermal power plants leave much room for reduction, particularly when the performance track record for STE technologies provides greater investor confidence. This is starting to be the case, especially after the 2.3 GW installed in Spain with an average of five years of continuous operation.

Regarding performance, the current conversion ratios from solar to electricity are in the range 15%–17%. The performance range of STE plants is expected to increase to 18%–20% and it could be further increased in case of technology breakthroughs.

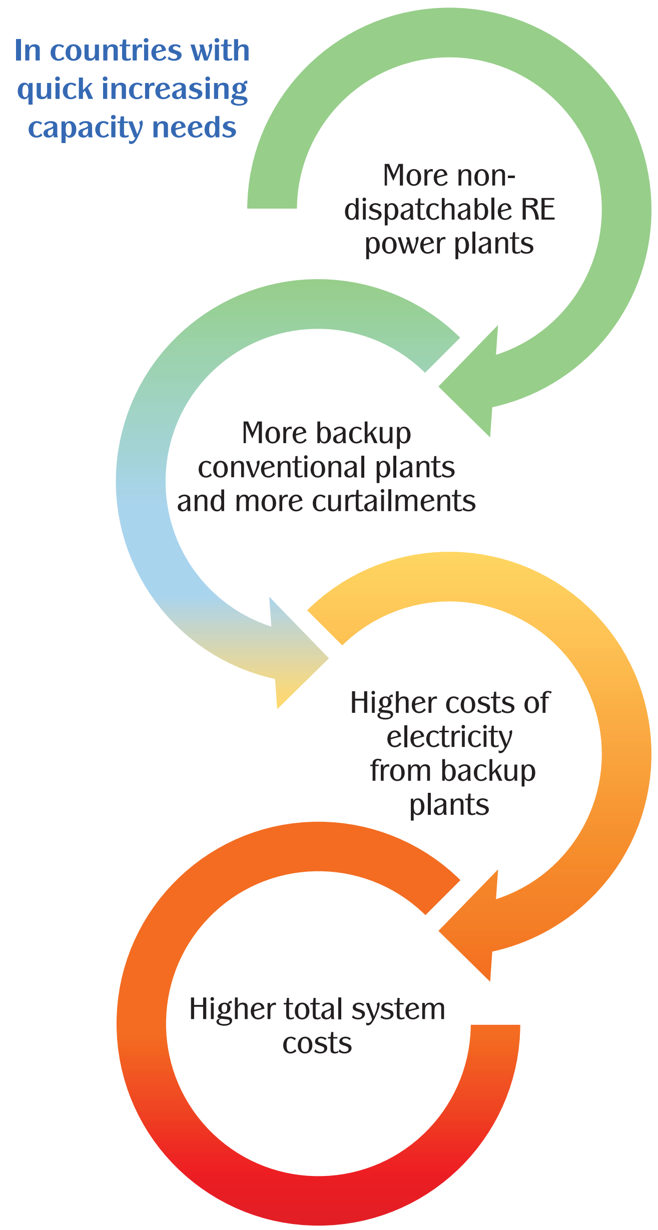


Figure 6: Side-Effects of Having More Intermittent Renewable Energy in the System

Technical Value: Reliability and Flexibility

As presented above, the world is at a turning point towards shifting from conventional fuel sources to renewable energy sources. Wind and PV are now the leading renewable energies around the world. Both wind and PV accounted for 73% of new energy installed capacity in 2015 in Europe, overtaking the conventional power sources, such as fuel oil and coal.

What matters now in the current phase of this transition is to know whether a steadily increasing share of non-dispatchable intermittent renewable energy in our energy mix is sustainable.

From a system perspective, non-flexible RES technologies do not account for “capacity”. They do account for preserving fossil fuels to be exploited, but a higher share of non-flexible RES will bring undesirable effects. For example, more non-flexible RES technologies in the system imply building back-up conventional plants, such as gas, coal, etc., and more curtailments. This also means that the costs of electricity produced by these back-up plants are much higher. Thus, the total system costs get subsequently also higher. Besides, the more intermittent renewable energy exists in the system, the less value it brings to the system, which is also revealed by the case study of California by NREL.

Technical Value: Reliability and Flexibility

Operating Experience

Case Study on STE Production in Spain:

Spain boasts proven operational experience for solar power plants with molten salt storage systems. The production has increased every year resulting in a higher contribution to the demand coverage by these plants. The optimization of production and its perfect coupling to the power demand curve makes the value of the STE production especially important among renewables. Some of the most important production records in 2015 are:

Important milestones in 2015

- ✓ Installed Power 2375 MW (52 plants)
- ✓ New yearly record 5.1 TWh
- ✓ Max. contribution > 8 %:

  At many moments from May to September
- ✓ Max. daily contribution around 5%:

  At many days in June, July and August
- ✓ Monthly production close to 4 %, 889 GWh in July

An example of the perfect coupling between production and demand is shown in the figure 7. All these records and experiences are a very positive reference for other countries that consider to develop STE.

The contribution of STE to the demand in Spain can be tracked at any time of day on real time or for any day in the past using the calendar as shown in figure 8.

The supply and demand curve demonstrated that on any sunny day the instant STE production in Spain is only 20% below the PV one in spite of the fact that the power installed in PV is more than double.

At the right bottom of this graph appears the hourly generation of STE plants during an extended day of operation. The plateau on the left shows the generation of the 18 plants with storage after sunset in Spain. These plants were producing nearly 800 MW until 5:30 am. Some plants even did not stop that day, delivering around 250 MW until the sun rose again.

