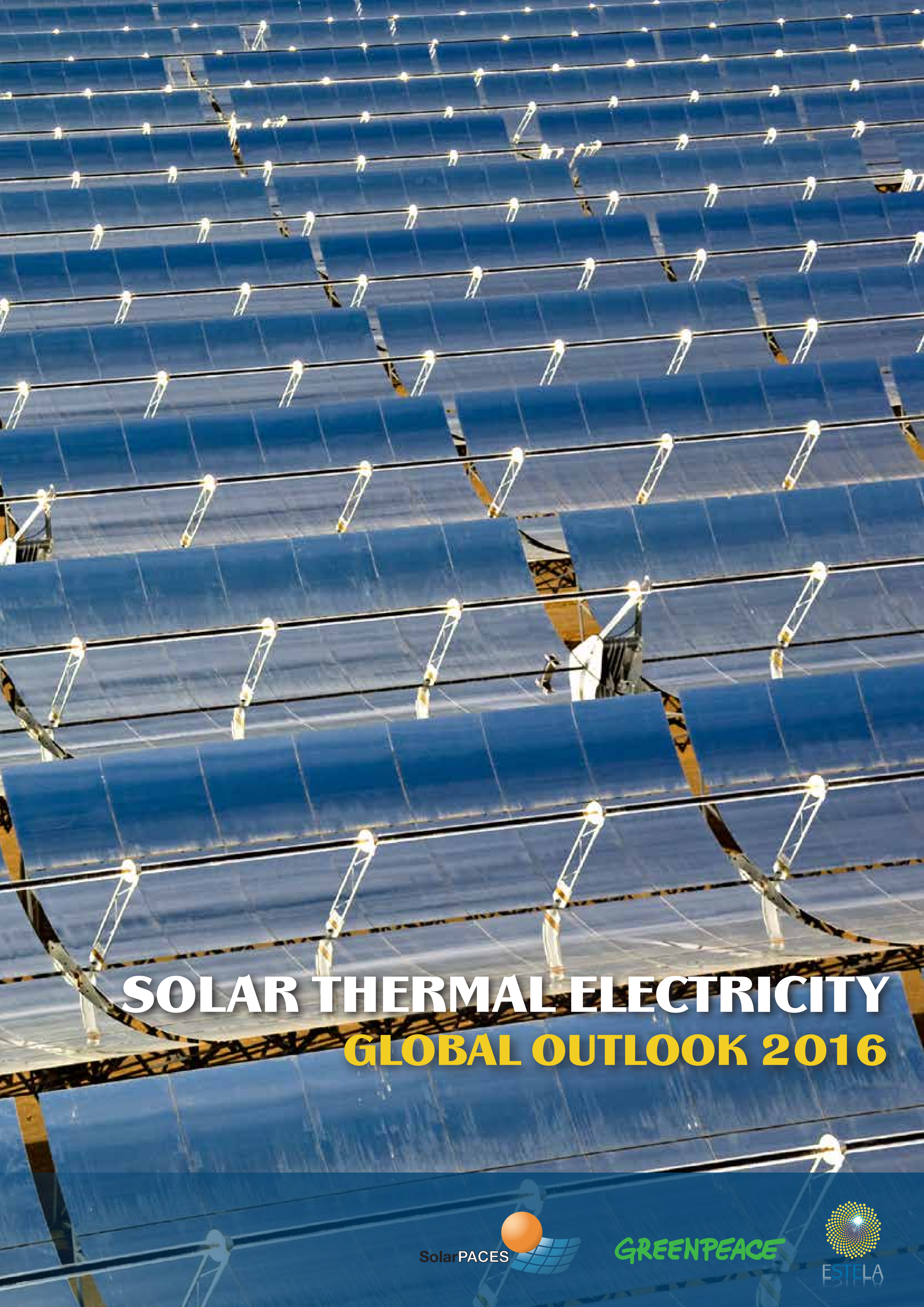

SOLAR THERMAL ELECTRICITY
GLOBAL OUTLOOK 2016

SolarPACES GREENPEACE ESTELA

This type of solar thermal power has an inexhaustible energy source, proven technology performance, and it is environmentally safe. It can be generated in remote deserts and transported to big populations who already have power supply problems. So what are we waiting for?

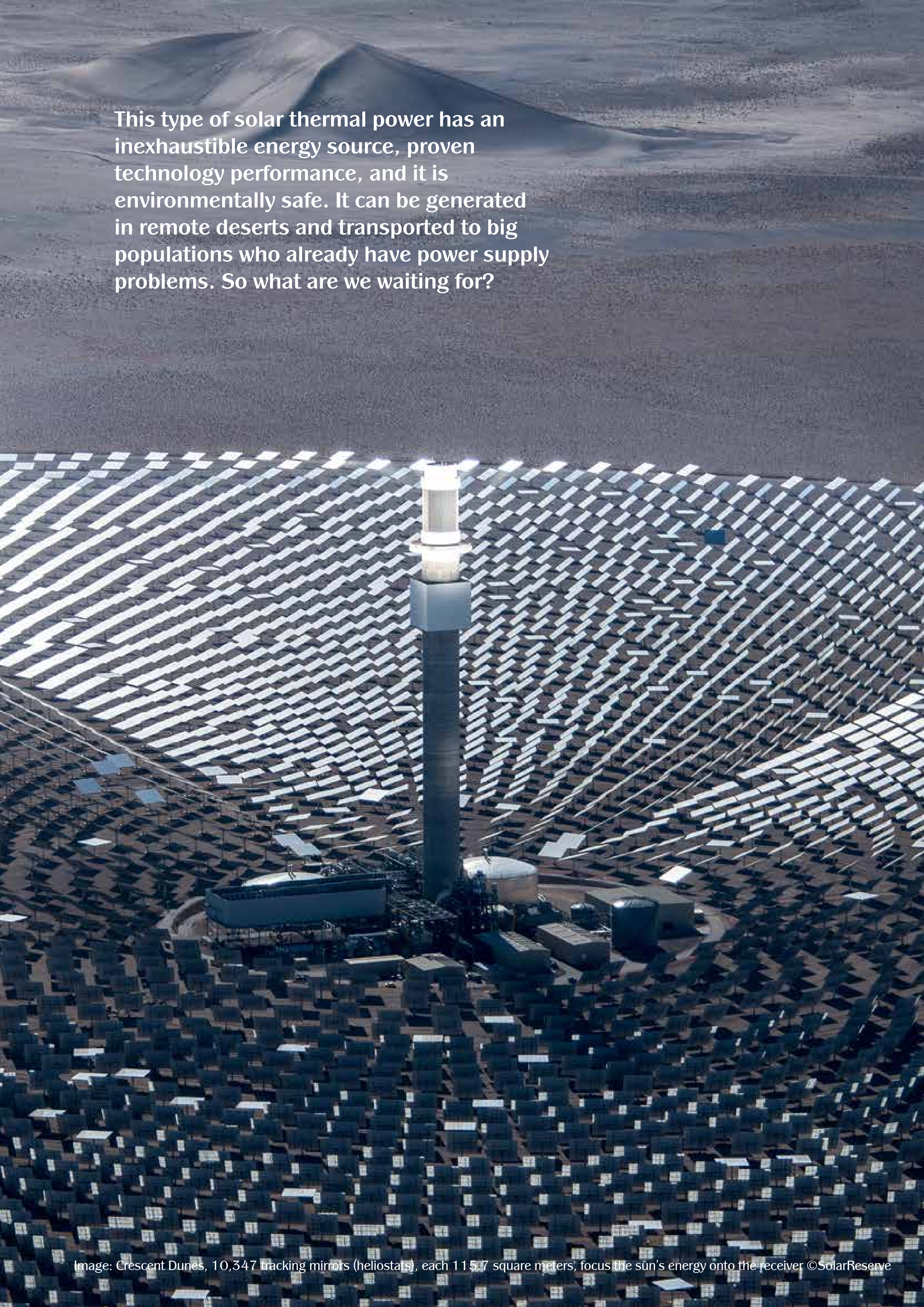

Image: Crescent Dunes, 10,347 tracking mirrors (heliostats), each 115.7 square meters, focus the sun's energy onto the receiver ©SolarReserve

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With advanced industry development and high levels of energy efficiency, solar thermal electricity could meet up to 6 % of the world's power needs by 2030 and 12% by 2050.

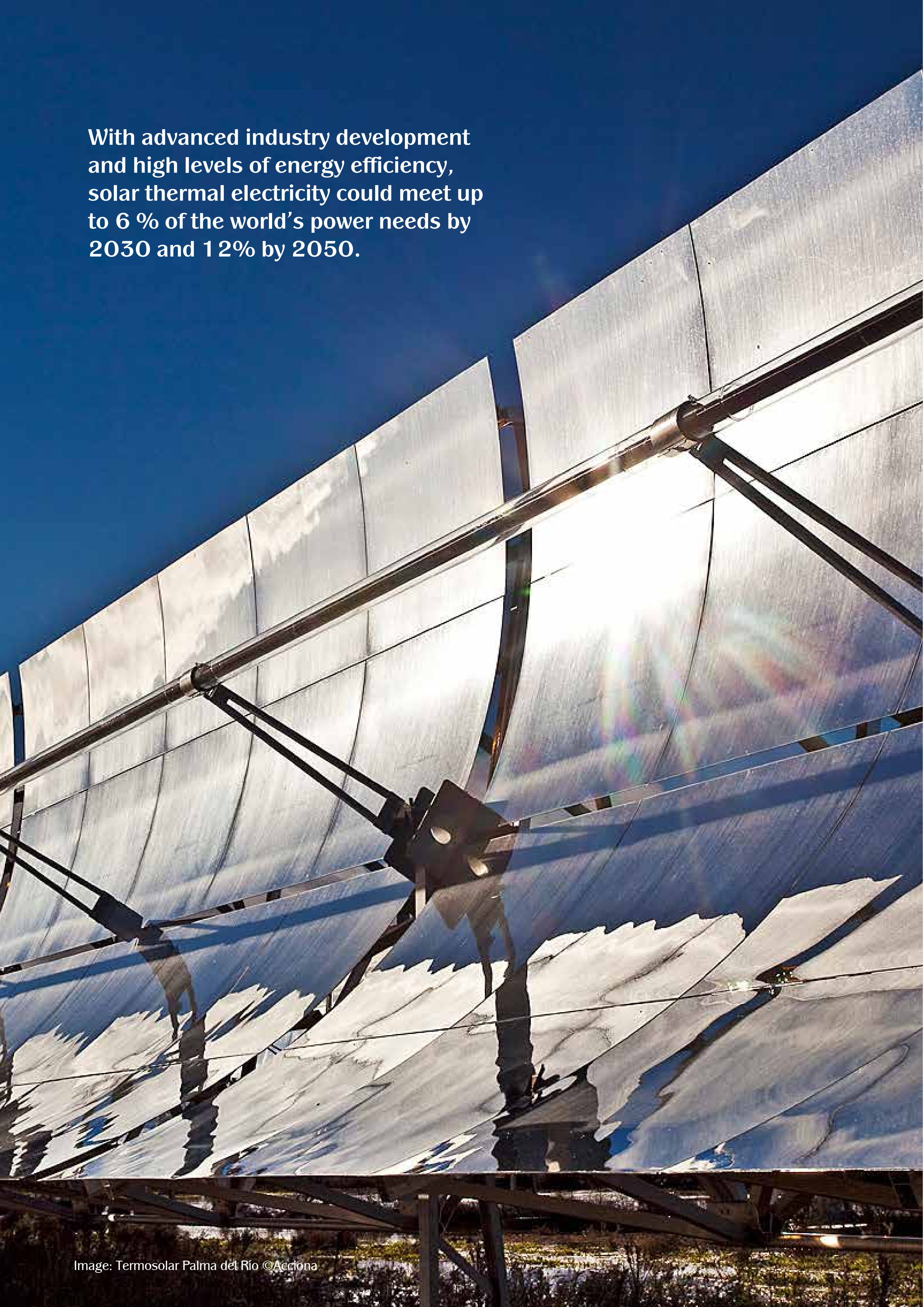

Image: Termosolar Palma del Río ©Acciona

Foreword

This is the 4th joint report of the European Solar Thermal Electricity Association (ESTELA), Greenpeace International and SolarPACES since 2003.

Just before the last edition was published in 2009, the annual market volume for STE hit the one billion US dollar mark. By the end of 2015, the sector concluded nearly a decade of strong growth. Whilst the installed capacity of STE in 2006 was only 0.5 GW, it has increased by a factor of 10 to almost 5 GW today.

The STE sector is now on a steady development pathway towards double digit GW capacity within the next 5 years, establishing a solid base for future growth. Especially for the firm supply of dispatchable power, for water purification and desalination purposes and for industrial process heat needs, STE technologies are in high demand and offer specific technical advantages.

We are delighted to see STE on a solid growth pathway and poised to establish itself as a third big player in the new “sustainable power generation industry”. With the potential for cost curves to decline significantly, STE has the potential to be economically viable in sunny regions across the world.

Although the sector experienced challenges due to political instability in key markets and strong competition with other renewable energy technologies – especially photovoltaic – the authors of this report are confident that solar thermal electricity is key to achieve a 100% renewables share by 2050 in a wise mix with other renewables. Bearing in mind that fighting climate change is among the most important tasks of mankind today, it is essential that the power generation sector becomes virtually CO_2 free by 2050.

Greenpeace developed a global energy vision – the Energy (R)evolution scenario – which provides a practical blueprint for rapidly cutting energy-related CO_2 emissions in order to help ensure that greenhouse gas emissions peak and then fall by 2020. This can be achieved whilst ensuring economies in China, India and other developing nations have access to the energy that they need in order to develop and STE plays an important role especially in this context.

The Global Solar Thermal Electricity Outlook 2016 goes one step further. Whilst the moderate STE market scenario is in line with the Energy (R)evolution scenario, the advanced scenario shows that this technology has even more to offer.

Globally, the STE industry could employ by 2030 as many as 2.7 million people whose job will be to take up a new role in fighting climate change and deliver up to 12% of the world’s electricity by 2050.

This is an inspiring vision not just for our political leaders, in light of the truly historic Paris Agreement agreed by 195 countries at the COP21 climate conference in December 2015, but also millions of citizens around the world: STE technology can indeed contribute to boosting local economies, providing reliable energy supply and most importantly, reducing CO_2 emissions by a significant amount in order to limit global temperature increase to 1.5°C. The climate clock is ticking and there’s no time to waste. To achieve zero emissions by 2050, we must act now and set ambitious goals on RES shares in the energy mix, aiming at legally binding targets to fast-track the switch from fossil fuels to renewable.

Dr. Sven Teske
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Dr. Luis Crespo
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Executive Secretary IEA SolarPACES

Avant-propos

Ce document est le 4ème rapport conjoint réalisé par l'Association Européenne pour la Promotion de l'Electricité Solaire Thermique (ESTELA), Greenpeace International et SolarPACES depuis 2003.

Peu avant la publication de notre dernier rapport en 2009, le marché de l'énergie solaire thermique avait atteint 1 milliard de dollars. Le secteur achève presqu'une décennie de croissance forte et continue en cette fin 2015. En effet, la capacité des installations d'énergie solaire thermique a été multipliée par 10, passant de 0,5 GW à presque 5 GW aujourd'hui.

Le secteur de l'énergie solaire thermique est en pleine expansion, et consolide ses bases pour une croissance future. Les technologies de l'énergie solaire thermique sont très demandées et proposent des avantages techniques spécifiques, notamment pour la redistribution de l'énergie, la purification et la désalinisation de l'eau et les procédés industriels gourmands en chaleur.

Nous sommes ravis de voir l'énergie solaire thermique prendre le chemin d'une croissance solide, en route pour devenir le 3ème acteur majeur dans le nouveau secteur de « la production d'énergie durable». Avec des coûts en baisse constante, l'énergie solaire thermique a le potentiel de devenir économiquement viable dans toutes les régions du monde dotées d'un bon niveau d'ensoleillement.

Malgré les défis imposés par l'instabilité politique dans des marchés clefs ainsi et par une forte concurrence avec d'autres secteurs d'énergie renouvelable, le photovoltaïque en particulier, les auteurs de ce rapport sont certains que l'énergie solaire thermique reste essentiel à la réalisation de l'objectif de 100% d'énergies renouvelables en 2050, grâce à un savant mélange avec d'autres technologies. La lutte contre le changement climatique étant l'un des devoirs les plus importants de l'humanité aujourd'hui, il est impératif pour le secteur énergétique de s'affranchir presqu'entièrement du CO_2 d'ici 2050.

Greenpeace a développé une vision énergétique globale, le Scénario de la Transition Energétique (Energy (R)evolution); un guide pratique pour réduire rapidement les émissions de CO_2 liées à la production d'énergie, afin que les rejets de gaz à effet de serre atteignent leur maximum puis retombent avant 2020. Ceci est possible en faisant en sorte que les économies de pays émergents, tels que la Chine ou l'Inde, aient accès à l'énergie dont elles ont besoin pour leurs développements et en donnant un rôle important à l'énergie solaire thermique dans ce contexte.

Le rapport sur les Perspectives Globales de l'Energie Solaire Thermique 2016 (The Global Solar Thermal Electricity Outlook 2016) va encore plus loin. Tandis que les scénarios modérés concernant le marché de l'énergie solaire thermique sont en accord avec celui de la Transition Energétique, les scénarios plus avancés montre que cette technologie peut offrir encore plus.

Globalement, l'industrie de l'énergie solaire thermique pourrait créer jusqu'à 2,7 millions d'emplois d'ici 2030, prenant ainsi une nouvelle place dans la lutte contre le changement climatique et atteignant une part de 12% dans la production mondiale d'électricité avant 2050.

Cette perspective est une source d'inspiration non seulement pour nos dirigeants politiques dans la continuité de l'accord historique de Paris, entre les 195 pays ayant participé à la conférence sur le climat, la COP 21, en décembre 2015, mais aussi pour des millions de citoyens à travers le monde: l'énergie solaire thermique peut effectivement donner un coup de pouce aux économies locales en fournissant une énergie fiable et surtout en réduisant les rejets de CO_2 de manière significative dans la perspective de limiter le réchauffement global à 1,5°C. L'horloge climatique tourne et il n'y a pas de temps à perdre. Afin de parvenir à « zéro émission » en 2050 nous devons agir maintenant et définir des cibles ambitieuses concernant la part des ressources renouvelables dans le mix énergétique. Nous avons besoin d'objectifs juridiquement contraignants pour accélérer la transition de l'énergie fossile vers l'énergie renouvelable.

Dr. Sven Teske
Greenpeace International

Dr. Luis Crespo
Président, ESTELA

Dr. Christoph Richter
Secrétaire, IEA SolarPACES

تمهيد

هذا التقرير هو الرابع الذي تصدره الجمعية الأوروبية للكهرباء الشمسية الحرارية («إستيلا») وغرينبيس الدوليّة ومنظّمة الطاقة الشمسية وأنظمة الطاقة الكيميائية «سولار بيسِز» معاً منذ 2003.

قبل نشر النسخة السابقة من التقرير في 2009 بلغ حجم السوق السنويّ للطاقة الشمسيّة الحرارية حافة المليار دولار أميركي. مع نهاية 2015 اختتم القطاع مرحلة نموّ كبير استمرّت حوالى عقد من الزمن. ففيما لم تتجاوز القدرة الاسمية للطاقة الشمسيّة الحرارية 0,5جيغاواط في 2006 ، شهدت ارتفاعاً هائلاً لتصل اليوم إلى حوالى ٥ جيغاواط2015

حالياً يشهد قطاع الطاقة الشمسية الحرارية نموّاً مستقرّاً نحو قدرة من عددين في السنوات الخمس المقبلة، ليشكّل أساساً متينا لنموّ مستقبلي. فعلى مستويات الامداد الثابت بالطاقة القابلة للتوزيع، وتكرير وتحلية المياه، وتوليد الحرارة من أجل العمليات الصناعية، تشهد تكنولوجيات الطاقة الشمسية الحرارية طلباً مرتفعاً كما انها توفّر مزايا تقنية محدّدة.

يسعدنا أن نشهد تقدّم الطاقة الشمسية الحرارية بثبات على طريق النمو واتجاه القطاع إلى احتلال المرتبة الثالثة بين كبار اللاعبين في «صناعة توليد الطاقة المستدامة» الجديدة. ومع امكانات هبوط منحنيات التكاليف بشكل كبير فقد تصبح الطاقة الشمسية الحرارية قابلة للحياة اقتصادياً في المناطق المشمسة حول العالم.

بالرغم من التحديات التي شهدها القطاع نتيجة الاضطرابات السياسية في أسواق رئيسية والمنافسة الكبرى من تكنولوجيات متجدّدة أخرى، لا سيما الفوتوفولطائيات، يؤكّد واضعو هذا التقرير على الحاجة إلى الدور المحوريّ الذي ستلعبه الكهرباء الشمسية الحرارية للوصول إلى 100 ٪ طاقة متجدّدة مع العام 2050، بالتآلف مع طاقات متجدّدة أخرى. ومع الأخذ في الاعتبار أن مكافحة تغيّر المناخ هي إحدى أهمّ مهامّ البشرية اليوم، من الضروري تجريد قطاع توليد الطاقة من ثاني أكسيد الكربون بالكامل تقريباً مع العام 2050 .

صاغت غرينبيس رؤية شاملة للطاقة أوضحتها في تقريرها «سيناريو ثورة الطاقة» الذي يطرح خطّة عمل لتخفيض سريع لانبعاثات ثاني أكسيد الكربون المرتبطة بالطاقة وضمان بلوغ غازات الدفيئة المنبعثة حدها الأقصى وبدء تراجعها في 2020 . ويمكن تحقيق ذلك مع ضمان حصول اقتصادات الصين والهند وغيرهما من الدول النامية على كمية الطاقة اللازمة للنموّ، حيث تلعب الطاقة الشمسية الحرارية دوراً مهماً في هذا الإطار بالذات.

ويذهب تقرير «المشهد العالمي للكهرباء الشمسية الحرارية 2016 أبعد من ذلك. ففيما يتماشى سيناريو سوق الكهرباء الشمسية الحرارية المعتدل مع سيناريو ثورة الطاقة، يثبت السيناريو المتقدّم أن هذه التكنولوجيا لديها أكثر بكثير لتقدّمه.

عالميّاً يمكن أن توظّف صناعة الكهرباء في العام 2030 ما قد يصل إلى ٧,٢ ملايين شخص، يتولون دوراً جديداً في مكافحة تغيّر المناخ لتوفير حوالى 12٪ من كهرباء العالم مع حلول 2050 .

هذه الرؤية مُلهِمة فعلاً، ليس فحسب بالنسبة إلى القادة السياسيين على ضوء اتفاق باريس التاريخي الذي أبرمته 195دولة في مؤتمر الأطراف الـ21للمناخ في كانون الأول/ديسمبر 2015 ، بل كذلك لملايين السكان حول العالم. فتكنولوجيا الكهرباء الشمسية الحرارية يمكن أن تساهم في تعزيز الاقتصادات المحلية وتوفير إمداد موثوق من الطاقة، وبالطبع في تقليص كبير لانبعاثات ثاني أكسيد الكربون في سبيل منع ارتفاع الحرارة الشامل أكثر من 1,5درجات مئوية. ساعة المناخ تدقّ والوقت ثمين. بالتالي، كي نتمكن من وقف الانبعاثات بالكامل مع العام 2050 علينا التحرّك فوراً لتحديد أهداف جريئة على مستوى حصص أنظمة الطاقة المتجدّدة في خليط الطاقة المعتمد، مع السعي إلى أهداف ملزمة قانوناً لتسريع الانتقال من الطاقة الأحفورية إلى المتجدّدة.

د. كريستوف ريشتر
أمين السرّ التنفيذي في "سولار بيسز"
الوكالة الدولية للطاقة

د. لويس كريسبو
رئيس "إستيلا"

د. سفين تيسك
غرينبيس الدولية

Executive Summary

What is Solar Thermal Electricity?

Solar Thermal Electricity, also known as concentrating solar power, produces heat or generates electricity by using mirrors to concentrate the sun's rays to a temperature typically between 400ºC and 1000ºC. There are a variety of mirror shapes, sun-tracking methods and ways to provide useful energy, but they all work under the same principle: driving a heat engine, usually a steam turbine, to generate electricity that can then be fed into the grid. The capacity of solar thermal power plants in operation today ranges between several MW and 400 MW, but could be larger still. Unlike photovoltaic installations, STE does not make sense at the level of distributed generation but at a large system scale. STE specifically can be integrated with thermal storage or in hybrid operation, offering firm capacity and dispatchable power on demand. This allows STE to balance, at a lower cost, CO_2-free intermittent energy sources, such as wind. STE is able to meet both peak and baseload demand.

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.

What will be the size of the market?

In the last ten years, STE has expanded rapidly from a newly introduced technology to become a reliable, energy generation solution. However, by the end of 2015, only 4.9 GW of solar thermal electricity projects were operational worldwide. The projects under construction at the time of writing will add at least another 300 MW over the next two years. These projects are located mostly in South Africa, India, the Middle East and Morocco.

The potential for STE to meet global electricity demand is far greater. Our analysis based on the Advanced scenario assumptions shows that concentrating solar power could meet up to 12% of the world's projected power needs in 2050.

Even under the Moderate scenario assumptions for future market development, the combined solar thermal power capacity worldwide would amount to approximately 20 GW by 2020 and 800 GW by 2050, with the deployment of 61 GW/yr. This would represent around 5% of global demand in 2050.

What are the benefits?

For this study, Greenpeace used a model to generate scenarios based on a Reference scenario or "business as usual" for world governments, as well as Moderate and Advanced scenarios based on realistic policies to support development of this clean, renewable technology. Under the Moderate scenario, the countries with the most sun resources, together, could:

- Create over €16 billion investment in 2020,[1] peaking at €162 billion in 2050;
- Create more than 70,000 jobs by 2020, and about 938,000 jobs in 2050; and
- Save 32 million tonnes of CO_2 annually in 2020 and rising to 1.2 billion tonnes in 2050.

To put the emission reduction figures in perspective, the CO_2 generated by China alone was 10.5 billion tonnes in 2013 while Germany's emissions amounted to 767 million tonnes. A recent report[2] estimated that global CO_2 emissions from fossil fuel use were 32.2 billion tonnes in 2013 – reaching a record high, which is 56.1% above the emission level in 1990 and 2.3% above 2012. In other words, at current rates, we will use up the remaining so-called "carbon budget" in the next 30 years and be unable to limit global temperature increases to 2ºC.

In the light of the Paris Agreement, agreed by nearly 200 countries across the world, we urgently need to revise current EU and national targets in order to achieve the goal of limiting global temperature increase to 1.5ºC. The 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. Only a stronger emissions target in line with the rapid decarbonisation of the energy sector and a higher share of renewable energy consumption will make this goal achievable.

A strong STE deployment programme, ensuring a STE market volume of around 30 GW per year, could avoid the need for new fossil fuel power plants and replace decommissioned fossil fuel power plants. In this way, STE technologies

1 About US$ 18.4 billion in 2020 (exchange rate €1= US$ 1.15).

2 IEA, 2015 preliminary edition, *CO_2 Emissions from Fuel Combustion.*

would strongly contribute to the reduction of global CO_2 emissions. STE dispatchability capabilities would also enable a further reduction in emissions by allowing increased penetration of intermittent renewable energy technologies in a reliable and affordable way.

For about 5% of the global investment in energy infrastructure of €158-186 billion each year, STE is a technology that can contribute to a "New Green Deal" for the economy.

What will determine the cost reduction curve reductions?

Costs for STE have already declined but further reductions are possible. The primary factor affecting the cost of STE is market volume. Just as with any other energy technology, costs come down along a solid deployment programme based on a political decision to establish a technology. Such a political decision leads to a positive investment climate with preferential financing conditions and/or tax and investment incentives. This will also create the conditions for progressively bringing to market innovative solutions that will, in turn, further reduce costs and increase business opportunities beyond the electricity sector in countries that decide to launch such programmes.

What kinds of measures are needed to increase deployment of STE?

In the last ten years, some national government decisions had boosted STE, triggering today's growth in installations worldwide. At the same time, the European market came to a screeching halt after Spain implemented extremely detrimental and retrospective changes to its solar market. Despite this, Spain remains the global market leader for STE, with almost half of STE capacity, 2.3 GW, installed in that country alone.

The measures needed to make solar thermal electricity work are:

- Financial incentives and national targets: such as a guaranteed sale price for electricity, feed-in-tariffs, renewable portfolio standards or preferential loan programs that apply to solar thermal electricity technologies as well as schemes that put a price on carbon emissions either through cap-and-trade systems or carbon taxes.
- Installation of new electricity transfer facilities and market mechanisms between nations and continents through the appropriate infrastructure and political and economic arrangements, so solar thermal energy can be moved from the best production sites to areas of high demand.
- Stable, long-term support for research and development to fully exploit the potential for further technology improvements and cost reduction.

With these key measures foundations in place, STE would be set to take its place as an important part of the world's energy mix.

Table 1: **Annual and cummulative CO_2 savings from STE Scenarios**

	2015	2020	2030	2040	2050
CO_2 Savings in million tonnes					
Reference (Current Policy)					
Annual CO_2 savings	9	17	43	86	143
Cumulative CO_2 savings	25	93	390	1,025	2,197
Moderate					
Annual CO_2 savings	9	35	212	653	1,251
Cumulative CO_2 savings	1,390	1,499	2,595	6,983	16,657
Advanced					
Annual CO_2 savings	9	67	580	1,564	2,772
Cumulative CO_2 savings	1,390	1,566	4,431	15,445	37,465

Figure 1: **Annual and cumulative CO_2 savings from STE Scenarios**

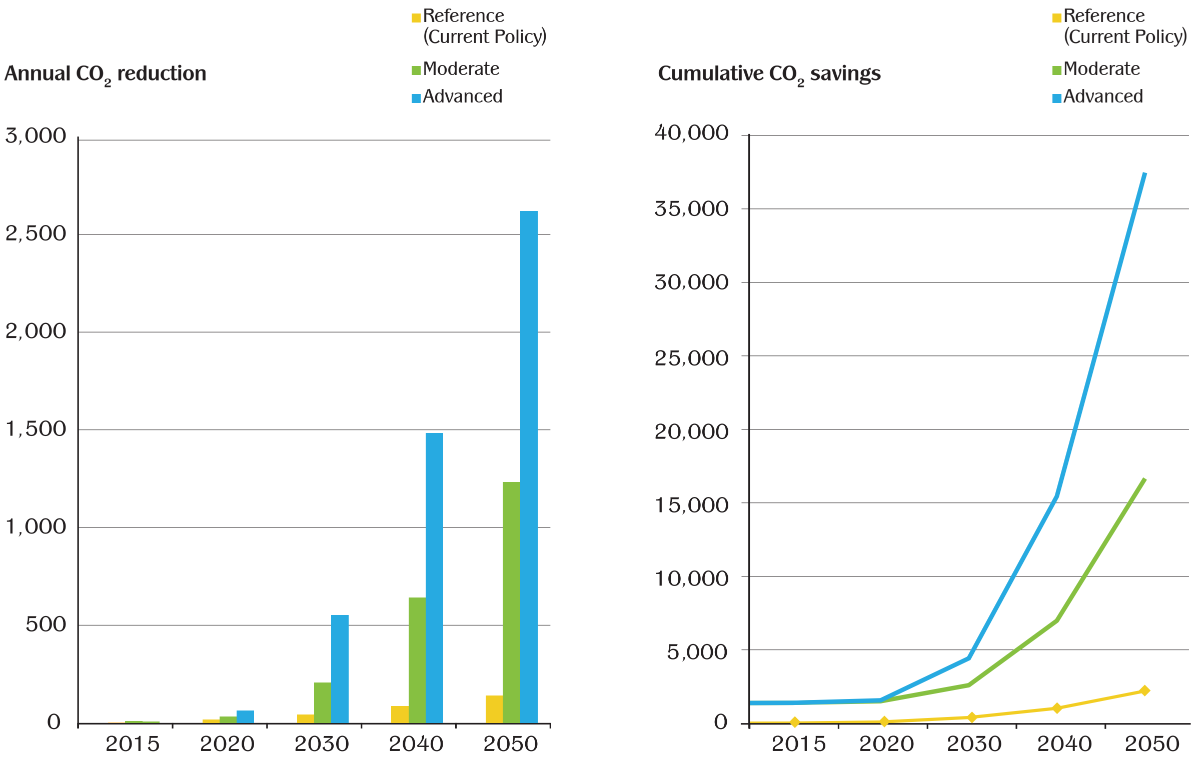


Table 2: **Market Projections for STE Development between 2015 and 2050 under Reference (Current Policy), Moderate and Advanced (Aggressive Development) Scenarios**

		2015	2020	2030	2040	2050
Investment and employment						
Reference (Current Policy)						
Annual Installation	MW/a	1,171	3,619	5,651	9,500	12,427
Cost	€/kW	4,287	3,485	2,814	2,688	2,674
Investment	€bn/a	1.57	1.34	2.15	4.60	4.53
Employment Job-year		18,904	16,981	29,180	62,545	70,197
Moderate STE Market growth						
Annual Installation	MW/a	1,075	4,834	18,876	36,652	61,654
Cost	€/kW	4,287	3,485	2,814	2,666	2,637
Investment	€bn/a	4.61	16.85	53.13	97.71	162.61
Employment Job-year		16,964	70,051	269,733	574,049	935,995
Advanced STE Market Growth						
Annual Installation	MW/a	797	11,950	49,758	75,455	131,143
Cost	€/kW	4,287	3,485	2,814	2,663	2,577
Investment	€bn/a	3.42	41.65	140.04	169.10	209.76
Employment Job-year		12,985	169,237	712,674	1,072,328	1,443,265

Image: Gemasolar Thermosolar Plant ©SENER/Torresol Energy

Synthèse

Qu'est-ce que l'énergie solaire thermique ?

L'énergie solaire thermique, ou « solaire thermique à concentration », produit de la chaleur ou de l'électricité grâce à des miroirs qui concentrent les rayons du soleil à une température comprise entre 400 et 1000°C. Il existe une grande variété de formes de miroirs, de techniques de centrage des rayons et de méthodes de production d'énergie utile, mais le principe reste le même : faire fonctionner un moteur thermique, typiquement une turbine à vapeur, pour produire de l'électricité qui peut être ensuite injectée dans le réseau. Aujourd'hui, la capacité des centrales solaires thermiques en activité varie entre quelques MW et 400 MW, mais elle peut être encore accrue. Contrairement aux installations photovoltaïques, l'énergie solaire thermique n'a de sens que dans des systèmes de taille industrielle. En particulier, cette énergie peut être intégrée dans des systèmes de stockage thermique ou des régimes hybrides, offrant une capacité fiable et une énergie redistribuable sur demande. L'énergie solaire thermique est ainsi capable d'équilibrer, à moindres coûts, des sources intermittentes d'énergie sans CO_2, telles que l'éolien ou le photovoltaïque Le solaire thermique est en mesure de répondre à la demande de pointe aussi bien qu'aux besoins en charge de base.

L'énergie solaire thermique est une source d'électricité sans carbone, particulièrement adaptée aux régions à taux d'ensoleillement élevé : l'Europe du sud, l'Afrique du nord et le Moyen-Orient, l'Afrique du Sud, certaines zones de l'Inde, de la Chine, le sud des Etats-Unis et l'Australie.

Quelle sera sa part du marché ?

Durant les dix dernières années, l'énergie solaire thermique a évolué : au départ technologie nouvelle, le solaire thermique est devenu une source fiable de production d'énergie. Néanmoins, en cette fin 2015, seulement 5 GW d'électricité solaire thermique sont installés dans le monde. Les projets en cours de réalisation au moment de la rédaction de ce rapport apporteront 820 MW supplémentaires dans les deux années à venir. Ces projets se trouvent principalement en Afrique du Sud, en Inde, au Moyen-Orient et au Maroc.

L'énergie solaire thermique possède un potentiel très élevé de répondre aux demandes énergétiques globales. D'après nos analyses, l'énergie solaire thermique pourrait pourvoir 12% des besoins mondiaux prévus pour 2050.

Même les prévisions les plus modérées concernant le développement futur du marché montrent que la capacité des différentes formes d'énergies solaires pourrait atteindre 20 GW en 2020 et 800 GW en 2050, grâce à une augmentation de 61 GW/an. Ce qui représentera 5% de la demande globale en 2050.

Quels sont les bénéfices ?

Pour les besoins de cette étude, Greenpeace a utilisé un modèle pour générer des scénarios basés sur un scénario de référence, ou de routine, pour les gouvernements du monde, ainsi que des scénarios Modérés et Avancés basés sur des politiques réalistes afin de soutenir le développement de cette énergie propre et renouvelable. Selon le scénario Modéré, les pays possédant le plus de ressources solaires, pourraient :

- Générer plus de 16 milliards d'euros d'investissement en 2020, culminant à 162 milliards d'euros en 2050 ;
- Créer plus de 70 000 emplois d'ici 2020, et autour de 938 000 emplois en 2050 ; et
- Eviter l'émission de 32 millions de tonnes de CO_2 par an jusqu'en 2020, allant jusqu'à 1,2 milliards de tonnes en 2050.

Pour mieux comprendre les chiffres de réduction d'émission de CO_2, on note que 10,5 milliards de tonnes ont été émis par la Chine seule en 2013, tandis que l'Allemagne a rejeté 767 millions de tonnes. Un rapport récent estime que les émissions globales de CO_2 dues à l'énergie fossile étaient de 32,2 milliards de tonnes en 2013 – un record supérieur de 56,1% aux niveaux de 1990 et de 2,3% à ceux de 2012. En d'autres termes, aux taux actuels nous épuiserons le reste du « budget carbone » sur les 30 prochaines années et nous serons incapables de limiter le réchauffement à 2°C.

Suite à l'Accord de Paris entre presque 200 pays, nous avons un besoin urgent de revoir les politiques de l'UE et les objectifs nationaux afin de pouvoir limiter l'augmentation de la température mondiale à 1,5°C. Les prévisions climatiques et énergétiques de l'UE pour 2030, à savoir une réduction de 40% des émissions en 2030 par rapport à celles de 1990, ne sont tout simplement pas suffisantes. Seul des engagements plus forts en accord avec une décarbonisation rapide du secteur énergétique et des parts grandissantes d'énergies renouvelables rendront ce but atteignable.

Un puissant programme de déploiement d'énergie solaire thermique, avec une part du marché de 30 GW par an, pourrait endiguer le besoin de nouvelles centrales d'énergie fossile et remplacer celles en fin de vie. Ainsi, les technologies de l'énergie solaire thermique contribueraient de manière significative à la réduction des émissions globales de CO_2. La capacité de redistribution de l'énergie solaire thermique permettrait une réduction supplémentaire des rejets en permettant une utilisation fiable et abordable des énergies renouvelables intermittentes.

Avec approximativement 5% des investissements mondiaux dans les infrastructures énergétiques (158 – 186 millions d'euros), l'énergie solaire thermique est une technologie qui aurait toute sa place dans la « Nouvelle Donne Verte » de l'économie.

Qu'est ce qui déterminera la réduction des coûts ?

Les coûts de l'énergie solaire thermique ont déjà diminué mais une réduction supplémentaire est possible. Le paramètre le plus important est le volume du marché. Comme pour toute autre technologie, les coûts baissent plus fortement dans le cadre d'un programme de déploiement solide basé sur une décision politique de soutenir une technologie particulière. Une telle décision produit un climat favorable aux investissements proposant des conditions de financement préférentielles et/ou des avantages d'impôts et d'investissement. Ceci crée également un contexte propice à l'émergence progressive de solutions innovantes qui, à leur tour, réduiront davantage les coûts et augmenteront les opportunités de développement au-delà du secteur de l'électricité dans les pays qui décideront de se lancer dans de tels projets.

Quelles mesures sont nécessaires pour augmenter le déploiement de l'énergie solaire thermique ?

Durant les dix dernières années, des décisions des gouvernements nationaux ont donné un coup de pouce à l'énergie solaire thermique, amorçant l'essor actuel des installations à l'échelle mondiale. Au même moment, la progression du marché européen a connu un arrêt brutal avec les changements désastreux et rétrospectifs appliqués par l'Espagne à son secteur solaire. En dépit de cela, l'Espagne reste le leader mondial du marché de l'énergie solaire thermique avec une production 2,3 GW, presque la moitié de la capacité mondiale.

