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The Global Evaluation of Concentrating Solar Power Technology and its Investment Costs

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Abstract

Nowadays the world trends toward the non-conventional energy resources such as solar energy. The most advantage of solar energy compared to other forms of clean energy is that there is no environmental pollution. In this study, the current status, developments, future projections and applications of Concentrating Solar Power (CSP) technology in the world were presented. CSP technology, consisting of four main CSP technology families called as parabolic troughs, lineer frensel reflectors, solar towers and parabolic dishes was evaluated in terms of investment costs. As a result of this study, CSP is still under 1% within the total global installed renewable power capacity. However, a constant increase is observed in this percentage ratio day by day. Also, CSP has the advantage of relatively low cost thermal storage, compared to other renewable technologies.

Keywords: Concentrating solar power (CSP), Installed power capacity, Investment, Cost.

Yoğunlaştırılmış Güneş Enerjisi Teknolojisi ve Yatırım Maliyetlerinin Küresel Değerlendirilmesi

Özet

Bugünlerde dünya, güneş enerjisi gibi konvensiyonel olmayan enerji kaynaklarına doğru eğilim göstermektedir. Diğer enerji kaynaklarıyla karşılaştırıldığında güneş enerjisinin en önemli avantajı, herhangi bir çevresel kirlilik oluşturmamasıdır. Bu çalışmada, yoğunlaştırılmış güneş enerjisi teknolojisinin (YGE) dünyadaki mevcut durumu, gelişimi, gelecekteki durumu ve uygulamaları sunulmuştur. Parabolik oluk, fresnel aynaları, güneş kuleleri ve parabolik çanak adı verilen dört ana teknolojiden oluşan yoğunlaştırılmış güneş enerjisi teknolojisi yatırım maliyetleri açısından değerlendirilmiştir. Sonuçta, dünyadaki toplam yenilenebilir kurulu güç kapasitesi içerisinde yoğunlaştırılmış güneş enerjisi kurulu kapasite oranının halen %1'in altında kaldığı; ancak gün geçtikçe bu oranın arttığı gözlenmektedir. Buna ilaveten, YGE'nin diğer yenilenebilir teknolojilere kıyasla nispeten düşük maliyetli ısıl depolama avantajına sahip olduğu görülmektedir.

Anahtar Kelimeler: Yoğunlaştırılmış güneş enerjisi (YGE), Kurulu güç kapasitesi, Yatırım, Maliyet

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1. INTRODUCTION

In recent years, energy demand has been increasing by parallel of population growth, increase in living standards, rapid urbanization and industrialization in the world. Renewable energy technology developments have created new challenges for some renewable industries, and particularly for equipment manufacturers, leading to industry consolidation. Renewable Energy Sources (RES) are becoming more affordable for a broader range of consumers in developed and developing countries alike. Markets, manufacturing, and investment shifted increasingly towards developing countries during 2012.

World energy related carbon dioxide emissions rise from 31.2 billion metric tons in 2010 to 45,5 billion metric tons in 2040 according to the IEO2013 Reference case [1]. We should change our current status; we have to initiate an energy revolution in which low carbon energy technologies play a vital role. If we are to reach our greenhouse gas emission goals, we must promote broad deployment of energy efficiency, many types of renewable energy, carbon capture and storage, nuclear power and new transport technologies [2]. The results of several life-cycle assessment studies show that renewable energy technologies have lifecycle CO_2 emissions that are significantly lower than fossil based technologies and comparable to those of nuclear generation [3-6]**.** Every major country and sector of the economy must be involved. In addition, we must ensure that investment decisions taken now do not saddle us with suboptimal technologies in the long term [2]. Within the renewable energy technology especially Concentrating Solar Power (CSP) technology implantation is growing faster than any other renewable technology. It offers an integrated solution to the coming decade’s global problems, i.e., climate change and associated shortage of energy, water and food [7-16].