Another interesting finding is that STE's capacity factor is much higher than PV. Below is a chart showing electrical power generated by PV and STE in Spain in June 2015, a typical hot summer month in Southern Europe. Based on 4.7 GW of installed capacity of PV in Spain, the PV capacity factor over this period of time was 25% while the STE capacity factor was 45% based on 2.3 GW of installed capacity during the same period of time. Another interesting fact is that PV was usually delivering not double as much but only 30% more power than STE at a given time of day before the storage systems are starting to be charged (i.e., around 11:00 am) in Spain.

Apart from the reliable and predictable supply and the perfect match with the demand curve of the Spanish system, it is the inertial contribution to the grid stability, and reactive power control provided by the STE plants is another important aspect.

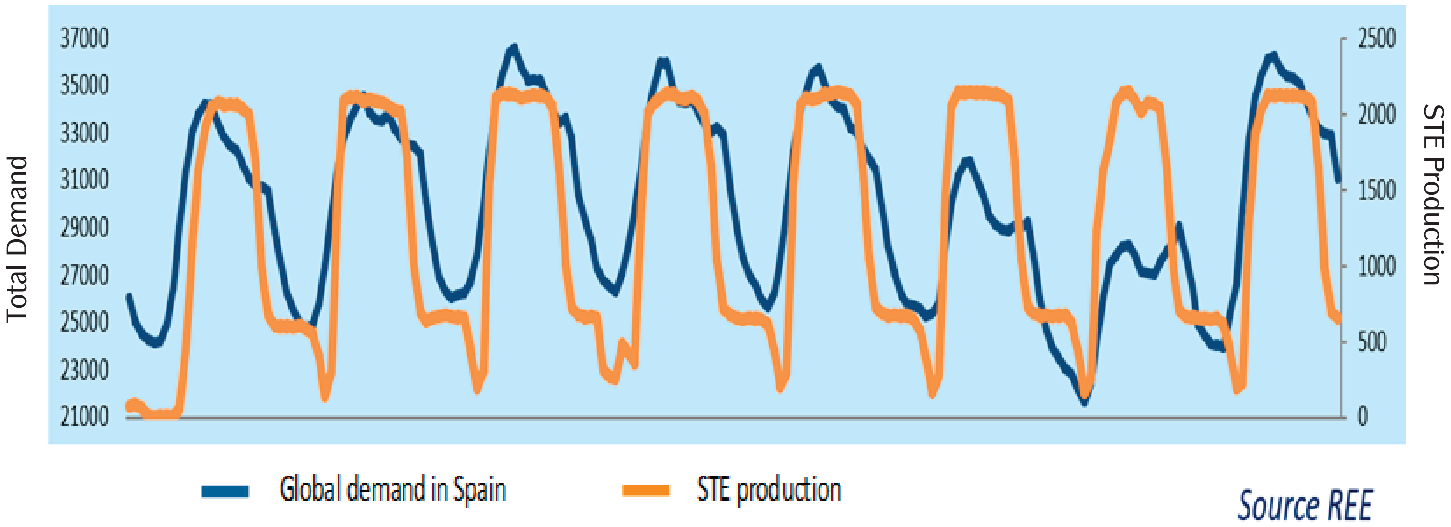


Figure 7: Typical weekly STE production in July 2015 in Spain

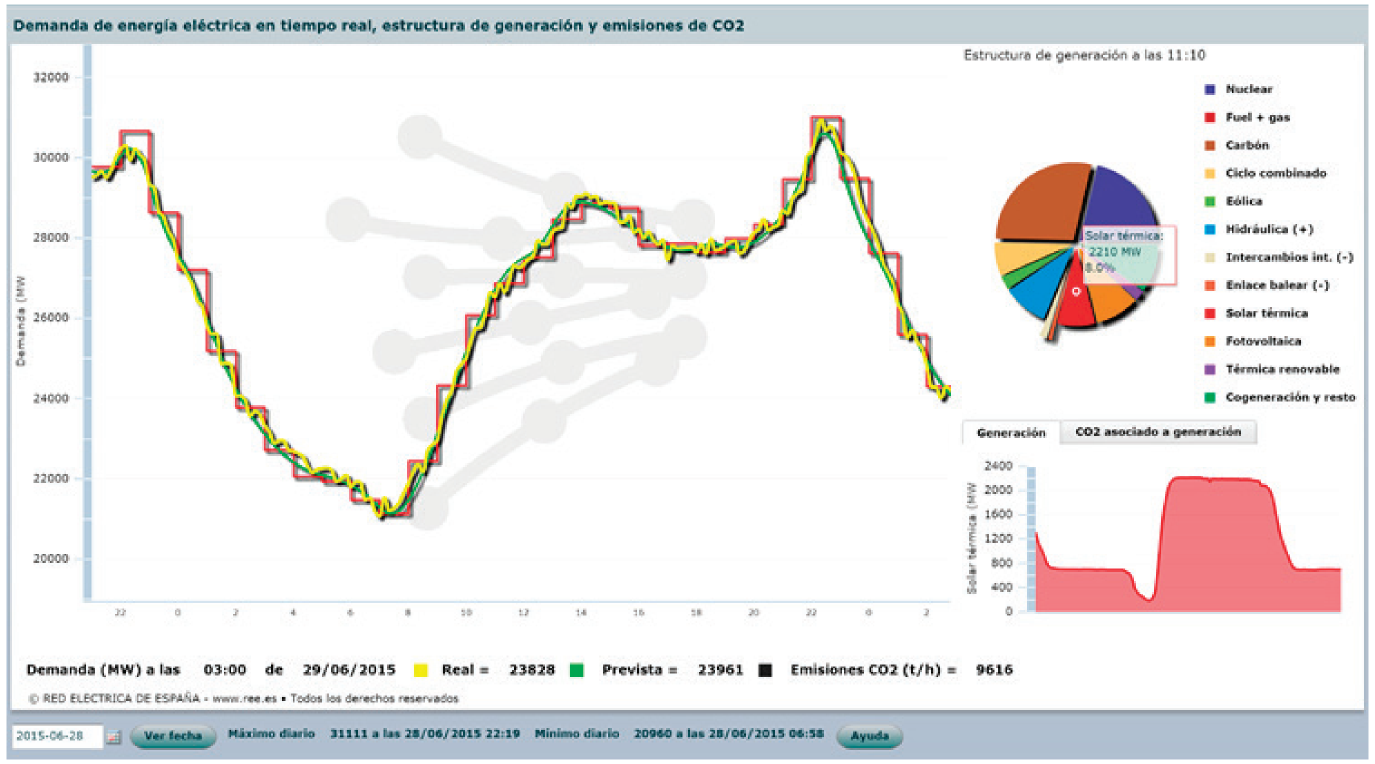


Figure 8: Electricity demand in real time tool showing the structure of generation and CO2 emissions on a normal summer day in 2015, provided by the Spanish national transmission and system operator – Red Eléctrica de España

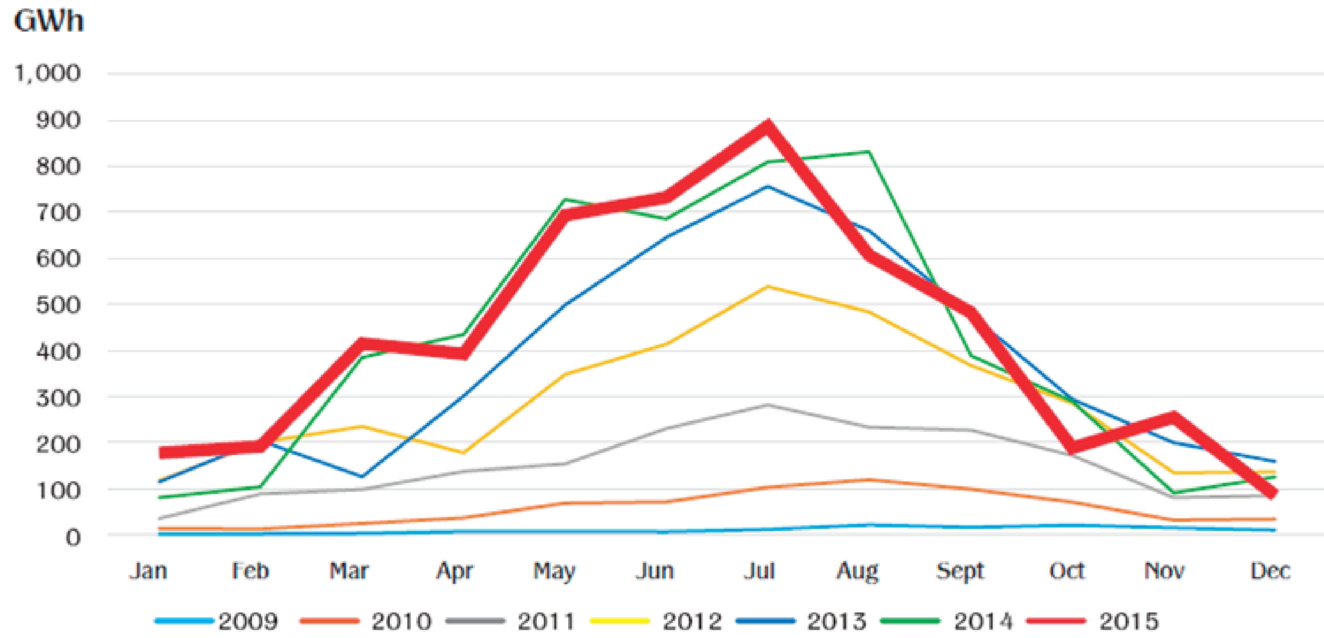


Figure 9: Annual electricity production from STE plants in Spain over 12 months from 2009 to 2015. Source: Solar Thermal Electricity: Global Outlook 2016, Greenpeace, SolarPACES, ESTELA.