Les mesures nécessaires pour le bon fonctionnement de l'énergie solaire thermique sont :

- Des avantages financiers en vue d'atteindre des objectifs au niveau national : des tarifs de rachat garantis et préférentiels, des normes imposant une proportion minimale d'énergies renouvelables dans le portefeuille énergétique ou des programmes de prêts à taux préférentiels appliqués aux projets d'énergie solaire thermique en complément d'une facturation des rejets de CO_2 grâce à des systèmes d'échange de droits d'émission ou de la taxe carbone.
- La mise en place de nouvelles installations de transfert d'électricité et de mécanismes de marché entre les nations et les continents grâce à des infrastructures adaptées et des arrangements politiques et économiques, pour assurer la mobilité de l'énergie thermique entrer les meilleurs sites de production et les régions de grande demande.
- Une coopération entre l'Europe, le Moyen-Orient et l'Afrique du Nord au sujet des marchés et du développement économique.
- Un soutien stable et durable à la recherche et au développement en vue d'exploiter pleinement le potentiel d'avancées technologiques continues et de réduction plus importante des coûts.

Avec la mise en œuvre de telles mesures, l'énergie solaire thermique serait en mesure d'assumer son rôle d'acteur majeur dans le bouquet énergétique de la planète.

Image: Shams 1 ©Shams Power Company / Francois Brice

الملخّص التنفيذي

تعريف الكهرباء الشمسية الحرارية

تنتج الطاقة الشمسية الحرارية، المعروفة كذلك بتسمية الطاقة الشمسية المركّزة، الحرارة أو تولّد الكهرباء باستخدام مرايا لتركيز أشعة الشمس على درجات حرارة تتراوح بين 400 وألف درجة مئوية. وتختلف أشكال المرايا ووسائل تتبّع الشمس، وطرق توفير الطاقة المفيدة، لكنها تتبع جميعا المبدأ نفسه: تحفيز محرّك حراريّ غالباً ما يكون توربيناً بخارياً لتوليد الكهرباء التي يمكن عندئذٍ إدخالها إلى شبكة التوزيع. اليوم تتراوح قدرات معامل الطاقة الشمسية الحرارية بين عدد قليل من الميغاواط و400 ميغاواط، لكن يمكن زيادتها. على عكس المنشآت الفوتوفولطائية، لا تبدو الكهرباء الشمسية الحرارية خياراً منطقيّاً من حيث التوليد الموزّع، بل على مستوى نظام واسع النطاق. بشكل خاص، يمكن تكاملها مع التخزين الحراري او في عملية هجينة، بحيث توفّر طاقة ذات قدرة ثابتة وقابلة للتوزيع بحسب الطلب. هذا ما يجيز للكهرباء الحرارية الشمسية أن تملأ ثغرات الموارد المتقطّعة من الطاقة الخالية من ثاني أكسيد الكربون، على غرار الريح. ويمكن للكهرباء الحرارية الشمسية تلبية مستوى الطلب الأقصى والأدنى معاً.

تشكّل الكهرباء الشمسية الحرارية مورداً كهربائياً بلا كربون يلائم المناطق التي تتعرّض إلى كميّة كبيرة من أشعة الشمس، كجنوب اوروبا وشمال افريقيا والشرق الأوسط وجنوب افريقيا وبعض أنحاء الهند والصين وجنوب الولايات المتحدة واستراليا.

حجم السوق المتوقّع

شهد قطاع الكهرباء الشمسية الحرارية توسّعاً سريعاً من تكنولوجيا فتيّة إلى حلّ موثوق لتوليد الطاقة. مع ذلك، لم تتجاوز مشاريع الكهرباء الحرارية الشمسية العاملة حول العالم 5 ميغاواط مع نهاية 2015، فيما يتوقّع أن تضيف مشاريع ما زالت طور الانشاء عند كتابة هذا التقرير، 820 ميغاواط إضافية على الأقل في العامين المقبلين. تقع هذه المشاريع بشكل أساسي في جنوب افريقيا والهند والشرق الأوسط والمغرب.

غير أن قدرة الكهرباء الشمسية الحرارية على تلبية الطلب العالمي على الكهرباء أكبر بكثير. فتحليلنا يظهر كيف يمكن لهذا القطاع تلبية 12٪ من حاجات العالم للطاقة في 2050.

وحتى استناداً إلى توقّعات معتدلة لنموّ السوق المستقبلي، يمكن أن تصل قدرة الطاقة الشمسية الاجمالية حول العالم إلى 20 جيغاواط تقريباً في 2020 و800 جيغاواط في 2050، مع توزيع 61 جيغاواط سنوياً. هذا يوازي حوالى 5٪ من الطلب العالمي في 2050.

الفوائد

اعتمدت غرينبيس في هذه الدراسة نموذجاً لتوليد سيناريوهات استناداً إلى سيناريو «بقاء الوضع على حاله» لدى حكومات العالم، وإلى سيناريو معتدل وآخر متقدّم مبنيين على سياسات واقعيّة لدعم تطوير هذه التكنولوجيا النظيفة المتجدّدة. في السيناريو المعتدل

تستطيع البلدان التي تملك أكبر قدر من الموارد الشمسية ان تحقق معاً ما يلي:

- تحفيز أستثمارات بقيمة تفوق 16 مليار يورو[1] في 2020 يمكن أن تصل إلى 162 ملياراً في 2050
- إنشاء أكثر من 70000 فرصة عمل حتى 2020، وحوالى 938000 فرصة عمل حتى 2050
- توفير 32 مليون طن من ثاني أكسيد الكربون سنويّاً في 2020، ما قد يرتفع إلى 1,2 مليار طن في 2050.

للمقارنة، نذكر أن ثاني أكسيد الكربون المنبعث من الصين وحدها بلغ 10.5 مليار طن في 2013، وألمانيا 767 مليون طن. وقدّر تقرير[2] نشر مؤخراً حجم انبعاثات ثاني أكسيد الكربون العالمية من استخدام الوقود الأحفوري بـ32,2 مليار طن في 2013، وهو رقم قياسي يفوق مستوى الانبعاثات في 1990 بنسبة 56,1٪ وفي 2012 بنسبة 2,3٪. كل هذا يعني، إن احتفظنا بهذه الوتيرة، أننا سنستنفد ما تبقى مما يسمّى «ميزانية الكربون» في السنوات الثلاثين المقبلة وسنفشل في إبقاء ارتفاع حرارة الكوكب الشاملة دون درجتين مئويتين.

على ضوء اتفاق باريس الذي وقعته حوالى 200 دولة، نحتاج فوراً إلى مراجعة الأهداف للاتحاد الأوروبي وللدول من أجل منع الاحترار من تجاوز 1,5 درجات مئوية. فأهداف الاتحاد الأوروبي للعام 2030 على مستوى المناخ والطاقة المتمثّلة بتقليص الانبعاثات بنسبة 40٪ مقارنة بمستويات 1990 لن تكفي. المطلوب تحديد هدف تقليص أكبر يسهم في تجريد قطاع الطاقة سريعاً من الكربون وزيادة حصة الطاقة المتجدّدة من الاستهلاك، وإلا فهذا الهدف يبقى بعيد المنال.

كما قد يؤدي برنامج مدروس لنشر الكهرباء الشمسية الحرارية يضمن بلوغ سوقها حوالى 30 جيغاواط سنويّاً إلى تفادي الحاجة إلى معامل جديدة للطاقة الأحفورية واستبدال تلك التي يحل أجلها. هكذا يمكن لتكنولوجيات الكهرباء الشمسية الحرارية المساهمة بقوة في تقليص الانبعاثات العالمية. كما يمكن لقدرات توزيعها مضاعفة تقليص النبعاثات لأنها تجيز زيادة انتشار تكنولوجيات الطاقة المتجدّدة المتقطّعة بشكل موثوق ومقبول الكلفة.

ويمكن أن تساهم تكنولوجيا الطاقة الشمسية الحرارية، بالنسبة إلى 5٪ تقريباً من الاستثمار العالمي في البنى التحتية الطاقويّة البالغة 158 إلى 186 مليار يورو سنويّاً، في بلورة «صفقة جديدة خضراء» للاقتصاد.

العناصر المحدّدة لانخفاض منحنى التكاليف

سبق أن شهدت تكاليف الطاقة الشمسية الحرارية تراجعاً، لكن يمكن إنجاز المزيد. العامل الأولي المؤثّر على التكاليف هو حجم السوق. فكما يجري لأي تكنولوجيا طاقة أخرى، تتراجع الأسعار استجابة لبرنامج نشر ثابت يطبّق لوجود إرادة سياسية بذلك. وهذه الارادة

1 حوالى 18,4 مليارات دولار أميركي (سعر الصرف 1 يورو = 1,15 دولار أميركي)

2 الوكالة الدولية للطاقة، النسخة التمهيدية 2015، «انبعاثات ثاني أكسيد الكربون من استهلاك الوقود»

السياسية تولّد مناخ استثمار إيجابياً يؤدّي إلى شروط تمويل تفضيلية و/أو حوافز ضريبية واستثمارية. بالتالي تتجمّع الشروط المطلوبة لتضمين السوق حلولاً مبتكرة تعزز بدورها تراجع الاسعار وزيادة الفرص أمام الأعمال لتتجاوز قطاع الكهرباء في الدول التي تقرّر تطبيق برامج مماثلة.

الاجراءات اللازمة لمضاعفة نشر الطاقة الشمسية الحرارية

في السنوات العشر الأخيرة عزّزت قرارات حكومات محلّية قطاع الطاقة الشمسية الحرارية، ما أثار النموّ الجاري حاليا في المنشآت حو العالم. في الوقت نفسه، شهدت السوق الأوروبية كبحاً مفاجئاً بعد تطبيق اسبانيا تعديلات رجعيّة ومضرّة جدّاً في سوقها الشمسية. بالرغم من ذلك، ما زالت اسبانيا رائدة السوق العالمية في هذا القطاع، حيث تضمّ وحدها نصف قدرة الطاقة الشمسية الحرارية بحجم 2,3 جيغاواط.

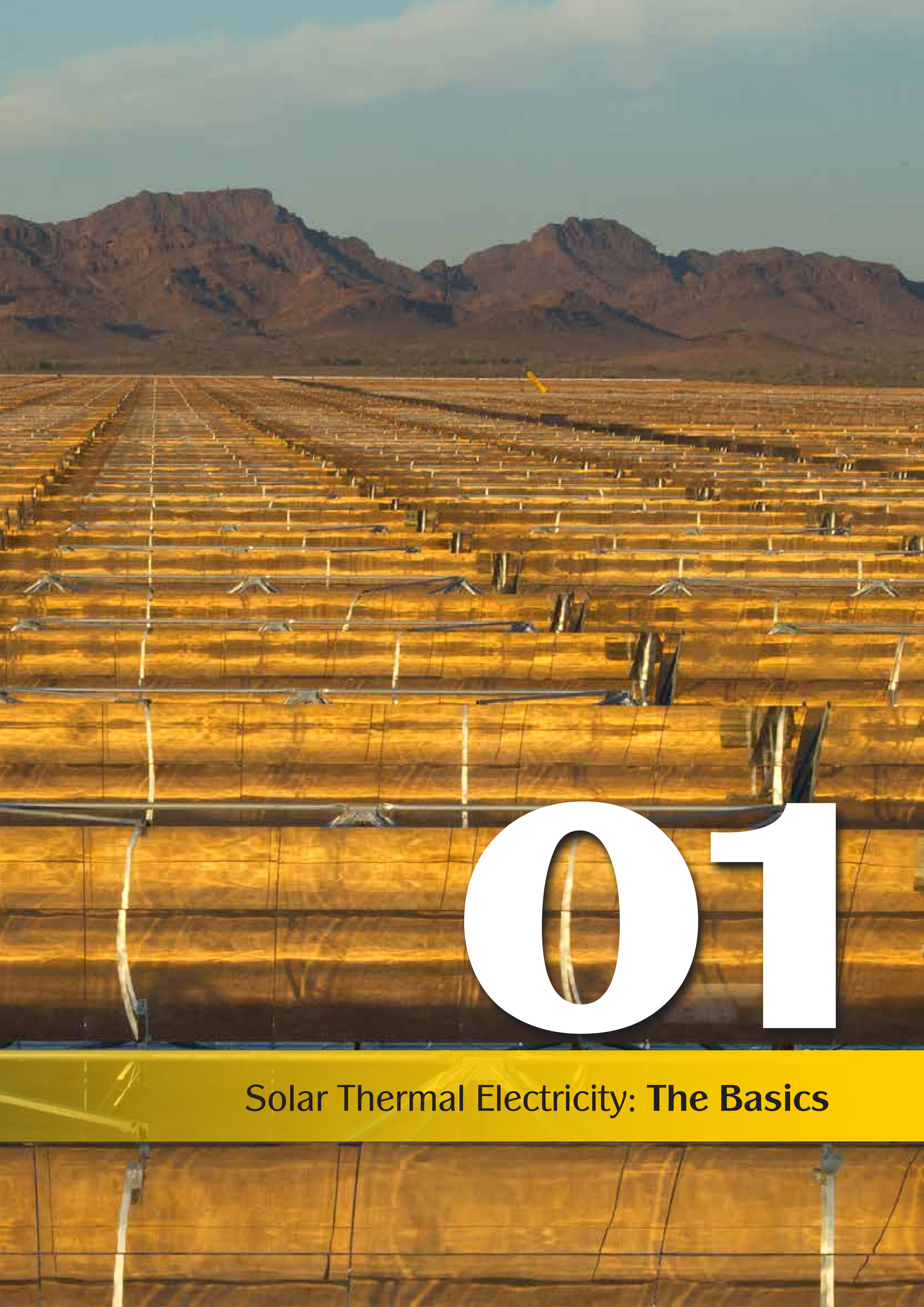
الاجراءات المطلوبة هي التالية:

- حوافز وأهداف وطنية مالية، على غرار سعر بيع مضمون للكهرباء وتعريفات إمدادات الطاقة المتجددة، ومعايير المحفظة المتجددة أو برامج قروض تفضيلية تنطبق على تكنولوجيات الكهرباء الشمسية الحرارية وخطط تفرض سعراً لانبعاثات الكربون سواء عبر أنظمة تحديد وتداول الانبعاثات أو ضرائب كربون.
- إقامة منشآت وآليات سوقيّة جديدة لنقل/توزيع الكهرباء بين الدول والقارات، باعتماد البنية التحتية المناسبة وتدابير سياسية واقتصادية. المطلوب نقل الطاقة الشمسية الحرارية من أفضل مواقع انتاجها إلى مناطق الطلب المرتفع.
- التعاون بين اوروبا والشرق الاوسط وشمال افريقيا على مستوى التنمية الاقتصادية والتكنولوجيا.
- توفير الدعم الثابت على المدى الطويل للأبحاث والتطوير لتحقيق أكبر قدر من التحسين في التكنولوجيا وتخفيض التكاليف.

مع تطبيق هذه الاجراءات المحورية يكون قطاع الكهرباء الشمسية الحرارية مستعدّاً للعب دوره المهمّ وسط مختلف أنواع الطاقة المتجدّدة في العالم.

Image: Shams 1 ©Shams Power Company / Francois Brice


Image: Solanan ©Abengoa



01

Solar Thermal Electricity: **The Basics**

The Concept

Solar Thermal Electricity, also known as Concentrating Solar Power, is a technology that produces electricity by using mirrors to concentrate direct-beam solar irradiance to heat a liquid, solid or gas that is then used in a downstream process for electricity generation.

We have known the principles of concentrating solar radiation to create high temperatures and convert it to electricity for more than a century but have only been exploiting it commercially since the mid-1980s. The first large-scale solar thermal power stations were built in the California Mojave desert. In a very short time, the technology has demonstrated huge technological and economic promise. It has one major advantage – a massive renewable resource, the sun, and very few downsides. For regions with similar sun regimes to California, STE offers the same opportunity as the large offshore wind farms in Europe.

Generation of bulk solar thermal electricity from solar thermal power plants is one of the technologies best suited to mitigating climate change in an affordable way by reducing the consumption of fossil fuels. Unlike photovoltaic technology, STE offers significant advantages from a system perspective, thanks to its built-in thermal storage capabilities. Solar thermal power plants can operate either by storing heat or in combination with fossil fuel power plants, providing firm and dispatchable power available at the request of power grid operators, especially when demand peaks in the late afternoon, in the evening or early morning, or even when the sun isn't shining.

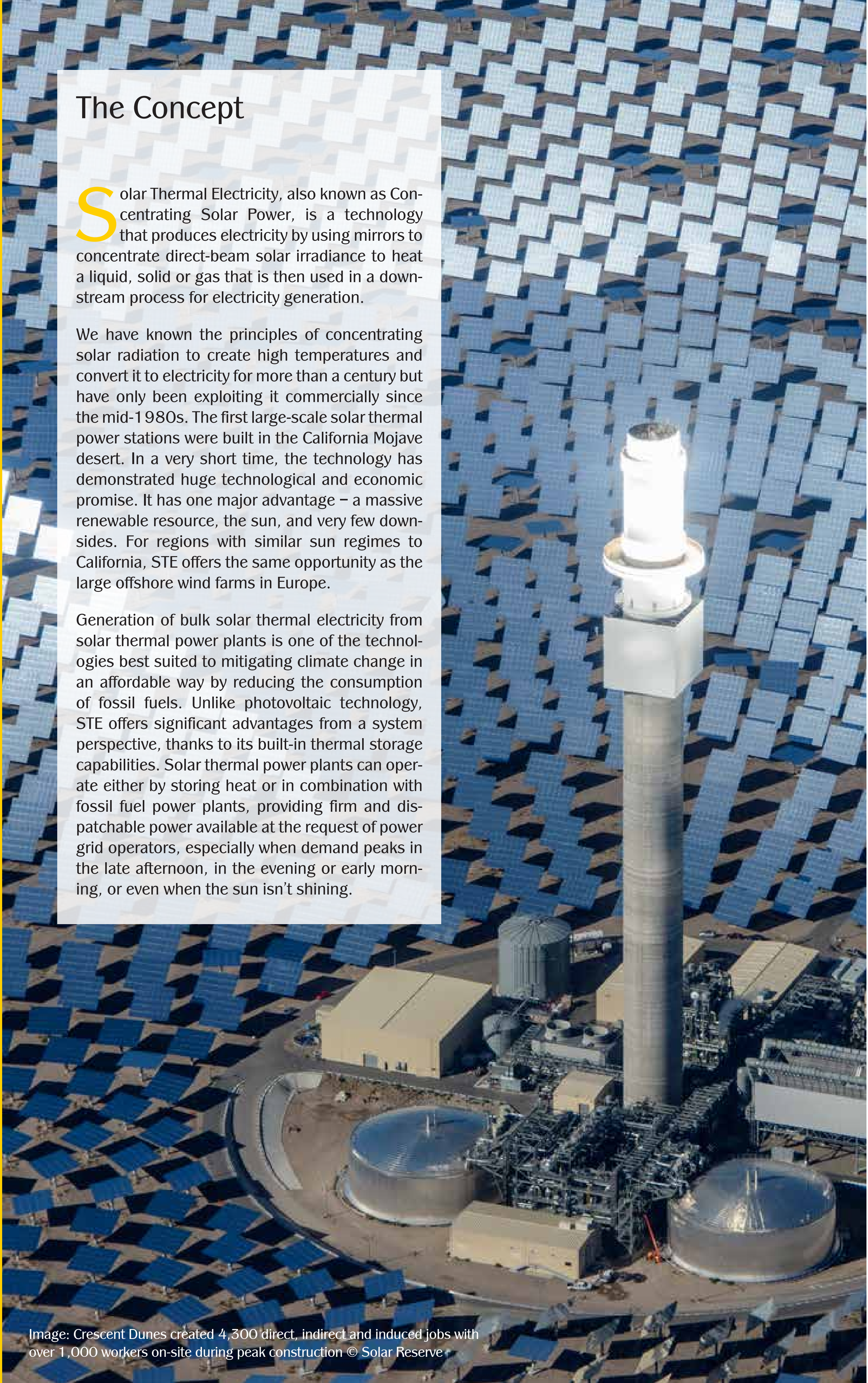


Image: Crescent Dunes created 4,300 direct, indirect and induced jobs with over 1,000 workers on-site during peak construction © Solar Reserve

Environment

The main benefit of STE systems is in replacing the power generated by fossil fuels, and reducing greenhouse gas emissions which cause climate change. Each square metre of STE concentrator surface, for example, is enough to avoid 200 to 300 kilograms of CO_2 each year, depending on its configuration. Typical STE power plants are made up of hundreds of concentrators arranged in arrays. The life-cycle assessment of the components and the land surface impacts of STE systems indicate that it takes around five months to 'payback' the energy that is used to manufacture and install the equipment. Considering the plants last at least 30 years with minimum performance losses, this is an excellent ratio. In addition, most of the STE solar field components are made from common materials that can be recycled and used again.

Economics

The cost of solar thermal power is going down. Experience in US shows today's generation costs are about 12 UScents/kWh for solar generated electricity at sites with very good solar radiation. The US Department of Energy's SunShot Initative predicts on-going costs as low as 6 UScents/kWh. STE technology development is on a steep learning curve, and the factors that will further reduce costs are technological improvements, mass production, economies of scale and improved operation. Concentrating solar power is becoming competitive with conventional, fossil fuelled peak and mid-load power stations. One of the benefits of adding more STE to the grid is that it can help stabilise electricity costs, mitigating fossil fuel price volatility and the impact of carbon pricing when it takes effect.

Hybrid plants combine concentrated solar power and fossil fuels. Some, which make use of special finance schemes, can already deliver competitively-priced electricity. For small-scale, off-grid solar power generation, such as on islands or in rural hinterlands of developing countries, STE is a compelling alternative to diesel engine generators, which are noisy, dirty and expensive to run.

Several factors are increasing the economic viability of STE projects, including reform of the electricity sector, rising demand for 'green power', and the development of global carbon markets for pollution-free power generation. Direct support schemes also provide a strong boost, like feed-in laws or renewable portfolio standards for renewable power in some countries. Last but not least, increasing fossil fuel prices will also help bring the price of STE in line with the cost of conventional power generation.

There is high initial investment for new solar thermal power plants, however. Over the entire life cycle of an STE power plant, the largest part of the cost corresponds to construction and associated debt. This means once the plant has been paid for – usually after 15 years – only operating costs of about 2-3 UScents/kWh remain. This makes STE cheaper than most any other source of energy competition, comparable to long-written-off hydropower plants.

Requirements for STE

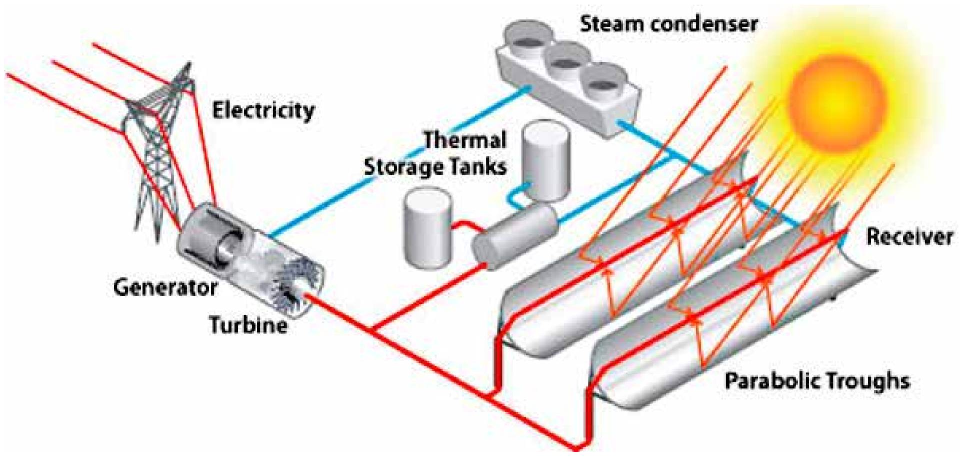
Solar thermal power requires direct sunlight, called 'beam radiation' or Direct Normal Irradiation (DNI). This is the sunlight which is not deviated by clouds, fumes or dust in the atmosphere and that reaches the earth's surface in parallel beams for concentration. Suitable sites must get a lot of this direct sun – at least 2,000 kWh of sunlight radiation per square metre annually. The best sites receive more than 2,800 kWh/m²/year.

Typical regions for concentrating solar are those that lack atmospheric humidity, dust and fumes. They include steppes, bush, savannas, semi-deserts and true deserts, ideally located within 40 degrees of latitude north or south. The most promising areas of the world include the south-western United States, Central and South America, North and Southern Africa, the Mediterranean countries of Europe, the Near and Middle East, Iran and the desert plains of India, Pakistan, the former Soviet Union, China and Australia.

In these regions, one square kilometre of land can generate as much as 100–130 GWh of solar electricity per year using solar thermal technology. This corresponds to the power produced by a 50 MW conventional coal- or gas-fired mid-load power plant. Over the total life cycle of a solar thermal power system, its output would be equivalent to the energy contained in more than 5 million barrels of oil.

Like conventional power plants, solar thermal power plants need cooling at the so-called "cold" end of the steam turbine cycle. This can be achieved through evaporative (wet) cooling where water is available or through dry cooling (with air), both of which are conventional technologies. Dry cooling requires higher investment and eventually leads to 5%–10% higher costs compared to wet cooling. Hybrid cooling options exist that can optimise performance for the site conditions and are under further development.

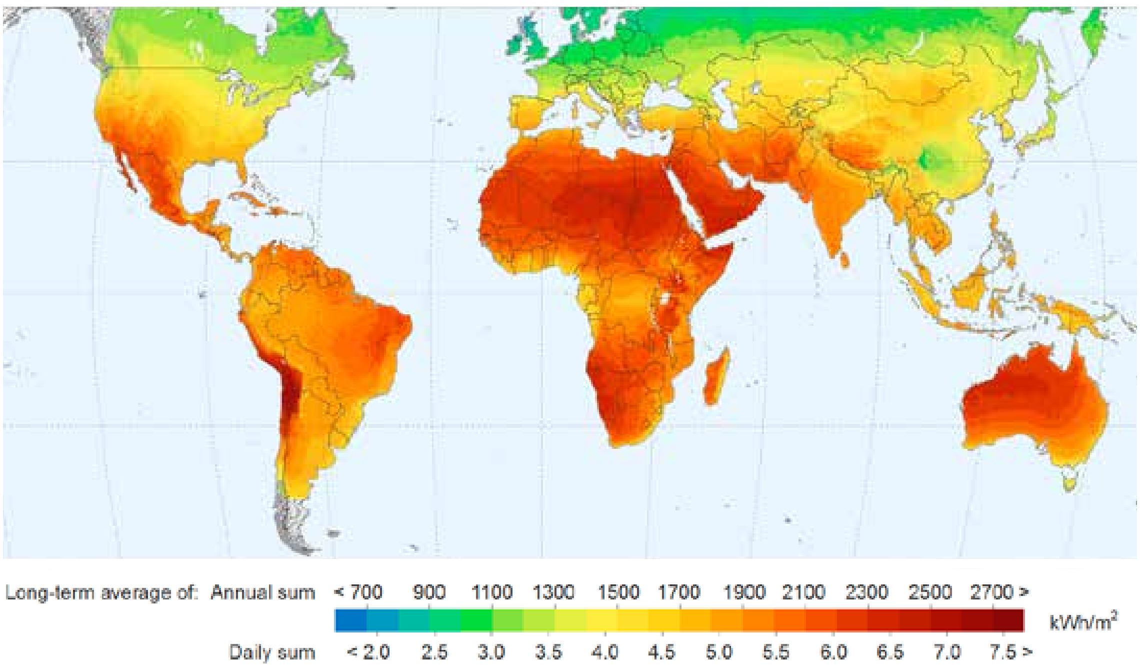
Figure 1.1: **Principle of a concentrating solar collector (left) and of a solar thermal power station for co-generation of electricity and process steam (right)**



Water consumption for use in wet cooling in the Spanish plants has proven to be half of the water needs per hectare, as compared with the consumption of agricultural crops, like corn or cotton in Andalucia, Spain. Also, STE uses 200 times less water than a coal power plant to produce the same amount of electricity, according to IRENA's soon-to-be-released regional report.

The huge solar power potential in the "Sun Belt" regions of the world often far exceeds local demand. This creates the potential for excess solar electricity to be exported to regions with a high demand for power but a less favourable solar irradiance. In particular, southern European and North African countries could harvest the sun for export to northern European countries in the medium and long-term. Of course, for any new development, local demand must be met first.

Figure 1.2: **World Map of Direct Normal Irradiation**[2]



3 SolarGIS © 2013 GeoModel Solar.

How It Works – the STE Technologies

A range of technologies are used to concentrate and collect sunlight and to turn it into medium to high temperature heat. This heat is then used to create electricity in a conventional way, i.e., run a turbine. Solar heat collected during the day can also be stored in liquid or solid media such as molten salts, steam, ceramics, concrete or phase-changing salt mixtures. At night, the heat can also be extracted from the storage medium to keep the turbine running. Solar thermal power plants work well to supply the summer peak loads in regions with significant cooling demand, such as Spain and California. With thermal energy storage systems they operate longer and even provide baseload power. For example, in Chile the 110MW Atacama STE plant with 17.5 hours of thermal storage, is capable of providing clean electricity 24 hours a day every day of the year. There are four main types of commercial STE technologies: parabolic troughs and linear Fresnel systems, which are line concentrating, and central receivers and parabolic dishes which are point concentrating central receiver systems, also known as solar towers.

Dishes with Stirling motors are not an appropriate technology for utility scale applications and therefore we will only refer to solar towers when talking about central receiver systems. Chapter 2 of this report provides information on the status of each type of technology and the trends in cost.

Since the last update on STE technologies in 2009, on-going progress has been made in the use of STE technologies outside of the electricity sector, namely solar fuels, process heat and desalination. Advances have also been made in storage systems for this technology. These developments are discussed in detail in chapter 2. Chapter 4 of this report review STE market development in different regions. Finally, a full list of the plants operating, in construction and proposed is provided in Appendix 1.

Dispatchability and Grid Integration

Dispatchability is the ability of a power producing facility to provide electricity on demand. Dispatchable power plants, for example, can be turned on and off and adjust their power output on demand. Conventional power stations, like fossil fuel plants, are dispatchable but produce, among other things, CO_2 emissions. STE plants, however, which produce electricity in a manner similar to conventional power stations, i.e., by driving a steam turbine, are also dispatchable.

Dispatchability is one of the characteristics that makes STE a favoured option among other renewable energy technologies. All solar thermal power plants can store heat energy for short periods of time and thus have a "buffering" capacity that allows them to smooth electricity production considerably and eliminates the short-time variations that non-dispatchable technologies exhibit during cloudy days.

What's more, thanks to thermal storage systems and the possibility of hybridisation,[4] solar thermal power plants can follow the demand curve with high capacity factors delivering electricity reliably and according to plan. Thermal storage systems also allow STE to provide power in the absence of direct solar radiation, such that periods of solar generation and demand need not coincide.

For this case, the solar thermal power plant supplies electricity when needed to help meet peak demand.

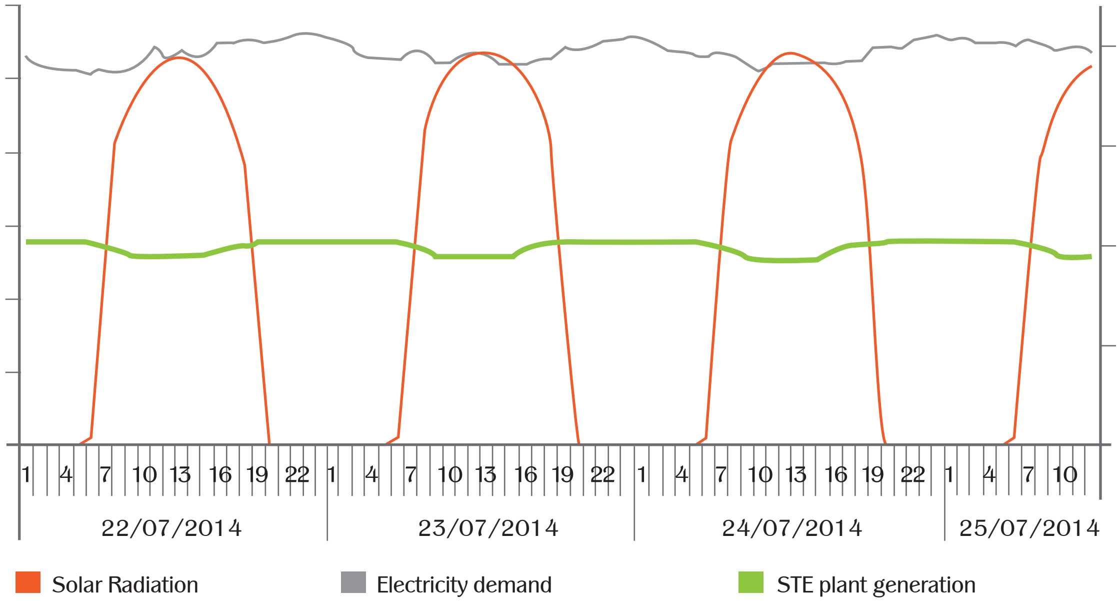
Firmness and dispatchability are the main benefits of STE. STE and other renewable energy technologies, such as PV and wind, can thus be combined in an energy system to balance supply. In this way, STE can replace fossil fuel power plants and contribute to a 100% renewable energy supply as one of the renewable technologies capable of following the demand curve and ensuring a 24/7 secure supply. STE plants can also contribute to the stability of the system, i.e., maintaining voltage and frequency within required ranges, and allowing further penetration and integration of intermittent sources without the need for fossil fuel back-up.

4 See *Hybridisation Possibilities* in Chapter 2
5 Abengoa
6 Abengoa

Below, we can demonstrate the dispatch of STE in several cases:

I. Baseload designed power plant

Figure 1.3: **Base-load Designed Power Plant**[5]



In this example the power plant ensures the electricity generation in a 24/7 basis.

II. Peaker designed power plant

Figure 1.4: **Peaker Designed Power Plant**[6]

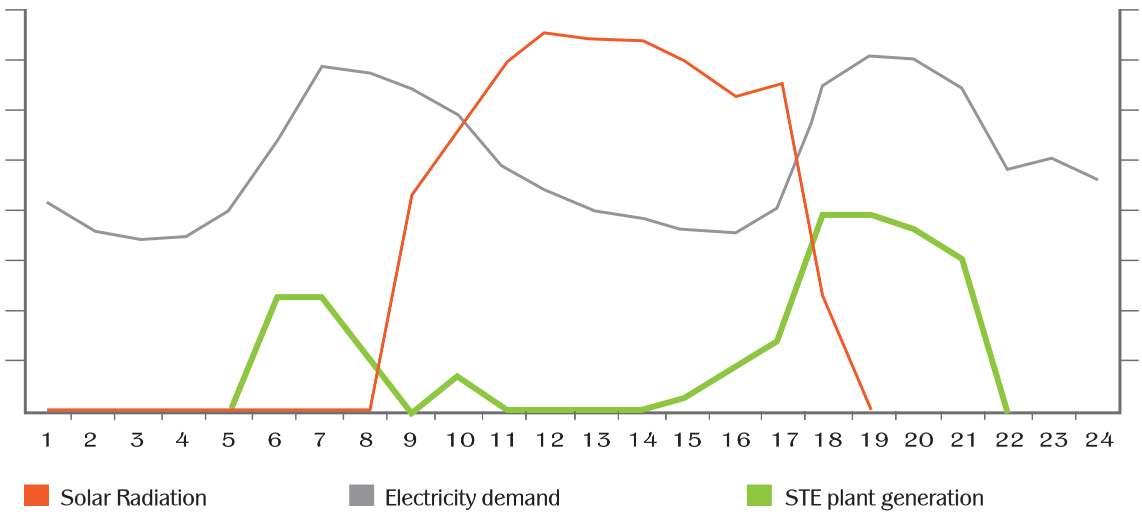


Image: Mojave Solar, 280 MW Parabolic Trough Plant in the Mojave Desert in California ©Abengoa

Other advantages of solar thermal electricity

- STE enhances electricity production from a local and free source substituting for fuels that are often imported from other countries.

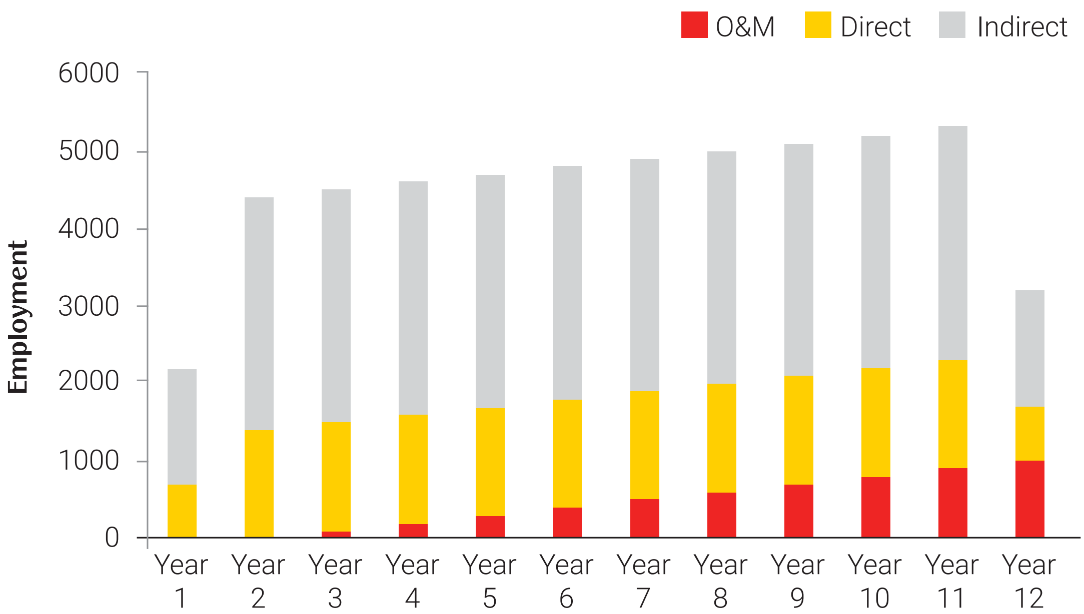
  Shams-1, the largest solar power plant in the Middle East, represents an important step forward in introducing renewable energy in Abu Dhabi, helping it meet its goal of achieving 7% of its primary energy consumption from renewable sources by 2020. The plant prevents approximately 175,000 tonnes of CO_2 emissions each year. This is equivalent to planting 1.5 million trees or eliminating the use of 15,000 cars in a city like Abu Dhabi.

- The development of STE project promotes the creation of local industries in emerging markets enlarging the supply chain. New local manufacturing operations are opened in order to supply the components needed, e.g. tubes, structures and mirrors.

- The construction and operation of STE plant can be a source of employment. A recent study showed that for each MW installed, 7 jobs are created during the construction of these types of plants (see Figure 1.5).

Image: Shams 1 ©Shams Power Company / Francois Brice

Figure 1.5: **Employment Breakdown in a STE Deployment Programme**[7]



7 Deloitte 'Impacto Macroeconómico del Sector Solar Termoeléctrico en España', 2012.


Planta Solar 10 and Planta Solar 20 ©Abengoa

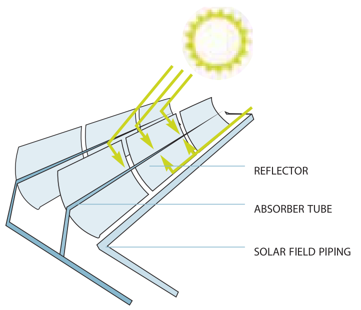
02

STE Technologies and Costs

Types of Generators

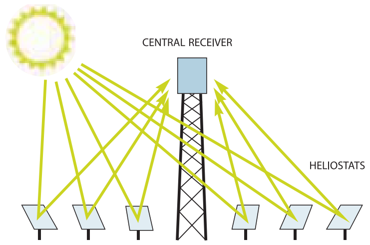
Concentrating Solar Power plants produce solar thermal electricity in a similar way to conventional power stations – using steam to drive a turbine. The difference is the energy for STE plants comes from solar radiation, which is converted to high-temperature steam or gas. Four main elements are required to do this: a concentrator, a receiver, some form of transport media or storage, and power conversion. Many different types of systems are possible, including combinations with other renewable and non-renewable technologies. So far, plants with both solar output and some fossil fuel co-firing have been favoured, particularly in the US and North Africa. Hybrid plants help produce a reliable peak-load supply, even on less sunny days. The major advantages and disadvantages of each of the STE technologies are listed in Table 2.1. Table 2.2 provides an approximate overview on the development stages of the main technologies in terms of installed capacities and produced electricity. A brief review of the generating technologies is provided below, followed by a more detailed discussion of each.