Although CSP currently requires higher capital investments than some other energy sources, it offers considerable long term benefits because of minimum fuel costs for backup/hybridisation. Moreover, initial investment costs are likely to fall steadily as plants get bigger, competition increases, equipment is mass produced, technology improves and the financial community gains confidence in CSP. In the near term, the economics of CSP will remain more favourable for peak and intermediate loads than for base loads [2].

In this study, an overview of CSP technology, current status, developments, future projections and applications in the world were emphasized. Next a detailed literature survey of CSP technology, consisting of four main CSP technology families called as parabolic troughs, lineer frensel reflectors, towers and parabolic dishes were conducted. The last section was focused on investment by technology and the investment cost of CSP included.

2. RENEWABLE ENERGY GROWTH

RES already play a major role in the energy mix in many countries around the world. In 2012, total renewable power capacity worldwide exceeded 1,470 GW in 2012, up about 8.5% from 2011 as shown in Table 1. Hydropower rose 3% to an estimated 990 GW, while other renewables grew 21.5% to exceed 480 GW. Globally, wind power accounted for about 39% of renewable power capacity added in 2012, followed by hydropower and solar PV, each accounting for approximately 26%.

The top countries for renewable power capacity at year’s end were China, the United States, Brazil, Canada, and Germany; the top countries for non-hydro capacity were China, the United States, and Germany, followed by Spain, Italy, and India. By region, the Brazil, Russia, India, China ans South Africa accounted for 36% of total global renewable power capacity and almost 27% of non-hydro renewable capacity. The EU had the most non-hydro capacity at the end of 2012, with approximately 44% of the global total.

RESs represent a rapidly rising share of energy supply in a growing number of countries and regions: In China, wind power generation increased more than generation from coal and passed nuclear power output for the first time. In the European Union, renewables accounted for almost 70% of additions to electric capacity in 2012, mostly from solar PV and wind power. In 2011, RESs met 20,6% of the region's electricity consumption and 13,4% of gross final energy consumption. In Germany, RESs accounted for 22,9% of electricity consumption (up from 20,5% in 2011), 10,4% of national heat use, and 12,6% of total final energy demand. The United States added more capacity from wind power than any other technology, and all RESs made up about half of total electric capacity additions during the year [17].

Table 1. Global installed renewable power capacity.

		2010	2011	2012
Renewable power capacity (total, not including hydro)	GW	315	395	480
Renewable power capacity (total, including hydro)	GW	1,25	1,355	1,47
Hydropower capacity (total)	GW	935	960	990
Bio-power generation	GWh	313	335	350
Solar PV capacity (total)	GW	40	71	100
Concentrating solar thermal power (total)	GW	1,1	1,6	2,5
Wind power capacity (total)	GW	198	238	283

3. CONCENTRATING SOLAR POWER

CSP systems concentrate solar energy 50 to 10,000 times to produce high-temperature thermal energy, which is used to produce electricity for distributed or bulk generation process applications. The basic concept of CSP is relatively simple: CSP devices concentrate energy from the sun's rays to heat a receiver to high temperatures. This heat is transformed first into mechanical energy and then into electricity. CSP also holds potential for producing other energy carriers (solar fuels). In CSP systems, highly reflective sun-tracking mirrors produce temperatures of 400°C to 800°C in the working fluid of a receiver. This heat is used in conventional heat engines (steam or gas turbines or Stirling engines) to produce electricity at solar-to-electric efficiencies for the system of up to 30%. Organized, large-scale development of solar collectors began in the United States in the mid-1970s under the Energy Research and Development Administration (ERDA) and continued with the establishment of the U.S. Department of Energy (DOE) in 1978. The first commercial plants began operating in California in the period 1984 to 1991. A drop in fossil fuel prices then led the federal and state governments to dismantle the policy framework that had supported the advancement of CSP. In 2006, the market reemerged in Spain and the United States, again in response to government measures such as feedin tariffs (Spain) and policies obliging utilities to obtain some share of power from renewables and from large solar in particular. As of early 2010, the global stock of CSP plants neared 1 GW capacity.

Projects now in development or under construction in more than a dozen countries (including China, India, Morocco, Spain and the United States) are expected to total 15 GW. Parabolic troughs account for the largest share of the current CSP market, but competing technologies are emerging. Some plants now incorporate thermal storage [2].