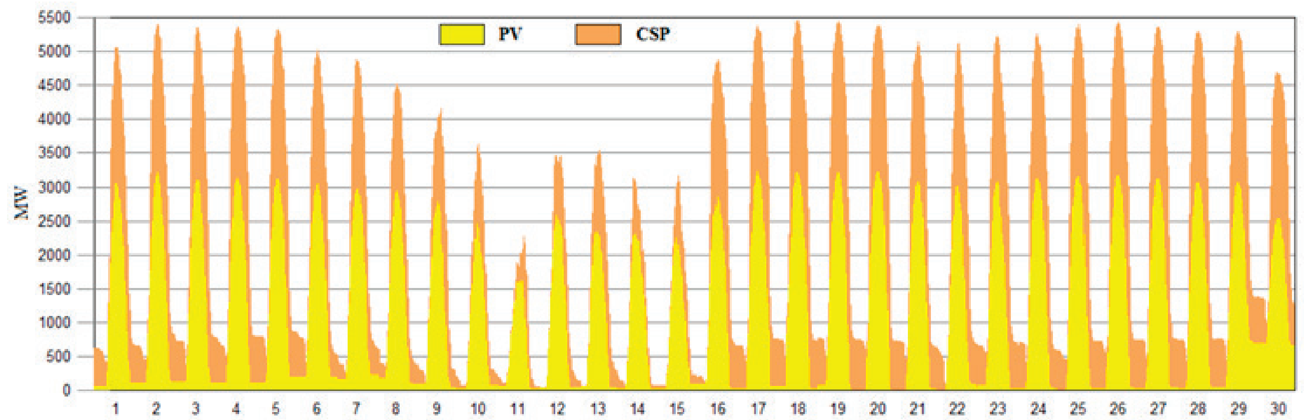
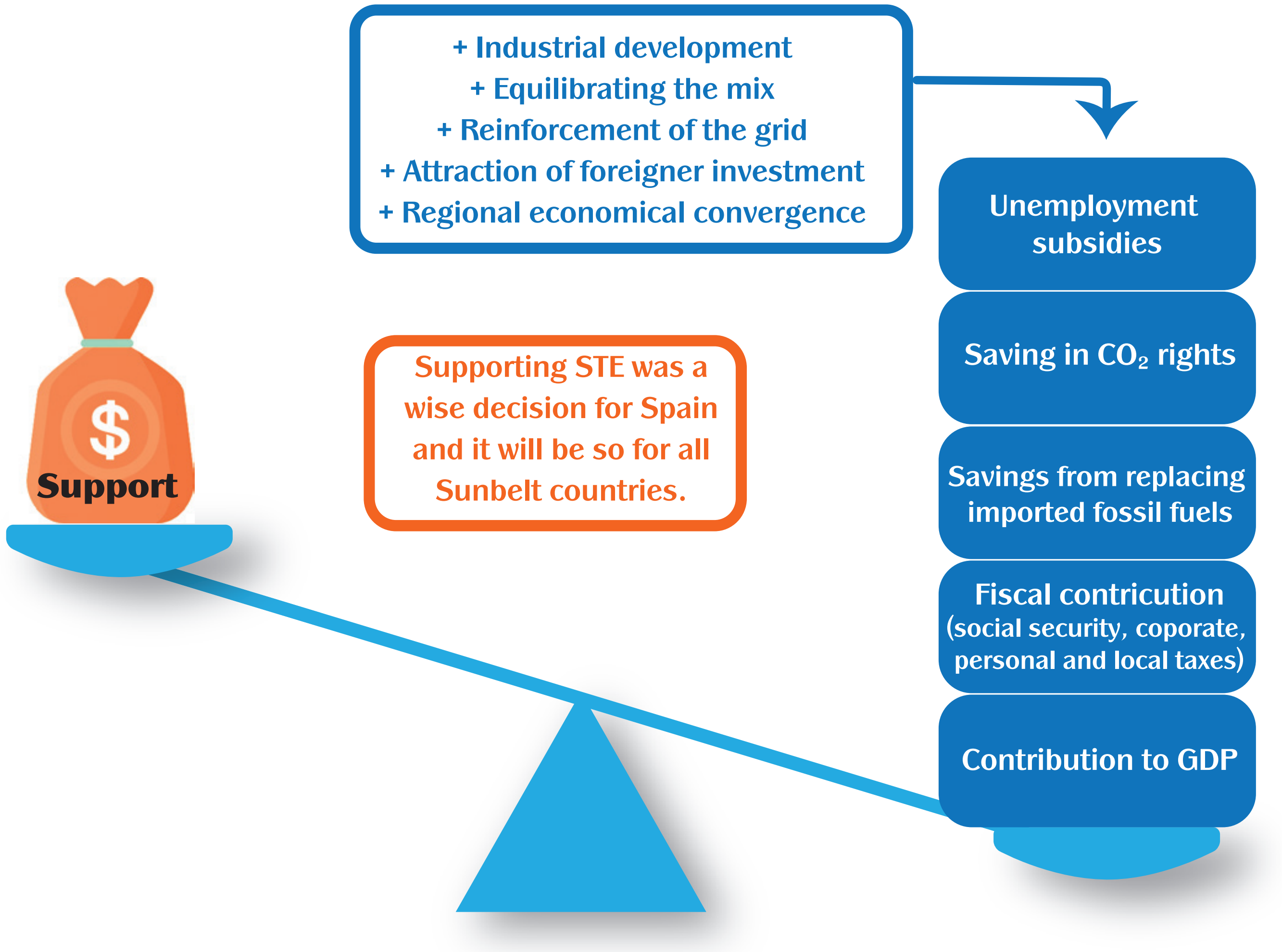


Figure 10: PV and STE generation for June 2015, Spain



Macroeconomic Value

Beyond dispatchability and grid integration issues giving a clear advantage to STE, the macroeconomic impacts of the deployment of this technology should also be taken into account by policy-makers.