Figure 2.1:
Parabolic Trough (PT)



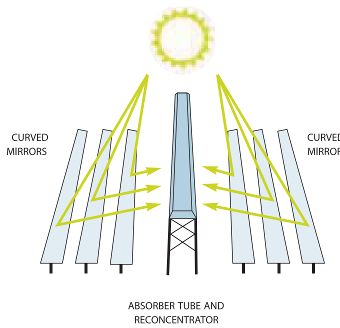
Parabolic Trough technology consists of rows or loops of parabolic trough-shaped mirror reflectors that are used to collect the solar radiation and concentrate it onto a thermally efficient receiver tube placed in the trough's focal line. The fluid is heated up to approximately 400°C by the sun's concentrated rays and then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator, which can either be part of a conventional steam cycle or integrated into a combined steam and gas turbine cycle. This fluid can also be used to heat a storage system consisting of two tanks of molten salt.

Figure 2.2:
Central Receiver (CR)



A circular array of heliostats (large mirrors with sun-tracking motion) concentrates sunlight on to a central receiver mounted at the top of a tower. A heat-transfer medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy that is used to generate superheated steam for the turbine. To date, the heat transfer media demonstrated include water/steam, molten salts, liquid sodium and air. If pressurised gas or air is used at very high temperatures of about 1,000°C or more as the heat transfer medium, the gas or air can be used to directly replace natural gas in a gas turbine. This application makes use of the excellent efficiency (60% and more) of modern gas and steam combined cycles.

Figure 2.3:
Linear Fresnel Reflector (LFR)



An array of nearly flat reflectors concentrate solar radiation onto elevated inverted linear receivers. Water flows through the receivers and is converted into steam. This system is linear-concentrating, similar to a parabolic trough, with the advantages of low costs for structural support and reflectors, fixed fluid joints, a receiver separated from the reflector system, and long focal lengths which allow the use of flat mirrors. The technology is seen as a potentially lower-cost alternative to trough technology for the production of solar process heat and steam.

Table 2.1: **Comparison of Main Technology Types for Solar Thermal Electricity**

	Parabolic Trough	Central Receiver	Fresnel Linear Reflector
Applications	Grid-connected plants, mid- to high- process heat (Largest single unit solar capacity to date: 280 MW in the US. Total capacity built: over 4115 MW)	Grid-connected plants, high temperature process heat (Largest single unit solar capacity to date: 392 MW in the US. Total capacity built: 593 MW)	Grid connected plants, or steam generation for use in conventional thermal power plants. (Largest single unit solar capacity to date:125MW in India. Total capacity built: 179 MW)
Advantages	▸ Commercially available – over 16 billion kWh of operational experience; operating temperature potential up to 500°C (400°C commercially proven) ▸ Commercially proven annual net plant efficiency of 14% (solar radiation to net electric output) ▸ Commercially proven investment and operating costs ▸ Modularity ▸ Good land-use factor ▸ Lowest materials demand ▸ Hybrid concept proven ▸ Storage capability	▸ Good mid-term prospects for high conversion efficiencies, operating temperature potential beyond 1,000°C (565°C proven at 10 MW scale) ▸ Storage at high temperatures ▸ Hybrid operation possible ▸ Better suited for dry cooling concepts than troughs and Fresnel ▸ Better options to use non-flat sites	▸ Readily available ▸ Flat mirrors can be purchased and bent on site, lower manufacturing costs ▸ Hybrid operation possible ▸ The most land-efficient solar technology, generating 1.5-to-3 times more power per acre of land than competing solar technologies (according to Ausra).
Disadvantages	▸ The use of oil-based heat transfer media restricts operating temperatures today to 400°C, resulting in only moderate steam qualities	▸ Projected annual performance values, investment and operating costs need wider scale proof in commercial operation	▸ Recent market entrant, only small projects operating

Table 2.2: **Operational Experience: Installed Capacities and Produced Electricity by Technology Type *(approximate numbers)***

Technology Type	No. of STE plants	Installed Capacity (MW)	Annual Expected Electricity Production (GWh)	Approx. capacity under construction (MW)
Parabolic Trough	73	4,115	10,000	719
Central Receiver	10	497	1,300	410
Fresnel	8	179	350	180

Parabolic Trough

Parabolic troughs are the most mature of the concentrating solar power technologies and they are commercially proven. The first systems were installed in 1912 near Cairo in Egypt to generate steam for a pump which delivered water for irrigation. At the time, this plant was competitive with coal-fired installations in regions where coal was expensive.

In the trough system, sunlight is concentrated by about 70–100 times on absorber tubes, achieving operating temperatures of 350ºC to 550ºC. A heat transfer fluid pumped through the absorber tube transfers the thermal energy to a conventional steam turbine power cycle. Most plants use synthetic thermal oil to transfer heat. The hot thermal oil is used to produce slightly superheated steam at high pressure, to feed a steam turbine connected to a generator to produce electricity. Thermal oil has a top temperature of about 400ºC, which limits the conversion efficiency of the turbine cycle. Researchers and the industry have developed alternatives. One example is the direct generation of steam in the absorber tubes, another using molten salt as the HTF. Prototype plants of both types are currently being built.

Currently, parabolic troughs are the most widely used technology around the world, particularly in Spain and the United States where the installed capacity of operating plants is over 2,370 MW and 1,836 MW, respectively. Plants range in size from 5 to 280 MW. Parabolic troughs are considered a “mature” technology. For example, in terms of supply chain, a number of manufacturers currently fabricate this technology. What’s more, there is good experience in engineering procurement and construction (EPC) and 20 years of operating experience allows for good confidence on the operation. Therefore, projects using parabolic trough technology can be considered low-risk.

A new generation of parabolic trough plants aims to reach a higher HTF temperature, allowing the full integration of the solar field and the storage system. This “second generation” should provide significant improvements in the average conversion efficiency and further reduction of costs. Although a demonstration plant has already been built, adequate operating experience is still needed and components with enhanced performance and durability are being studied and developed.

Image: Palma del Río II ©Acciona

The Andasol plant, the first parabolic trough power plant in Europe, is a first-of-its-kind, utility-scale demonstration of the EuroTrough design and thermal storage using molten salt technology.

The SEGS and Solnova plants use a system where the plant can operate by burning natural gas on days when sunlight is weak. Parabolic trough systems are suited to a hybrid operation called Integrated Solar Combined Cycle (ISCC), where the steam generated by solar is fed into a thermal plant which also uses fossil fuel generated steam, typically from natural gas. Currently, the 20 MW Hassi R'mel in Algeria, 20 MW ISCC Al Kuraymat in Egypt, and 20 MW Ain Beni Mathar Plant ISCC in Morocco are examples of the operational ISCC solar thermal power plants, forming an interim step towards complete solar generation in the energy mix.

Case Study: Solar Energy Generating System – *Pioneering the technology in California*

Nine STE plants were constructed in the US Mojave desert by Israeli/American company Luz between 1984 and 1991, with the combined capacity from three separate locations at 354 MW – the world's second largest solar thermal generating facility. These plants are known collectively as Solar Energy Generating System. The plants use solar-generated steam and gas back-up, but the gas component is limited to 25% of the total heat input. In total, SEGS consists of more than 2 million square metres of parabolic trough mirrors. The plants were built with US$ 1.2 billion, in private risk capital and institutional investors. However, Luz had early difficulties making a profit due to market issues resulting from energy price fluctuations and issues with its tax status. However, the technology is proven and shows that solar thermal power plants have a potentially long operating life. Today, just the three plants at Kramer Junction are delivering 800–900 million kWh of electricity to the Californian grid every year, reaching a total accumulated solar electricity production of almost 9 billion kWh. This is roughly half of the solar electricity generated worldwide to date. Since construction of the SEGS plants, operation and maintenance costs by at least one third. Trough component manufacturing companies have made significant advances in improving absorber tubes, process know-how and system integration. The annual plant availability consistently exceeds 99%. Anecdotally, the plant performance level has dropped only about 3% in 20 years of operation.

Source: SolarPACES

Image: SEGS Solar Plants ©NextEra

Case Study: Andasol Solar Power Plants – *Using thermal storage in Spain*

The Andasol solar power project located in Andalusia is a 150 MW solar thermal power station and Europe's first commercial plant to use parabolic troughs. It uses tanks of molten salt for thermal energy storage. The Andasol project consists of three plants: Andasol 1 (completed in 2008), Andasol 2 (completed in 2009) and Andasol 3 (completed in 2011), with a gross electricity output of around 525 GWh per year and a combined collector surface area of 1.5 million m^2.

Each plant has an electricity output of 50 MW and operates with thermal storage. The plants are designed to optimise heat exchange between the heat transfer fluid circulating in the solar field and the molten salt storage medium and the water/steam cycle. With a full thermal reservoir, the turbines can run for about seven and a half hours at full-load even in rainy weather or long after the sun has set. The heat reservoirs are two tanks 14 m high and 36 m in diameter and contain liquid salt. Each provides 28,500 tons of storage medium. Each plant supplies up to 200,000 people with electricity and saves about 149,000 tonnes of CO_2 per year compared with a modern coal power plant.

Source: ACS Cobra

Image: Andasol Solar Power Plants ©ACS Cobra

Case Study: Solana – *Largest solar thermal power plant using parabolic trough in Arizona*

Solana is a 280 MW solar thermal power plant with six hours of molten-salt thermal energy storage. Located near Phoenix, in the Arizona desert, Solana covers 777 ha of land. It generates enough electricity to supply approximately 71,000 homes and avoids 427,000 tonnes of CO_2 every year. Solana solar thermal created about 15,000 construction jobs with the plant employs 85 full-time workers.

Source: Abengoa

Image: Solana ©Abengoa

Central Receiver

Central receiver (or solar tower) systems use a field of distributed mirrors – heliostats – that individually track the sun and focus the sunlight on a receiver at the top of a tower. By concentrating the sunlight 600–1000 times, they achieve temperatures from 800°C to well over 1000°C. The solar energy is absorbed by a working fluid and then used to generate steam to power a conventional turbine. In over 15 years of experiments worldwide, solar tower plants have proven to be technically feasible in projects using different heat transfer media (steam, air and molten salts) in the thermal cycle and with different heliostat designs.

The high temperatures available in solar towers can be used not only to drive steam cycles, but also for gas turbines and combined cycle systems. Such systems can achieve up to 35% peak and 25% annual solar electric efficiency when coupled to a combined cycle power plant.

The efficiency of these plants is usually better than parabolic trough plants, because fluid temperatures are higher. This leads to better thermodynamic performance and it also facilitates storage: smaller volumes are possible because of the higher temperature difference between the cold and the hot tanks.

With the technology proven, there are now several landmark projects currently operating in the world. Three commercial size power plants of this type are located in Spain, notability the Solucar Solar Complex, with the operating PS-10 solar tower of 11 MW; the PS-20 with a 20 MW capacity and 0.5 hours of steam storage; and the 20 MW Gemasolar with a molten salt heat storage. In the United States, a few larger projects are currently operating or under construction in California and Nevada. The largest one is Ivanpah Solar Electric Generating System, which began commercial operation in 2013. At 392 MW, it is by far the biggest solar power plant in the world. A 110 MW Crescent Dunes Solar Energy plant located in Nevada is another solar thermal power plant using solar tower technology, with molten salt thermal energy storage. The plant currently under construction features advanced molten salt power tower energy storage capabilities. The project is expected by early next year to deliver enough firm, reliable electricity from solar energy to power 75,000 homes in Nevada during peak demand periods, day and night, whether or not the sun is shining.

Early test plants were built in the 1980s and 1990s in Europe and USA. These included SOLGATE which heated pressurised air; Solar II in California that used molten salt as heat transfer fluid and as the thermal storage medium for night time operation; and the GAST project in Spain that used metallic and ceramic tube panels. The concept of a volumetric receiver was developed in the 1990s within the PHOEBUS project, using a wire mesh directly exposed to the incident radiation and cooled by air flow. This receiver achieved 800°C and was used to operate a 1 MW steam cycle.

Image: Planta Solar 10 and Planta Solar 20 ©Abengoa

Case Study: PS10 and PS20 – *World's first commercial solar towers in Spain*

The Solucar Complex in Seville is home to the world's first solar towers, PS10 and PS20. PS10 is an 11 MW plant with a central receiver. Its solar field is comprised of 624 Solucar heliostats, covering an area of 75,000 m^2. Each heliostat tracks the sun on two axes and concentrates the radiation onto a receiver located on tower that is 115 m tall. The receiver converts 92% of received solar energy into steam. The plant generates enough electricity to power 5,500 households.

The PS20 is twice as big and was constructed after PS10 began operating. PS20 works in the same way as its predecessor, with a solar field of 1,255 heliostats and a tower of 160 meters. The plant can power 12,000 homes with the electricity it produces.

Both plants have thermal storage that allows for 30 minutes of full production even after the sun goes down. Thermal storage in this case is used to boost power production under low radiation conditions. Additionally, the PS plants can use natural gas for 12% -15% of their electrical production.

Source: Abengoa

Case Study: Gemasolar – *The world's first baseload solar power plant.*

Gemasolar is the first commercial scale plant in the world to combine central tower receiver and molten salt heat storage technology. The plant has been operational since May 2011. The importance of this plant lies in its technological uniqueness, as it has paved the way for other plants of this type, such as the recently commissioned Tonopah plant and the upcoming new Noor 3 pant in Morocco.

Gemasolar, with its 20 MW installed capacity, can supply 110 GWh per year. It can produce electricity about 6,400 hours per year – a capacity factor of 75%. The plant provides clean, safe power to 25,000 homes and reduces CO_2 emissions by more than 30,000 tons a year. The molten salt storage tank permits independent electrical generation for up to 15 hours without any solar feed. In the summer of 2013, the plant achieved continuous production, operating 24 hours per day for 36 consecutive days, a result which no other solar plant has attained so far.

Gemasolar's power tower has a height of 140 meters. The receiver on top of the tower is like a radiator that is heated to a temperature of about 565ºC by the sunlight reflected by 2,650 heliostats with a total reflective surface of about 300,000 m^2.

Source: SENER/TORRESOL Energy

Image: Gemasolar Thermosolar Plant ©SENER/Torresol Energy

Linear Fresnel Reflector

Linear Fresnel Reflectors (LFR) are also based on solar collector rows or loops. However, in this case, the parabolic shape is achieved by almost flat linear facets. The radiation is reflected and concentrated onto fixed linear receivers mounted over the mirrors, combined or not with secondary concentrators. One of the advantages of this technology is its simplicity and the ability to use low cost components. Direct saturated steam systems with fixed absorber tubes have been operated at an early stage of use with LFR technology. This technology eliminates the need for HTF and heat exchangers. Increasing the efficiency depends on superheating the steam. Superheated steam up to 500°C has been demonstrated at pilot plant scale and the first large commercial superheated LFR plant has recently begun operation.

Since steam is the working fluid, LFR technology is usually fitted with a steam storage system. Molten salt storage systems can be also implemented. Furthermore, PCM storage systems are currently demonstrated at pilot plant scale.

More than 200 MW of LFR plants are currently operating or under construction. After a first pilot scale application in Australia, a few new pilot plants were developed and tested in Spain and the United States. In 2012, the first commercial 30 MW Puerto-Errado 2 plant began operating in Spain. France has already constructed two Linear Fresnel pilot plants and is currently building two additional commercial plants with this technology. Sized 9 MW and 12 MW, and named Llo and Alba Nova 1, these plants are being built by CNIM and SOLAR EUROMED, respectively. In Australia, two plants are currently operating with this technology, sized 6 MW and 9.3 MW. A 44 MW plant is also under construction at Kogan Creek. In India, Reliance Power has completed and connected to the grid a 125 MW Compact Linear Fresnel Reflector plant, designed and constructed by AREVA Solar. (see Case Study *Dhursar*).

Compared to other technologies, the investment costs per square meter of collector field using LFR technology tend to be lower because of the simpler solar field construction. Also, the use of direct steam generation promises relatively high conversion efficiency and a simpler thermal cycle design. The Fresnel design uses less expensive reflector materials and absorber components. It has lower optical performance and thermal output but this is offset by lower investment and operation and maintenance costs. The Fresnel system also provides a semi-shaded space, which may be particularly useful in desert climates for agriculture. Acting like a large, segmented blind it could shade crops, pasture and water bodies to protect them from excessive evaporation and provide shelter from the cold desert sky at night. Many improvements in the absorber tubes and the geometry are under development. Some of those ongoing improvement efforts relate to the shape and the disposition of mirrors to accommodate some of the peculiarities of this technology.

Therefore, LFR offers high thermal performance and low cost, as well as various cost competitive thermal energy storage solutions. Hence, LFR is becoming one of the STE technologies capable of achieving very low LCOE costs.

In addition to electricity generation, LFR technology is also quite useful for direct thermal applications, such as cooling or industrial process heat applications. Very low cost LFR collectors are providing 200°C-300°C steam solutions at a competitive cost for process heat applications such as desalination, food processing and pharmaceutical industries. Low cost LFR collectors are providing 250°C-500°C steam solutions at very competitive cost to hybrid STE – fuel fired combined cycle or Enhanced Oil Recovery applications.

Case Study: Dhursar – *The world's largest STE project based on Compact Linear Fresnel Reflector (CLFR) technology*

Reliance Power's 125 MW STE project, located at Jaisalmer District, Rajasthan, India, was successfully connected to the grid in November 2014. It is the largest solar thermal power plant in Asia and also the world's largest STE project based on CLFR technology. This STE plant is part of the first phase of an ambitious Indian program, the Jawaharlal Nehru National Solar Mission, which aims to install 22,000 MW of solar power capacity by 2022. This project's 125 MW can generate up to 280 GWh of electricity every year.

Rajasthan Sun Technique Energy, a wholly owned subsidiary of Reliance Power, was awarded the contract to build a 250 MW STE project in April 2012. The innovative CFLR technology for the project, provided by AREVA Solar (US subsidiary of AREVA SA, France), is simple in design, requires less land and is more efficient than other solar thermal technologies available.

When completed, the 250 MW STE project will result in the avoidance of nearly 557,000 metrics tons of CO_2 emissions a year, compared to a similar sized coal-fired power generation plant. At peak, this project will create 500 construction jobs and 40 O&M positions.

Source: AREVA Solar

Image: Puerto Errado 2 ©Novatec Solar and ABB

Case study: Puerto Errado 2

Puerto Errado 2 (PE2), the 30 MW solar thermal power station built by Novatec Solar using linear Fresnel technology, has been operating since August 2012 in Murcia, Spain. The technology uses direct steam generation and, unlike other solar thermal technologies, does not require heat exchangers and oil-filled absorber tube networks for heat transfer. Instead, this highly economical and proven concept utilizes compact, almost flat glass mirrors, with a mirror surface of 302,000 m^2. The uniquely efficient solar boiler produces superheated steam directly at a temperature of up to 270° C and a pressure of 55 bar.

PE2's electrical output is generated exclusively by solar power and produces approximately 50 million kWh of electricity per year, enough to power 15,000 Spanish homes. Annually, this avoids the generation of over 16,000 metric tonnes of CO_2 emissions.

Source: Novatec solar and ABB

Cost Trends for Solar Thermal Electricity

Solar thermal power plants have shown significant cost reductions in the recent years, even though the deployment level is around 5 GW worldwide. This means that there is huge room for further cost reduction based on both volume and technological improvements. For instance, commercial experience from the first nine SEGS plants in California, built between 1986 and 1992 and operating continuously since, shows that power generation costs in 2004 dropped by around two-thirds. The first 14 MW unit supplied power at 44 UScents/kWh dropping to just 17 UScents/kWh for the last 80 MW unit.[8] With technology improvements, scaleup of individual plant capacity, increasing deployment rates, competitive pressures, thermal storage, new heat transfer fluids, and improved operation and maintenance, the cost of STE-generated electricity has dropped even further since then.

As with all solar thermal power plants, high initial investment is required for new plants. Over the entire life cycle of the plant, about 80% of the cost is from construction and associated debt, and the rest is from operation. Therefore, financial institution confidence in the new technology is critical. Only when funds are available without high risk surcharges can solar thermal power plant technologies become competitive with medium-load fossil fuel power plants. Once the plant has been paid for, only operating costs, which are currently about 2-3 UScents/kWh, remain, and the electricity is cheaper than almost any other source, comparable, for example, to long-written-off hydropower plants.

However, the cost of solar thermal power plants is more difficult to track precisely as there are relatively few new large-sized projects. What's more, projects built in recent years vary greatly in terms of design, configuration, size and type of thermal storage used, dispatch profile, support mechanisms and financing conditions. These factors complicate cost analyses and make comparisons between projects difficult. Unlike for wind or PV, the simple reference to the nominal power of a solar thermal power plant does not provide enough information to figure out either the investment cost or the cost of the kWh produced.

In technical terms, the data of the nominal power of the plant plus the solar multiple,[9] which reflects how much energy is gathered in the solar field at the design point in comparison with the required thermal power to run the turbine at nominal conditions, will be enough to size the plant.

Nevertheless, most STE literature does not refer to the solar multiple, but to the power of the turbine and the thermal storage capacity in terms of the number of hours it is able to keep the plant running at nominal power after sunset. The capacity factor – in terms of the percentage of hours operating at nominal power over the course of a year – is another way to point out the storage capability of the plants.

Normally once the size of the plant is known, its annual energy production can be calculated using the solar resource at the given site. Then, CAPEX and OPEX data along with the specific discount factor for the investment provide the basis to calculate the cost per kWh produced by the plant. But nowadays, the requirements on the dispatch profile are adding new variables in designing the plants. This makes it even more difficult to determine the required investment per MW and the per kWh cost of a solar thermal plant with a given nominal power.

The capital expenditure will depend on the type of service that a solar thermal power plant is providing along with some country specific factors. Each – parabolic trough, central receiver or linear Fresnel reflector – has different costs, although the two most commonly used technologies are similarly priced. At the time of writing, there are no commercial Fresnel plants with thermal storage, but this is an option for future projects.

Large differences exist in the per kWh prices paid to STE projects around the globe. STE projects in the US have executed PPA prices for as low 12 UScents/kWh while projects in Spain were paid a FIT price of 29 €cents/kWh until the recent reforms. Prices per kWh in other countries, such as Morocco, South Africa and India, fall somewhere in between these figures. However, the differences in pricing readily explained when the differences in DNI, size of the plant, PPA or FiT duration, escalation, grants, financing conditions, requested return on investments, etc., are taken into account.

8 For reference, the cost of electricity from the first 14 MWe unit was 25UScents/kWhe (1985 dollars).

9 For example, a steam cycle power station with a solar multiple 1 has one solar field just large enough to provide nominal turbine capacity under nominal irradiation conditions. A STE plant with a solar multiple 2 would have a solar field twice as large and a thermal energy storage system large enough to store the energy produced by the second solar field during the day.

ESTELA, the European Solar Thermal Electricity Association, has developed an easy tool[10] to account for these differences and convert the current contracts of commercial projects into the corresponding price of a standard plant of 150 MW, five hours of thermal storage, 25-year PPA with no escalation, no public support (e.g., grants or subsidized loans), and typical financing and ROI conditions. The harmonized costs can be shown within a band with lower costs in places with high DNI levels (i.e., California or Nevada) and higher costs in moderate DNI sites (i.e., southern Europe).

Here are some remarks on the discount factors for consideration:

Size of the plant: It is quite clear that the cost of electricity from a 50 MW plant will be higher than the cost for a 150 MW one. This is not only because of the relative differences in investment per MW, but also due to the impact of O&M costs as well. The differences in equivalent sizes depending on the size of the thermal storage must be also considered.

PPA duration: If the PPA (or FIT) of a given project lasts 20 years, the harmonized cost for a 25-year period has to be correspondently lower. Should the PPA be established for a 30-year period, the effect on the harmonized costs would be opposite. The discounted cash flows at usual Weighted Average Cost of Capital will provide the answer.

PPA escalation: Some PPAs include escalation clauses either for the whole price or for the embedded O&M cost. As the standard project does not consider escalation at all, the harmonized cost would be higher if these items were taken into account.

Grants and subsidized loans: The effect of any kind of grants, or subsidized loans can be determined from the discounted cash flow calculations. Removing them will provide increases in the harmonized cost.

Return on Investments: In some projects, especially when public investors are part of the ownership, the expected ROI is known and therefore its effect can be taken into consideration when interpreting the price of the project into the price of the standard one.

Currency exchange rate: This is another variable which can introduce some noise when trying to compare past figures with current rates.

10 Understanding the costs of STE plants: http://www.estelasolar.org/wp-content/uploads/2015/11/Understanding-the-costs-of-STE-plants_ESTELA-DCSP-PROTERMOSOLAR.pdf.

Taking into account the facts and figures from the past years and the expected trends for cost reduction, costs are expected decline as shown in Figure 2.4. These curves correspond to the best estimates of the STE industrial companies within ESTELA and they are fully consistent with the harmonized costs of all the solar thermal power plants built in the past in the US, Spain, India, Morocco, and South Africa, at their respective construction time.

As shown in Figure 2.4, 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 as 30 GW accumulated by 2025.

Interestingly, the forecasts of the US Department of Energy's SunShot Initiative[11] are much more aggressive. Their goal is to bring the cost of solar thermal electricity down to 6 UScents/kWh by 2020 not only based on the impact of technological development on the cost of components, but also on reductions in other costs, such as permitting, EPC and financing.

Room and reasons for cost reduction

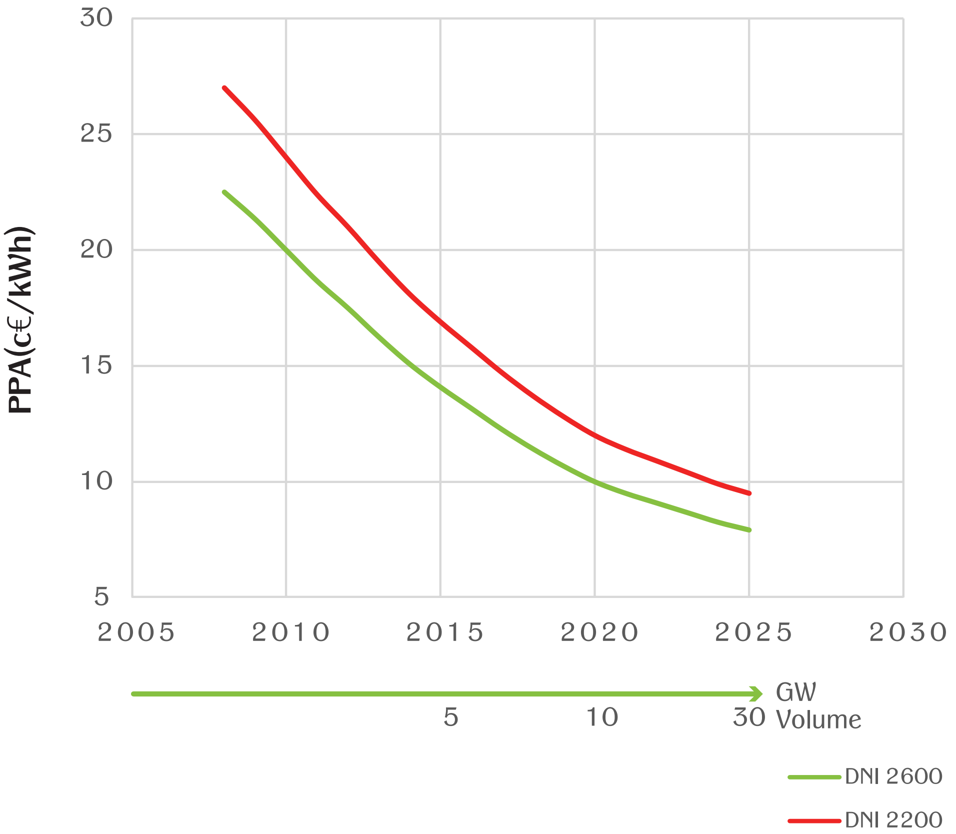
When comparing the almost 5 GW of solar thermal power plants installed with the 370 GW of wind or 177 GW of PV, it is obvious STE technologies have a huge potential for significant cost reductions.

Moreover, scale factors, new materials, more efficient manufacturing processes and assembly activities on site will certainly contribute to cost reduction. In addition, better performing solar field designs, higher temperatures for working fluids and the use of new power blocks with larger conversion efficiencies will further contribute to lowering the cost of the solar thermal electricity.

Table 2.3 lists the current and expected costs of the main systems of a typical solar thermal power plant.

11 U.S. Department of Energy – SunShot Initiative from: http://energy.gov/eere/sunshot/concentrating-solar-power.

Figure 2.4: **Required value for a 25-year PPA without escalation for a 150 MW five-hour thermal storage**



In addition to what can be identified 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. These costs must be reduced in aggregate and as a percentage of overall CAPEX costs. Importantly, structured financing costs for solar thermal power plants have 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 if breakthroughs apply.

Figure 2.5: **LCOE of new-built solar thermal power plant with storage and STE generation[14]**

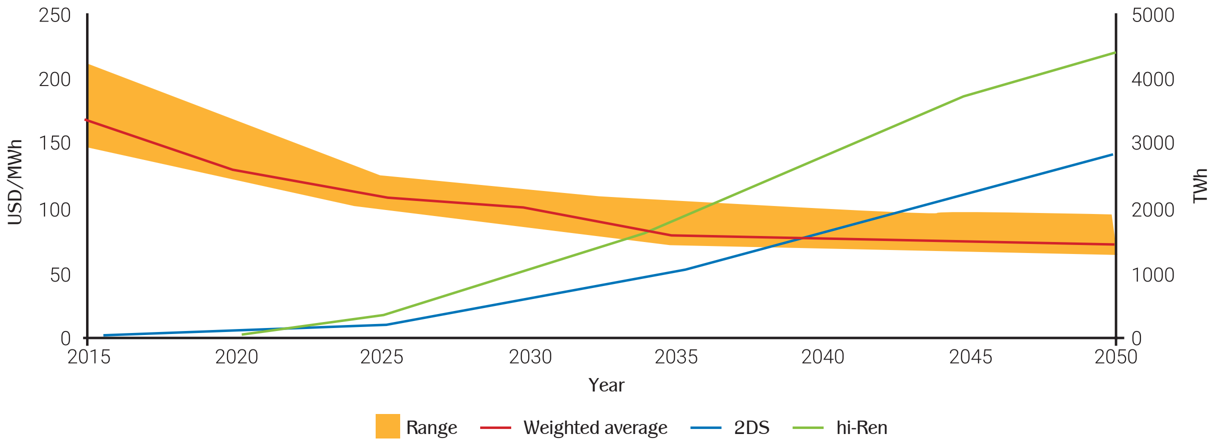


Table 2.3: **Drivers for cost reduction in STE**

	Today	2025
A) Solar field incl. HTF (€/m²)	160 – 250	100 – 160
B) Thermal Storage (€/kWhth)	26 – 30	18 – 21
C) PowerBlock (€/kWe)	720 – 765	700 – 790
D) System Efficiency	15% – 17%	18% – 20%

A) Solar Field

1. Collector with larger Aperture (trough)
2. Improved optics through higher accuracy heliostats, improved field layout (tower)
3. Advanced assembly procedure, industrialized assembly, industrial automatization in manufacturing; (sub) supplier standards; standardized design
4. Higher reflectivity, higher cleanliness
5. Improved durability
6. Improved absorber coating
7. Wireless power supply and control (heliostat)
8. Improved optics through higher accuracy heliostats, improved field layout (tower)
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
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

Image: Crescent Dune's 1.1 GW-hour storage capability is almost 40 times the size of the largest battery storage project in construction or built to date ©SolarReserve

To provide solar thermal electricity after sunset, thermal energy is stored in very large quantities. Thermal energy storage systems are an integral part of almost all solar thermal power plants built today. These systems allow for, among other things, balancing system operations, i.e., short-term variations of electricity production. Since 2010, thermal storage has been used in 40% of Spanish plants, providing an average of five to ten hours storage, depending on the DNI. Critically, as noted by the IEA, "when thermal storage is used to increase the capacity factor, it can reduce the levelised cost of solar thermal electricity." [13] What's more "(t)hermal storage also has a remarkable 'return' efficiency, especially when the storage medium is also used as heat transfer fluid. It may then achieve 98% return efficiency – i.e. energy losses are limited to about 2%."[14]

Presently, we can distinguish three categories of storage media that can be used in solar thermal power plants but each category is at a different stage of maturity:

- Advanced sensible heat storage systems

These types of systems are used in most state-of-the-art solar thermal power plants with "two-tank molten salt storage" (two tanks with molten salts at different temperature levels). The development of new storage mediums with improved thermal stability, such as molten salt mixtures, will allow higher temperatures to be attained. Higher temperatures enable increased energy density to be achieved within the TES and lower the specific investment costs for the system. Improvements to TES systems would have the potential to reduce CAPEX and also to improve efficiency.

- Cost-effective latent heat storage systems

Latent heat storage has not been implemented in commercial solar thermal power plants yet, but there are several research activities ongoing to support the introduction and use of phase changing materials in TES technologies. The use of latent heat storage offers new possibilities for DSG helping to achieving cost competitiveness with sensible heat technologies.

- Thermochemical storage systems

To date, there are no known commercial systems for thermochemical TES in solar thermal power plants. Research into the application of this technology started 40 years ago. Development projects assume potentials in energy density up to ten times higher than a comparable sensible heat TES.

12 IEA, 2014, "Technology Roadmap: Solar Thermal Electricity 2014 edition", OECD/IEA.

13 IEA, 2014, "Technology Roadmap: Solar Thermal Electricity 2014 edition", OECD/IEA.

14 IEA, 2014, "Technology Roadmap: Solar Thermal Electricity 2014 edition", OECD/IEA.

Hybridisation possibilities

For solar thermal power plants, hybridisation is the combination of solar energy with heat from other sources, such as biomass or fossil fuels.

The advantages of hybridisation are:

- Ability to convert the collected solar power with higher efficiency;
- Enhancing dispatchability to cover peak demand and deliver energy on demand;
- Overcoming the variability of solar radiation;
- Reducing start-up time; and
- Minimising the generation cost (LCOE).

Steam produced with solar energy can be used to boost the capacity of a conventional fossil fuel power plant, saving fuel, reducing CO_2 emissions and achieving higher solar energy conversion efficiencies.

All solar thermal power plants (PT, CR and LFR), with or without storage, can be equipped with fuel-powered backup systems that help to prepare the working fluid for start-up, regulate production and guarantee capacity (Figure 2.6 below). The fuel burners (which can use fossil fuel, biomass, biogas or, possibly, solar fuels) can provide energy to the HTF or the storage medium or directly to the power block. In areas with relatively lower DNI, fuel-powered backup makes it possible to almost completely guarantee the production capacity of the plant at a lower cost than if the plant depended only on the solar field and thermal storage.

Fuel burners also boost the conversion efficiency of solar heat to electricity by raising the working temperature level; in some plants, they may be used continuously in hybrid mode. STE can also be used in hybrid mode by adding a small solar field to fossil fuel plants such as coal plants or combined-cycle natural gas plants in so-called integrated solar combined-cycle plants (ISCC) There are operating examples in several northern African countries with solar fields of 25 MW equivalent and, in the United States, there are examples with a larger solar field (75 MW). A positive aspect of solar fuel savers is their relatively low cost: with the steam cycle and turbine already in place, only components specific to STE require additional investment.

Figure 2.6: **Combination of storage and hybridisation in a solar thermal power plant**

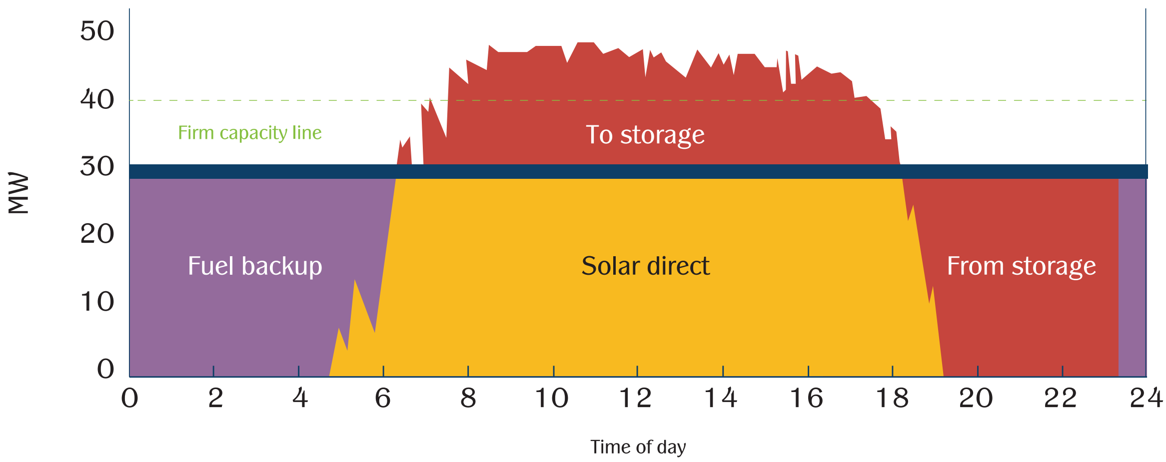


Image: Solana ©Abengoa

03

Other Applications of STE Technologies

Process Heat

Since the last report on STE deployment, STE has taken off in countries where political and financial support is available. Now that it is maturing, we can look beyond traditional electricity applications towards more innovative applications. Among these, solar process heat stands out as a smart and productive way to get the most out of STE technologies.

Many industries need high heat processes, for example in sterilization, boilers, heating and for absorption chilling. A 2008 study commissioned by the IEA[14] determined that in several industrial sectors, such as food, wine and beverage, transport equipment, machinery, textile, pulp and paper, about 27% of heat is required at medium temperature (100ºC–400ºC) and 43% at above 400ºC.

The deployment of solar thermal in industrial applications is increasing rapidly, albeit from a very low level. In 2010, the IEA-SHC[15] reported about 42 MWth worldwide (60,000 m^2).[16] In 2014, 132 solar thermal plants for industrial applications were reported worldwide with a total capacity of over 95.5 MWth (>136,500 m^2).[17] Only 17 plants have collector areas larger than 1,000 m^2, most other plants are small-scale pilot projects. Around 30% of the installations use PT or LFR collector systems, which are seen as the most suitable for the capture of heat for industrial processes.

STE can already be considered an economic option to install on-site for a range of industry applications requiring medium to high heat. The IEA study recommended that the sectors most compatible with process heat from solar concentrating technology are food (including wine and beverage), textile, transport equipment, metal and plastic treatment and chemical. The most suitable applications and processes include cleaning, drying, evaporation and distillation, blanching, pasteurization, sterilisation, cooking, melting, painting and surface treatment. Solar thermal or STE could also be utilised for space heating and cooling of factory buildings. The use of towers for high temperature heat processes like that required in ceramics is currently under research.

PT-1 solar thermal systems employ PT collectors that concentrate the sun's energy to deliver heat to applications in the industrial and commercial sector.

Image: PT-1 solar thermal systems ©Abengoa

The PT-1 system automatically tracks the sun throughout the day. The parabolic collector concentrates sunlight onto the receiver, where thermal energy is absorbed by a heat transfer fluid, typically

15 Vannoni, Battisti and Drigo, 2008, Department of Mechanics and Aeronautics - University of Rome "La Sapienza". Potential for Solar Heat in Industrial Processes, Commissioned by Solar Heating and Cooling Executive Committee of the International Energy Agency.

16 The Solar Heating and Cooling Programmeme (SHC) was established in 1977. It was one of the first programmemes of the IEA.