The CSP market continued to advance in 2012, with total global capacity up more than 60% to about 2,550 MW as seen in Figure 1 and Table 2. The market doubled relative to 2011, with Spain accounting for most of the 970 MW brought into operation. From the end of 2007 through 2012, total global capacity grew at an average annual rate approaching 43%. Figure 2 shows the growth of CSP electricity production by region. This projection takes into account a significant amount of electricity transportation.

Table 2. Concentrating Solar Power (CSP) Global Capacity and Additions, 2012.

Country	Total End-2011	Added 2012	Total End-2012
	(MW)		
Spain	999	951	1,950
United States	507	0	507
Algeria	25	0	25
Egypt	20	0	20
Morocco	20	0	20
Australia	3	9	12
Chile	0	10	10
Thailand	5	0	5
World Total	1,580	970	2,550

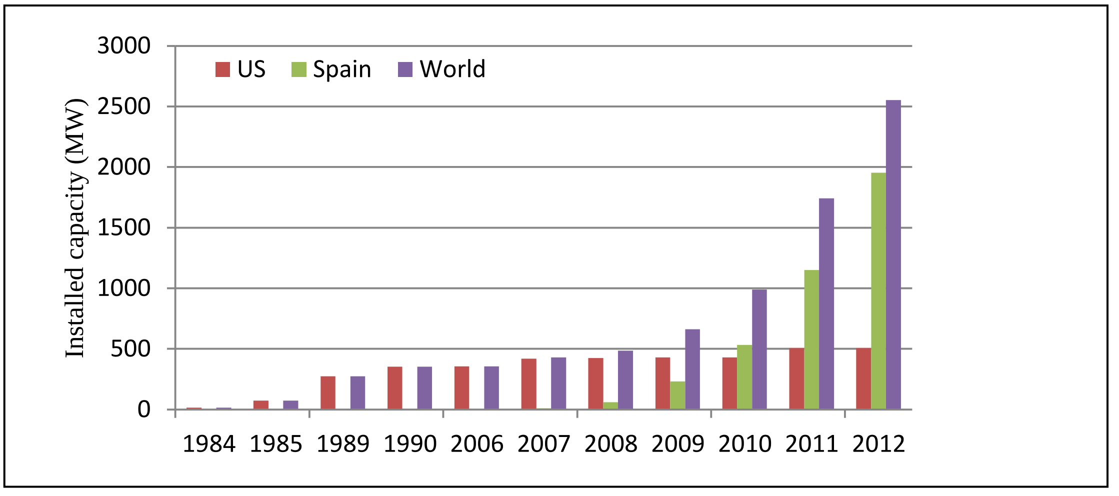

Figure 1. Concentrating solar thermal power global installed capacity, 1984-2012 [17].

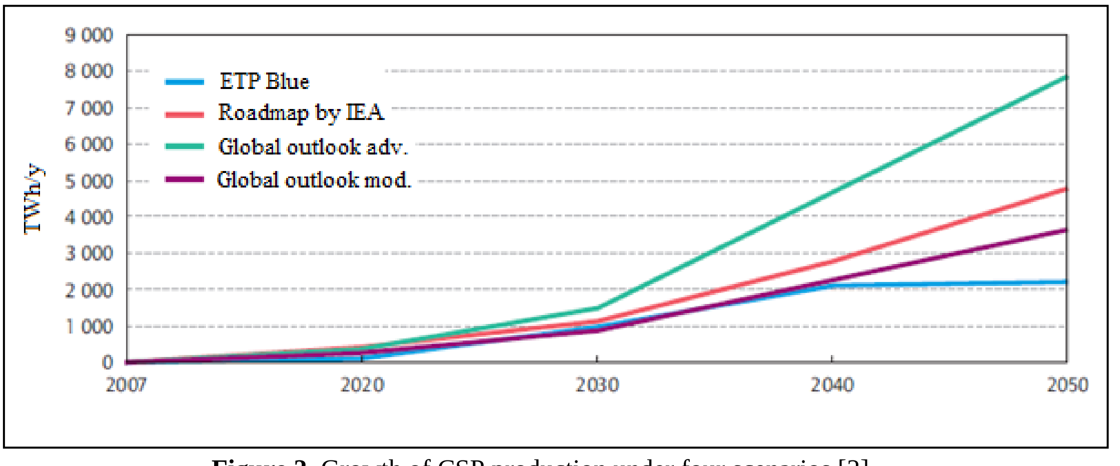

Figure 2. Growth of CSP production under four scenarios [2].