The deployment of STE does not just generate electrical power, but brings also a bundle of macroeconomic benefits and positive environmental impacts, more than any other technologies. According to the Deloitte's study on macroeconomic impact of STE industry in Spain in 2011 for Protermosolar[6], the subsidies received on tariffs for the period 2008-2010 in Spain are much lower to the economic returns arising from the construction of the STE plants:

- Reaching national renewable energy penetration targets: The deployment of STE helped Spain supported the achievement of its national renewable energy targets and made Spain the world leader in STE markets and technology.
- Contribution to GDP: Construction and plant operation activities brought a great positive contribution to the Spanish GDP.
- Job creation: On average, building a 100 MW plant brings for the design, manufacturing and assembling nearly 4,000 job-equivalent/yr., and about 60 full job-equivalent/yr. for operation and maintenance during the entire lifespan of the plant.
- RD&I activity's contribution to GDP: STE industry also brings contribution to GDP through Research, Development and Innovation.
- CO_2 emission rights saving: Achieving IEA's roadmap's vision of 1000 GW of installed STE capacity by 2050 would avoid up to 2.1 gigatonnes of CO_2 emissions annually.
- Savings from replacing imported fossil fuels: STE production could avoid importing more than 481,000 tonnes oil equivalent (toe) a year.
- Savings from unemployment subsidies: By providing employment to the sectors being heavily hit by the financial crisis, millions of subsidies for unemployment would be saved.

6 Macroeconomic impact of STE industry in Spain in 2011, carried out by Deloitte, on request of Protermosolar, the Spanish Association of Solar Thermal Industry, October 2011

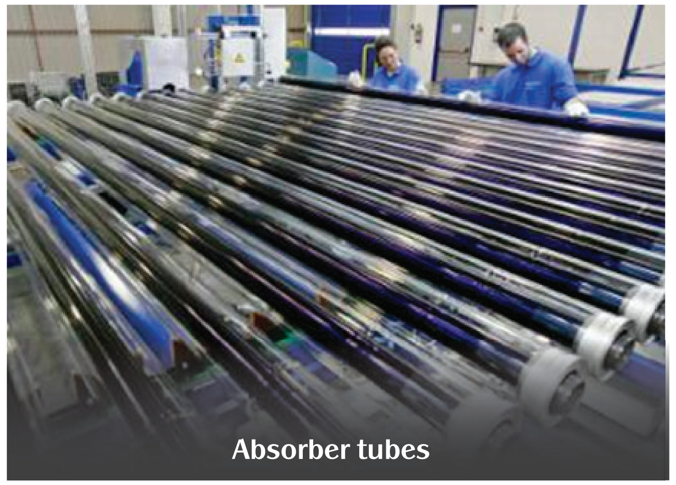
Industry Localization for Solar Field Components

The STE industry has created manufacturing and engineering jobs across Europe, such as solar field components: absorber tubes, mirrors, collector structures, etc. Moreover, other direct jobs are also created during planning and construction phrases, for example, construction works, engineering of conventional power plants, electricity transmission infrastructures and galvanizers, etc.

Moreover, reinforcement of some industry and auxiliary sectors, for instance, piping and tanks, heat exchangers, boilers, telecommunication and control, cleaning, environmentalists, labs, etc., are involved too. Also, enlargement of supplier's subsidiaries in the country, such as promotion, maintenance, spare parts, etc., are also impacted.

The whole value chain of the industry will continue to support local economies in case of more stable STE deployment programmes in Europe.

Examples components needed for STE deployment and other direct effects on industry:


Absorber tubes


Curved mirrors


Collector structure


Reorientation of other mature industries:
- Construction, civil works
- Engineering of conventional power plants
- Electricity Transmission Infrastructures
- Galvanizers


Reinforcement of some industry sectors:
- Piping and tanks
- Heat exchangers
- Boilers- Cabling
- Telecommunication and control


Huge impact in auxiliary sectors:
- Cleaning, environmentalists, labs,
- Road transport
- Training

Images: Photo courtesy of ESTELA members

Image: DLR researcher Miriam Ebert in Almeria tests the reflective properties of a parabolic mirror ©DLR

Example on Local Involvement Potential in MENA Region

According to Ernst & Young findings[7] related to the case study in the MENA region, STE can not only deliver affordable clean energy, but also create local jobs in MENA, at various levels:

- Local / international EPC contractors: limited local know-how for project development;
- Strong share of components and equipment imported (no import taxes, doubt on local ability to supply in quantity and timely);
- Few highly skilled workers.

Ernst & Young also emphasised that market size will be key to create a local industry in MENA region. It is estimated that under a moderate scenario – having 1 GW for home market by 2020, 4,500 permanent jobs will be created across five MENA countries and STE will contribute US $2.2 billion dollar to countries' GDPs. By 2025, cost will drop about 36%. Ernst & Young's calculations show that under a more aggressive scenario – having 5 GW for home market plus 2 GW for potential export, STE will employ 34,000 permanent positions across five MENA countries and bring US $14.3 billion dollar to countries' GDPs. By 2025, cost will drop about 40%.

According to ACWA's estimation, currently more than 36% of the costs for a STE parabolic trough project construction can be sourced locally with positive effects on tariff reduction; this figure amounts to 45% for a central receiver project (see figure 11 and 12).

The reported experiences on the Noor plants in Morocco and on the ongoing plants in South Africa confirmed the high expectations on the macroeconomic impacts on countries' economies.