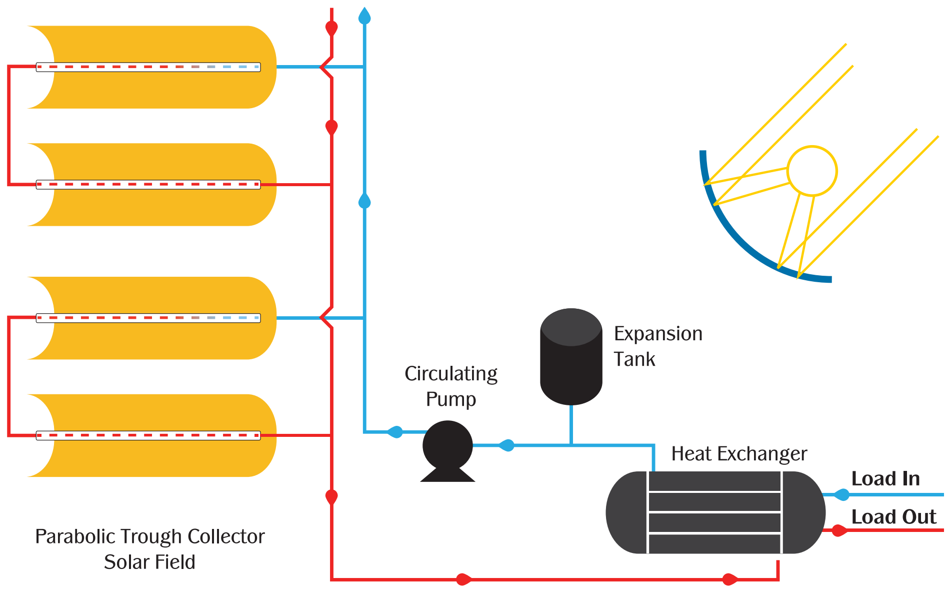
17 Lauterbach, C. et al,, "Solar heat for industrial processes –Technology and potential", http://www.solarthermalworld.org/sites/gstec/files/solar-heat-for-ind-processes-christoph-lauterbach.pdf.

18 Christoph, Brunner, 2014, "Solar Heat for Industrial Production Processes - Latest Research and Large Scale Installations", AEE INTEC.

water that is pumped through the collectors. The fluid is heated to the desired temperature and delivered to the process loads using a heat exchanger.

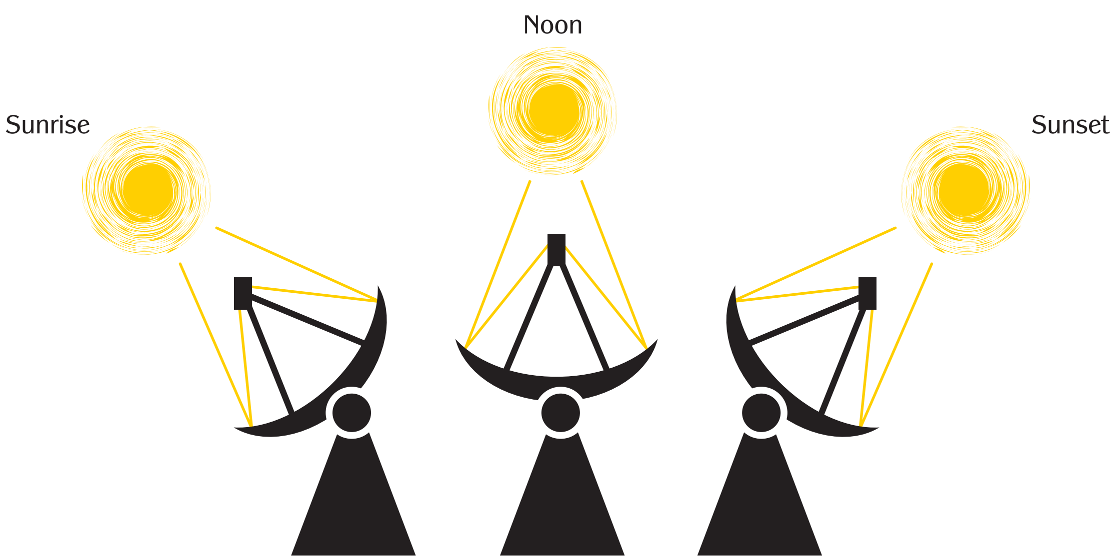
Compared to fixed-tilt collectors (flat plates), tracking is advantageous because the collectors operate longer during the day and energy delivery is more efficient and uniform throughout the day.

Figure 3.1: **Parabolic trough collector concentrating the sun's rays onto the receiver[18]**



PT systems are easily scalable and economically deliver heat from 49ºC to over 200ºC. Thermal energy storage tanks can be incorporated to deliver heat 24/7 or to meet specific schedules.

With a collector operating temperature up to 250ºC, this solar thermal technology meets the heat requirements of a wide range of industrial and commercial enterprises including:



19 Source: Abengoa

- Food & Beverage
- Automative
- Distilleries
- Textile
- Mining
- Pharmaceutical
- Paper
- Plastics
- Chemical
- Refineries
- Metal Processing
- Buildings

The PT-1 system is designed for ground installations and the RMT system is a smaller version of the PT-1 system, designed for installations on roofs.

Images: PT-1 solar thermal systems ©Abengoa

After 30 years of operation, the aluminum collectors and steel piping system can be profitably recycled and reused for future plants as no hazardous materials are used in the system.

Case Study: Minera El Tesoro – *Atacama Desert, Chile*

At 10 MW, the Minera El Tesoror plant is one of the largest industrial applications of solar thermal technology in the world. It's been operating since 2012. The thermal energy generated by the project supplies an electro-winning process and thermal energy storage tanks allow for 24/7 heat delivery.

Image: Minera El Tesoro ©Abengoa

Case Study: *Solar hot water installation in a federal correctional institution, United States*

Located in Littleton, Colorado, this project has been operational since 2010 and has a capacity of 1.25 MW. The thermal energy generated by the system provides for the domestic hot water heating supply at a federal correctional institution. The integrated hot water storage tanks allow for a 24/7 hot water supply.

Image: Solar hot water installation ©Abengoa

Case Study: *Frito Lay, United States*

This 3 MW solar heating system has been operating in Modesto, California since 2008. It's the largest solar heat system in the US. Owned by Frito Lay, the system generates 300 psig of steam to heat cooking oil for Sun Chips.

Image: Solar heating system ©Abengoa

A new application for STE is its use for Enhanced Oil Recovery. Solar EOR uses solar collector systems to concentrate the sun's energy to heat water and generate steam. The steam is then injected into an oil reservoir to reduce the viscosity, or thin, heavy crude, thus facilitating its flow to the surface. Thermal recovery processes, also known as steam injection, have traditionally burned natural gas to produce steam. Solar EOR is proving to be a viable alternative to gas-fired steam production for the oil industry. So far, solar EOR pilot plants in the US and Middle East are using direct steam PT and tower systems.

Desalination

Desalination is the process of turning seawater into freshwater for drinking or irrigation. Major desalination plants are operating today all over the world, mostly using reverse osmosis and some using thermal distillation. Large-scale desalination has been controversial, however, primarily because it's an energy intensive process and marine life can suffer harm as a result of seawater intake and discharge of super-concentrated salt water. From a sustainability perspective, large-scale desalination is seen almost as a last resort – the preference is for more efficient use of water, better accountability, reuse of wastewater, and use of enhanced distribution and advanced irrigation systems. Most desalination plants either run on grid electricity or are directly powered by oil and gas. The carbon footprint of these plants, as a result, can be significant.

Fortunately, STE holds the potential to power desalination plants and avoids the emissions issue. With the growth and increasing affordability of STE, researchers have started looking into how desalination could address water scarcity. It should come as no surprise that areas with large amounts of solar radiation are often also places with limited water supplies. A 2007 study by the German Aerospace Centre[20] on the use of STE for desalination of seawater examined the potential of this technology to provide water to the large urban centres in the Middle East and North Africa. The study concluded that the solar resource in the region is more than adequate to provide energy for desalination required to meet the growing water deficit in these areas.

The report also shows that only four of the 19 countries in the region have renewable freshwater resources that exceed 100 cubic litres per person per year, which is generally considered to be the water poverty line. The current water deficit in the region is estimated at 50 billion m^3/yr and is expected to grow to three times that amount by 2050. The study goes on to predict that energy from solar thermal power plants will become the least cost option for electricity at below 4 €cents/kWh and desalinated water at below 40 €cents/m^3 in the next two decades. A key finding is that management and efficient use of water, along with the use of enhanced distribution and irrigation systems, reuse of wastewater and better accountability can avoid about 50% of the long-term water deficit of the MENA region. Solar desalination could have a role to play in providing the other half, using “horizontal drain seabed-intake” and advanced nanotechnology for membranes to minimise the environmental impact of discharging a high salt load into living systems.

DLR suggests that the most appropriate technology mix would be either STE providing the electricity to a RO process membrane desalination, or STE providing both electricity and heat to a thermal “multi-effect” desalination system. Currently, most of the desalted water in the MENA region is provided by a process called Multi-Stage Flash desalination. This is not considered a viable future option for solar powered desalination, because the energy consumption is too high.

The conclusion is that advanced STE systems have the potential to operate cleaner desalination plants with extremely low environmental impacts[21] compared to today's conventional desalination systems at about 20% higher investment cost, but using a fuel, i.e., the sun, that has no costs.

According to the Deutsche CSP,[22] two solar desalination pilot plants using PT collectors, heat storage tanks and Multi-Effect Desalination technology have already been realized in Australia and Qatar. Each produces 10 m^3 of freshwater per day.[23] More recently, in April 2013, a Fresnel Concentrating Solar Thermal desalination demonstration plant was completed at Al Jubail by Saline Water Conversion Corporation. This demonstration plant shows that STE technology can provide desalinated water at affordable costs compared to other conventional sources.

20 German Aerospace Centre (DLR), 2007, “Aqua-CSP: Concentrating Solar Power for Seawater Desalination.” Available at: http://www.dlr.de/tt/aqua-csp.

21 Individual plant locations would need to be chosen carefully to allow rapid discharge and dilution of brine, and subject to a thorough environmental analysis to avoid impacts to important marine life.

22 Deutsche CSP is the German Association for Concentrated Solar Power (http://deutsche-csp.de/en/).

23 Deutsche CSP; Integration of Solar Process Heat Systems, Joint Saudi-German CSP Workshop, 19th - 20th November 2013.

Image: Solar thermal desalination power plant at AL JUBAIL- Kingdom of Saudi Arabia – courtesy of SWCC and Hitachi Zosen Corporation.

Solar Fuels

To meet the challenge of producing large quantities of cost-effective fuel directly from sunlight, there is now rapid development in solar thermochemical production of fuels. Some processes encompass upgrading fossil fuels with solar energy input, thus cutting a proportion of greenhouse gas emissions. The ultimate goal, however, is for solar fuel technologies based on processes that are completely independent of any fossil fuel resources.[24]

Considerable scope exists for developing cost-effective solar thermochemical hybrid technologies involving solar reforming of natural gas, using either steam or carbon dioxide, and solar-driven gasification of carbonaceous feedstock (fossil fuels, biomass, carbon-containing wastes). These processes have been extensively studied in solar concentrating research facilities with small-scale solar reactor prototypes. The first generation of industrial solar reforming and gasification pilot plants using solar tower concentrating systems are coming into operation. Ultimately, solar reforming and gasification are an efficient means of storing intermittent solar energy in a transportable and dispatchable chemical form.

Solar hybrid fuels combine solar energy with a carbonaceous fuel, such as natural gas or coal, to form a product that embodies both renewable and fossil energy. This is done by using concentrated, high temperature solar energy to provide the heat to drive endothermic (heat absorbing) chemical reactions that convert the particular fossil fuel into intermediate and final products such as liquid transport fuels. In the longer term, however, there will be a need for truly renewable technologies for the production of solar fuels and chemicals.

In this context, the use of metal oxide redox cycles for water and carbon dioxide splitting is one promising route based on developments to date and the current scale of R&D devoted to this option. In fact, much attention is focussed on the solar production of hydrogen and carbon monoxide, which form a synthesis gas (syngas)

24 SolarPACES, Report: "Roadmap to Solar Fuels". Available at: http://www.solarpaces.org/press-room/news/item/85-solar-paces-report-roadmap-to-solar-fuels.

that can be further processed to liquid fuels such as methanol, diesel, and jet fuel. Although hydrogen is a potentially clean alternative to fossil fuels – especially for transport uses – currently more than 90% of hydrogen is produced using process heat from fossil fuels, mainly natural gas. Generating hydrogen merely from water and solar energy would result in a completely clean fuel with no hazardous wastes or climate-changing by-products. This is the vision outlined in the European Commission's 'European hydrogen and fuel cell roadmap', which runs to 2050.

Another focus presently lies on the conversion of carbon dioxide into sustainable hydrocarbons. Similar to the thermochemical splitting of water into hydrogen and oxygen, carbon dioxide can be split into carbon monoxide and oxygen. Synthesis gas generated in this way can be further processed via conventional processes – e.g. Fischer-Tropsch synthesis – to liquid fuels, which will be indispensable for the following decades, especially for applications like air transportation.[25]

Solar fuels can be used in several ways: burned to generate heat, fed into turbines or engines to produce electricity or motion, or directly used to generate electricity in fuel cells and batteries. By storing solar energy in a fuel like hydrogen or syngas, it can be retrieved when needed, and is available even when the sun is not shining.

There are basically three routes for producing storable and transportable fuels from solar energy:

- *Electrochemical:* Solar electricity made from photovoltaic or concentrating solar thermal systems followed by an electrolytic process.
- *Photochemical/Photobiologica:* Direct use of solar photon energy for photochemical and photobiological processes.
- *Thermochemical:* Solar heat at high temperatures followed by an endothermic thermochemical process.

High-temperature thermochemical processes efficiently convert concentrated solar energy into storable and transportable fuels. What's more, solar fuels produced via thermochemical processes can become competitive with conventional fossil fuel-based processes at current fuel prices, provided credits for CO_2 mitigation and pollution avoidance are applied. This means that solar fuels could play an indispensable role in a 100% renewably-powered world, substituting, for example, for the fossil fuels currently used in transport, aviation and shipping. Solar fuels could also serve as a form of energy storage, produced during times of excess electricity and used at a later date.

A viable route for the production of solar fuels is using solar electricity generated by STE technology, followed by co-electrolysis of water and carbon dioxide in solid oxide cells.[26] This emerging technology can be considered as a benchmark for other routes that offer the potential of energy-efficient large-scale production of hydrogen and syngas. Further R&D in sustainable fuel technologies is warranted to cope with the European Union's World Energy Technology Outlook scenario that, for example, predicts a hydrogen demand equivalent to about one billion tons of oil in 2050.

Cost considerations

The economic competitiveness of solar fuel production is determined by the cost of fossil fuels and the actions we must take to protect the world's climate by drastically reducing CO_2 emissions. Both the US DOE and the European Commission have a clear vision of the future hydrogen economy, with firm targets for hydrogen production costs. The US target for 2017 is \$3.00/gge[27], and the EU target for 2020 is €3.50/kg.[28]

The projected cost of hydrogen produced by STE and electrolysis ranges from 15 to 20 UScents/kWh, or US\$5.90 to \$7.90/kg hydrogen (assuming solar thermal electricity costs of 8 UScents/kWh).

The economics of large-scale solar hydrogen production has been assessed in several studies which indicate that solar thermochemical production of hydrogen fuel can eventually be competitive with electrolysis of water using solar-generated electricity. As indicated above, it can even become competitive with conventional fossil fuel-based processes at current fuel prices, especially with credits for CO_2 mitigation and pollution avoidance.

The ability to export renewable fuels from sun-rich regions like Australia or South Africa to

25 Furler P., Scheffe J.R., Steinfeld A., 2012."Syngas production by simultaneous splitting of H2O and CO_2 via ceria redox reactions in a high-temperature solar reactor," Energy & Environmental Science, Vol. 5, pp. 6098-6103, 2012.

26 Graves C.R, 2010, "Recycling CO_2 into Sustainable Hydrocarbon Fuels: Electrolysis of CO_2 and H2O", PhD Thesis, Columbia University, New York.

27 1 gge equals about 1 kg of hydrogen.

28 Meier, A, Sattler, C, 2008, "Solar Fuels from Concentrated Sunlight", Published by SolarPACES, www.solarpaces.org.

consumers with a strict CO_2 emission policy, increases the potential market opportunity for solar-produced hydrogen or syngas. The IEA-SolarPACES implementing agreement has carried out roadmap studies on industry involvement and market penetration of solar fuels in South Africa, Australia, and China. The study on hybrid solar fuels in Australia, especially, is closely linked to national Australian and Japanese efforts by ARENA[29] and SIP,[30] respectively.

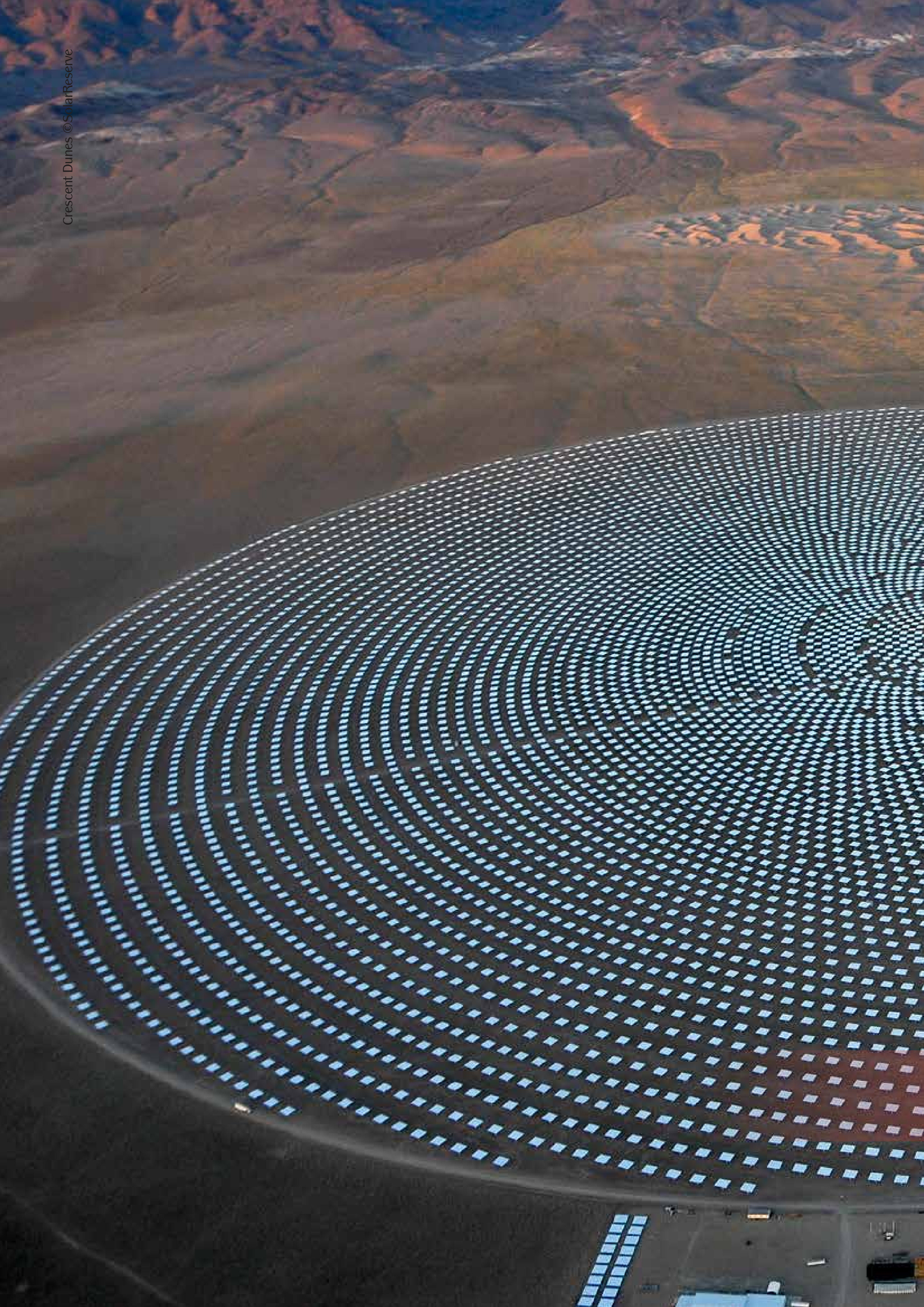
To this end, further R&D and large-scale demonstrations of solar fuel technologies are needed. This would increase achievable efficiencies and reduce investment costs for materials and components. As more commercial solar thermal power plants come on line, in particular solar towers, the price of solar thermal hydrogen production will drop, since heliostats are one of the most expensive components of a solar chemical production plant.[31]

Image: Birds resting on a parabolic trough tube ®CSP Services/DLR

29 ARENA: Australian Renewable Energy Agency http://arena.gov.au/.

30 SIP: Cross-ministerial Strategic Innovation Promotion Programme http://www.jst.go.jp/sip/index.html.

31 Note that hydrogen generation via PV and electrolysis shows low efficiency due to the variations in power supply, which has negative effects on the membrane operation. Dispatchable STE power would avoid this problem.


Crescent Dunes ©SolarReserve

04

Market Situation by Region

World Overview

As of 2015, the installed capacity of STE increased to almost 5 GW with the connection of a number of large-scale solar thermal power plants to the grid, in Spain and the US in particular. Around 61% of the operational STE plants are located in Spain, whereas 18% are located in the US.

Over the past three years, market interest has shifted away from the traditional markets of Spain and the US to emerging markets like South Africa, Morocco and Chile, due to their high solar resources and political commitment to solar energy.

The levelised electricity cost of STE plants depends on both the available solar resource and development costs of investment, financing and operation. Plants under the same price and financing conditions, in the southwestern US or Upper Egypt will have levelised electricity cost 20%-30% lower than in southern Spain or the North African coast. This is because the amount of energy from direct sunlight is up to 30% higher (2,600-2,800 kWh/m^2/yr compared to 2,000–2,100 kWh/m^2/yr). The solar resource is even lower in France, Italy and Portugal. The best solar resource in the world is in the deserts of South Africa and Chile, where direct sunlight provides almost 3,000 kWh/m^2/yr.

The economic feasibility of a project is determined by both the available solar resource at the site and then by power sale conditions. If the local power purchase price does not cover the production cost, then incentives or soft loans can cover the cost gap between the power cost and the available tariff. Environmental market mechanisms like renewable energy certificates could be an additional source of income, in particular in developing countries.

All the STE plants in the US were pre-financed by developers and/or suppliers/builders and received non-recourse project financing only after successful start-up. In contrast, all STE projects in Spain received non-recourse project financing for construction. Extensive due diligence preceded financial closure and only prime EPC contractors were acceptable to the banks, which required long-term performance guarantees accompanied by high failure penalties. In markets like South Africa and India, a reverse bidding system has been used to ensure a competitive tariff for the PPA. STE with storage is increasingly becoming a pre-requisite in government tenders around the world.

'Bankability' of the plant revenue stream has been the key to project finance in Algeria, Spain and the US. Different approaches have been long-term power purchase agreements and FITs, but it has taken considerable effort during years of project development to remove the barriers and obstacles to bankability. In Spain, one major barrier for industry development was the right of the government to change tariffs every year, which gave no long-term business plan income security.

International Policy Frameworks

There is one major and still active international policy instrument relevant to STE at the moment – the Mediterranean Solar Plan.[32]

The Mediterranean Solar Plan was announced in mid-2008 under the Union for the Mediterranean with an initial forecast of 10 GW of STE by 2020, reflecting the potential in the region for the technology to provide both local and export power. The MSP is a result of collaboration on promoting renewable energy between the EU and its Southern and Southeast Mediterranean neighbours, involving support to the production of solar energy in North Africa and energy efficiency to support significant energy savings in the Mediterranean region.

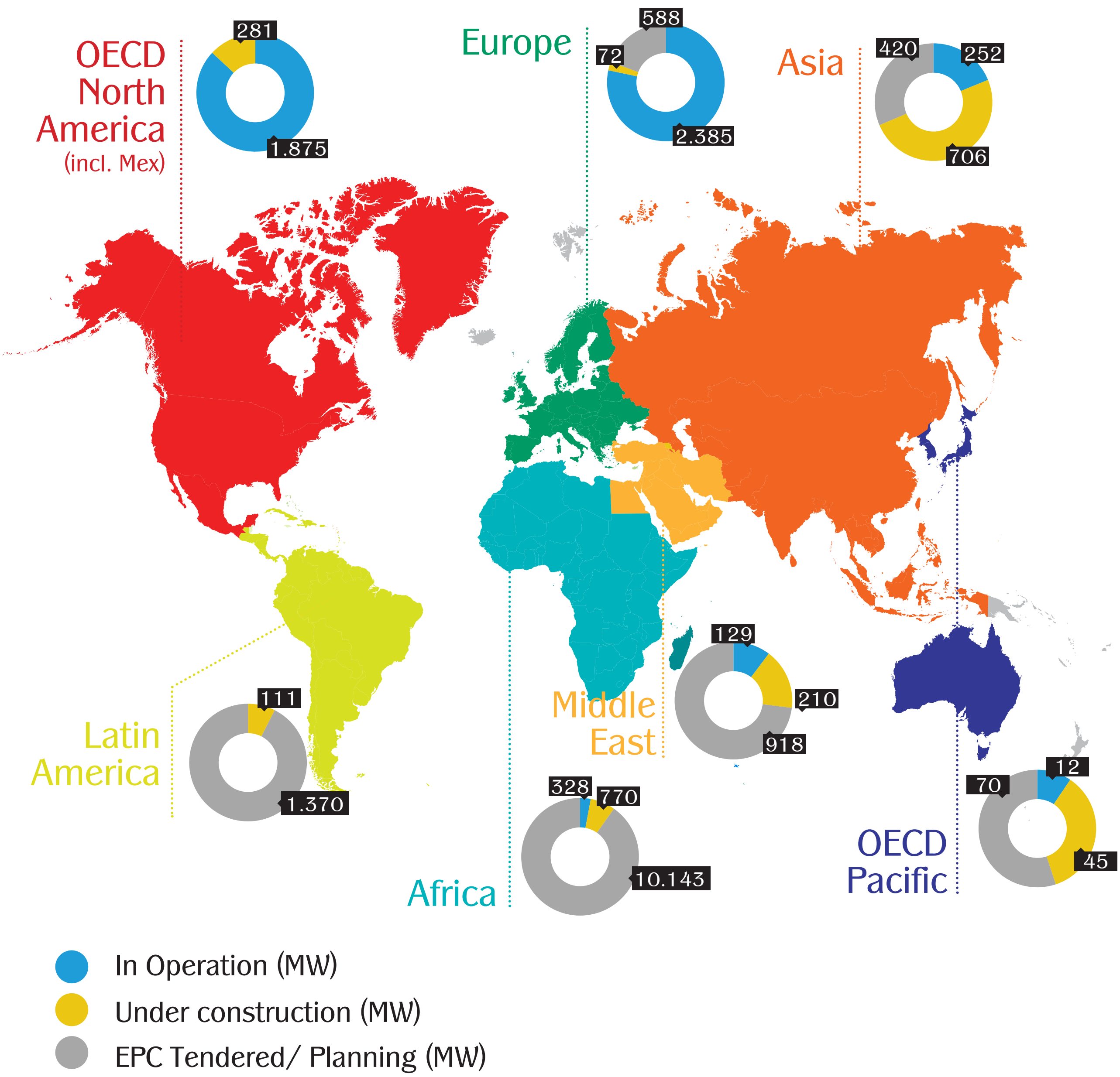
Although the 10 GW goal may seem unrealistic, progress has been made, such as in Morocco with three big solar thermal power plants under construction along with ambitious prospects for 2020 mainly for supplying its local demand. Plans for solar thermal power plant deployment for internal consumption have also been announced in other Mediterranean countries in Africa. However, the MSP's success regarding exporting power depends on high-voltage connections between Tunisia and Italy and Turkey and Greece, as well as on the reinforcement of the interconnection of the Iberian Peninsula with France. This last point caused important hesitations for Spain, which are now removed after knowing the priority that has been given to the electrical interconnection in the Juncker's Energy package. On the other hand, political instability in the region remains a major barrier to the implementation of the MSP.

The European Union is supporting the MSP

34 See, Union for the Mediterranean (UfM), http://ufmsecretariat.org/.

through a number of projects including the "Paving the Way for the Mediterranean" Solar Plan launched in October 2010. Moreover, other projects, such as the "Support for the Enhanced Integration and the Improved Security of the Euro-Mediterranean Energy Market" and the second phase of the project "Energy Efficiency in the Construction Sector"', will help create the conditions for renewable energy development and increased energy efficiency in the Mediterranean region. Additionally, the EU Neighbourhood Investment Facility provides support to infrastructure investments in the region in cooperation with the European Finance Institutions.[33] For example, regarding financial tools and risk management mechanisms, the UfM Secretariat worked in close collaboration with the European Investment Bank in order to fully trigger the Mediterranean Solar Plan-Project Preparation Initiative by the end of 2014. MSP-PPI aims to provide technical assistance to support project preparation and development in the areas of renewable energy, energy efficiency and renewable energy transmission capacities for connections to the grid in the region. The programme, addressed to the Mediterranean Partner Countries eligible under the European Neighbourhood Investment Facility, is financed by the European Commission, and the UfM Secretariat will be actively involved in the work of its Steering Committee.[34]

Figure 4.1: **Current market situation across the world**



33 See, The Africa-EU Partnership at: http://www.africa-eu-partnership.org/success-stories/mediterranean-solar-plan-links-north-africa-europe.

34 Union for the Mediterranean, 2014, Activity Report. Available at: http://ufmsecretariat.org/wp-content/uploads/2015/04/Report_web_FINAL.pdf.

Middle East and India

Israel

In 2002, the Israeli Ministry of National Infrastructures, which is responsible for the energy sector, made STE a strategic component of the electricity market. Israel introduced feed-in incentives for solar IPPs from September 2006, effective for 20 years. This was following a feasibility study on STE incentives completed in 2003 and evaluated by the Israeli Public Utilities Authority.[35] Also in 2002, the Israeli government set a national goal of 5% renewable energy electricity production to be reached by 2016. In order to further reduce its dependence on fossil energy, the Israeli government has since set a new target to cover 10% of the country's electricity need through renewable energy by 2020 and 50% (or more) by 2050. Those goals were translated by the Ministry of National Infrastructures to an installed capacity goal of 2,760 MW by 2020.[36] This set of goals would mean a total production of 6.43 TWh from renewable sources by 2020.[37] A new feed-in tariff for large-scale STE and PV plants was introduced in 2011 to help meet these objectives, introducing a quota of 460 MW.

The 231 MW Ashalim complex includes two solar thermal power plants which, will generate 2% of Israel's total installed capacity. The first phase of the Ashalim complex – 121 MW with CR technology, now entering construction and expected to be operational by mid-2017, is being built by a joint venture named Megalim between France's Alstom, US developer Brightsource and Israeli energy and infrastructure fund NOY. The second phase of the project – 110 MW with PT – is being built by Negev Energy, a joint company established by Spanish group Abengoa and Israel's Shikun & Binui, in the Ashalim area of the Negev Desert. It is expected to be operational by 2018.[38] The Israel Electricity Corporation will buy the electricity generated by the plant under a 25-year PPA. In addition to avoiding more than 300,000 tonnes of CO_2 emissions a year, the solar plant will also retain enough heat to continue producing power through the night. The Ashalim complex will be Israel's biggest solar plant and one of the world's largest STE complexes.

Israel is moving to an era where more supportive regulations are created for renewable technologies with a net positive cost-benefit market value in the long run. Beginning in 2008, the PUA, for example, began issuing regulations to enable the production of electricity by the private market. In 2013, the PUA started preparing grid parity and net-metering regulations to further integrate renewable energy into the Israeli electricity market and allow the local market to flourish and harvest the benefit of renewables, especially solar power, which Israel is blessed with.

35 Following this, Greenpeace published a cost-benefit analysis for solar energy in Israel, indicating that the country could use up to 2,000 MW of solar power by 2025.

36 The Green Energy Association of Israel, http://www.renewable.org.il/he-il/english.htm.

37 SolarPACES.

38 Abengoa Solar.

Turkey

Turkey is in an advantageous position for solar energy, compared to the rest of Europe, due to its high DNI levels. The Turkish government has set a renewable electricity production goal of 30% by 2023.

Turkey enacted its first specific renewable energy law in May 2005 (the "Law on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy"). The renewable energy law works in line with "Renewable Energy Source Certificates". The law introduced fixed tariffs for electricity generated from renewable energy sources and a purchase obligation for the distribution companies holding retail licenses from the certified renewable energy producers.

The current financial incentive for STE technology is calculated as the sum of a base tariff (13.3 UScents/kWh) plus a domestic manufacturing adder, which is assigned when certain components are locally sourced. The adders are structured as reported below:

- Vacuum tubes 2.4 UScents/kWh
- Reflecting surface panels 0.6 UScents/kWh
- Solar tracking systems 0.6 UScents/kWh
- Heat energy storage systems 1.3 UScents/kWh
- Tower and steam production system 2.4 UScents/kWh
- Stirling engine 1.3 UScents/kWh
- Integration of solar panels and mechanical systems 0.6 UScents/kWh

Therefore the maximum contribution for localizing the supply chain is 9.2 UScents/kWh and the ceiling for the FIT is 22.5 UScents/kWh.[39]

The 5 MW Greenway STE Mersin Solar Tower Plant was the first operational commercial plant in Turkey. Natural circulation direct steam generation boiler is used at the plant, which achieved commerical operation in March 2013.

39 CSP Today.

Jordan

Jordan has a long-standing interest in large-scale solar thermal power generation. Over the last decade, there have been several proposals and analyses of solar thermal potential in Jordan, although there have been difficulties progressing due to the instability in the Middle East.

Currently, Jordan relies heavily on imported primary energy, about 96%. Demand for energy is increasing at a rate of 5.5%, whilst electricity demand is growing 7.5% per year. Growth in demand for energy and electricity is expected to double by 2020. At the same time, the country is eager to reduce its dependence on energy imports and diversify its energy resources.

The solar energy potential in Jordan is enormous as it lies within the Sun Belt region of the world. Average annual solar radiation ranges between 5 and 7 kWh/m^2, which suggests a potential of at least 1,000 GWh of solar-generated electricity per year. However, solar energy, like other forms of renewable energy, remains underutilized in Jordan. According to the National Energy Research Centre, however, the government expects to increase the share of renewable energy to 10% by 2020. Solar's contribution to that target is expected to be 300 MW to 600 MW (STE, PV and hybrid power plants).[40] The government hopes to construct the first STE demonstration project in the short to medium term in Aqaba. Plans are also underway for a solar desalination plant.

One of the most promising potential investments is the installation of more than 250 MW of STE in Jordan's Ma'an development zone through a series of private sector projects. At full capacity, these Ma'an projects could meet some 4% of the Jordan's electricity needs, reducing reliance on electricity imports from neighbouring countries. Surplus energy could in turn be sold to Syria, Egypt and Palestine, whose networks are connected to Jordan.

In 2013, the French company Solar Euromed was awarded the international call for tenders that was open for several STE technologies.[41] The Jordanian Authorities officially designated Solar Euromed for the construction and commissioning of the WECSP power plant. The tender award demonstrates the cost competitiveness of the LFR technology. The project is also located in Ma'an, near Al-Fujeij village in the Southern part of the Kingdom of Jordan. The site has excellent an excellent DNI, even for Jordan, at more than 2,600 kWh/m^2/yr.

40 See, EcoMENA, http://www.ecomena.org/solar-energy-jordan.

41 See, Solar Euromed, http://www.solareuromed.com/en/wecsp.

United Arab Emirates

The UAE is another region with great solar potential. The amount of solar radiation received ranges between 2,050 kWh/m^2/yr and 2,800 kWh/m^2/yr, which is among the best in the world.

The UAE began actively promoting the development of solar power generation in April 2008. Both emirates have ambitious initial targets: Abu Dhabi wants solar to account for 7% of its output by 2020, whilst Dubai is aiming for 5% by 2030. Abu Dhabi has launched projects using both PV and STE technologies, whilst Dubai is currently focusing on PV systems.

In January 2013, the UAE inaugurated the largest stand-alone STE plant in the Middle East, Shams 1. At 100 MW, Shams 1 extends over an area of 2.5 km^2, with a solar field consisting of 768 PT collectors. The project generates enough electricity to power 20,000 homes and avoids 175,000 tonnes of CO_2 emissions every tear.

Despite the considerable potential for STE in the UAE, the industry has experienced slower-than-expected industry growth to date, lagging behind other Sun Belt countries. It is expected, however, that the UAE will soon formulate a more concrete local content policy to create a new market as it has the necessary resources, including the infrastructure and labour force needed to localise the STE supply chain.

India

India has also a very promising solar resource, with annual global radiation of between 1,600 kWh/m^2 and 2,200 kWh/m^2, which is typical of tropical and sub-tropical regions. The Indian government estimates that just 1% of the country's landmass could meet its energy requirements until 2030.[42] On the solar market development front, the National Action Plan on Climate Change puts forwards some specific policy measures, including research and development to lower the cost of solar energy production and maintenance, establishing a solar energy research centre, and a target of least 1,000 MW of STE by 2017.

The Jawaharlal Nehru National Solar Mission is a major initiative of the Indian government as well as state governments to promote sustainable growth and address India's energy security challenges. The JNNSM seeks to establish India as a global leader in solar energy, by creating the policy conditions for the quick diffusion of solar technologies across the country. The Mission has set a target of 20 GW to be executed in three

42 Prime Minister's Council on Climate Change, Government of India, 2008, "National Action Plan on Climate Change."

phases (first phase from 2012 to 2013, second phase from 2013 to 2017 and third phase from 2017 to 2022). The Mission also designates the National Thermal Power Corporation's Vidyut Vyapar Nigam Ltd as the Nodal Agency for procuring solar power by entering into a PPA with solar power generation projects. CERC has set a tariff cap of INR 15.31 for solar thermal power projects.[43]

Under phase one of the NSM, 470 MW of STE was allocated. In April 2014, the Ministry of New and Renewable Energy and the state-run Solar Energy Corp. of India confirmed that the STE target for 2015 would be reduced from 1,080 MW to 100 MW. This came after only one project out of seven successfully met the March 2014 deadline under Phase 1 of the JNSM.

India currently has an installed STE capacity of 235 MW. This includes the 50 MW Godawari plant, the 50 MW Megha plant and the 125 MW Reliance Areva project. The Reliance Areva project is the world's largest operational LFR plant.

Iran

The Islamic Republic of Iran has shown an interest in renewable energy technology, including solar power, and is keen to exploit its abundant solar resource with STE technology. The government also wants to diversify its power production away from the country's oil and natural gas reserves.

The Iranian Power Development Company undertook a comprehensive feasibility study on an Integrated Solar Combined Cycle with trough technology from the Electric Power Research Center (now the NIROO Research Institute) and Fichtner (now Fichtner Solar). The study has identified that Esfahan, Fars, Kerman and Yazd are all excellent regions for installing solar thermal power plants in Iran, but Yazd, where the entire high plateau is characterized by an annual DNI of over 2,500 kWh/m²/yr, was finally selected as the site for the first plant. Iran had approached GEF with a request to finance part of the cost of the solar field. As GEF was not in the position to allocate any additional resources for this request, Iran, in 2005, changed the initial plant configuration with a solar component of 64 MW to a configuration with a solar field equivalent to 17 MW. The Yazd ISCC began operation in 2010.[44] No new developments in the market have been announced since then.

43 CSP Today Global Tracker.

44 SolarPACES.

North and South Africa

Algeria

Algeria has excellent solar resources of over 2,000 kWh/m²/yr direct sunlight. Nationally, the government has a goal to provide 10%-15% of energy from renewable resources by 2030. Beyond this, the Algerian government would like a close partnership with the European Union, in which Algerian plants deliver green energy needed for Europe to meet its energy and climate targets. A new company called New Energy Algeria was created to enhance participation of the local and international private sectors.

In March 2004, the Algerian government published the first feed-in law[45] of any OECD country, with elevated tariffs for renewable power production in order to promote the production of solar electricity in integrated solar combined cycles. This decree sets premium prices for electricity production from ISCCS, depending on the solar share. A 5%-10% solar share can earn a 100% tariff, whilst a project with a solar share over 20% would receive up to 200% of the regular tariff.