The growth of CSP electricity production by region according to four scenarios is shown in Figure 3. This projection takes into account a significant amount of electricity transportation. The roadmap put forward by [2] foresees a rapid expansion of CSP capacities in countries or regions with excellent direct normal irradiance (DNI), and computes its electricity production as progressively growing percentages of the overall consumption forecast in IEA climate friendly scenarios in these regions as shown in Table 3.

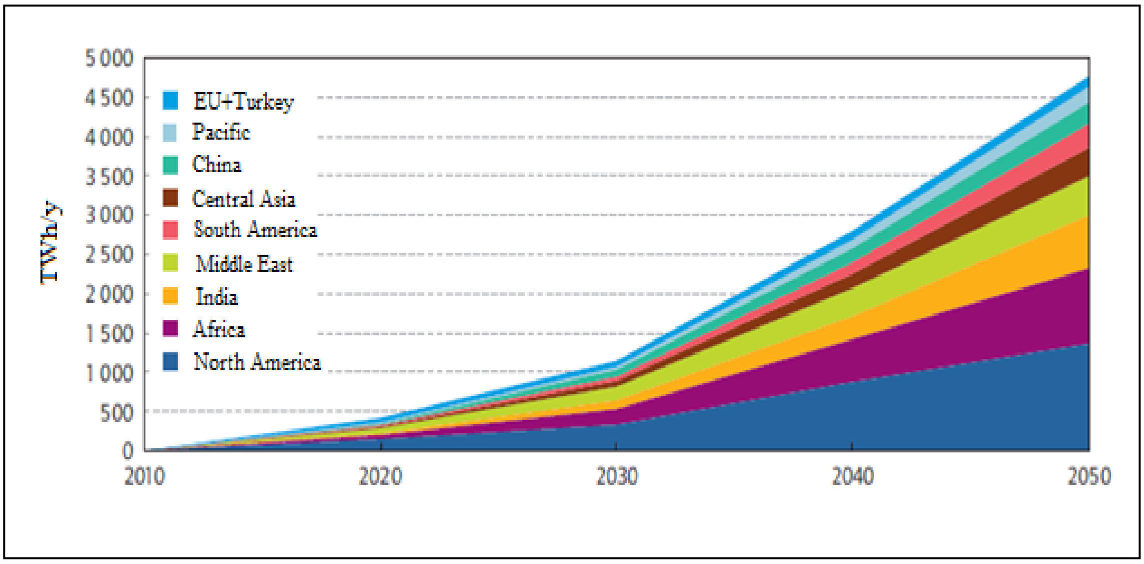

Figure 3. Growth of CSP production by region [2]

Table 3. Electricity from CSP plants as shares of total electricity consumption [2].

Countries	2020	2030	2040	2050
Australia, Central Asia,[4] Chile, India (Gujarat,Rajasthan), Mexico, Middle East, North Africa, Peru, South Africa, United States (Southwest)	5%	12%	30%	40%
United States (remainder)	3%	6%	15%	20%
Europe (mostly from imports), Turkey	3%	6%	10%	15%
Africa (remainder), Argentina, Brazil, India (remainder)	1%	5%	8%	15%
Indonesia (from imports)	0,5%	1,5%	3%	7%
China, Russia (from imports)	0,5%	1,5%	3%	4%

[4] Includes Afghanistan, Kazakhstan, Kyrgyzstan, Pakistan, Tajikistan, Turkmenistan, and Uzbekistan.