7 Syndicat des Energies Renouvelables: Etude des retombées économiques potentielles de la filière solaire thermodynamique française, Ernst & Young, 2013 (http://www.enr.fr/userfiles/files/EY_SER%20201311104.pdf)

STE Components	Annual output of a typical factory (MW/year)
Steel structures	50-200 MW
Mirrors	200-400 MW
Receivers	200-400 MW
Electric & electronic	Scalable
HTF	Scalable

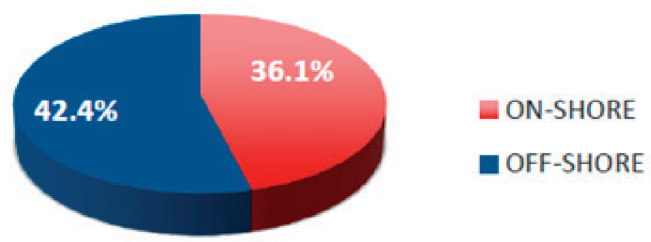


Figure 11: Competitive Localisation of STE Parabolic Trough plant (Middle East), ACWA Power

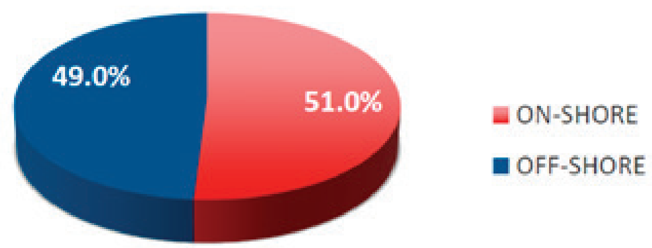
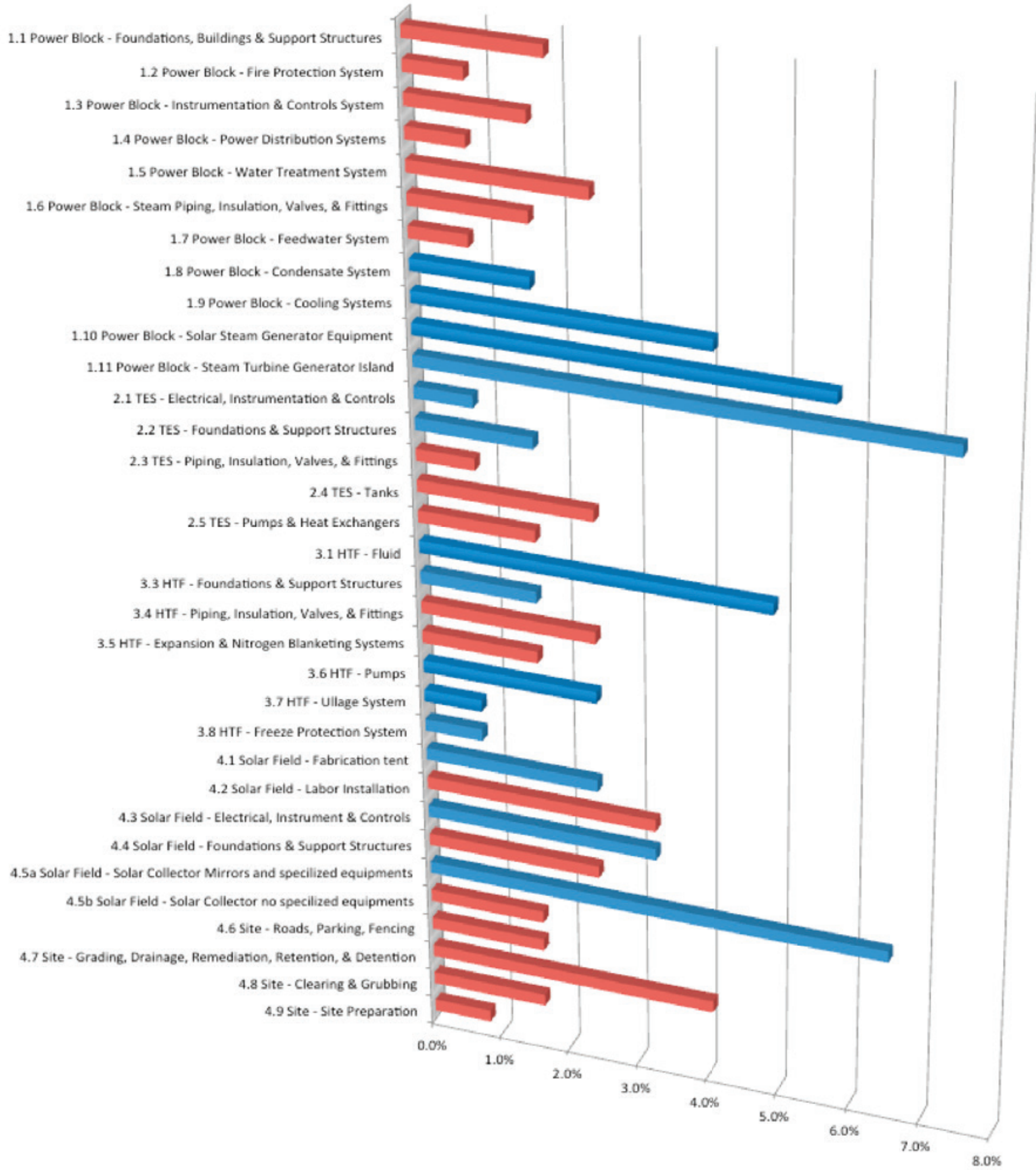
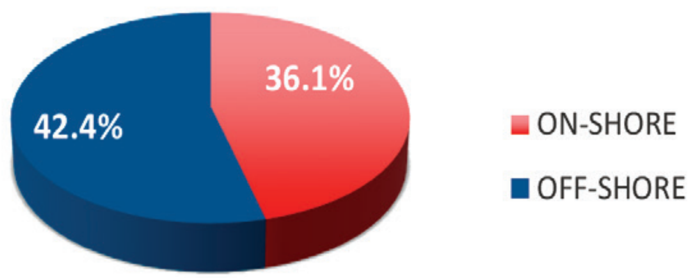