In February 2015, Algeria's Ministry of Energy announced plans which include the development of 2 GW of STE, 13.5 GW of solar PV and 5 GW of wind energy. Altogether, the Ministry is targeting the installation of 22 GW of renewable energy by 2030, of which 4.5 GW would be connected by 2020.

Algeria currently has one operational solar thermal power plant – the 25 MW Hassi-R'mel ISCC project developed by Abengoa, Cofides and New Energy Algeria.

Morocco

Morocco has a target to develop 2 GW of solar power by 2020. The Renewable Law 13-09, approved in 2010, provides a legal framework for the creation and operation of facilities producing electricity from renewable energy sources. It allows public and private corporations to compete with Morocco's National Electricity Office, the publicly-owned utility, in the production of electricity from renewable energy as well as have access to the electricity transmission system operated by ONE.

Morocco's solar plan is overseen by the Moroccan Agency for Solar Energy. Recently, 160 MW of STE (Noor I) was successfully connected to

45 "Decret Executif 04-92" in the Official Journal of Algeria No.19.

Moroccan grid in Feb 2016 and 300 MW are under development (Noor II and Noor III). The latest tender for solar in Morocco was for a 50 to 70 MW PV project called Noor IV. As its name suggests, Noor IV would be part the same Noor Ouarzazate complex, which is home to the Noor I, II and III STE projects. Expressions for interest were launched in March 2015.

Egypt

Egypt lies within the Sun Belt area, where DNI ranges between 2,000 kWh/m²/yr in the north and 3,200 kWh/m²/yr in the south. In February 2008, the Supreme Council of Energy set a target to generate 20% of the country's electricity from renewable energy by 2020, including 12% from wind, 5.8% from hydro and 2.2% from solar (STE and PV).

Two pre-feasibility studies on parabolic-trough and central tower technologies were conducted in 1995 followed by a SolarPACES START mission in 1996. Following that, Egypt decided to build its first 150 MW ISCC system with a 30 MW PT solar field. The first phase detailed feasibility report was completed in 2000, followed by a short list of qualified and interested developers in 2001. The project stalled, however, due to the unexpectedly high exchange rate of US Dollar-to Egyptian Pound.

In mid-2003, the World Bank, as the main financial institution involved in this effort, decided to change its approach, allowing private sector participation in a 5-year ownership and maintenance contract. In 2007, contracts were awarded to Iberdrola and Mitsui and a consortium of Orascum and Flagsol to build the ISCC project at Kuraymat with a US$ 50 million grant under GEF-OP7. The plant was put into commercial operation in 2011. The capacity of the ISCC Kuraymat project is 140 MW, including a solar share of 20 MW. The solar field consists of 1,920 PT collector modules, arranged in 40 loops, with a total effective aperture area of 130,800 m².

Egypt is currently developing its second STE project, the 100 MW Kom Ombo plant with PT technology in Upper. The development of the project is being led by NREA and is supported by the KfW, African Development Bank and the World Bank. The project is expected to be completed by 2017.

Plans for two additional solar thermal power plants have also been announced – the 250 MW Taqa STE Plant and the 30 MW Marse Alam. These two plants will be located in an area of Egypt where electricity demand is expected to increase significantly in the coming years.

South Africa

South Africa relies predominately on coal to meet its electricity needs. Currently, 91% of installed capacity is comprised of coal, gas and nuclear stations, 5% hydropower and 4% renewables.

Recently, the South African government, together with the national utility Eskom (which owns the country's coal power plants and manages the grid), developed a programme to facilitate development and deployment of renewable energy technologies. This programme is called the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP).While South Africa has made progress through four rounds of the REIPPPP, there are still significant artificial limits in place, and many remaining barriers to renewable energy, which have yet to be addressed. The country's DOE plans to extend programme to the rest of Africa over the next five years. In October 2015, during the South African International Renewable Energy Conference, the Energy Minister announced that an additional 1,500 MW of solar energy has been allocated for a solar park in the Northern Cape. Whilst this is a win for solar energy and a large part of this allocation is likely to be given to STE, this largely symbolic announcement does not amount to a significant increase in the overall government targets for renewable energy.

South Africa has approved 600 MW of STE within a period of less than five years. In addition, the competitive bidding tariff system has seen a drop in tariffs from ZAR 2.85/kWh when the REIPPPP initiative was launched in November 2011 to ZAR 1.46/kWh, which was achieved by the lowest bidder in bid window 3.5.

South Africa's first STE project KaXu Solar One, which means "open skies" in the local Nama language, came online in March 2015. This plant was bid in Round 1 of the REIPPPP. Kaxu Solar One is a 100 MW PT plant and covers an area of three km². It is made up of 1,200 collectors: each collector has ten modules, each module has 28 mirrors, and for 336,000 mirrors in total. The mirrors track the movement of the sun. The Kaxu facility has up to two and a half hours of molten salt thermal storage.

Khi Solar One is a 50 MW superheated steam tower, which was awarded preferred bidder status in the first window of the REIPPPP. It has commenced commercial operation in February 2016.

Bokpoort STE is a 50 MW power plant that uses parabolic technology. It was awarded preferred bidder status in the second window of the REIPPPP. This STE power station has nine hours of storage and will be capable of providing round the clock electricity generation and operating as a baseload facility.

Xina Solar One, located in Pofadder, and Karoshoek Solar One/Ilanga CSP1, being developed at Karoshoek Solar Valley, were awarded and will be operated as semi-peaking plants. They are designed to meet South Africa's daily evening peak demand, which occurs between 4:30 pm and 9:30 pm, with a combined capacity of 200 MW and five hours of thermal storage each. Once complete, they will play an essential role by providing five hours of firm peak demand electricity every day of the year at tariffs lower than the OCGT's that run on diesel and are currently used by South Africa's energy utility to provide peaking electricity. These projects are expected to come online in 2017/18.

Awarded Khathu and Redstone projects will also operate as semi-peakers and have a combined capacity of 200 MW and five hours of storage each. These projects are expected to come online in 2018/19.

South Africa has taken significant steps in the development and deployment of utility scale STE power stations in the Southern African Development Community. However, the remaining barriers prevent South Africa from fully realising its potential as a renewable energy leader on the African continent. Given the need to develop the SADC economy and to migrate to a low carbon future, the deployment of STE power stations in South Africa and the region as a whole can play a key role in the re-industrialisation of the SADC economy and position the region as a market leader in the manufacturing of STE components both for the regional and international markets. Unlocking this potential will, however, require real leadership from regional governments.

Europe

Current European policy framework

Whilst the EU, as a whole, is making good progress towards meeting its 2020 climate and energy targets[46], an integrated policy framework for the period up to 2030 is needed to ensure regulatory certainty for investors and a coordinated approach among EU Member States. The 2030 targets, as agreed on 23 October 2014, are as follows:

- Reducing greenhouse gas emissions by at least 40% below 1990 levels by 2030;[47]
- Increasing the share of renewable energy to at least 27%;[48] and
- Increasing energy efficiency by at least 27%.[49]

This framework will drive continued progress towards a low-carbon economy. It aims to build a competitive and secure energy system that ensures affordable energy for all consumers, increases energy security, reduces dependence on energy imports and creates new opportunities for growth and jobs. At the time of this writing, the discussion on how Member States will achieve their respective 2030 targets is on-going. STE technologies will help Europe increase the share of renewable energy to more than 27% and contribute to reaching 45%-60% to the energy mix in Europe by 2030. The European Council has also set the goal of achieving 15% interconnection capacity and emphasized the need for the full implementation of the internal electricity market. This will make it possible for the whole European continent to benefit from sustainable and manageable STE electricity.

Spain

Spain is the current STE market leader in installed capacity with 2,375 MW. The majority of STE projects in Spain use PT technology. But Spain also hosts projects using solar tower technology (one with molten salts and two with steam), LFR (two projects with a combined capacity of 31 MW) and a 22 MW hybrid PT with biomass power plant. Around 40% of the STE capacity has storage systems based on molten salt, which gives a lot of flexibility to the generation. As the operation of some of these plants extends back to 2007, Spain boasts proven operational experience for power plants with molten salt storage systems. What's more, production at these plants has increased every year with the plants meeting a greater share of demand as a result. 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:

- Maximum contribution 8.5% (most of the time between May to September);
- Maximum daily contribution around 5% (in many days in June, July and August); and
- Monthly production about 4% (889 GWh in July and August).

46 Available at: https://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy.

47 To achieve the overall 40% target, the sectors covered by the EU emissions trading system would have to reduce their emissions by 43% compared to 2005. Emissions from sectors outside the EU ETS would need to be cut by 30% below the 2005 level. This will need to be translated into Member State targets. The European Council has outlined the main principles to achieve this.

48 Renewable energy will play a key role in the transition towards a competitive, secure and sustainable energy system. The Commission proposed an objective of increasing the share of renewable energy to at least 27% of the EU's energy consumption by 2030. The European Council endorsed this target which is binding at EU level.

49 The European Council endorsed an indicative target of 27% to be reviewed in 2020, having in mind a revised 30% target.

Figure 4.2: **Annual production and demand share in Spain**

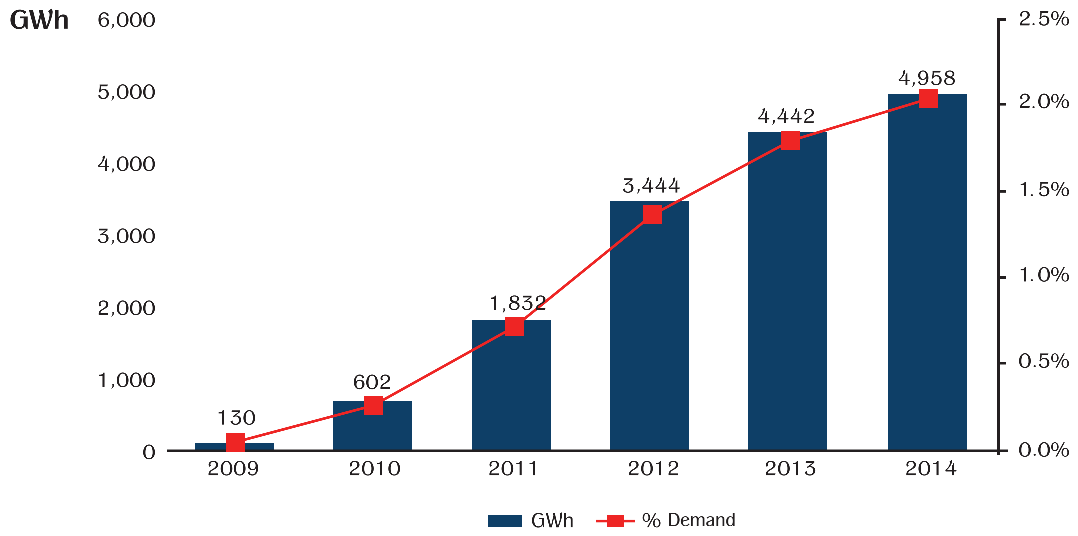
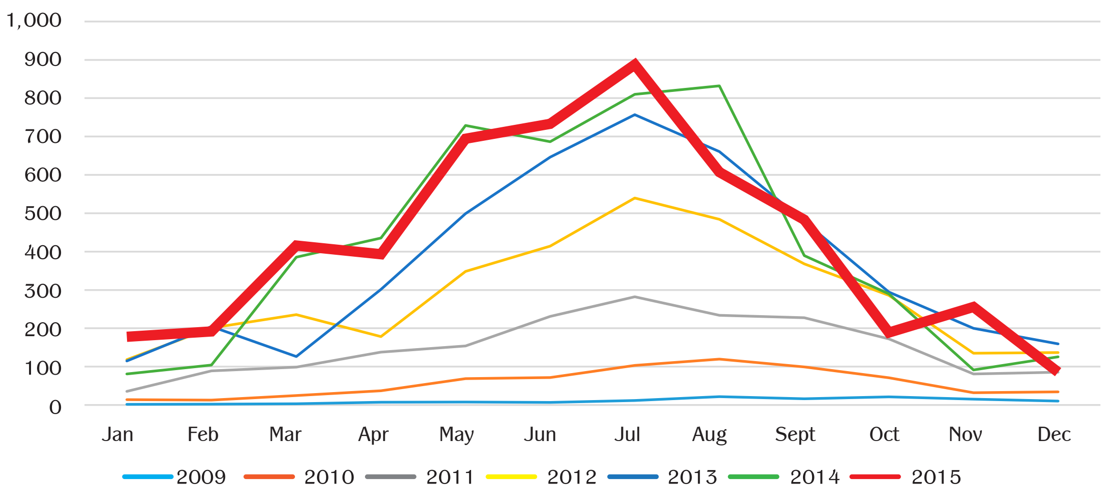
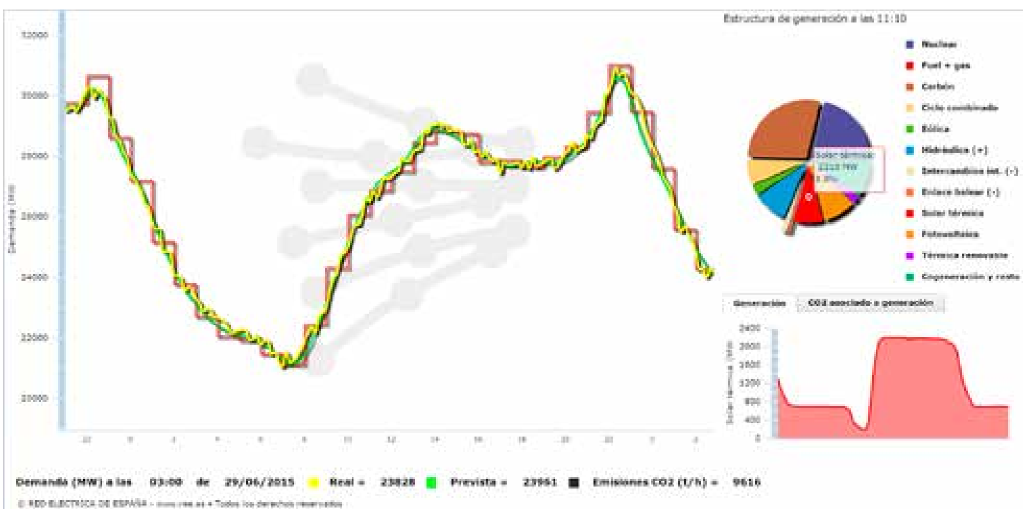


Figure 4.3: **Annual electricity production from solar thermal power plants in Spain over 12 months from 2009 to 2015**



An example of the perfect coupling of the production with the demand illustrated in Figure 4.3. All these records and experiences are a very positive reference for other countries that want to implement plans to develop STE.

Figure 4.4: **Screen capture of the electricity demand in real time tool showing the structure of generation and CO_2 emissions on a normal summer day in 2015, provided by the Spanish national transmission and system operator – Red Eléctrica de España[51]**



France

The Minister of Energy and Sustainable development has declared its interest in STE technologies and that it would consider such technologies in a new facilitating process for informal and direct proposals related to innovative solar and marine technologies. In particular, this new process should include a portfolio of solar thermal power plants in order to promote thermal energy storage and hybridization.

Several STE projects are under construction:

- ALBA NOVA 1, located on Corsica Island of France, a 12 MW Fresnel STE project, which started construction in April 2014. Commissioning and start up is expected to happen by end of 2015.
- LLO, located in the French Pyrenees, is a 9 MW Fresnel STE project, which received all necessary permits in 2014, and construction started at the beginning of 2015. Commissioning and start up are expected by mid-2017.

Italy

Since the completion of a 5 MW PT pilot plant in Sicily in 2010, no new plants have come online. ANEST, the Italian Association of STE, confirms 17 projects are currently in the promotion stage, for a total installed capacity of about 360 MW – 190 MW in Sicily, 120 MW in Sardinia and 50 MW in Basilicata region. The announced plants cover all the STE technologies and will come online by 2017. Of the 17 projects, six of the large plants and two of the medium plants will be on the mainland. The remaining nine projects are smaller than 5 MW and based on LFR technology for both electricity production and heat applications.

Other European Countries

Cyprus is awaiting publication of its FIT. But one project is already under construction with funding from the NER 300 initiative.[51] Named the EOS project, this 25 MW facility consists of an array of small towers along with innovative graphite storage system.

In Greece, two projects were approved under the NER 300 initiative – MINUS tower in Crete and MAXIMUS dish in mainland. It's unclear if either of these projects will move forward, however, given the current political and economic situation.

Image: The first solar thermal power plant in Chile is being developed within the Atacama-1 complex in Cerro Dominador ©Abengoa

50 See, https://demanda.ree.es/demanda.html.

51 NER 300 is one of the world's largest funding programmes for innovative low-carbon energy demonstration projects. The programme is conceived as a catalyst for the demonstration of environmentally safe carbon capture and storage and innovative renewable energy technologies on a commercial scale within the European Union. For more information, see Chapter 7: Successful Financing Instruments.

North and South America

United States

In the US, three primary incentives have enabled the growth of STE:

- Federal Investment Tax Credit. The Energy Policy Act of 2005 created a 30% ITC for commercial and residential solar energy systems that applies to STE.[52] The ITC provides credits equal to 30% of the eligible property that is placed in service by the end of 2016. After this date, the commercial credit will drop to 10% unless Congress acts to extend the credit.
- State renewable portfolio standards. Most US states have now established an RPS, which requires the increased production of electricity from renewable energy sources, such as wind and solar. These include the southwest states that have the best solar resources in the US.
- US DOE Loan Guarantees. DOE is authorized to provide loan guarantees for projects that "avoid, reduce or sequester air pollutants or greenhouse gases; employ new or significantly improved technologies and provide a reasonable prospect of repayment."[53]

The combination of these three incentives has led to the construction of five STE projects totalling over 1,300 MW. Each of the five projects were awarded loan guarantees that totalled US$ 5.84 billion.

Present Status of Market

By 2014, the primary incentives for STE projects were no longer available. Several states had just about reached their RPS goals, the loan guarantee programme was no longer funding utility-scale STE projects, and the long-lead time required to build solar thermal power plants made the ITC unavailable because the projects would have to be placed in service by the end of 2016. As a result, no projects started construction after the five that received loan guarantees. Those five became operational between 2013 and 2015.

Of the five projects, three were PT and two were CR. One of the troughs and one of the towers included thermal storage. Utilities, state energy regulators, and the financial community are evaluating the projects to determine if they operate as planned and produce the amount of power predicted. This is especially true for the solar tower projects, which are the first commercial towers operating in the US, and the two projects with storage, which are the first commercial STE projects in the US to using molten salt storage.

Future Prospects of Market

Several things are on the horizon that could impact the US market for STE:

- EPA's Clean Power Plan. This Plan would requires a 30% reduction in CO_2 emissions from the electricity sector by 2030. Renewable energy is emphasized in the Plan as one way to achieve this reduction. The final rule for the Plan was issued in 2015.
- Increasing RPS targets. US states have announced or are currently considering increases to their renewable energy mandates. Hawaii, for example, has committed to 100% renewable electricity by 2040. In California, the Governor has proposed to raise the state's RPS to 50%.
- Extension of the ITC.

Chile

Chile is one of the new emerging markets for STE, as well as one of the countries with the highest solar radiation in the wold. At the moment, however, Chile's electricity sector relies heavily on coal, diesel and gas.[54] Concerns related to economics, energy security and climate change have prompted the government to draw up a new energy policy, the "Estrategia Nacional de Energía" 2012-2030. The main goals of this policy are to generate 20% of the country's electricity from clean energy sources and to interconnect the SIC[55] and SING.[56] These aims could increase the capacity installed in the Chilean market and it could be an opportunity for supplying local mines with energy produced by STE technologies.

Due to Chile's great solar conditions, STE is already competitive with conventional sources. Currently, the first solar thermal power plant in Chile is being developed within the Atacama-1 complex in Cerro Dominador. The project is a 110 MW solar thermal electric tower with 18 hours of thermal storage system in molten salts, allowing the plant to provide electricity 24 hours a day.

52 Although it was to be in effect only from January, 2006 through December, 2007, it was extended twice; first through the Tax Relief and Health Care Act of 2006, which extended it for one additional year, and then the Emergency Economic Stabilization Act of 2008, which extended it until December 31, 2016.

53 See, Energy Policy Act 2005.

54 Source: CDEC-SIC/CDEC-SING y CNE..

55 Central Interconnected System (SIC) is comprised by 5 electric subsystems in the central area of Chile: from Quellón to the island of Chiloé.

56 Northern interconnected System (SING) supplies the north area of Chile, from Arica to Coloso. Mainly, its generation is based on gas and local mines.

Image: Delingha phase 1 ©SUPCON

Asia - Pacific

China

After 20 years of perseverance, a breakthrough was made in China's STE project construction. In August 2012, the first MW level solar power tower plant in China the Beijing Badaling solar thermal power plant was put into full operation.

In September 2014, National Development and Reform Commission set a FIT of RMB 1.2 yuan/kWh for the 50 MW Delingha solar thermal power plant operated by SUPCON Group. The first phase of the project, which has a 10 MW capacity and gas boiler for superheat, has been in commercial operation since July 2013. National Basic Research Programme (973 Programme), National High-tech R&D Programme (863 Programme), National Science Foundation of China (NSFC) and National Technical Innovation Fund for Medium and Small- Size Enterprise all give long-term support to STE technology.

With the support of the government and private sector investment, many PT collector systems have been put into operation, and several LFR and Stirling solar thermal demonstration systems have been built in the past several years.[57]

To promote technical innovation and build an industry technology innovation chain, National Solar Thermal Energy Alliance was established in October 2009. The country is also advancing research into STE and currently has 25 sets of solar thermal collecting experiment facilities. The supply chain for STE has also started developing. A total of 15 companies, for example, can produce PT vacuum receiver tubes; five companies can mass produce trough glass reflector mirrors; two companies could provide the EPC for solar tower type collector systems; two companies can produce turbines for solar thermal electricity, and there is one joint venture company in the country that combines BrightSource's advanced STE technology with Shanghai Electric's leading equipment manufacturing and EPC services.

According to "The 12th Five-Year Plan on Renewable Energy Development", the installed STE capacity by 2015 was expected to be 1 GW. Current installed capacity in the country, however, is about 12 MW. Nevertheless, China has more than 30 solar thermal power projects planned, the total capacity of which (if all realized) would amount to about 3 GW. In December 2014,

57 Source: China National Solar Thermal Energy Alliance.

the National Energy Administration issued the "Notice on Drawing up 13th Five-Year Plan on Solar Energy Development by General Affairs Department of National Energy Administration." STE is an important part of this next plan, which is of great significance for STE industry.

Australia

Currently, the cost of STE in Australia is higher than commercially viability will allow. Despite ongoing and active representations from the concentrating solar thermal industry in Australia, at the time of this writing, no material policy initiatives have been proposed by the government to support dispatchable renewable power generation such as STE with large-scale energy storage. However, the government has provided indications that reviews of the renewable energy target for the period beyond 2020 are likely to consider dispatchability and energy storage as key elements.

A parallel initiative, partly funded the Australian Renewable Energy Agency[58], has been established with the goal of reducing the cost of STE technology specifically. This initiative, known as the 'Australian Solar Thermal Research Initiative is managed by the CSIRO in a dedicated directorate. ASTRI has received commitments of funding of approximately AUD$ 70 million over eight years, subject to securing partial funding from industry sources. A review of the ASTRI will take place in 2017, the mid-point of the ASTRI programme period.[59]

Presently, only two STE projects are operational in Australia, both partly funded by Australian Renewable Energy Agency. They are:

- The Vast Solar Pty limited 6MWth (1.1 MWe) Pilot CR project, located in Central Western New South Wales. Construction of the Vast Solar Pilot Project was completed in May 2015, and commissioning is underway at the time of writing. Once operational, this will be Australia's only electricity grid-connected solar thermal power plant with thermal energy storage.[60]
- The CSIRO Energy Transformed Flagship STE facility, located at West Mayfield, near Newcastle in New South Wales. This facility is primarily used for research and development, including research into solar chemistry and solar gas synthesis, and is also the location from which the ASTRI programme referred to earlier is managed.[61]

Compact Linear Fresnel Reflector technology was proposed for three projects in Australia, however, none are currently in operation.[62]

A 44 MWth CLFR system (utilising the AREVA Solar CLFR system) was planned for the CS Energy Kogan Creek coal-fired power station.[63] Unfortunately, due to contractual issues between the parties, the project has not been completed. No date has yet been set for commencement of operations.

Regarding planned STE projects, Vast Solar has announced plans to develop a 30 MW STE project with four hours of thermal energy storage, also to be located in Central Western New South Wales. At the time of writing, environmental planning approvals and electricity grid connection approvals are progressing for this project, and Vast Solar is planning for commencement of construction around January 2016. The project is intended to have a 22 month construction period, with commissioning planned for early 2018. This project has at a total estimated installed cost under AUD$100 million and LCOE approaching that of wind-power projects. If these capital costs and LCOE levels are achieved, this could potentially open up significant opportunities for uptake of STE in Australia (with implications for cost structure in STE projects internationally).

58 ARENA was established in 2011 and brings together a number of agencies of government that previously existed with responsibility for the promotion of renewable energy in Australia. ARENA incorporates the former Australian Solar Institute. ARENA's objectives are to increase the deployment of renewable energy and reduce the cost of renewable energy in Australia.

59 The ASTRI is primarily a research initiative, and is undertaken through a collaboration of many of Australia's leading STE research institutions, including CSIRO, Australian National University, University of Adelaide, University of Queensland and others. ASTRI is not intended to provide funding for demonstration projects on a major scale, but may lead to development of demonstration project for which funding may be provided by ARENA.

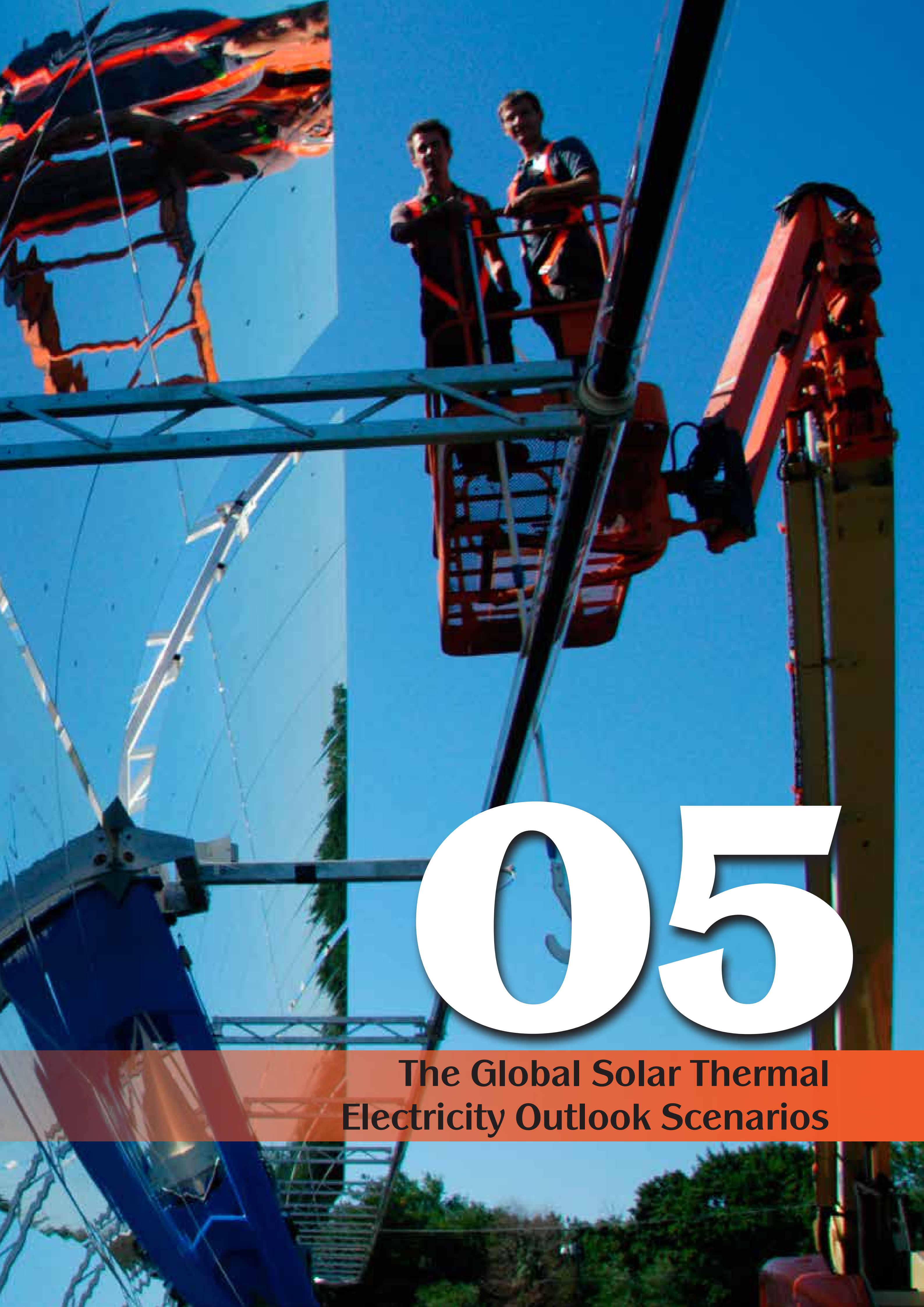
60 See, http://arena.gov.au/project/vast-solar-6mw-concentrating-solar thermal-pilot-project/.

61 See, http://www.csiro.au/en/Research/EF.

62 A 1 MWe CLFR plant was constructed in 2003 at the Liddell coal-fired power station in New South Wales utilising the Australia-developed AREVA Solar (formerly Ausra) CLFR technology. Subsequently a slightly larger CLFR system was added to the Liddell power plant, utilising the Novatec Solar CLFR technology (Australian-German developed). Neither of these systems is currently in operation.

63 The Kogan Creek CLFR system was to deliver steam into the re-heat cycle of the coal-fired power generator, in one of the largest STE hybrid demonstration projects yet planned globally.

Solar Parabolic Trough Collector Shape Measurement ©CSP Services

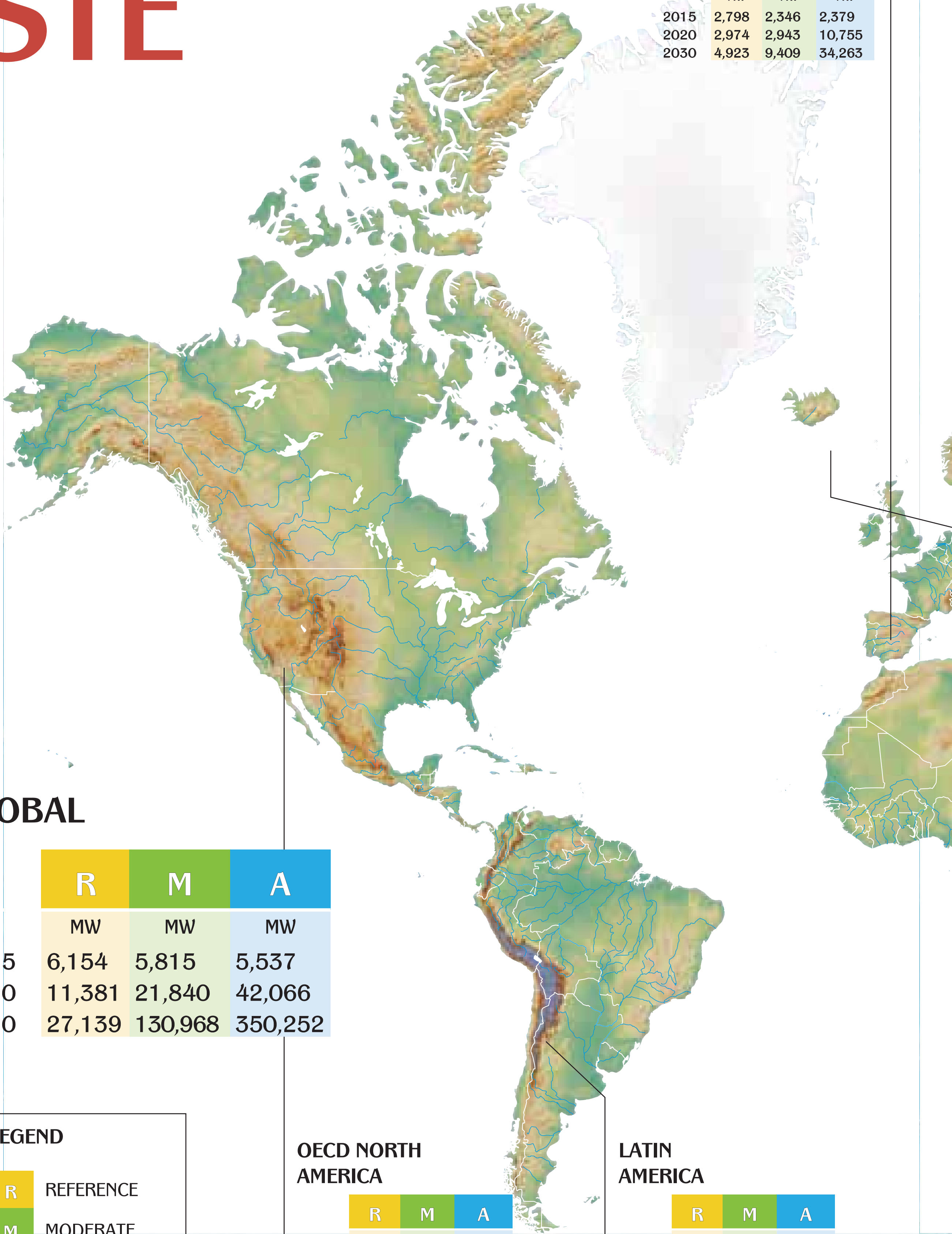


05

The Global Solar Thermal Electricity Outlook Scenarios

RENEWABLE RESOURCE

STE



EUROPE (EU-28)

	R	M	A
	MW	MW	MW
2015	2,798	2,346	2,379
2020	2,974	2,943	10,755
2030	4,923	9,409	34,263

GLOBAL

	R	M	A
	MW	MW	MW
2015	6,154	5,815	5,537
2020	11,381	21,840	42,066
2030	27,139	130,968	350,252

LEGEND

R REFERENCE

M MODERATE

A ADVANCED

OECD NORTH AMERICA

	R	M	A
	MW	MW	MW
2015	2,611	2,581	2,245
2020	4,971	8,434	9,700
2030	8,927	27,025	102,677

LATIN AMERICA

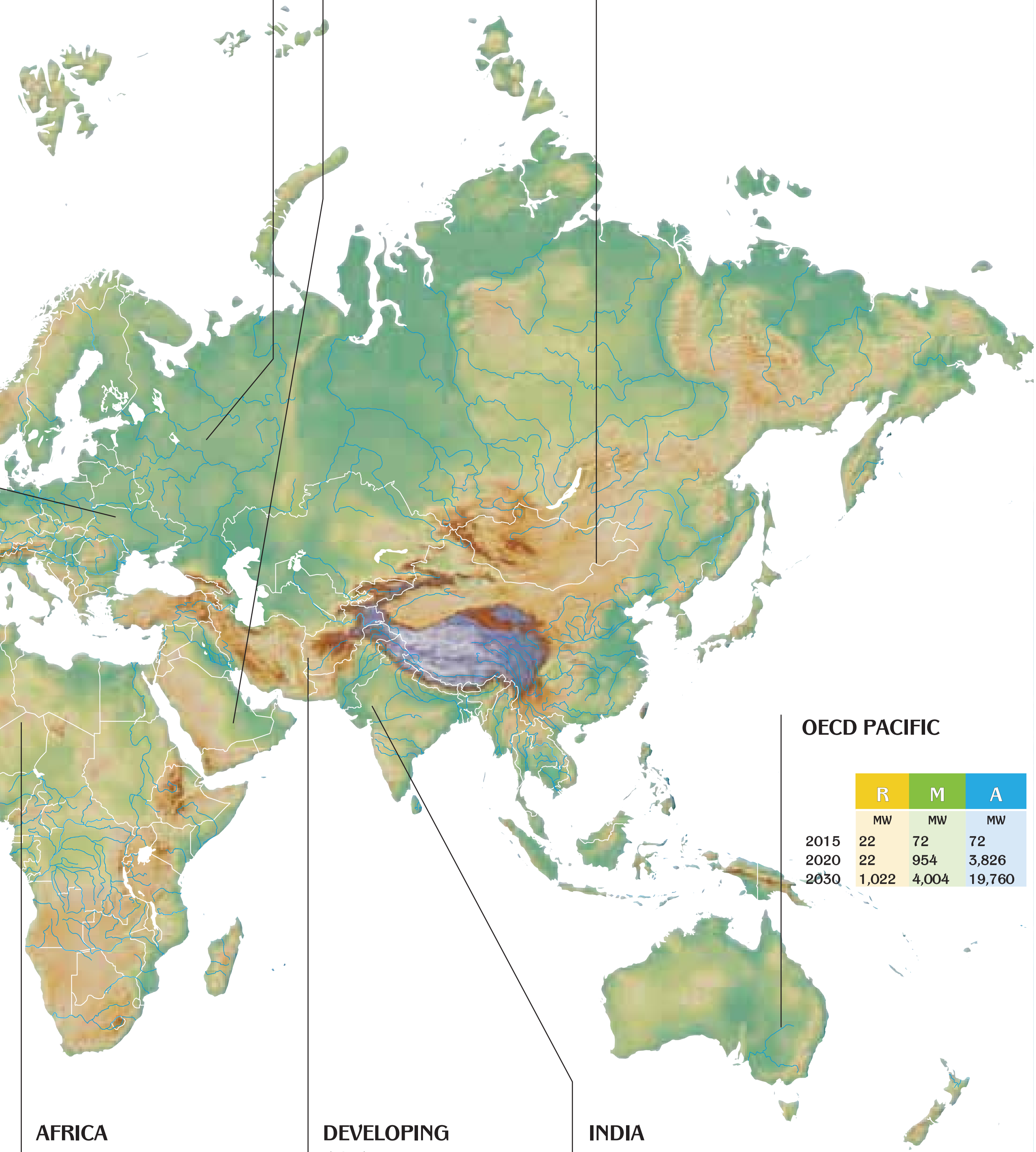
	R	M	A
	MW	MW	MW
2015	34	39	64
2020	83	207	4,917
2030	1,007	1,048	23,142

MIDDLE EAST

	R	M	A
	MW	MW	MW
2015	267	317	317
2020	1,993	2,229	4,503
2030	5,024	16,647	67,836

CHINA

	R	M	A
	MW	MW	MW
2015	2	34	34
2020	2	1,449	1,449
2030	1,002	31,340	41,825



OECD PACIFIC

	R	M	A
	MW	MW	MW
2015	22	72	72
2020	22	954	3,826
2030	1,022	4,004	19,760

AFRICA

	R	M	A
	MW	MW	MW
2015	95	106	106
2020	1,010	2,541	3,596
2030	4,057	26,265	40,542

DEVELOPING ASIA

	R	M	A
	MW	MW	MW
2015	5	55	55
2020	5	1,961	8,135
2030	1,005	8,135	8,135

INDIA

	R	M	A
	MW	MW	MW
2015	307	259	259
2020	307	1,098	1,224
2030	307	6,867	11,576

In this section, the future potential of STE up to the year 2030, and 2050 is examined, as a model for what is possible both technically and economically. The outlook is based on assumptions of how the industry will progress under different types of market conditions.

The Scenarios

Three different scenarios are outlined for the future growth of solar thermal electricity around the world.

Reference scenario

This is the most conservative scenario based on the projections in the IEA's 2014 World Energy Outlook, Current Policies scenario. This scenario takes into account existing policies and measures, but includes assumptions such as continuing electricity and gas market reform, the liberalisation of cross-border energy trade and recent policies aimed at combating pollution.

Moderate scenario

This scenario takes into account all policy measures to support renewable energy either under way or planned around the world. It also assumes that the targets set by many countries for either renewables or concentrated solar power are successfully implemented. Moreover, it assumes increased investor confidence in the sector established by a successful outcome from the most current round of climate change negotiations, which culminated at UNFCCC COP-21 in Paris, France, on 12th December 2015. The adopted Paris Agreement to address climate change was agreed by 195 countries and is expected to unleash a new wave of actions and investments towards a low carbon, resilient and sustainable future. The commitment to limit global average temperature increase to 1.5°C above pre-industrial levels requires net zero greenhouse gas emissions by the second half the century and effectively means fossil fuels should be phased out by 2050. Up to 2019, the figures for installed capacity are closer to forecasts than scenarios because the expected growth of worldwide markets over the next five years is based on orders for solar power plants that have already been made. After 2019, the pattern of development is more difficult to anticipate.

Advanced scenario

This is the most ambitious scenario. It examines how much the STE industry could grow in a best case 'concentrated solar power vision'. The assumption here is that all policy options in favour of renewable energy, along the lines of the industry's recommendations, are selected and the political will exists to carry them out. The scenario also assumes a rapid and coordinated increase of new grid capacity (especially HVDC) to harvest solar energy through solar thermal power plants at the optimal sites and export it to industrial countries and emerging economies with high and growing electricity demand. Whilst again, the development after 2019 is more difficult to predict, this scenario is designed to show what the concentrated solar power sector could achieve if it is given adequate political commitment and encouragement.

Energy efficiency projections

In the modelling, these three scenarios for STE worldwide are set against two projections for the future growth of electricity demand. Importantly, these projections do not just assume that growing energy demand by consumers must be matched purely by increasing supply. Instead, they assume greater emphasis on policies and measures to use energy more efficiently. This approach not only improves energy security, reduces greenhouse gas emission, it also makes economic and environmental sense.

Reference Energy Efficiency Projection: This is the more conservative of the two global electricity demand projections, again based on data from IEA's 2014 World Energy Outlook, extrapolated to 2050. It does not take into account any possible or likely future policy initiatives and assumes, for instance, that there will be no change in national policies on nuclear power. The IEA's assumption is that in the absence of new government policies, the world's energy needs will raise inexorably. Under the reference efficiency scenario global demand would almost double from the baseline 23,234 TWh in 2013 to 30,620 TWh by 2030.

High Energy Efficiency Projection: This sets IEA's expectations on rising energy demand against the results of a study on potential energy efficiency savings developed by DLR and the Ecofys consultancy in 2012. It describes ambitious exploitation of energy efficiency measures, focusing on current best practice and available technologies, and assumes that continuous innovation takes place. In this projection, the biggest energy savings are in efficient passenger and freight transport and in better insulated and designed buildings, which together account for 46% of worldwide energy savings. Under this projection, input from the DLR/Ecofys models shows how energy efficiency savings change the global electricity demand profile. Although it assumes that a wide range of technologies and initiatives have been introduced, their extent is limited by the barriers of cost and other likely roadblocks. Even with realistic limits, this projection still shows global demand increasing by much less than under the reference projection. With high energy efficiency, global demand in 2030 would be 26,892 TWh and by 2050, demand would be 21% lower than under the Reference scenario.

Core Results

The Global Solar Thermal Electricity Outlook scenarios shows the range of possible outcomes depending on the choices we make now for managing demand and encouraging growth of the STE market. In the next five years, we could see as little as 941 MW of STE installed each year under the Reference scenario, to as much as 11,950 MW annually under the Advanced scenario.

Even under the Moderate scenario of fully achievable measures, the world would have a combined STE capacity of over 22 GW by 2020 and 781 GW by 2050, with an annual deployment of up to 61 GW. This would generate 54 TWh in 2020, by 2050 this would increase to 2054 TWh or around 5% of global demand. This scenario would require over €16 billion in investment by 2020, increasing raising to €162 billion by 2050. In the Moderate scenario, 935,000 jobs would be created in 2050.

In the Moderate scenario, 32 million tonnes of CO_2 emissions would be avoided annually in 2020, increasing to 1.2 billion tonnes in 2050. The CO_2 savings under the moderate scenario would be comparable to 3.5% of today's global CO_2 emissions.

Under an Advanced scenario, with high levels of energy efficiency, STE could meet up to 12% of the world's power needs in 2050.

Table 5.1: **Market Projections for STE Development between 2015 and 2050 under Reference (Current Policy), Moderate and Advanced (Aggressive Development) Scenarios**

		2015	2020	2030	2040	2050
Investment and employment						
Reference (Current Policy)						
Annual Installation	MW/a	1,171	3,619	5,651	9,500	12,427
Cost	€/kW	4,287	3,485	2,814	2,688	2,674
Investment	€bn/a	1.57	1.34	2.15	4.60	4.53
Employment Job-year		18,904	16,981	29,180	62,545	70,197
Moderate STE Market growth						
Annual Installation	MW/a	1,075	4,834	18,876	36,652	61,654
Cost	€/kW	4,287	3,485	2,814	2,666	2,637
Investment	€bn/a	4.61	16.85	53.13	97.71	162.61
Employment Job-year		16,964	70,051	269,733	574,049	935,995
Advanced STE Market Growth						
Annual Installation	MW/a	797	11,950	49,758	75,455	131,143
Cost	€/kW	4,287	3,485	2,814	2,663	2,577
Investment	€bn/a	3.42	41.65	140.04	169.10	209.76
Employment Job-year		12,985	169,237	712,674	1,072,328	1,443,265

Full Results

Reference scenario

The Reference scenario is derived from the IEA's 2014 World Energy Outlook. It starts off with an assumed annual new capacity additions of 1.5 GW of STE increasing to 3 GW/yr by 2020. Growth rates continue at around 10% per year until 2035, and then decrease to around 5% by 2040. After 2040, the scenario assumes no significant further growth of STE. As a result, the scenario foresees the following:

- By the end of this decade, cumulative global STE capacity would have reached 11 GWs, producing 28 TWh per year, and providing 0.1% of the world's electricity demand.
- By 2030, cumulative global STE capacity would be 21GW, producing around 54 TWh, and providing 0.2%-0.25% of the world's electricity demand, depending on whether low or high levels of energy efficiency measures are introduced.
- By 2050, cumulative global STE capacity would be 42 GW but the penetration of solar power would be no higher than 0.3 % globally.

Moderate scenario

Under the Moderate scenario, growth rates are expected to be substantially higher than in the Reference scenario. The assumed cumulative annual growth rate starts at 26% for 2016, and increases to 28% by 2020. By 2030, the growth rate falls gradually to 17% until it reaches 8% in 2040 and 6% after 2050. As a result, the scenario foresees the following:

- By the end of this decade, cumulative global STE capacity would reach 22 GW, with annual additions of 4.8 GW.
- By 2030, cumulative global STE capacity would be as high as 131 GW with annual additions of 18.8 GW. By 2050, the world would have a cumulative global STE capacity of over 781 GW, with the annual market running close to 62 GW.
- In terms of generated electricity, the Moderate scenario would mean over 344 TWh of electricity produced by STE in 2030. Depending on demand side development, this would account for 1.1%-1.3% of global demand in 2030 and 5%-5.9% in 2050.

Advanced scenario

Under the Advanced scenario, the assumed growth rate starts at 29% in 2016. By 2030, it has decreased to around 20%, and decreases further to 10% per year by 2035.Thereafter, the annual growth rate levels out at around a 5%. As a result, the scenario foresees the following:

- By 2020, cumulative global STE capacity would have reached 42 GW, with annual additions of around 11.9 GW.
- By 2030, cumulative global STE capacity would be over 350 GW, with annual additions of around 50 GW. This would lead to STE capacity of almost 940 GW by 2040, with an annual market volume of 75 GW.
- By 2050, the word's total fleet of STE plants would have a capacity of 1,600 GW.
- In terms of generated electricity, the Advanced scenario would mean 103 TWh produced by STE in 2020, 920 TWh in 2030 and over 4,300 TWh by 2050. Depending how much demand has been curbed by energy efficiency, solar power would cover 3%-3.4 % of global electricity demand in 2030 and as much as 10.6%-12.6% by 2050

Under an Advanced scenario, with high shares of solar electricity from STE plants, 2.6 Gt of CO_2 could be avoided by 2050, making a significant contribution to protect the world´s climate whilst providing a substantial share of electricity to the world's power needs.

Figure 5.1: **Cumulative STE Capacity**

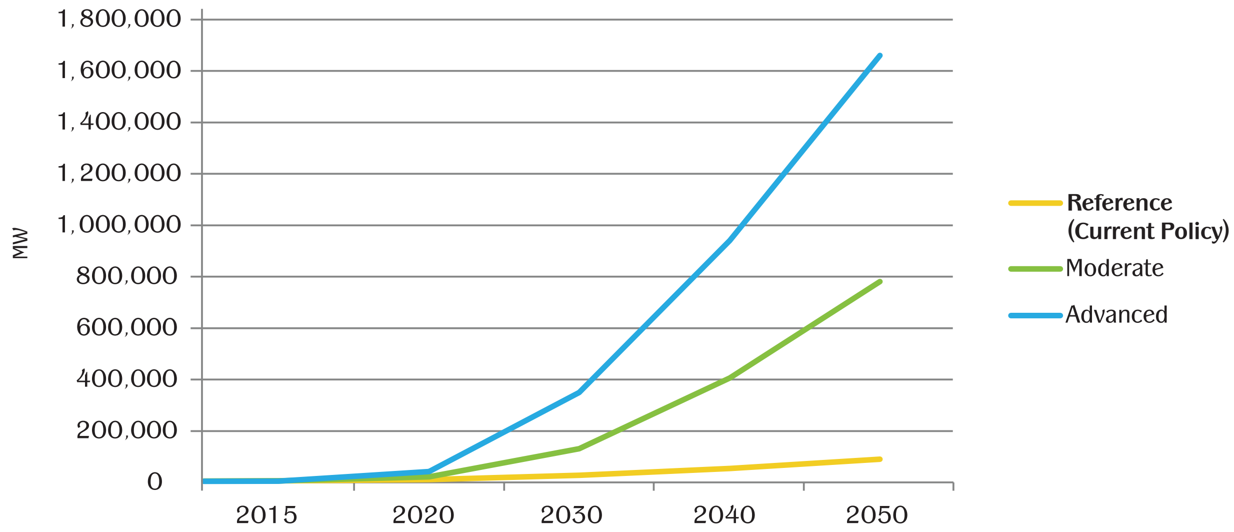


Table 5.2: **Cumulative STE Capacity under three scenarios**

Cumulative Capacity		2015	2020	2030	2040	2050
Reference (Current Policy)						
	(MW)	6,154	11,381	27,319	54,225	90,749
	(TWh/a)	15	28	72	143	238
Moderate						
	(MW)	5,815	21,840	130,968	406,745	781,230
	(TWh/a)	14	54	344	1,069	2,053
Advanced						
	(MW)	5,537	42,066	350,252	940,232	1,660,693
	(TWh/a)	14	103	920	2,471	4,364

Regional breakdown

All three scenarios for STE are broken down according to the regions of the world used by the IEA, with a further differentiation in Europe. For this analysis, the regions are defined as Europe (EU-28 and the rest of Europe), the Eastern Europe and Eurasia (former Soviet Union states, apart from those states now part of the EU), North America, Latin America, China, India, the Pacific (including Australia, South Korea and Japan), Developing Asia (the rest of Asia), the Middle East and Africa. A list of countries covered by each of the regions is shown in Appendix 4.

The level of solar power capacity expected to be installed in each region of the world by 2020 and 2030 is shown in figures 5.2, 5.3 and 5.4.

- *Reference Scenario:* North America would continue to dominate the world market. By 2030, the US and Mexico would host 33% of global STE capacity, followed by Europe and Middle East each at 18%. The next largest region would be Africa with 15%.

- *Moderate scenario:* North America's share is much smaller – only 21% by 2030, with China contributing 24% and major installations in North Africa (20%), Middle East (13%), Europe (7%), India (5%) and finally OECD Asia Oceania (3%), mainly in Australia.
- *Advanced scenario*: North America's share would stand at 29% by 2030, for almost one third of global STE capacity, whilst Europe's share would be 10%, behind the Middle East (19%), Africa and China (both 12%), but ahead of Australia (6%) and India (3%). In the Moderate and Advanced scenarios, developing Asia and Eastern Europe and Eurasia would play only a minor role.

Table 5.3: **Outlook for cumulative installed capacity of STE per region in 2020 and 2030**

	OECD North America	Latin America	Europe (EU-28)	Africa	Middle East	India	Dev. Asia	China	OECD Pacific	Global Total
Reference (Current Policy)										
2020	4,971	83	2,989	1,010	1,993	307	5	2	22	11,381
2030	8,927	1,007	4,968	4,057	5,024	307	1,005	1,002	1,022	27,319
Moderate										
2020	8,434	207	2,968	2,541	2,229	1,098	1,961	1,449	954	21,840
2030	27,025	1,048	9,636	26,265	16,647	6,867	8,135	31,340	4,004	130,968
Advanced										
2020	9,700	4,917	10,890	3,596	4,503	1,224	1,961	1,449	3,826	42,066
2030	102,677	23,142	34,759	40,542	67,836	11,576	8,135	41,825	19,760	350,252

Figure 5.2: Potential regional installation of STE under the Current Policy scenario

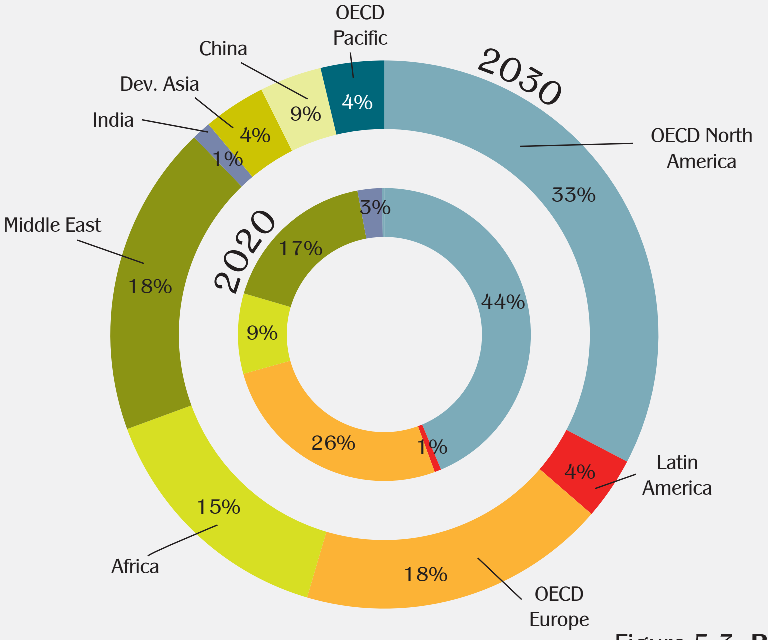


Figure 5.3: Potential regional installation of STE under the moderate development scenario

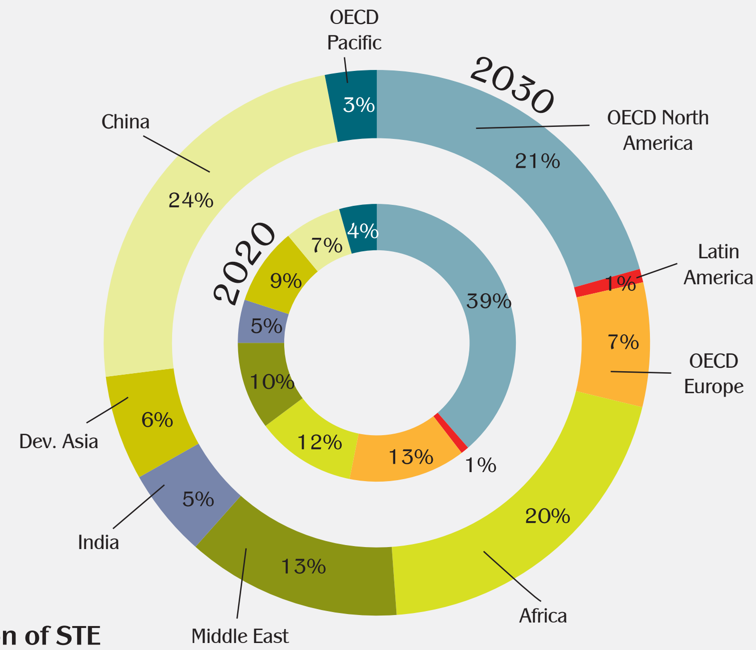


Figure 5.4: Potential regional installation of STE under the advanced development scenario

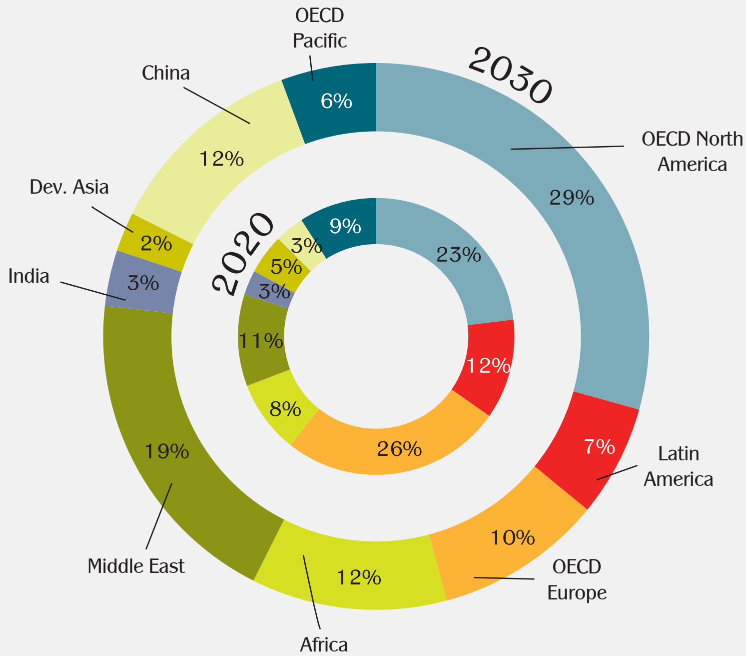


Figure 5.5: **STE Penetration under three scenarios**

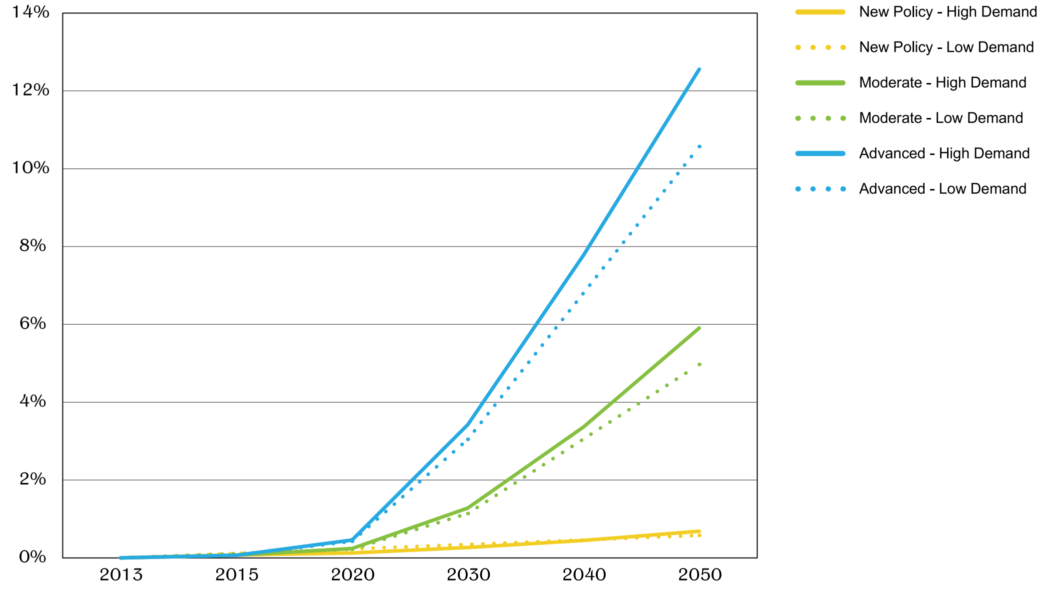


Table 5.4: **STE Penetration under three scenarios**

Cumulative Capacity		2015	2020	2030	2040	2050
STE Market Growth under current policy						
STE power penetration of Worlds electricity in % - Reference	(%)	0.1%	0.1%	0.2%	0.4%	0.6%
STE power penetration of Worlds electricity in % - Energy (R)evolution (Energy Efficiency)	(%)	0.1%	0.1%	0.3%	0.4%	0.7%
Moderate STE Market growth						
STE power penetration of Worlds electricity in % - Reference	(%)	0.1%	0.2%	1.1%	3.0%	5.0%
STE power penetration of Worlds electricity in % - Energy (R)evolution (Energy Efficiency)	(%)	0.1%	0.2%	1.3%	3.4%	5.9%
Advanced STE Market Growth						
STE power penetration of Worlds electricity in % - Reference	(%)	0.1%	0.4%	3.0%	6.9%	10.6%
STE power penetration of Worlds electricity in % - Energy (R)evolution (Energy Efficiency)	(%)	0.1%	0.5%	3.4%	7.8%	12.6%

Investment

Generating increased volumes of STE electricity will require a significant investment over the next 35 years. At the same time, the increase in installed STE capacity will have tremendous economic and environmental benefits.

In each of these outlook scenarios, the investment value of the future STE market has been assessed on an annual basis. The value assumes a gradual decrease in the capital cost per kilowatt of installed STE capacity.

- In the Reference scenario, the annual value of global investment would be €1.3 billion in 2012. Because of a rather flat market volume projection over the next decades, the annual investment level would remain between €1.2 billion and €1.5 billion to 2050.
- In the Moderate scenario, the annual value of global investment would be €16.8 billion in 2020, increasing to €53 billion by 2030 and peaking at €162 billion in 2050.
- In the Advanced scenario, the annual value of global investment reaches €41.6 billion in 2020, increasing to €140 billion by 2030 and increasing further to €169 billion in 2040 and €209 billion in 2050.

These figures may appear large, but they represent only a portion of the total level of investment in the global power industry. During the 1990s, for example, annual investment in the power sector was running at some €158-186 billion each year.

Generation costs

Various parameters need to be taken into account when calculating the generation costs of STE. The most important are the capital cost of STE plants and expected electricity production. The second is highly dependent on the solar conditions at a given site, making good site selection key. Other important factors include O&M costs, the lifetime of the turbine and the discount rate.[64]

The total cost per generated kWh of electricity is traditionally calculated by discounting and levelising investment and O&M costs over the lifetime of a STE power station, then dividing this by the annual electricity production. The unit cost of generation is thus calculated as an average cost over the lifetime of the power plant, which is normally estimated at 25 years. In reality, however, the actual costs will be lower when a power plant starts operating, due to lower O&M costs, which will increase as the plant ages.

Taking into account all these factors, the cost of generating electricity from concentrated solar power currently ranges from approximately 15 €cents/kWh at high DNI sites up to approximately 20 €cents/kWh at sites with a low average solar resource. With increased plant sizes, better component production capacities and more suppliers and improvements from R&D, costs are expected to fall to between of 12-18 €cents/kWh by 2020. Besides the estimation of further price drops, the gap with generation costs from conventional fuels is expected to decrease rapidly due to increased prices for conventional fuels in global markets. The competitiveness with mid-load plants might be achieved in the next 10 to 15 years.

STE has a number of other cost advantages compared to fossil fuels, which these calculations do not take into account, including the following:

- 'External costs' of electricity production. Renewable energy sources such as solar have environmental and social benefits compared to conventional energy sources such as coal, gas, oil and nuclear. These benefits can be translated into costs for society, which should be reflected in the cost calculations for electricity output. Only then can a fair comparison of different means of power production be established. The ExternE project, funded by the European Commission, has estimated the external cost of gas at around 1.1-3.0 €cents/kWh and coal at as much as 3.5-7.7 €cents/kWh.
- The fuel cost risk related to conventional technologies. Since STE does not require any fuel, there is no risk of fuel price volatility as compared to other generating technologies such as gas, coal and oil. A generating portfolio containing substantial amounts of concentrated solar power would reduce exposure to fossil fule price volatility and stabilize energy costs. In an age of limited fuel resources and high fuel price volatility, the benefits of this are immediately obvious.

Employment

The employment generated in the scenarios is a crucial factor to weigh alongside other costs and benefits of STE. High unemployment rates are a drain on economies and any technology which demands a substantial level of skilled and unskilled labour is of considerable economic importance. Job creation should feature strongly in political decision-making over different energy options.

A number of assessments of the employment effects of solar power have been carried out in Germany, Spain and the US. The assumption made in our analysis is that for every MW of new capacity, the annual market for STE will create 10 jobs through manufacturing, component supply, solar project development, installation and indirect employment. As production processes are optimised, this level will decrease, falling to eight jobs by 2030 under the Reference scenario. In addition, employment in regular operations and maintenance work at solar farms will contribute a further one job for every MW of cumulative capacity.

64 See, Cost Trends for Solar Thermal Electricity in Chapter 2 for detail discussion on this.

Table 5.5: **Assumed job numbers created by STE under Reference, Moderate and Advanced scenarios**

	Reference		Moderate		Advanced	
Year	Jobs Manufation & Installation (Job years)	Jobs O&E	Jobs Manufation & Installation (Job years)	Jobs O&E	Jobs Manufa-tion & Installa-tion (Job years)	Jobs O&E
	(Jobs/MW)	(Jobs/MW)	(Jobs/MW)	(Jobs/MW)	(Jobs/MW)	(Jobs/MW)
2005	10	1	10	1	10.00	1.00
2010	10	1	10	1	10.00	1.00
2015	10	1	11	1	8.82	0.86
2020	10	1	10	1	8.55	0.81
2030	9	1	10	1	8.10	0.77
2040	9	1	9	1	7.65	0.72
2050	8	1	9	1	7.20	0.68

The results of the analysis are as follows:

- Under the Reference scenario, around 17,000 jobs would be created by 2020 and 70,000 jobs by 2050.
- Under the Moderate scenario, more than 70,000 jobs would be created by 2020 and about 936,000 jobs by 2050.
- Under the Advanced scenario, up to 169,000 new jobs would be created by 2020, increasing to 1.4 million jobs by 2050.

Table 5.6: **Outlooks for Employment in STE**

	2015	2020	2025	2030	2035	2040	2045	2050
Jobs total								
Reference (Current Policy)	18,904	16,981	27,061	29,180	42,760	62,545	63,878	70,197
Moderate	16,964	70,051	139,197	269,733	440,977	574,049	696,642	935,995
Advanced	12,985	169,237	418,664	712,674	931,683	1,072.328	1,198.116	1,443.265

Table 5.7: **CO_2 savings by STE under Reference, Moderate and Advanced scenarios.**

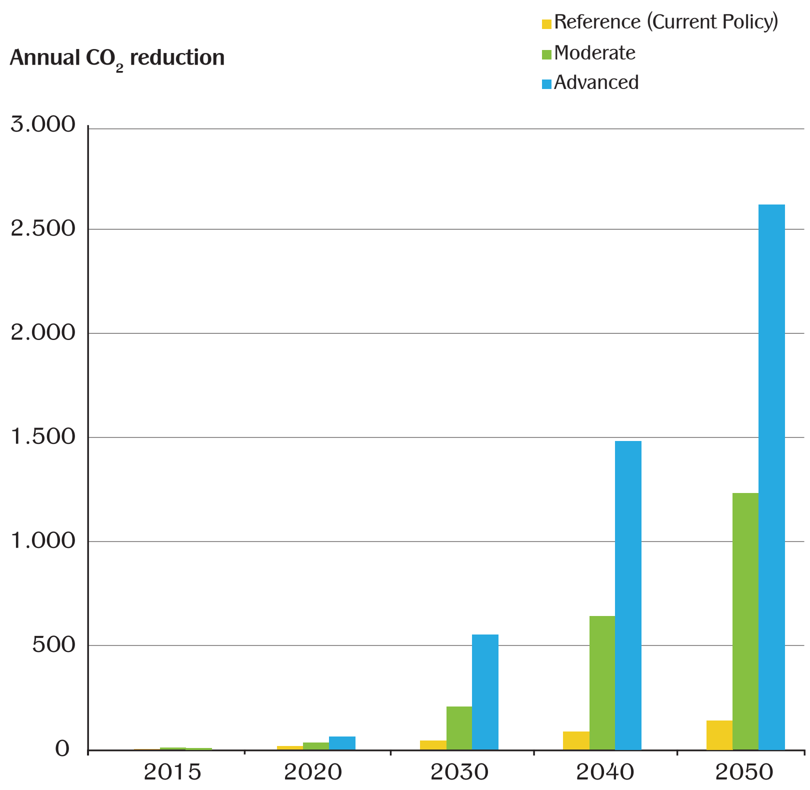
	2015	2020	2025	2030	2035	2040	2045	2050
CO_2 Savings in million tonnes								
Reference (Current Policy)								
Annual CO_2 savings	9	17	28	43	60	86	114	143
Cumulative CO_2 savings	25	93	211	390	653	1,025	1,539	2,197
Moderate								
Annual CO_2 savings	9	32	85	207	401	641	915	1,232
Cumulative CO_2 savings	1,390	1,499	1,825	2,595	4,215	6,983	11,064	16,657
Advanced								
Annual CO_2 savings	8	62	214	552	991	1,483	2,012	2,619
Cumulative CO_2 savings	1,390	1,566	2,339	4,431	8,680	15,445	24,930	37,465

Carbon dioxide savings

A reduction in CO_2 emissions is the most important environmental benefit from solar power generation.[65]

The level of from CO_2 emissions avoided by STE depends on fuel, or combination of fuels, the solar electricity is displacing. Calculations by the World Energy Council show a range of CO_2 emission levels for different fossil fuels. Assuming that coal and gas will still account for the majority of electricity generation in 20 years' time – with a continued trend for gas generation to replace coal – this analysis uses a figure of 600 tonnes per GWh as the average amount that solar generation can reduce CO_2 emissions.

Figure 5.5: **Annual CO_2 emission savings by STE under Reference, Moderate and Advanced scenarios (in millions of tonnes)**



This assumption is further justified by the fact that around half of the cumulative solar generation capacity expected by 2020 will be installed in the OECD regions, i.e., North America, Europe and the Pacific. The trend in these countries is for a significant shift from coal to gas and/or wind and PV. In other regions, the CO_2 reduction will be higher due to the widespread use of coal burning power stations. Taking account of these assumptions, the expected annual saving in CO_2 by STE generation would be:

- *Reference scenario*: 17 million tonnes of CO_2 would be avoided annually by 2020, rising to 143 million tonnes in 2050. By 2020, cumulative CO_2 savings would be 93 million tonnes of CO_2, increasing to almost 2.2 billion tonnes by 2050.
- *Moderate scenario:* 32 million tonnes of CO_2 would be avoided annually by 2020, rising to 1.2 billion tonnes in 2050. By 2020, the cumulative CO_2 savings would be about 1.5 billion tonnes, increasing to just over 16.7 billion tonnes by 2050.
- *Advanced scenario*: 62 million tonnes of CO_2 would be avoided annually by 2020, rising to 2.7 billion tonnes by 2050. By 2020, almost 1.6 billion tonnes of CO_2 would be avoided, increasing to almost 37.5 billion tonnes by 2050.

65 Modern solar technology has an extremely good energy balance. The CO_2 emissions related to the manufacture, installation and servicing over the average 20 year lifecycle of a solar turbine are "paid back" after the first three to six months of operation.

Main Assumptions and Parameters

Growth rates

The Advanced scenario assumes growth rates for STE of more than 20% per year, which is high for an industry that manufactures heavy equipment. Market growth rates in this scenario are based on analyses of the current STE market. However, both the solar PV and the wind industry have shown much higher growth rates in recent years. For example, global wind power capacity has grown at an average cumulative rate of more than 30%, over the last ten years – 2014 was a record year with more than 51 GW of new installations, bringing the total up to over 370 GW. Assumed growth rates eventually decline to single figures across all three scenarios, but with the level of solar power capacity possible in 40 years' time, even small percentage growth rates would translate into large numbers of MWs installed each year.

Average power capacity

This scenario conservatively assumes that the average size of solar plants will gradually increase to 100 MW in 2020 and then level out. Whilst single solar dishes can have a capacity of up to 25 kW, the size of PT power stations are already between a few MW to over 250 MW. It is expected that STE power stations will continue to grow to an average size of 200-300 MW per location. However, the figure may be higher in practice, requiring fewer power plants to achieve the same installed capacity. It is also assumed that each STE power plant operates for 40 years, after which it will need to be replaced. This replacement of older power plants has been taken into account in the scenarios.

Capacity factor

The scenario assumes that the capacity factor of STE plants will increase steadily from the estimated average capacity factor today of 30%, to 45% in 2020 and 54% by 2030, based on increased integration of thermal storage and optimal siting. The scenario projects that the average global capacity factor will reach 34% by 2015.

'Capacity factor' refers how much of the nameplate capacity a solar thermal power plant installed in a particular location will deliver over the course of a year. The capacity factor depends on the solar resource at a given site, and with STE it can be increased by thermal storage. The solar field can be sized so it's larger than the nominal capacity of the steam turbine (this ratio is referred to as solar multiple) and the excess heat generated stored to run the turbine at a later time. In principle, nearly 100% of capacity could be built at appropriate sites, making STE a possible baseload option. As an example, a 100 MW STE power plant operating at a 30% capacity factor will deliver 263 GWh of electricity in a year.

Capital costs and progress ratios

The capital cost of producing solar power plants has fallen steadily over the past years as manufacturing techniques improve. Plant design has been largely in PT technology, but solar towers are starting be used more frequently. Mass production and automation will result in economies of scale and lower installation costs over the coming years. The general conclusion from industrial learning curve theory is that costs decrease by about 20% each time the number of units produced doubles. A 20% decline is equivalent to a progress ratio of 0.80. Studies of developement of the solar power industry to-date show that progress through R&D and learning have already dropped prices by 37%-40%. In the calculation of cost reductions in this report, experience has been related to numbers of units, i.e., power plants and not MW capacity. The increase in average unit size is therefore also taken into account.

The full potential of future design optimisations has not been utilised. The cost of STE power plants has fallen significantly overall, but the industry is not yet recognised as having entered the "commercialisation phase", as understood in learning curve theories.

Capital costs per kilowatt of installed capacity are taken as an average of €4,300 in 2015, falling to €3,485 in 2020 in all three scenarios.

Table 5.7: **Assumed average costs per kW**

Average CAPEX STE in €/kW	2015	2020	2025	2030	2035
Solar thermal power plants	4,287	3,485	3,037	2,814	2,657
Average OPEX STE in €/kWh	2015	2020	2025	2030	2035
Solar thermal power plants	20	18	17	16	15

Notes on Research

The projections for world electricity demand used in this report were developed for Greenpeace's Energy (R)evolution. For more information on how energy efficiency and other factors are incorporated in to the Reference scenario, please consult that report. The Energy (R)evolution is available for download at www.greenpeace.org

Image: Puerto Errado 1 ©Novatec Solar

Image: Solana ©Abengoa

06

Dispatchable STE for Interconnected Power Markets

The Interconnection between the Iberian Peninsula and the rest of Europe

In 2014, an alarm light went on about energy security in Europe. The European Commission released its Energy Security Strategy aiming to ensure a stable and abundant supply of energy for European citizens and the economy. So-called energy security stress tests were carried out.[66] The result showed that significant investments in energy infrastructure and a diversification of energy sources are needed to reduce dependency on fossil fuels and nuclear power supply.[67]

In such context, STE appears as a reliable and sustainable technology that is able to substitute for fossil fuel imports and does not need back-up capacity in order to meet electricity demand. Promoting STE technology is therefore in the common interest of the EU Member States striving for energy security. Dedicated, strategic investments in the form of long-term contracts for STE are required to help make Europe less dependent on energy imports.

Moreover, STE should also be seen as a technology of common interest, due to its positive effect on the electricity system and to the effects on the EU economy (technological leadership, job creation, etc.). Making use of the Cooperation Mechanisms[68] foreseen in the RES Directive 2009/28/EC[69] can help also foster the deployment of STE and stabilise the energy supply in Europe. This Directive aims at facilitating cross-border support of energy from renewable sources without affecting national support schemes. It introduces optional cooperation mechanisms between EU Member States which allow them to agree on the extent to which one Member State supports the energy production in another and on the extent to which the energy production from renewable sources should count towards the national overall target of one or the other.

Regarding this, clean electricity produced by STE can be exported to neighbouring countries where they have less RES resources. For example, in northern Europe, winds blow stronger during winter whilst the sun shines more in the summer. Therefore, STE in the south of the EU and wind power in its north have a perfect seasonal fit for stable and firm energy supply. Thus, the entire EU could actually profit from STE's ability to stabilize the grid and increase energy independence. Cooperation mechanisms will not only bring greater flexibility for Members States with low potential and/or expensive generation costs to partially meet their national targets in other countries, but also reduce the overall costs to realise the RES 20% European target.

With respect to infrastructure for carrying out cooperation mechanisms, the interconnected electricity transmission network system plays a crucial role. ENTSO-E, the European Network of Transmission System Operators for Electricity, provided the updates on the Ten-Year Network Development Plan 2014 package concerning the Continental South West Regional Investment Plan[70] for the next two years.[71]

66 See, http://ec.europa.eu/energy/en/topics/energy-strategy/energy-security-strategy.

67 In order to address long-term security of supply challenges, the Strategy proposed actions such as: (1) Increasing energy efficiency and reaching the proposed 2030 energy and climate goals; (2) Increasing energy production in the EU and diversifying supplier countries and routes. This includes further deployment of renewables; and(3)Completing the internal energy market and building missing infrastructure links to quickly respond to supply disruptions and re-direct energy across the EU to where it is needed.

68 See, http://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive/cooperation-mechanisms.

69 See, http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32009L0028.

70 See, ENTSO-E, TYNDP. Available at: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20RgIP%20CSW_.pdf.

71 The TYNDP for Electricity is so far the most comprehensive and up-to-date pan-European reference for the transmission electricity network. It presents and assesses all relevant pan-European projects under a specific timeframe defined by the analyzed scenarios. The TYNDP is a biannual report published every even year by ENTSO-E and acts as a basis to derive the list of Projects of Common Interest following its publication.

72 IEA, 2014, "Technology Roadmap: Solar Thermal Electricity 2014 edition", OECD/IEA.

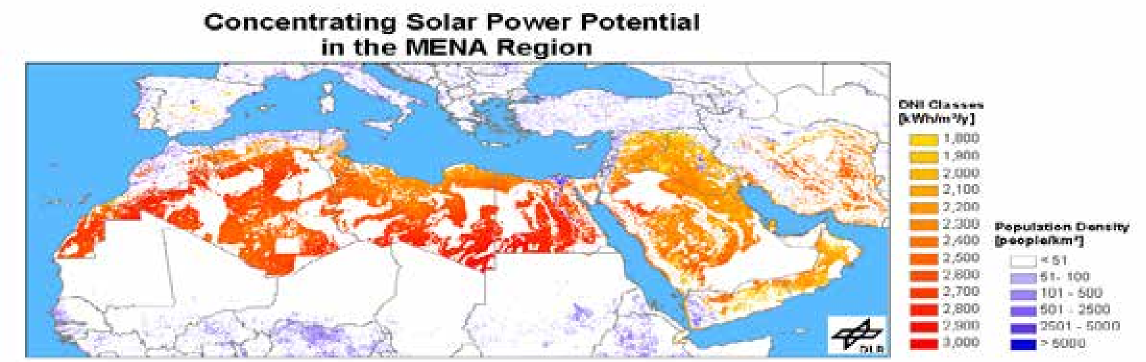
The Mediterranean Region

Technically, it would only take 0.04% of the solar energy from the Sahara Desert to cover the electricity demand of the EU28. Just 2% of the Sahara's land area could supply the world's electricity needs. This concept is staggering. With the potential for large-scale STE applications, electricity export from Northern Africa to Western Europe is an increasingly viable option. However, it requires massive investment in large, landmark plants and high voltage transmission lines to transfer the power while minimising transmission losses.

STE for Mediterranean/ MENA region

The MENA region is emerging as an attractive destination for STE deployment. It has amongst the world's best solar resources for STE: abundant sunshine, low precipitation, plenty of unused flat land close to transmission grids.