Figure 12: Competitive Localisation of STE Central Receiver plant (Middle East), ACWA Power

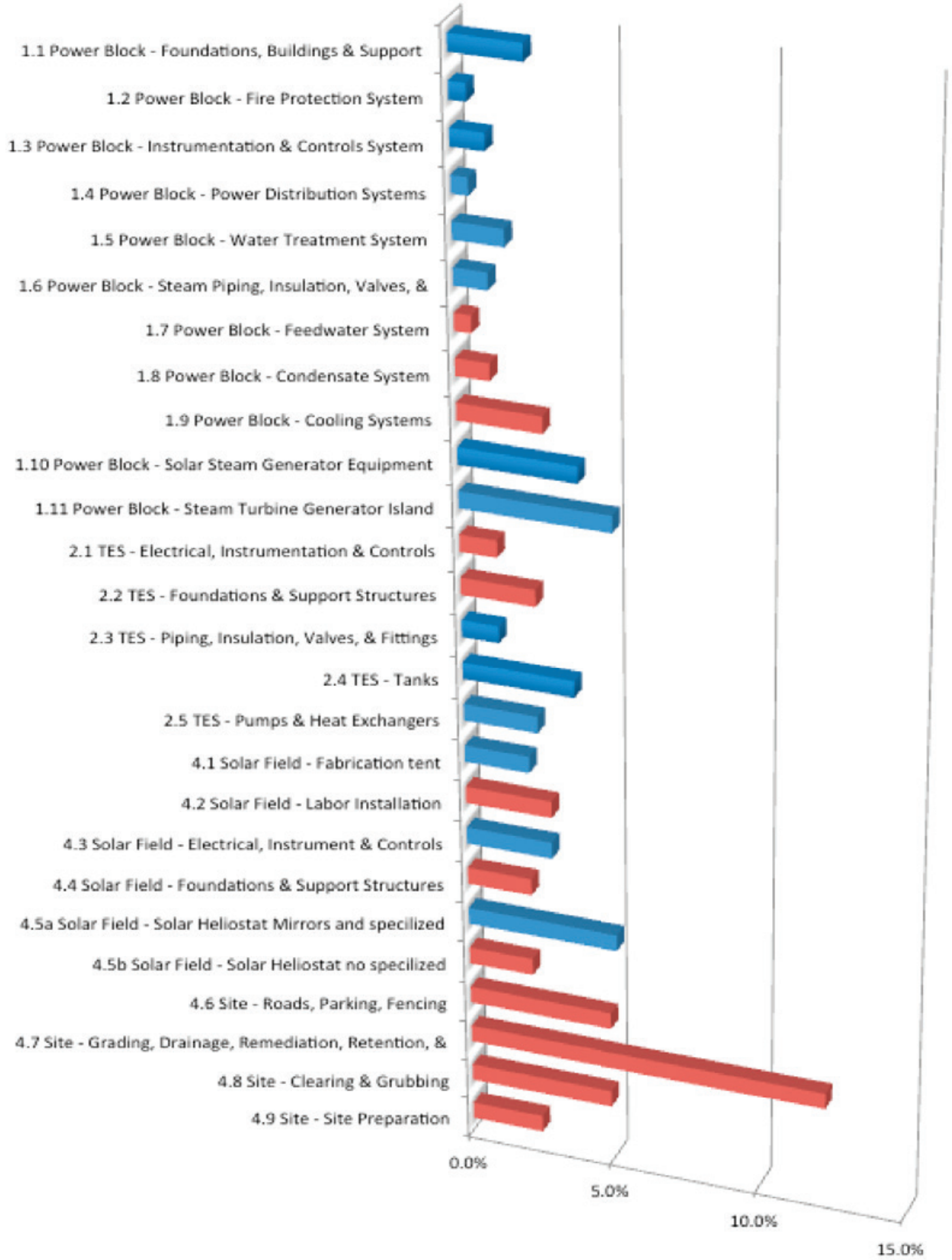
Competitive Localisaion of STE: PArabolic Trough Plant in the Middle East

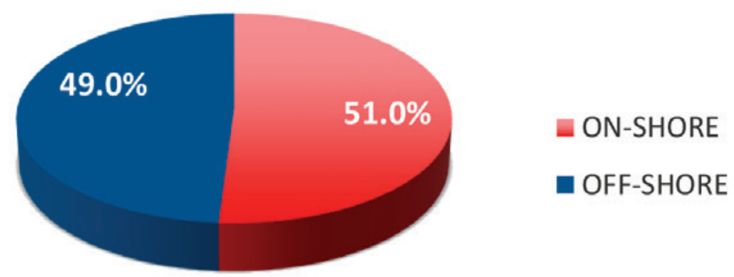




Source: *ACWA Power, 2015*

Competitive Localisaion of STE: Central Receiver Plant in the Middle East





Source: *ACWA Power, 2015*

OUTLOOK

According to the IEA technology Roadmap 2014, STE will be the largest source of electricity in the Sunbelt countries, especially in the Middle East and in Africa. This roadmap forecasts a STE's for global electricity production of 11% by 2050 – STE will reach 980 GW of global deployment by 2050, generating 4,380 TWh power worldwide .