Figure 6.1: **STE Potential in the MENA Region** [73]



The IEA estimates that Africa and the Middle East would need 84 GW[73] of solar thermal electricity generation by 2030. With demand doubling every decade throughout the MENA region, there is a constant struggle to cover peak demand, which often occurs after sunset. STE with storage is a recognized and sustainable answer to address this challenge. As a secure electricity supply, STE also meets a prerequisite for economic development and growth, which are essential for political stability. Ultimately, increasing the standard of living and stability in the EU's "Southern Neighbourhood" is crucial for European cooperation policy and security. A market for STE in the MENA region would be an opportunity for the European industry to expand operations and create new jobs on both sides of the Mediterranean.

Current targets for STE deployment indicate strong growth in the coming decades, driven by a motivation to create local employment. According to IRENA and a World Bank report conducted by Ernst & Young and Fraunhofer, MENA countries have adopted different measures to develop appropriate policies and instruments to localise the value chain and provide more domestic employment opportunities. The highest local content for STE would likely be achieved in areas such as construction, fabrication of metal structures, mirrors, float glass and certain engineering tasks.

Commercial STE deployment in the MENA region is growing, with the completion of Shams 1 (100 MW, PT) in the United Arab Emirates, and Noor 1 (160 MW, PT) in Morocco, and the progression of Noor II (200 MW, PT) and Noor III (150 MW, CR) that have been awarded. The Shagaya project (50 MW, PT) with ten hours storage and dry cooling has also been awarded in Kuwait and ambitious plans in Saudi Arabia are foreseen with a target of 25 GW by 2040.

ISCC is an option which is being explored in some countries to provide a fast contribution of concentrated solar thermal fields to gas savings with a limited investments. However, the solar share in the generation of electricity in ISCC will be rather limited by the design constraints of the combined cycles and therefore a wide penetration of STE will only be achieved through standalone or hybrid plants. The world's first ISCC power plant was Ain Beni Mathar built in 2010 (Morocco) followed by Algeria and Egypt. Two ISCC projects with 50 MW of capacity from STE are under development in Saudi Arabia.

73 DLR

Different plant optimisation practices are required in MENA to achieve LCOE reduction and meet water requirements. However, implementing these practices is not always easy. Harsh weather conditions in the MENA region's desert landscape make cost-efficient technology deployment a challenge. Extensive dust, sand and heat, necessitate additional O&M work leading to higher costs. Selecting STE technologies with higher availability, reduced downtime requirements and easy-to-use operational philosophies is one way to mitigate the high O&M expenses associated with these challenging geographical characteristics.

Solar Energy Scenario for the Mediterranean Solar Plan

As mentioned above, the Mediterranean countries and the Middle East are one of the world's most attractive regions for STE. But it bears repeating:

- The solar resource is exceptionally good;
- Large areas of unused (desert) land are available, in particular on the southern and eastern shores of the Mediterranean Sea; and
- The Mediterranean region is a home to a world class industry and skilled workforce needed to develop, finance, construct, and operate solar power plants.

Evidence of the region's excellent conditions for solar power is the fact that a number of landmark deals have been closed in recent years, such as the Ourzazate solar thermal power plants in Morocco and several PV projects in the Gulf region and Jordan.

The typical load profile in the region is dominated by air conditioning during the hot hours of the day and an evening peak. In some parts of the region, in particular the Arab Peninsula, air conditioning is creating almost a baseload profile during summer months since outside temperatures remain high even at night. Therefore, STE with storage could play an important role in the transition to a sustainable energy supply, providing baseload renewable energy generation every hour of the day.

Another factor favouring development of STE in the region is that the southern and eastern Mediterranean countries have steady population and electricity demand growth rates which double the energy demand about every ten years. Hence, new generating capacity is needed to meet increasing demand, and opting for STE would avoid locking in CO_2 emissions for decades to come.

Contrast this situation with the European part of the Mediterranean region, which is characterized by stagnating demand and overcapacities, nevertheless, investment in new solar capacities will be needed over time as southern European economies recover from the crisis, existing fossil and nuclear power stations retire and EU energy policy requires increasing reliance on renewable energy. Assessments such as those published by the industry initiative Dii[74] show that in the mid- to long-term, it will be economically attractive to export dispatchable renewable electricity from solar thermal power plants with storage from North Africa and the Middle East to Europe.

Aside from being an ideal technology to meet the region's need for reliable, sustainable and affordable electricity, STE in the Mediterranean region has further advantages. For example, the European STE industry is a global leader and the uptake of STE in the region can create skilled jobs in manufacturing and services. These jobs can provide the region's young, large workforce with employment opportunities they might not otherwise while benefting the region both economically and socially. Investments in STE in

74 Such as *Desert Power 2050* and *Desert Power: Getting Started*.

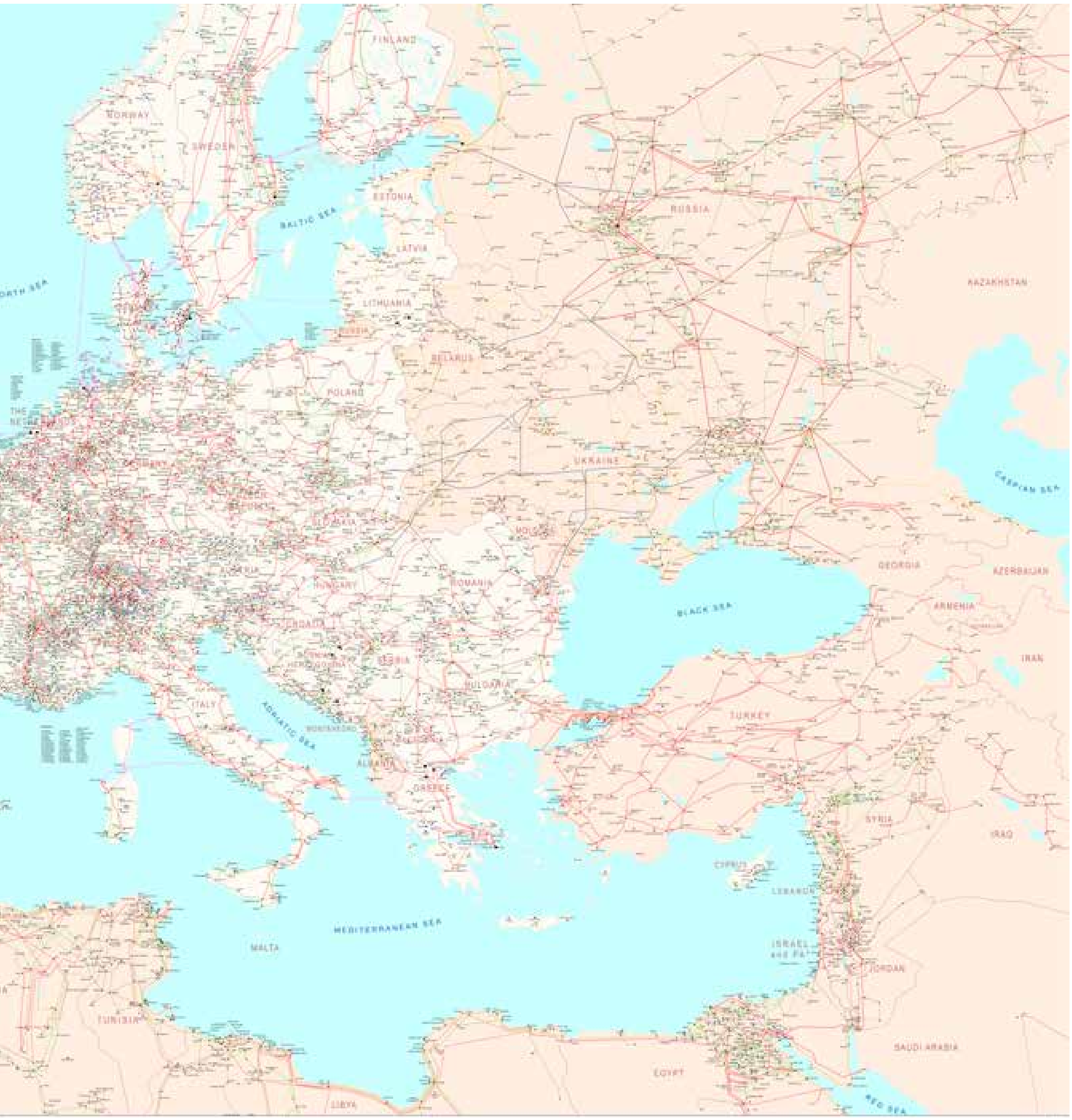


Image: Interconnected Network Map ©ENTSO-E; Source: www.entsoe.eu

the Mediterranean can therefore help to address two of the region's most pressing problems: transitioning to a sustainable energy supply and employment.

Whilst investing in STE in the Mediterranean region have many clear advantages, market development has so far been slow due to a number of challenges. For example, policymakers have a tendency to favour short-term solutions to energy problems rather than addressing root causes and private sector investment into infrastructure is generally very limited.[75] All of the key challenges are of a political nature, since the main technical and economic barriers to large-scale deployment of STE with storage will be resolved by technical innovation and cost reduction. In order to leverage private capital, for example, reliable investment frameworks and open market structures are required. Public-private partnerships can be one way to mobilize private capital. Regardless, it is essential to ensure stable conditions for non-governmental actors in the power sector.

Recently, the uptake of mature renewable technologies, such as PV and wind, has increased in the Mediterranean region and on the Arab Peninsula. The first STE projects have also come online in Morocco. With continued political support, more STE projects will follow since the techno-economic conditions make STE with storage a logical option to address the increasing electricity demand in the Mediterranean region.

75 See, Obstacle and Barriers in Chapter 7.

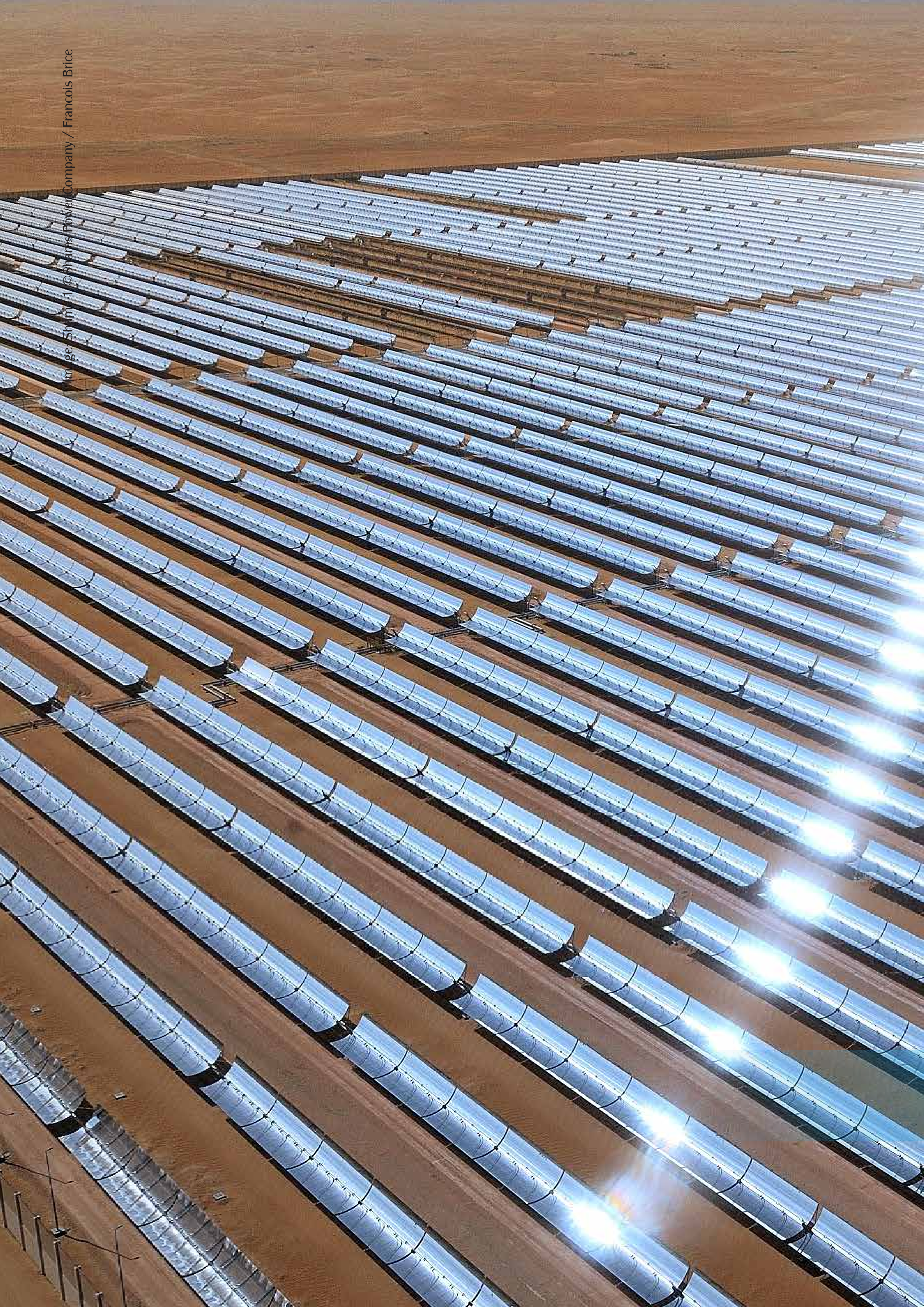


Image: Shams 1 © Shams Power Company / Francois Brice

07

How to Get There From Here: Policy Recommendations

The Solar Thermal Electricity Outlook Scenarios in Chapter 5 show that with advanced industry development and high levels of energy efficiency, solar thermal power could meet **up to 6 % of the world's power needs by 2030 and 12% by 2050**.

Strong market growth of STE will be triggered by a number of factors. Securing the technical and economic viability for the next round of projects is the first step. This requires, among other things, stable pricing and/or incentives to bridge any initial gap in levelised electricity costs, along with corresponding cost reductions of the components and the power produced. Effective financial supports are vital as the high up-front capital investment still constitutes one of the primary barriers to rapid STE deployment. Another key driver of rapid STE deployment is having efficient structures for off-take in order to secure project financing and power purchase agreements.

New markets and market opportunities, for example, will emerge from exporting power from southern Europe to northern Europe, or North Africa to Europe. These new markets will be vital for the long-term development of the industry. A strong research and development policy is also required to achieve further technical improvements.

As true as it is that Europe is not the region where the most significant development of STE is expected to occur, Europe remains a leader for this technology. The first projects realized in Europe based on smart FITs were no doubt a success both in terms of technology achievements and positive impacts on the European economy. The governments of the relevant EU Member States, with the European Commission playing a supporting role, must now put the additional measures in place to keep things moving in the right direction. Together with other renewable resources like wind, PV, geothermal, ocean energy and sustainable forms of bioenergy, STE has a major role to play in the global energy transition needed to prevent a catastrophic climate change.

Obstacles and Barriers

Barriers to STE deployment in Europe

In Europe, the most dramatic development since the last release of this report was the sudden change of the regulatory and legal framework in Spain that brought the further development of STE to a halt in the EU.

Due to this situation and to the substantial damage suffered by investors, who have filed claims against the Spanish government in international courts, further STE market development will happen outside of Europe. However, the Spanish experience makes abundantly clear that investor protection is another major issue to be solved for improving the deployment conditions for STE.

Included below is a list of the primary political, legal and technical and legal barriers in Europe for STE deployment.[76]

Political and legal barriers:

- Non-use of cooperation mechanisms as established in the RES Directive 2009/28/EC.
- Lack of a post-2020 RES framework with a clear governance model to achieve the 2030 RES targets in Europe.
- Lack of interest on the part of governments to engage in cooperation on RES target achievement.
- Lack of trust regarding on the continuity of a RES target framework beyond 2020. These factors go beyond mere technical considerations on how to jointly match excess and surplus of RES production.
- Uncertainty around sanctions for non-compliance with RES targets.
- A high degree of uncertainty on quantifiable costs and benefits, design options of cooperation mechanisms and difficulties for EU Member States to forecast their own RES target achievements.
- Lack of transmission infrastructure, in particular to move electricity over long distances, and market integration.

Barriers to STE deployment in Mediterranean region

As mentioned earlier in Chapter 6, although investing in STE in the Mediterranean region have many clear advantages, market development has been slow due to a number of challenges. These challenges tend to fall into three broad categories: political willingness, grid infrastructure and connections and cost and availability of financing.

Political willingness:

- Policymakers have a tendency to favour short-term solutions to problems in the energy sec-

76 ECOFYS: Cooperation between EU Member States under the RES Directive, 2014.

tor (e.g. diesel generators or inefficient gas turbines or ex-post changes to tariffs) rather than addressing the root cause of issues related to energy security and other matters. Such short-term oriented political decisions undermine private sector confidence in the viability of long-term investments.

- Countries with the technical capabilities and ability to pioneer innovative technological approaches are often not those with the need for new power plant capacity. Hence, a high level of political cooperation throughout the region is required to combine each actors' strengths and needs and expand the market for STE technology.

Grid infrastructure and connections:

- In some sub-Saharan regions, the grid infrastructure is often limited and underdeveloped. In many instances, the capacity of the electric grid is the determining factor when it comes to sizing a solar thermal power plant.

Cost and availability of financing:

- STE projects require large up-front investment.
- Private sector investment into infrastructure, including the energy sector and STE, is generally very limited. The conditions for private project development and investment hamper the engagement of private investors.
- Price competition from PV. STE has higher average electricity costs compared to PV, which has led some countries to favour investment in PV over STE.

Barriers to STE deployment in Australia

Several market factors contribute to the lack of STE deployment:

- High relative cost of STE in Australia.[77]
- Oversupply of coal-fired and gas power generation capacity (both CCGT and OCGT).
- Competition from other renewable energies.[78]
- Over-investment in electricity network infrastructure, which has increased the cost of electricity, distribution and transmission.
- Concentration of market power in the electricity market in Australia results in a very limited number of parties able to write power purchase contracts for a sufficiently long tenor to satisfy project financiers.
- There is no national framework for STE support such as those adopted in Spain, India, and South Africa. There is also no 'portfolio standard' like there is in the US.

This combination of factors results in challenging market conditions for STE as a new entrant in the Australian market. Wholesale electricity costs are low by international standards, peak demand pressures have significantly reduced due to the rapid uptake of solar PV, wind power has secured a large part of the renewable energy market and has rapidly demonstrated falling costs. What's more, utilities, regulators and financiers apply highly conservative cost and performance assumptions to STE project proposals due to lack of demonstrated STE in Australia to date.

For STE to succeed in Australia therefore, significant capital cost and LCOE reductions, among other things, must be achieved.

What policies have been proven to work effectively for boosting STE?

Recent years have seen a rapid growth of support mechanisms globally and a strong commitment to support STE deployment. Among all deployment policies, FITs have been the dominant regulatory instrument around the world. FITs are often funded through fixed or premium payments on electricity tariffs or funded through alternative mechanisms entirely, such as tax revenues.

Long-term and stable FITs have proven to be the most efficient instrument for sustainable renewable market penetration. Between 2007 and 2012, support schemes in Spain demonstrated that the right level of tariff increased the market for STE exponentially. Similar tariffs and support policies brought significant progress to STE deployment in Europe and helped STE become competitive with conventional energy generation.

As of 2015, there are only a few FITs supporting STE deployment in the world. Current levels of support are shown in table 7.1

77 Australia is a relatively high-cost market for labour, EPC, insurance, land, water, and cost of capital. These attributes mean that, despite Australia's exceptional solar resources, the relative cost of STE in Australia is relatively high.

78 High uptake of PV for residential consumers in recent years has reduced market peak demand, and wind power development has added to electricity oversupply in certain regions.

Table 7.1: **Current status of FIT legislation worldwide**

Country	FIT Value	Enacted	Remark
Algeria	300%	2013	Premium per kWh above a base tariff that may be intended to be the annual average price of electricity, but to date this has not been explicitly determined.
China	CNY 1.2/kWh	2014	
Israel	16.3 UScents/kWh (14.6 €cents/ kWh)	2009	
South Africa	ZAR 1.65/kWh (10.8 €cents/kWh)	2013	Round 3 Base period[78]
	ZAR 4.45/ kWh (29.3 €cents/kWh)	2013	Round 3 Base period[79]
	ZAR 1.37/kWh (9 €cents/kWh)	2015	Expedited Round
	ZAR 3.69/kWh (24.3 €cents/kWh)	2015	Expedited Round
Italy	29.1-34.1 €cents/kWh	2015	
Greece	26.5-28.5 €cents/kWh		
India	Up to 10 rupees/kWh (19 UScents/kWh or 16.5 €cents/kWh)	2008	
Turkey	22.5 UScents/kWh	2013	

Italy

The incentive scheme created by the *Decreto Ministeriale* of July 2012 has ended. It has been replaced by a new Decree which will come into effect in December 2015. Under the new incentive scheme, a total of 120 MW of solar thermal power plants will be funded: 100 MW devoted to plants larger than 5 MW, 20 MW allocated for the smaller ones. The FIT ranges from 29.1 to 34.1 €cent/kWh. It is differentiated between small and large plants and according to the expected integration fraction with other energy sources. Another important aspect is that the new Decree requires thermal storage in order to be eligible for the incentives. ANEST, the Italian national association for STE, is actively committed to guaranteeing (and safeguarding) incentives for the period 2015-2017.

South Africa

South Africa, thanks to the tariff system established by the REIPPP, presents a great opportunity for STE because of the added value it provides, in terms of dispatchability, as compared to many other renewable energy resources. The REIPPP tariff system, called time-of-day, aims to compensate generators in accordance with demand. This means that demand is high, the tariff increases. In Round 3, the base tariff is ZAR 1.65/kWh, and almost triple that amount during peak hours.

This way of compensating energy generation is very favourable for STE, given its rapid response capabilities thanks to the storage. As the REIPPP has advanced, the tariffs have decreased significantly from Round 1 to the 2015 Expedited Round. The current tariff is 17% less than it was in Round 3.

Australia: FITs/contracts for difference – State and Territory government initiatives

Only one jurisdiction in Australia operates a FIT system – the Australian Capital Territory. ACT also has a renewable energy target of 90% by 2020, a target it is well on the way to achieving. The ACT government has created legislation for 'reverse auctions' for renewable energy generation, in order to meet its renewable energy targets at the lowest possible cost. At the time of this writing, a third round is planned as the 'Next Generation Solar' auction, intended to secure capacity of solar power with energy storage. The Next Generation Solar auction is likely to seek up to 50MW total capacity, most likely divided between a number of projects.

In light of the hostility of the Australian Federal government to renewable energy, a number of states are considering introducing renewable energy targets similar to those of the ACT government, potentially with similar 'reverse auction' processes underpinning implementation.

79 Base tariff periods: 05:00-16:30 & 21:30-22:00

80 Peak tariff period: 16:30-21:30

Special financial vehicle and loan guarantees

Although FITs are the main driver of STE deployment, support should also come from a well-coordinated combination of sources: renewable energy support, strategic energy security investments, cohesion funds, as well as resources for development and cooperation. According to the Climate Policy Initiative,[81] if international financial institutions and committed national governments joined forces to deploy 5-15 GW of STE, this could reduce electricity production costs by around 14%-44% and make STE competitive in countries like Morocco and South Africa. IFIs can also improve the effectiveness of international financial support by adjusting loan requirements according to technology maturity, harmonising loan and regulatory requirements for large STE projects and reducing foreign exchange hedging costs of IFI loans for developers.

Morocco

In Morocco, the government launched the Morocco Solar Plan in order to archive the a national goal of reaching 42% of installed capacity (or 6,000 MW) from renewable energy, including 2,000 MW of solar capacity by 2020, contributing around 14% of the energy mix in the country's electricity supply. In order to archive this, the Moroccan government set up a special financial vehicle, called the Moroccan Agency for Solar Energy, to mobilise and blend domestic public funding with international financial instruments[62], such as loans from Clean Technology Fund, African Development Bank, the World Bank, and the European Investment Bank.

Financing Needs

As discussed in the previous section *Obstacles and Barriers*, high up-front capital investment constitutes one of the barriers to rapid STE deployment. Additionally, the cost of electricity generated by STE plants is often slightly higher than the cost of electricity from conventional fossil fuel technologies. However, costs are expected to come down due to large-scale deployment and technology improvements.

Since the deployment of STE is still less than that of other technologies, private banks view these projects as higher risk, such that project financing has proven to be an obstacle for STE project developers in recent years. Project developers continue to have difficulties obtaining bank debt to fund their projects, due to the lack of long-term data on STE deployment and the irrational perception of STE as a risky and immature technology.

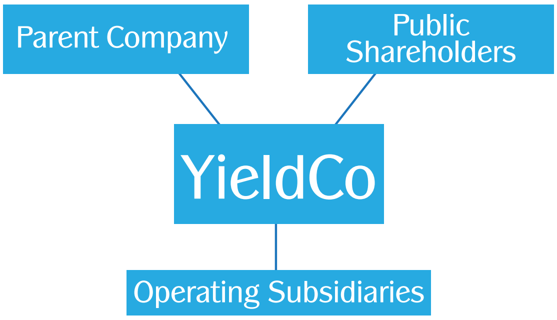
As mentioned in the previous section, support mechanisms for STE have increased rapidly. Among all of the support policies, public finance schemes, such as FITs, have been the dominant mechanism for project financing across the world. According to the Climate Policy Initiative, more than 98% of the STE plants were supported by public financing in the last few years, including FITs or premiums in Spain, subsidized PPAs in India, Morocco and South Africa, or grants, tax credits and public guarantees and low-cost loans in the US. These support policies fill the gap between costs and market revenues (sometimes call the "viability gap"), in order to scale up deployment of STE and drive down costs.

What are the new tools to open up avenues for financing STE? Recently, YieldCos have shown themselves to be a very effective and popular way for utility-scale renewable project developers to replenish capital. A number of developers have formed YieldCos in the US since 2013. YieldCo stands for yield company and is a growth-oriented, publicly traded company formed to hold operating assets that generate long-term, low-risk cash flows.[82] Such a model allows investors to single out the cash flows generated by power plant assets without exposing investors to other aspects of the parent company's business.

81 Climate Policy Initiative, 2014, "The role of Public Finance in CSP: Lesson Learned,", June 2014.

82 See, Renewable Energy World Magazine, May/June 2015 Issue.

Figure 7.1: **An organisation structure of a YieldCo**



Like any other investment instruments, this kind of investment vehicle has both pros and cons.[83]

Pros:

- This type of investment provides large-scale renewable project developers with a ready repository for its completed projects to raise new capital and gives the YieldCo the promise of growth.
- YieldCos are less speculative and carry lower risk than other investment vehicles because they are comprised of completed projects with long-term PPAs in place.
- A YieldCo can provide a geographically diverse portfolio of several power plant projects.
- Cash flows from YieldCos are not dependent on fossil fuel prices, so they do not carry a commodity price variable.

Cons:

- High cost of an IPO and the need to keep acquiring projects to maintain cash flows and stock value.[84]
- YieldCos depend on having a pipeline of new projects to add to their portfolios for growth. There is an exposure risk to future legislative and tax policies, which might not be favourable towards renewables.
- Equity assets will likely be influenced by fluctuations in stock markets.
- For STE in particular, as it is a relatively new energy technology, there are concerns about the lifespan of these assets and maintenance costs in 20 or 30 years.

There are also other YieldCo-like equity vehicles that provide developers with viable capital raising options, without the associated challenges.[85] For example, many private equity funds are made up of financial investors who purchase contracted projects that are nearly completed or ready for construction. Unlike publicly held YieldCos, these funds are more flexible over time and have limited terms, such as 12-15 years.

Although the European market differs from the US market, where power plants with smaller installed capacity are often more evenly distributed amongst more owners, YieldCos or YieldCo-like investment vehicles could work well in European markets as they provide low cost capital in big volumes.

Over the next few years, more YieldCos will be operating in European markets and further evolution of these investment vehicles is expected.

Successful Structures for Off-take

Key factors and drivers for a successful STE project deployment programme

To date, many factors favour STE deployment around the world, such as environmental and climate protection targets, as well as a desire in many countries for a more sustainable and secure energy system. However, these factors have not yet triggered large-scale STE deployment around the world.

Other conditions, such as efficient structures for offtake, are needed in order to secure project financing and starting bidding procedures. Such structures would build on essential factors, like regulations from governments that mandate power purchase deals lasting for at least the duration of the financing term. Without such a secured PPA, long-lasting infrastructure such as STE plants are not bankable.

83 See, http://www.greentechmedia.com/articles/read/what-you-need-to-know-about-how-yieldcos-for-clean-energy-work.

84 See, Renewable Energy World Magazine, May/June 2015 Issue.

85 See, Renewable Energy World Magazine, May/June 2015 Issue.

Figure 7.2: **Key factors and major drivers for a successful project implementation**

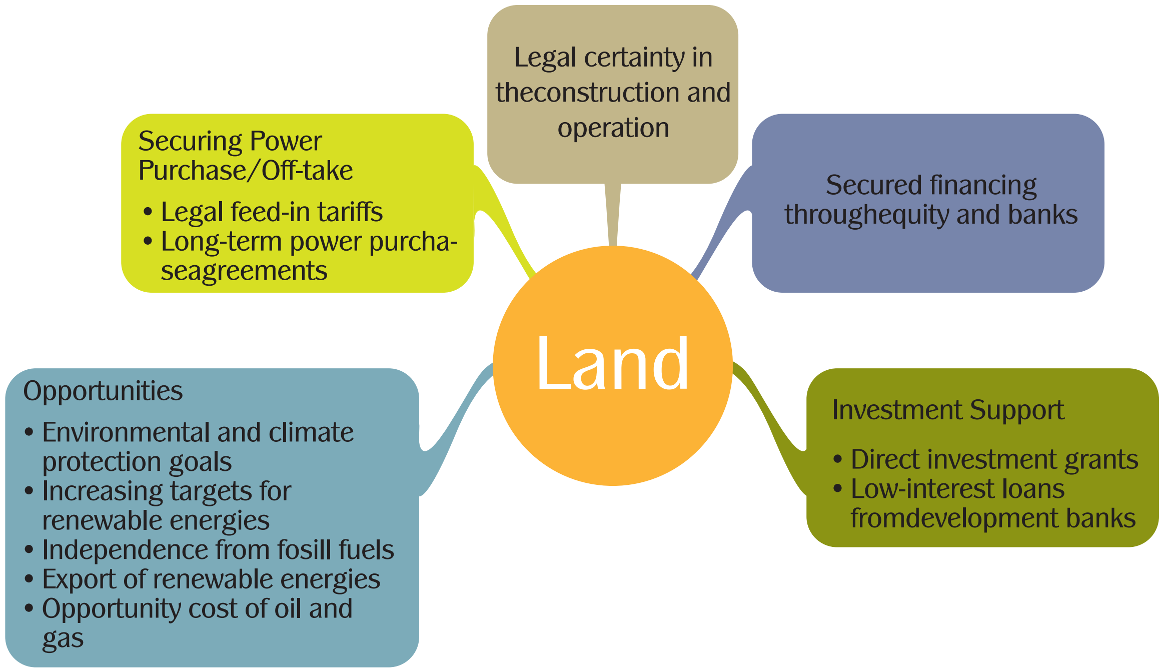
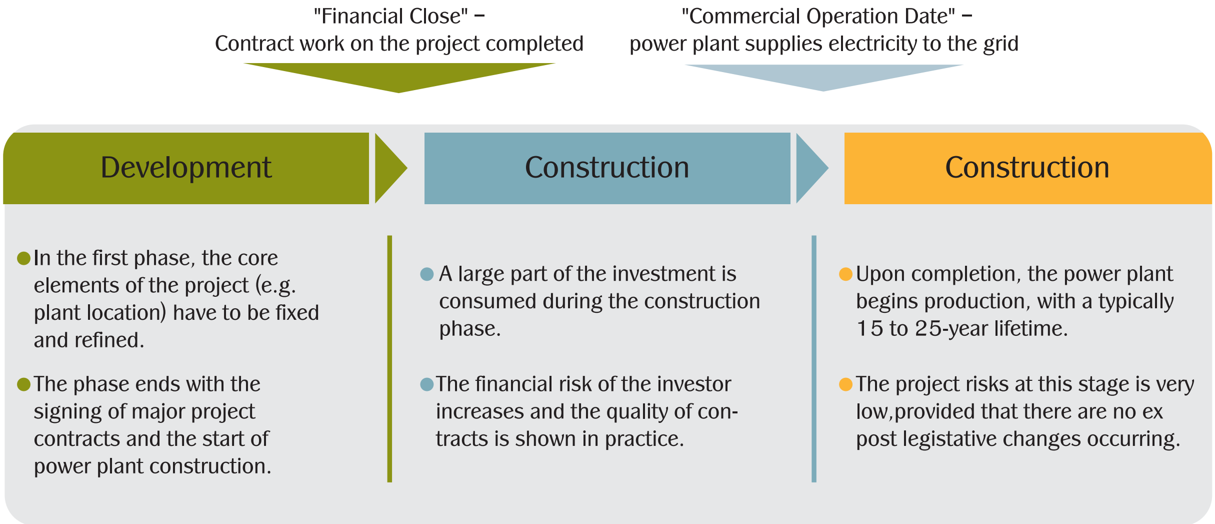


Figure 7.3: **Life cycle of a STE power plant project**



PPAs can be negotiated as a single PPA (for a single plant) or for several plants (parallel PPAs negotiations), where a specific power volume is tendered and more than one PPA granted up to the tendered power volume. A great advantage of this approach is that the bidders can choose the power plants themselves, which gives bidders more room for optimization of the tariff. This incents bidders to select sites with the best irradiation, which in turn can help minimize project costs.

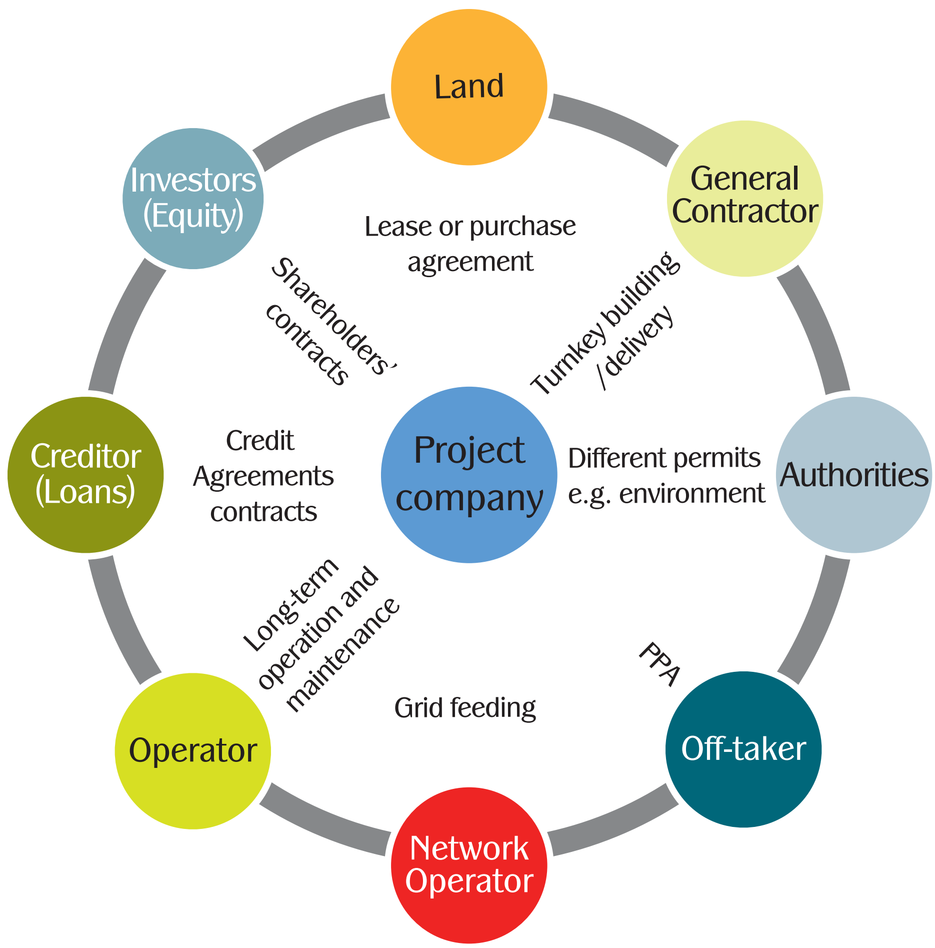
Additional advantages of such a tendering procedure include:

- Avoiding excessive administrative burdens for the contracting authority due to a flood of offers, as high demands are made on the submission of offers.
- Setting a high hurdle for participation with a financial risk for project developers whose bids do not meet all requirements on time. But an offer that is not completed in time for a round can be submitted in the next one.
- Reducing costs of various administrative and approval processes due to improved technologies and the increasing experience.

Once the PPA is negotiated and the perspective is clear, several conditions are checked:

- Finding a suitable site. Land use rights must be secured for several decades.
- Obtaining access to the high-voltage grid and the construction site. The right of network access and the access to the site, along with other necessary approvals, must be firmly secured.
- Carrying out assessments and studies. The measurement of radiation and a number of studies for technical planning, such as an environmental impact assessment and a soil study have to be carried out.
- Securing project finance. A thorough examination of all the risks of the project takes place in this phase, since the revenues of the project represent the only collateral. This process is often lengthy, but bank loan approval is also an important quality criterion. Usually, in order to obtain such a loan commitment, a contract must be executed with the EPC and O&M contractors.

Figure 7.4: **The most important components and contracts of a STE plant project**



PPA success factors

Executing a PPA and obtaining project financing requires a range of conditions to be met. The elements to best ensure that STE project proponents can successfully secure a PPA and go on to obtain project financing are outlined below.

Issues dependent on the legal framework

- Solvency and reliability of the off-takers. In many countries, a state guarantee is an adequate instrument for improving the investment climate/investor confidence.
- The number of required permits as well as the procedures to obtain such permits must be transparent and objective for all potential investors. Ideally, the maximum processing time for permits is fixed by law and permits are enforceable by investors once project development has started.
- Clear international arbitration procedures in the event of disputes must be defined in order to reduce the risk exposure of investors to legal changes by, for example, a local government or authority, especially when the off-taker is a state-controlled entity.
- An explicit government guarantee for the PPA is needed to provide additional security in order to gain the trust of investors and banks. Otherwise, the perceived risk of default for the PPA increases.
- The authorities themselves must be independent bodies and must not have any commercial interest in the project.
- Network access must be granted by an independent body, which does not compete with the project developers.
- Reliable and secure ownership or use rights at the project site for the duration of the PPA, plus a buffer of several years is essential. This applies not only for the site itself, but also for road access and grid connection.

The financing conditions (partly defined or impacted by the respective legal conditions)

- Financial security from bidders. This should not exceed a level (e.g. 10-20 €/MW) that would unreasonably increase overall project costs.
- Contractual penalties should be foreseen in case of delays in construction, power generation below the contractually agreed volume or high maintenance/repowering costs.
- Project finance setup. Guarantees for financing entities lay in the contractually defined revenues from the power sales of revenue, which leads, in many cases, to a debt-ratio of 60%-80%.
- The network charge for the projects should be “shallow,” which means including only the actual costs for connecting the project to the grid, but not the cost to eliminate bottlenecks elsewhere in the network.
- Accountability and transparency in the tendering process.
- Appropriate distribution of risks between the contracting authority and tenderers is also important, i.e., risks should always be borne by the party who can control them.

Issues depending on the site of the future plant

- Property rights for the project duration and several years beyond must be clear and trustworthy.
- In the case of parallel PPAs, where bidders can choose the site of their project, the grid connection points can be chosen according to specific principles: either “lower tariff” or “first-come-first-served”. The advantage of the “lower tariff” principle is the provision of the connection point coincides with the interest of the off-taker and grid capacity is not reserved for projects prior to concrete implementation.
- The local transmission system operator should bear the risk of non-completion for agreed transmission infrastructure upgrades and connection points, including the application of the “Take-or-Pay” principle.

Bidding procedures

- The contracting authority must have a deep understanding of the technical, legal and financial aspects of the power plant and all related contracts. This relies on professional consultants to ensure sufficient depth and quality of the tender documents and a thorough evaluation of the tenders.
- A timetable for tenders should be respected by all parties in order to increase reliability, speed and credibility of the process.
- The creation of complex services for power plants may take more than six months to complete after the publication of the tender documents. Since the rates for the plant usually have a validity of 12 months, the preferred bidder should be named for the current tariff

within three months after tender. The remaining nine months are reserved to reach financial closing – a reasonable period for the completion of a number of contracts.

- A reliable announcement of the tender and the general criteria should be published one to two years in advance so that the bidders have enough time to work out all the necessary details.

Successful Financing Instruments

As concluded by CPI, public financing from national governments has been the key driver for STE development in the last few years. In order to make national policies more effective in encouraging deployment of STE, they should do the following:

- Provide sufficient financial support to drive deployment;
- Ensure that support can be sustained over time to avoid boom and bust;
- Ensure the cost of support falls to reflect decreasing technology costs over time;
- Align public and private actors' financial interests to reduce the perception of policy risk and the cost of renewable energy support;
- Make reliable on-site solar irradiation data available;
- Consider low cost and/or long-term debt as one of the cheapest ways for national governments to support renewable energy deployment;
- Move away from flat power tariffs to renumneration that more accurately reflects the value of STE's flexible power supply to the energy system;
- Encourage longer-term more private and local debt in order to secure long-term financing and reduce currency risks.

Currently there are several financing instruments available for STE investments in Europe and around the world. These funding programmes are mostly set up by the European Commission and supported by the European Investment Bank.

The European Structural and Investment Funds

The Structural Funds and the Cohesion Fund are financial tools established to implement the regional policy of the EU. They aim to reduce regional disparities in income, wealth and opportunities. The current Regional Policy framework is set for a period of seven years, from 2014 to 2020. The Structural Funds are made up of the European Regional Development Fund and the European Social Fund. Together with the Common Agricultural Policy, the Structural Funds and the Cohesion Fund comprise the great bulk of EU funding, and the majority of total EU spending.

The ERDF is the most likely to contribute to the development of the STE sector in Europe. It supports programmes addressing regional development, economic change, enhanced competitiveness and territorial cooperation throughout the EU. Funding priorities include modernising economic structures, creating sustainable jobs and economic growth, research and innovation, environmental protection and risk prevention. Investment in infrastructure also retains an important role, especially in the least-developed regions.

Horizon 2020 – The programme for Research and Innovation 2014-2020

Horizon 2020 is the EU funding programme for research and innovation running from 2014 to 2020 with a €80 billion budget. The calls for proposals related to energy are gathered under the 'Secure, clean and efficient energy' part of the programme, where a budget of €5.93 billion has been allocated to non-nuclear energy research. Out of this figure, more than €200 million is earmarked to support European Institute of Innovation and Technology activities, subject to a mid-term review.

The majority of the calls where STE companies can apply are gathered under the Low-Carbon-Energy focus area. The topics covered aim to increase efficiency, reduce cost and improve dispatchability, and are in line with the R&D priorities identified by the sector through the implementation plan of the STE industrial Initiative of the SET-Plan. Public-private partnerships with EU-earmarked money could also be envisaged, involving a consequent number of private companies.

NER 300 (New Entrants' Reserve)

"NER300" is a financing instrument managed jointly by the European Commission, European Investment Bank and Member States, so-called because Article 10(a) 8 of the revised Emissions Trading Directive 2009/29/EC contains the provision to set aside 300 million allowances (rights to emit one tonne of CO_2) in the New Entrants' Reserve of the European Emissions

Trading Scheme for subsidising installations of innovative renewable energy technology and carbon capture and storage.

NER 300 is one of the world's largest funding programmes for innovative low carbon energy demonstration projects. The programme is conceived as a catalyst for the demonstration of environmentally safe carbon capture and storage and innovative renewable energy technologies on a commercial scale within the European Union. Today, two rounds of calls for tenders have taken place and innovative STE projects have been selected for funding in Italy, Spain, Cyprus and Greece. Unfortunately, delays in the development of the selected plants have occurred as a result of difficulties experienced by national public funding authorities, who have to co-finance the project.

EUROGIA 2020:

EUROGIA2020's[86] goal is to support and promote international partnerships developing innovative projects in low carbon energy technologies. It is a bottom-up, industry driven, market oriented programme which addresses all areas of the energy sector, from renewable energy to efficiency, and reduction of the carbon footprint of fossil fuels. EUROGIA2020 is a cluster of the EUREKA network, a decentralized intergovernmental initiative started in 1985 to enhance European competitiveness by supporting businesses, research centres and universities that take part in trans-national projects. It addresses all innovative energy technologies that will reduce the carbon footprint of energy production. STE technologies are also eligible for funding. Project proposals can be submitted at any time during the year.

InnovFin: EU Finance for Innovators

Under Horizon 2020, the new EU research programme for 2014–2020, the European Commission and the European Investment Bank have launched a new generation of financial instruments and advisory services to help innovative firms access finance more easily. Through 2020, "InnovFin – EU Finance for Innovators"[87] will offer a range of tailored financial products, totalling about €24 billion, for research and innovation by small, medium and large companies and the promoters of research infrastructures. InnovFin financial products are backed by funds set aside by the EU, under Horizon 2020, and by the EIB. As the EIB normally finances up to 50% of investment costs, InnovFin is expected to support €48 billion of final R&I investments.

"InnovFin – EU Finance for Innovators" builds on the success of the Risk-Sharing Finance Facility (2007–2013) developed under the seventh EU framework programme for research and technological development, which financed 114 R&I projects to the tune of €11.3 billion and provided loan guarantees worth over €1.4 billion.

Clean Energy Finance Corporation

The Clean Energy finance Corporation is an Australian government-owned financial institution with the specific mandate to support and assist the promotion of investment in clean energy, energy efficiency and renewable energy. The CEFC was established as part of the package of measures introduced by the previous Australian government in relation to Australia's carbon emissions reduction programme, and received an allocation of funds raised from the Australian carbon market system.

The current conservative government has proposed the abolition of the CEFC. As of the time of this writing, however, the government, has not succeeded in securing sufficient votes in Australia's parliament to repeal the legislation under which the CEFC is established.

CEFC has a mandate to ensure it achieved financial returns at least equivalent to returns available on Australian government bonds. CEFC operates like a commercial bank, however with a high degree of specialisation and innovation in lending for renewable and clean energy and energy efficiency investments. CEFC works closely with Australia's finance sector to initiate syndication, to educate and to demonstrate financial innovations aimed at increasing the involvement of commercial finance institutions in Australia in renewable energy investment.

86 EUREKA is an international network of 41 member states and the European Commission whose aim is to raise the competitiveness and productivity of European companies through innovation and technology-based product development. It supports European innovation by organizing international R&D&I collaboration projects between SMEs, research centers, universities and large industry.

87 See,http://www.eib.org/attachments/innovfin_faq_en.pdf.

Recommendations

Mandatory, binding renewable energy targets

To keep the world within a safe level of climate change, CO_2 emissions from the energy sector must be phased out as soon as possible, but no later than 2050.

The major policy approaches and measures required to achieve this goal are:

- Phase out all subsidies for fossil fuels and nuclear energy as well as subsidies that encourage the use of these fuels.
- Bring down emissions before 2020 and agree on legally binding greenhouse gas emission cuts to 2050. Renewable energy projects should be selected based on a system-wide planning approach that considers electric grid reliability as well as CO_2 emission reduction and cost.
- Internalise the external (social and environmental) costs of energy production through "cap and trade" emissions trading or a carbon tax.
- Mandate strict efficiency standards for all energy-consuming appliances, buildings and vehicles.
- Establish legally binding targets for renewable energy and combined heat and power generation.
- Reform the electricity markets by guaranteeing priority access to the grid for renewable power generators.
- Make sure that policy frameworks are stable and predictable.
- Continue with price support mechanisms to correct market failures in the electricity sector.
- Implement policy reforms, such as "time-of-day" pricing and weighted renewable energy certificate systems, to encourage and reward large-scale renewable energy storage in order to provide reliable, dispatchable renewable energy and reduce investment in electricity network (poles and wires) infrastructure.
- Conduct an on-going evaluation to identify opportunities to adapt and improve policies. This is particularly important for long-lived support policies.
- Provide defined and stable returns for investors, for example, through FIT programmes.
- Increase research and development budgets for renewable energy and energy efficiency.
- Harness local action to ensure global renewable energy uptake.
- Get the policy mix right in developing countries.

In addition to these global approaches, measures to boost STE, to the level where it can account for 12% of the world's energy demand in 2050 are as follows:

Market creation measures

Spain and the US show how big potential markets can be for STE, when the right market mechanisms are in place. Opening up the massive potential of other regions requires:

- Kyoto instruments such as the Clean Development Mechanism and Joint Implementation to be applicable to STE and include mechanisms that are bankable and sufficient.
- Governments to install demand instruments and promote feed-in-laws as the most powerful instrument to push generation.
- Full implementation of the Mediterranean Solar Plan to open the European transmission grid for solar power from North Africa and secure power imports by implementing demand "pull" instruments.
- Using the Cooperation Mechanisms foreseen in the RES Directive 2009/28/EC[88] and opening the renewable energy market to operate inside and outside the European Union, effectively letting renewable electricity cross intra-European borders. Such an interchange would require bankable transnational renewable transfer tariffs.
- Improving regulatory frameworks, such as allowing for long-term transmission rights and strengthening the internal electricity market through new transmission lines (especially between the Iberian Peninsula and the rest of Europe, also in Italy and Greece) to increase EU energy security.
- European organisations to engage and partner with Northern Africa. Africa has an unlimited solar resource, which can be accessed by sharing technology, know-how and employment. This would build up an industrial and human resource base for the implementation of STE in those countries, develop economic

88 ECOFYS: Cooperation between EU Member States under the RES Directive, 2014.

relationships and create an investment framework by supporting electricity market liberalization in North Africa.

Specific policy measures

FITs

Long-term and stable FITs have proven as the most efficient financial instrument for sustainable renewable market penetration. The general consensus among industry players is that a legislated tariff of between 24-27 €cents/kWh with a guarantee of 20 to 25 years is required in southern Europe to make projects bankable. FITs also need to:

- Be stable in order to provide investor confidence that the premiums will not change, so that project returns on investment can be met.
- Avoid retroactive policy changes, as these changes are highly damaging to investor confidence. Have clear and published time-scales for project eligibility
- Consider a period after which the tariff is lowered, for example, after projects are paid-off, so as not to have an unnecessary effect on the price for electricity.
- Be comprehensive, so that it can achieve concrete targets and minimise investment risks.
- Be aligned between public and private actors' financial interests to reduce the perception of policy risk and the costs of renewable energy support.
- Be adaptable and able to respond to market signals and be able to adapt to changing circumstances. Policies should also be regularly reviewed.
- Be long-term, realistic and sufficient to drive deployment.
- Be tailored to country conditions. A policy that has led to success in one country may not bring the same policy outcomes in another.

Loan Guarantees

To provide greater access to investment funds requires new loan guarantee programmes via existing windows at multilateral banks, existing national lending programmes and global environmental programmes such as GEF, UNEP, and UNDP for STE for North Africa's developing economies.

Supporting new technology development

As with any developing industry, next generation technologies will significantly drive down costs. This requires:

- Funding for pre-commercial demonstration plants so next generation technologies can enter the market.
- Loan guarantees for demonstration plants to cover technology innovation risk.
- Research and development funding for material, component and system development (e.g. coatings, storage, direct steam/molten salt systems, adapted steam generators and beam down).
- Selection of renewable energy projects on the basis of a system-wide planning approach that considers electric grid reliability as well as CO_2 emission reduction and cost.
- Quantifying the value of STE storage in supporting grid reliability and using that in the tendering selection process.

Similar to the requirement for distributed generation being a percentage of the RPS, renewable technologies with energy storage should also be a required percentage of the RPS in the US.

Solar Fuels

For solar fuels, the ultimate goal is developing economically viable technologies for solar thermochemical and electrolysis processes that can produce solar fuels, particularly hydrogen. Recommended policy measures include:

- Immediate and accelerated implementation of research and development to transition from today's fossil fuel-based economy to tomorrow's solar driven hydrogen economy. The EU-FP6 project INNOHYP-CA (2004-2006) has developed a roadmap which shows the pathway to implementing thermochemical processes for massive hydrogen production.
- Early demonstration of large-scale hydrogen production using existing electrolyser technologies, and newer high temperature/high pressure electrolyser technology, powered by STE with energy storage (enabling high capacity utilisation of the electrolyser and balancing of the plant, and delivering high capital efficiency) to prove viable industrial-scale supply chains to underpin hydrogen based production in major industrial economies.
- Development and demonstrations of solar chemical production technologies to prove technically and economic feasibility.
- A clear decision to start the transition from fossil fuels to renewable energies and from

petrol to hydrogen. Concrete steps from governments, regulators, utility companies, development banks and private investors to develop infrastructure and create new markets.

Process Heat

Measures to support further development of STE technologies to provide process heat include:

- Economic incentives for industries willing to invest in solar thermal aimed at reducing payback periods. This could include, for example, low interest rate loans, tax reduction, direct financial support, third party financing. To date, only local examples of these support schemes have been applied.
- Early demonstration and pilot solar thermal plants in industries, including advanced and innovative solutions, like small concentrating collectors.
- Providing information to industrial sectors to make them more aware of issues around process heat, namely:
  - The real cost of heat production and use of conventional energy sources and their relevance in the total industry management cost; and
  - The benefits of using appropriate solar thermal technology.
- Support further research and innovation to improve technical maturity and reduce costs, especially for applications at higher temperatures.

Image: Parabolic trough collector ©CSP Services/DLR

About the authors

SolarPACES

SolarPACES is an international cooperative organization bringing together teams of national experts from around the world to focus on the development and marketing of concentrating solar power systems (also known as solar thermal power systems). It is one of a number of collaborative programmes managed under the umbrella of the International Energy Agency to help find solutions to worldwide energy problems. The organisation focuses on technology development and member countries work together on activities aimed at solving the wide range of technical problems associated with commercialization of concentrating solar technology. In addition to technology development, market development and building of awareness of the potential of concentrating solar technologies are key elements of the SolarPACES programme.

ESTELA

ESTELA, the European Solar Thermal Electricity Association, is a non-profit industry association created in 2007 to support the emerging European solar thermal electricity industry for the generation of green power in Europe and abroad, mainly in the Mediterranean region. ESTELA represents STE sector from industry to research institutions, active along the whole STE value chain: promoters, developers, manufacturers, utilities, engineering companies, research institutions. Joining hands with national associations – Protermosolar (Spain), ANEST (Italy), Deutsche STE (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 worldwide promoting the solar thermal electricity sector.

Greenpeace International

Greenpeace is a global organization that uses non-violent direct action to tackle the most crucial threats to our planet's biodiversity and environment. Greenpeace is a non-profit organization, present in 40 countries across Europe, the Americas, Asia and the Pacific. It speaks for 2.8 million supporters worldwide, and inspires many millions more to take action every day. To maintain its independence, Greenpeace does not accept donations from governments or corporations but relies on contributions from individual supporters and foundation grants.

Greenpeace has been campaigning against environmental degradation since 1971 when a small boat of volunteers and journalists sailed into Amchitka, an area west of Alaska, where the US government was conducting underground nuclear tests. This tradition of 'bearing witness' in a non-violent manner continues today, and ships are an important part of all its campaign work.

Appendixes

Appex.1: List of current solar thermal power plants in operation and under construction in 2015

Operating

Country	Power Plant Name	Installed Capacity (MW)	Elect. Generation (GWh/a)	Type	Company/ Developer	Install Date	Remarks
Algeria	Hassi R'mel	25	n/a	PT	Abengoa Solar	2011	Hybrid & ISCC
Australia	NovatecSolar Liddell Solar Expansion	9	15.1	LFR	Novatec Solar	2012	
Australia	Lake Cargelligo Solar Thermal Power Station	3	n/a	CR	Lloyd Energy Systems/ Graphite Energy	2011	Demo plant
Canada	Medicine Hat ISCC	1.1	1.5	PT	Skyfuel	2014	
China	Badaling Solar Thermal Pilot Plant	1.5	1.95	CR	IEE-CAS	2012	R&D
China	Xinjian Turpan 180 kW CSP pilot plant	0.18	n/a	PT	Guodian Qingsong Turpan New Energy	2012	R&D
China	Delingha Solar Thermal Plant (10/50)	10	120	CR	Zhejiang SUPCON Solar Energy Technology	2013	
Egypt	ISCC Al Kuraymat	20	34	PT	NREA (New Renewable Energy Authority) & Solar Millennium	2011	Hybrid & ISCC
France	Thémis - Project Pégase	1.3	n/a	ISCC	PROMES-CNRS	2006	Testing Facility
France	Augustin Fresnel 1	0.25	n/a		Solar Euromed	2011	Testing Facility
Germany	Jülich	1.5	n/a	CR	KRAM & DLR & Others	2009	Testing Facility
India	Indian Institute of Technology CSP Project	3	n/a	PT	Abengoa	2011	
India	National Solar Thermal Power Plant	1	n/a	PT	IIT Bombay	2013	
India	Bikaner	2.5	n/a	CR	ACME	2011	
India	Godawari	50	118	PT	Godawari Green Energy Limited	2013	
India	Reliance Areva CSP 1 (Dhursar)	125	280	LFR	Reliance Power AREVA	2014	
India	ACME Rajasthan Solar Power 1	2.5	n/a	CR	Entegra	2011	
India	Megha Solar Plant	50	110	PT	Megha Engineering & Infrastructure	2014	
India	Ramanathapuram Deslination plant	1.06	n/a	LFR	KG Design Services & Empereal Inc.	2012	Deslination plant
Iran	Yazd Integrated Solar Plant (YSEPP)	17	n/a	PT & ISCC	Parhoon Tarh	2009/2010	
Iran	Shiraz Solar Plant	0.5	n/a	PT		2008	
Israel	Solar Energy Development Center (SEDC)	6	n/a	CR	Bright Source	2008	
Italy	Archimede	5	9.2	PT	ENEL	2010	
Italy	Archimede Molten Salt Loop	0.35	0.28	PT	Archimede Solar Energy & Chiyoda Corporation	2013	Demo plant
Italy	Zasoli	0.2	n/a	LFR		2013	
Italy	Rende	1	3	PT		2014	
Morocco	Ain Beni Mathar Plant ISCC	20	55	PT	L'Office National de l'Électricité (ONE)	2011	Hybrid & ISCC
Morocco	NOOR 1	160	175	PT	ACWA/Aries/TSK	2015	Completion end of 2015 or beginning of 2016
Morocco	Airlight Energy Ait Baha	3	2.4	PT	Airlight	2014	
South Africa	KaXu Solar One	100	330	PT	Abengoa Solar	2015	
Spain	Plataforma Solar Almería	50	n/a		CIEMAT	1980	R&D Testing Facility

Country	Power Plant Name	Installed Capacity (MW)	Elect. Generation (GWh/a)	Type	Company/ Developer	Install Date	Remarks
Spain	Andasol 1	20	158	PT	Cobra & RREEF & ANTIN	2008	
Spain	Andasol 2	50	158	PT	Cobra & RREEF & ANTIN	2009	
Spain	La Risca - Alvarado 1	50	105.2	PT	Acciona / Mitsubishi Corp.	2009	
Spain	Puerto Errado 1	1.4	2	LFR	Novatec	2009	
Spain	Ibersol Puertollano	50	103	PT	IBERCAM (Iberdrola Solar de Puertollano)	2009	
Spain	Central La Florida	50	175	PT	Renovables Samca	2010	
Spain	Extresol 2	50	158	PT	Cobra	2010	
Spain	Palma del Río II	50	114.5	PT	Acciona	2010	
Spain	Majadas	50	104.5	PT	Acciona	2010	
Spain	Arcosol 50 / Valle 1	50	175	PT	Torresol	2011	
Spain	Central La Dehesa	50	175	PT	Renovables Samca	2011	
Spain	Extresol 3	50	158	PT	Cobra	2011	
Spain	Gemasolar	20	110	CR	Torresol	2011	
Spain	Helioenergy 1 (Ecija Solar Complex)	50	95	PT	Abengoa Solar & EON	2011	
Spain	Lebrija 1	50	120	PT	Simens/Valoriza	2011	
Spain	Manchasol 2	50	158	PT	Cobra	2011	
Spain	Termosol 50 / Valle 2	50	175	PT	Torresol	2011	
Spain	Aste 1A	50	170	PT	Aries Termosolar & Elecnor & Eiser = Dioxipe Solar	2012	
Spain	Aste 1B	50	170	PT	Aries Termosolar & Elecnor & Eiser = Dioxipe Solar	2012	
Spain	Consol Orellana	50	118	PT	Acciona	2012	
Spain	Helioenergy 2 Ecija Solar Complex)	50	95	PT	Abengoa Solar & EON	2012	
Spain	Helios I (Castilla-La Mancha)	50	97	PT	Abengoa Solar	2012	
Spain	Helios II (Castilla-La Mancha)	50	97	PT	Abengoa Solar	2012	
Spain	La Africana	50	170	PT	Magtel, TSK, Ortiz	2012	
Spain	Guzmán	50	104	PT	FCC & Mitsui	2012	
Spain	Morón	50	100	PT	Ibereólica Solar	2012	
Spain	Olivenza 1	50	100	PT	Ibereólica Solar	2012	
Spain	Puerto Errado 2	30	49	LFR	Novatec & EBL & IWB & EWZ & EKZ & EWB	2012	
Spain	Solaben 2 (Extremadura Solar complex)	50	100	PT	Abengoa Solar & ITOCHU	2012	
Spain	Solaben 3 (Extremadura Solar complex)	50	100	PT	Abengoa Solar & ITOCHU	2012	
Spain	Termosolar Borges	22.5	98	PT	Abantia / Comsa EMTE	2012	
Spain	Arenales PS	50	166	PT	OHL / STEAG / RREEF	2013	
Spain	Casablanca	50	160	PT	Cobra	2013	
Spain	Enestar Villena	50	100	PT	FCC & Otros	2013	
Spain	Solaben 1 (Extremadura Solar complex)	50	100	PT	Abengoa Solar	2013	
Spain	Solaben 6 (Extremadura Solar complex)	50	100	PT	Abengoa Solar	2013	
Spain	Termosol 1	50	180	PT	Nextera & FPL	2013	
Spain	Termosol 2	50	180	PT	Nextera & FPL	2013	
Spain	PS20 (Solucar complex)	20	48	CR	Abengoa Solar - Plataforma Solúcar	2009	
Spain	Manchasol I	50	158	PT	Cobra	2011	
Spain	Solnova 4 (Solucar complex)	50	113.5	PT	Abengoa Solar - Plataforma Solúcar	2010	
Spain	Extresol 1	50	158	PT	Cobra	2010	

Country	Power Plant Name	Installed Capacity (MW)	Elect. Generation (GWh/a)	Type	Company/ Developer	Install Date	Remarks
Spain	Solarcor 1 (El Carpio Solar complex)	50	100	PT	Abengoa Solar & JGC Corp	2012	
Spain	Palma del Río I	50	114.5	PT	Acciona	2011	
Spain	PS10 (Solucar complex)	11	23.4	CR	Abengoa Solar - Plataforma Solúcar	2007	
Spain	Carboneras	50	170	PT	Endesa & DLR	2011	Testing Facility
Spain	Astexol II	50	170	PT	Aries Termosolar & Elecnor & Eiser = Dioxipe Solar	2012	
Spain	Solarcor 2 (El Carpio Solar complex)	50	100	PT	Abengoa Solar & JGC Corp	2012	
Spain	Solnova 1 (Solucar complex)	50	113.5	PT	Abengoa Solar - Plataforma Solúcar	2010	
Spain	Solnova 3 (Solucar complex)	50	113.5	PT	Abengoa Solar - Plataforma Solúcar	2010	
Spain	Andasol 3	50	175	PT	Ferrostaal & Solar Millennium & RWE & Rhein Energy & SWM	2011	
Thailand	Kanchanaburi TSE 1	5	8	PT (DSG)	Thai Solar Energy Company Ltd.	2011	
Turkey	Greenway CSP Mersin Solar Plant	5	n/a	CR	Greenway	2013	
United Arab Emirates	Shams 1	100	210	PT	Masdar & Abengoa&Total	2013	
USA	Saguaro Solar Power Station	1.16	2	PT	Arizona Public Service	2006	
USA	Nevada Solar One	64	134	PT	Acciona	2007	
USA	Kimberlina Solar Thernal Energy Plant	44	44	LFR	Areva (Ausra)	2008	
USA	Holaniku at Keyhole Point	2	4	PT	Keahole Solar Power, LLC	2009	
USA	Cameo hybrid	2	n/a	PT	Xcel Energy	2010	Hybrid & coal plant
USA	Martin Next Generation Solar Energy Center (MNGSEC)	75	155	PT	Florida Power & Light Company (FPL)	2010	Hybrid & coal plant
USA	BrightSource Coalinga	13	n/a	CR	BrightSource	2011	
USA	Ivanpah Solar Power Facility (3 plants - ISEGS)	392	1079.2	CR	BrightSource Energy	2013	
USA	Solana Generating Station	280	944	PT	Abengoa Solar	2013	
USA	Abengoa Mojave Solar Park	280	600	PT	Abengoa Solar	2014	
USA	Genesis Solar Energy Project	250	300	PT	NextEra Energy	2014	
USA	Tooele Army Depot	1.5	n/a	PD	Infnia	2014	
USA	Solar Energy Generating Systems (SEGS - 9 plants)	354	662	PT	Florida Power & Light Company (FPL)	1984-1990	
USA	Sierra Sun Tower	5	n/a	CR	eSolar	2009	
USA	Crescent Dunes Solar Energy Project	110	485	CR	SolarReserve	2015	
Total		**4,979.5**					

Under Construction

Country	Power Plant Name	Installed Capacity (MW)	Elect. Generation (GWh/a)	Type	Company/ Developer	Install Date	Remarks
Australia	Kogan Creek Solar Boost	44	44	LFR	AREVA	2013	Hybrid - Coal
Australia	Jemalong Solar Thermal Station	1.1	2.2	CR	Vast Solar	2014	
Brazil	Helioterm	1		PT	Centro de Pesquisas de Energia Eletrica+Companhia Hidro Electrica do Sao Francisco+Universidade Federal de Pernambuco	2014	
Chile	Planta Solar Cerro Dominador (Atacama-1)	110		CR	Abengoa	2018	
China	E Cube Energy Dish pilot plant	1		PD		2013	Demo plant
China	Yanchi	92.5		PT & ISCC	Hanas New Energy Group	2014	
China	CPI Golmud Solar Thermal Power Plant	100		PT	China Power Investments Corporation		
China	HelioFocus China Orion Project I	1		PD	China Guodian Corporation+Heliofocus	2013	
China	HelioFocus China Orion Project II	10		PT	China Guodian Corporation+Heliofocus	2014	
China	HelioFocus China Orion Project III	60		PT	China Guodian Corporation+Heliofocus	2015	
China	Himin Solar Fresnel Demo Plant	2.5	5.25	LFR	Himin Solar	2014	Demo plant
China	Huaneng Sanya	1.5		LFR	China Huaneng Group		Demo plant
China	Tianwei 1.5 MW CSP pilot plant	1.5		PT	China Datang GroupTianwei New Energy Holding		Demo plant
China	Yumen Gansu Solar Thermal Pilot Plant	10		PT	Tianwei New Energy Holding+China Datang Group	2014	Demo plant
China	Jinshawan	27.5		CR			
China	Erdos Solar Thermal Power Plant	50		PT	China Datang Corporation	2014	
China	Delingha Solar Thermal Plant (40/50)	40		CR	Zhejiang SUPCON Solar Energy Technology		
France	Centrale Solaire Thermoynamique Llo	9			CNIM	2015	
France	Alba Nova 1	12	25	LFR	Solar Euromed	2014	
India	Diwakar Solar Projects	100		PT	Lanco Solar Energy	2014	
India	KVK Energy Solar Project	100		PT	KVK Energy Ventures Private Limited	2014	
India	Gujarat Solar One	28	130	PT	Cargo Solar Power	2014	
India	Aurum Renewable Energy	20		LFR	Aurum Renewable Energy Private Limited	Solar Mission	
India	Abhijeet Solar Project	50		PT	Corporate Ispat Allowys Limited	Solar Mission	
India	Rajasthan Solar One	10		PT		2014	
Israel	Ashalim	110		PT	Abengoa	2014	
Italy	Archimede	1	2,3	PT	ARCHIMEDE SRL	2015	
Jordan	Joan 1	100		LFR	MENA Cleantech AG (Areva (Ausra))	2013	
Mexico	Agua Prieta II Project	14	34	PT	Abengoa	2013	Hybrid + ISCC
Morocco	NOOR 2	170		PT	ACWA		
Morocco	NOOR 3	200		CR	ACWA		
South Africa	Bokpoort	50	224	CCP	ACWA/Solafrica	2016	
South Africa	Xina Solar One	100		PT	Abengoa (40%), Industrial Development Corporation (IDC), Public Investment Corporation (PIC)	2014	

Country	Power Plant Name	Installed Capacity (MW)	Elect. Generation (GWh/a)	Type	Company/ Developer	Install Date	Remarks
South Africa	Khi Solar One	50	180	CR	Abengoa Solar	2016	
South Africa	Redstone CSP	100		CR	Solar Reserve / ACWA		
South Africa	Ilanga CSP1	100		PT	Karoshoek Consortium	2016	
Spain	Planta Cáceres	50		PT	Cobra	2013	
USA	Mojave Solar Park	250	600	PT	Abengoa		
USA	Stillwater CSP-Geothermal	17	3	PT		2014	
Total		**2,194.6**					

Appex.2: List of on-going projects related to the interconnection of the Iberian Peninsula to the rest of Europe

Eastern Interconnection ES-FR

Investm-ent ID	Connection From/To (substation names)	Description	Expected TYNDP commi-ssioning	Evolution driver description
36	Sta.Llogaia (ES)- Baxias (FR)	New HVDC (VSC) bipolar interconnection in the Eastern part of the border, via 320kV DC underground cable using existing infrastructures corridors and converters in both ending points.	2015	Answering all concerns expressed during the authorization process in Spain and environmental issues in France led to postponing the investment. Both issues have been solved.
505	Sta.Llogaia (ES)-?	Converter station of the new HVDC (VSC) bipolar interconnection in the Eastern part of the border, via 320kV DC underground cable using existing infrastructures corridors.	2015	Works completed in 2014; commercial operation expected after test period at the same time as the cable (investment 36).
506	Baixas (FR)-?	Converter station of the new HVDC (VSC) bipolar interconnection in the Eastern part of the border, via 320kV DC underground cable using existing infrastructures corridors.	2015	Works completed in 2014; commercial operation expected after test period at the same time as the cable (investment 36).
38	Gatica (ES)- Aquitaine (FR)	New HVDC interconnection in the western part of the border via DC subsea cable in the Biscay Guif	2022	The technical consistency of the project progress and the commissioning date is now defined more accurately.

The updated version of the Regional Investment Plan Continental South West as part of TYNDP 2016[1] was released in the summer of 2015. Changes compared to TYNDP 2014 will be the following:[2]

- Differentiated focus and release of the regional development plans and the final TYNDP report
- Updated Scenarios for 2030
- New Guidelines for the Inclusion of Projects in the TYNDP
- Publication of TYNDP 2016 Candidate Projects
- Publication of Monitoring Update of the TYNDP 2014 Projects
- Full Implementation of the EC Approved Cost Benefit Analysis Methodology (CBA Methodology)

1 Detailed procedure for submitting projects: https://www.entsoe.eu/news-events/announcements/announcements-archive/Pages/News/Infrastructure-ENTSO-E-Invites-Project-Applications-for-Inclusion-in-the-TYNDP-2016.aspx and https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/TYNDP_2016_User_guide_application_for_projects.pdf.

2 Methodology for inclusion of projects in the TYNDP 2016 is described here: https://www.entsoe.eu/major-projects/ten-year-network-development-plan/ten%20year%20network%20development%20plan%202016/Pages/default.aspx.

Appex.3: Summary of Key Parameters in Scenarios

Year	Cumulative (GW)	Global Annual Growth Rate (%)	Annual (MW) incl, Re-powering	Capacity factor (%)	Production (TWh)	STE penetration of world´s electricity in % (low demand)	STE penetration of world´s electricity in % (high demand)	CO_2 reduction (with 600g CO_2/kWh) (annual Mt CO_2)	Avaoided CO_2 since 200XX (cumulative Mt CO_2)	Capital Costs (€/kW)	Investment (€1000)	Jobs total
2015	6	24%	1,205	28%	15	0.1%	0.1%	9	25	4,287	1,572,737	18,904
2020	11	10%	1,017	28%	28	0.1%	0.1%	17	93	3,485	1,344,916	16,981
2025	19	9%	1,597	28%	47			28	211	3,037	2,046,142	27,061
2030	27	7%	1,680	30%	72	0.2%	0.3%	43	390	2,814	2,146,766	29,180
2035	38	7%	3,726	30%	100			60	653	2,611	3,166,441	42,760
2040	54	7%	4,738	30%	143	0.4%	0.4%	86	1,025	2,688	4,603,987	62,545
2045	73	5%	5,228	30%	191			114	1,539	2,681	4,495,325	63,878
2050	91	4%	5,339	30%	238	0.6%	0.7%	143	2,197	2,674	4,529,034	70,197
2015	6	23%	1,075	28%	14	0.1%	0.1%	9	1,390	4,287	4,607,025	16,964
2020	22	28%	4,834	28%	54	0.2%	0.2%	32	1,499	3,485	16,848,911	70,051
2025	57	19%	9,248	28%	141			85	1,825	3,037	28,089,558	139,197
2030	131	17%	18,876	30%	344	1.1%	1.3%	207	2,595	2,814	53,126,673	269,733
2035	254	13%	29,763	30%	668			401	4,215	2,677	79,682,744	440,977
2040	407	8%	36,652	30%	1,069	3.0%	3.4%	641	6,983	2,666	97,708,169	574,049
2045	580	7%	45,931	30%	1,524			915	11,064	2,654	121,880,107	696,642
2050	781	6%	61,654	30%	2,053	5.0%	5.9%	1,232	16,657	2,637	162,611,073	935,995
2015	6	17%	797	28%	14	0.1%	0.1%	8	1,390	4,287	3,416,739	12,985
2020	42	40%	11,950	28%	103	0.4%	0.5%	62	1,566	3,485	41,652,081	169,237
2025	145	24%	28,519	28%	356			214	2,339	3,037	86,618,782	418,664
2030	350	17%	49,758	30%	920	3.0%	3.4%	552	4,431	2,814	140,041,928	712,674
2035	628	11%	61,156	30%	1,651			991	8,680	2,677	161,595,632	931,683
2040	940	7%	75,455	30%	2,471	6.9%	7.8%	1,483	15,445	2,663	169,737,944	1,072,328
2045	1,276	6%	99,155	30%	3,354			2,012	24,930	2,640	188,006,650	1,198,116
2050	1,661	5%	131,143	30%	4,364	10.6%	12.6%	2,619	37,465	2,577	213,678,138	1,443,265

Appex.4: List of countries in IEA Regions

Regions	Countries
OECD Europe:	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom
Eastern Europe/Eurasia:	Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina,
Transition Economies:	Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, Serbia and Montenegro, the former Republic of Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Lativa, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus1), Malta1)
OECD North America:	Canada, Mexico, United States of America
OECD Pacific:	Australia, Japan, Korea (South), New Zealand
India:	India
Non-OECD Asia:	Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Macao, Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Vietnam, Vanuatu
Latin America:	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts-Nevis-Anguila, Saint Lucia, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela
Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
Africa:	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Marocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe
China:	People's Republic of China including Hong Kong

Appex.5: Abbreviations

ANEST	Associazione Nazionale Energia Solare Termodinamica (Italian association for STE industry
ACT	Australian Capital Territory
AfDB	African Development Bank
ARENA	Australian Renewable Energy Agency
ASTRI	Australian Solar Thermal Research Initiative
AUSTELA	Australian Solar Thermal Energy Association
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CEFC	Clean Energy Finance Corporation
CLFR	Compact Linear Fresnel Reflector
CNRS	French National Centre for Scientific Research
CO	Carbon monoxide
CO_2	Carbon-dioxide
CPI	Climate Policy Initiatives
CR	Central Receiver
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	Concentrated Solar Power
CTF	Clean Technology Fund
DCSP	Deutsche CSP – The German national STE association
DLR	German Aerospace Center
DNI	Direct Normal Irradiation
DOE	Department of Energy
DSG	Direct Steam Generation
EC	European Commission
EERA	European Energy Research Alliance
EIB	European Investment Bank
EII	European Industrial Initiative
ENTSO-E	European Network of Transmission System Operators
EOR	Enhanced Oil Recovery
EP	European Parliament
EPC	Engineering Procurement Construction
ERANET	European Research Area Network
ESIF	The European Structural and Investment Funds
ESTELA	European Solar Thermal Electricity Association
EU	European Union
EU ETS	EU emissions trading system
FIT	Feed-in-Tariff
FP6	The 6th Framework Programme for European Research and Technological Development from 2002 until 2006
FP7	The 7th Framework Programme for European Research and Technological Development from 2007 to 2013
GDP	Gross Domestic Product
GEF	Global Environment Facility
gge	Gasoline Gallon Equivalents
Gt	Gigatonne
$GtCO_2$	Gigatonnes CO_2
GUISMO	Guidelines CSP Performance Modeling
GWh	Giga Watt hour
H_2O	Water
HTF	Heat Transfer Fluid
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IEA-SHC	Solar Heating and Cooling Programme, created by IEA
IFIs	International Financial Institutions
IPO	Initial Public Offering
IRENA	The International Renewable Energy Agency
ISCC	Integrated Solar Combined Cycle
ITC	Federal Investment Tax Credit (US)
JI	Joint Implementation
JNNSM	Jawaharlal Nehru National Solar Mission
KfW	KfW Development Bank
KPI	Key Performance Indicator
kWh	Kilo Watt hour
kWp	Kilo Watt peak
LCOE	Levelised Cost of Electricity
LF	Linear Fresnel reflector
LWC	Levelised Water Cost
MASEN	Moroccan Agency for Solar Energy
MD	Membrane Distillation
MED	Multi-Effect Distillation
MENA	Middle East and North Africa

MOST	Ministry of Science and Technology (China)
MoU	Memorandum of Understanding
MS	Member States (EU)
MS	Molten Salt
MSF	Multi-Stage Flash
MSH	Molten Salt Heater
MSP	Mediterranean Solar Plan
MSP-PPI	Mediterranean Solar Plan-Project Preparation Initiative
MW_e	Mega Watt of electricity
MW_{th}	Mega Watt of thermal energy
NER 300	New Entrants' Reserve 300
NG	Natural gas
NIF	EU Neighbourhood Investment Facility
NREAP	National Renewable Energy Action Plan
NSFC	National Science Foundation of China
O&M	Operation and Maintenance
OCGT	Open Cycle Gas Turbine
OECD	The Organisation for Economic Cooperation and Development
OPEX	Operation expenditure
PCM	Phase Change Material
PD	Parabolic Dish
PPA	Power Purchase Agreement
PT	Parabolic Trough
PUA	Israeli Public Utilities Authority
PV	Photovoltaic
R&D	Research and Development
REFIT	Renewable Energy Feed-In-Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme in South Africa
RES	Renewable Energy Sources
RES Certificate	Renewable Energy Source Certificates
RET	Renewable energy target (Australia)
RO	Reverse Osmosis
ROI	Return on Investments
RPS	Renewable Portfolio Standards
SADC	Southern Africa Development Community
SASTELA	South Africa Solar Thermal and Electricity Association
SEGS	Solar Energy Generating Systems
SET-Plan	Strategic Energy Technology Plan
SIC	Central Interconnected System (Chile)
SING	Northern interconnected System (Chile)
SIP	Cross-ministerial Strategic Innovation Promotion Programme
SolarPACES	Solar Power And Chemical Energy Systems
STE	Solar Thermal Electricity
SWCC	Saline Water Conversion Corporation
syngas	Synthesis gas
TES	Thermal Energy Storage
TSO	Transmission System Operator
TWh	Terawatt hour
TYNDP	Ten-Year Network Development Plan
UAE	United Arab Emirates
UfM	Union for the Mediterranean
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	The United Nations Framework Convention on Climate Change
WB	World Bank
wt%	Percent in weight
YieldCo	Yield company

Image: Researcher tests the reflective properties of a parabolic mirror ©DLR/Miriam Ebert

Andasol ©ACS Cobra, TSK Flagsol and Schott/ Paul Langrock