It is estimated in the hi-Ren scenario that that would be 4% of STE installed capacity in Europe by 2050 (about 28 GW).

To put it simply, we would need to triple the current deployment by 2030 and almost six times by 2050. Needless to say that in case of such a deployment, STE would become a fully mature technology with low costs, just like wind and PV.

It is also estimated in this IEA report that combining STE and PV, solar electricity comes close to wind power, hydropower and nuclear, providing up to 27% of global electricity by 2050. In the hi-Ren scenario, solar electricity becomes the leading source of electricity globally from 2030 on.

"The value of STE will increase further as PV is deployed in large amounts, which shaves mid-day peaks and creating or beefing up evening and early morning peaks."

"From a system perspective, STE offers significant advantages over PV, mostly because of its built-in thermal storage capabilities. STE is firm and can be dispatched at the request of power grids operators, when demand peaks in the late afternoon, in the evening, or early morning, or when the sun isn't shining," commented the IEA report.

In order to unlock the true potential of all renewable energy resources, adding flexible RES technologies in the energy mix is a must.

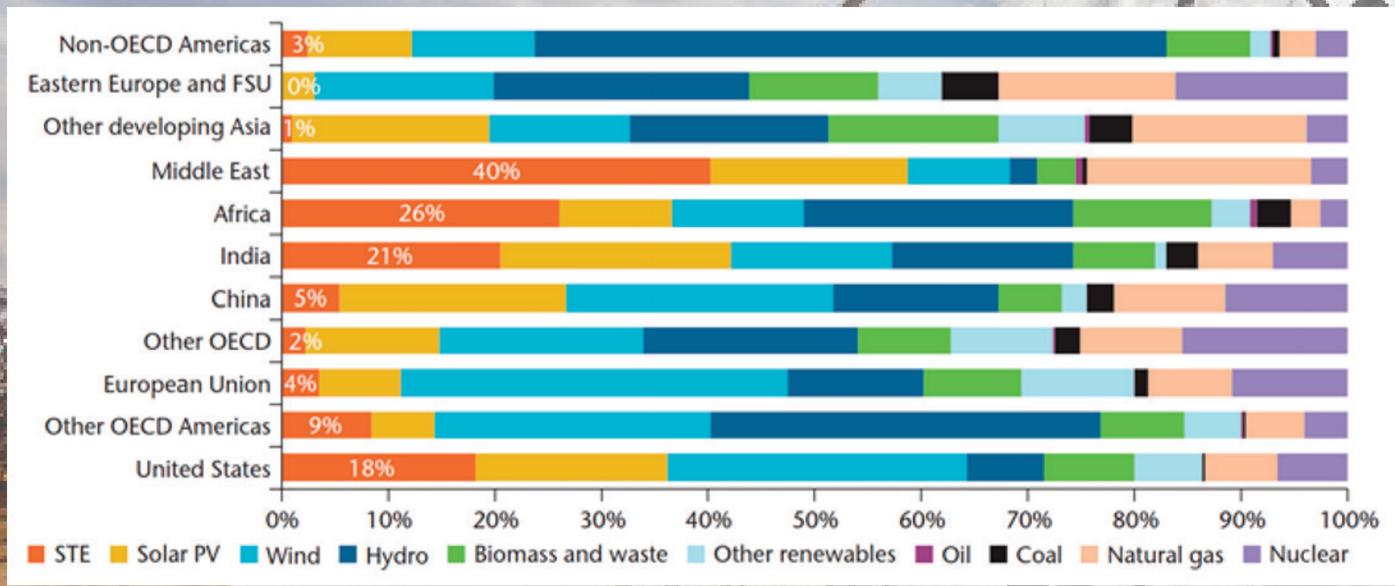


Figure 13: Generation mix by 2050 in the hi-Ren Scenario, by region. Source: IEA, Technology Roadmap: Solar Thermal Electricity, 2014

Image: Majadas ©ACCIONA

CONCLUSION

So far, politically agreed targets for 2030 or 2050 are usually expressed as percentages of RES in a given system.

To date, such targets are still welcome and also helpful, but they leave aside the respective added value of each RES technology.

It's time to set ambitious goals and have them tightly linked to achieve a high ratio of dispatchable vs. non-dispatchable RES generation. It is important to point out at this time – in this crucial energy model transition process – that STE is a technology that can supply baseload electricity like fossil-fueled power stations do. This is vital to realize as most of the old conventional coal and nuclear plants will be decommissioned sooner or later.

On such a basis, far-sighted strategic decisions will open the way to an optimized and better integrated future energy mix. The climate clock is ticking and there's no time to waste. Otherwise, a CO2-free power system by 2050 will not be possible and there will be soon no more business cases for RES investments at all.

- STE is – and will continue to be – the necessary choice when planning addition of new capacity in sunny countries.
- STE will be also the preferred choice for policy makers when all the impacts – technical and economical – are duly taken into account.