3.1. Current Technologies for Power Production

At present, there are four main CSP technology families called as parabolic troughs, lineer frensel reflectors, towers and parabolic dishes.

The schematic appearance of CSP technology is given in Figure 4.

3.1.1. Parabolic Troughs (Line focus, mobile receiver)

Parabolic trough collectors capable of generating temperatures greater than 500 ºC were initially developed for industrial process heat applications [18]. Parabolic trough systems consist of parallel rows of mirrors (reflectors) curved in one dimension to focus the sun's rays.

The mirror arrays can be more than 100 m long with the curved surface 5 m to 6 m across. Stainless steel pipes (absorber tubes) with a selective coating serve as the heat collectors. The coating is designed to allow pipes to absorb high levels of solar radiation while emitting very little infrared radiation. The pipes are insulated in an evacuated glass envelope. The reflectors and the absorber tubes move in tandem with the sun as it crosses the sky. All parabolic trough plants currently in commercial operation rely on synthetic oil as the fluid that transfers heat from collector pipes to heat exchangers, where water is preheated, evaporated and then superheated. The superheated steam runs a turbine, which drives a generator to produce electricity. After being cooled and condensed, the water returns to the heat exchangers.

Parabolic troughs are the most mature of the CSP technologies and form the bulk of current commercial plants. Most existing plants, however, have little or no thermal storage and rely on combustible fuel as a backup to firm capacity. For example, all CSP plants in Spain derive 12% to 15% of their annual electricity generation from burning natural gas. Some newer plants have significant thermal storage capacities.

3.1.2. Linear Fresnel Reflectors (Line focus, fixed receiver)

Linear Fresnel reflectors (LFRs) approximate the parabolic shape of trough systems but by using long rows of flat or slightly curved mirrors to reflect the sun's rays onto a downward-facing linear, fixed receiver. A more recent design, known as compact linear fresnel reflectors (CLFRs), uses two parallel receivers for each row of mirrors and thus needs less land than parabolic troughs to produce a given output. The main advantage of LFR systems is that their simple design of flexibly bent mirrors and fixed receivers requires lower investment costs and facilitates direct steam generation (DSG), thereby eliminating the need for and cost of heat transfer fluids and heat exchangers. LFR plants are, however, less efficient than troughs in converting solar energy to electricity and it is more difficult to incorporate storage capacity into their design [18].

3.1.3. Solar Towers (point focus, fixed receiver)

A number of experimental power tower systems and components have been field-tested around the world in the past 15 years, demonstrating the engineering feasibility and economic potential of the technology [18]. Solar towers, also known as central receiver systems, use hundreds or thousands of small reflectors (called heliostats) to concentrate the sun's rays on a central receiver placed atop afixed tower. Some commercial tower plants now in operation use DSG in the receiver; others use molten salts as both the heat transfer fluid and storage medium.

The concentrating power of the tower concept achieves very high temperatures, thereby increasing the efficiency at which heat is converted into electricity and reducing the cost of thermal storage. In addition, the concept is highly flexible; designers can choose from a wide variety of heliostats, receivers, transfer fluids and power blocks. Some plants have several towers that feed one power block.

3.1.4. Parabolic Dishes (point focus, mobile receiver)

Dish/engine technology is the oldest of the solar technologies, dating back to the 1800s when a number of companies demonstrated solar powered steam Rankine and Stirling-based systems [18]. Parabolic dishes concentrate the sun's rays at a focal point propped above the centre of the dish. The entire apparatus tracks the sun, with the dish and receiver moving in tandem. Most dishes have an independent engine/generator at the focal point. This design eliminates the need for a heat transfer fluid and for cooling water. Dishes offer the highest solar-to-electric conversion performance of any CSP system. Several features – the compact size, absence of cooling water, and low compatibility with thermal storage and hybridisation – put parabolic dishes in competition with PV modules, especially concentrating photovoltaics, as much as with other CSP technologies. Very large dishes, which have been proven compatible to thermal storage and fuel backup, are the exception. Promoters claim that mass production will allow dishes to compete with larger solar thermal systems.

Parabolic dishes are limited in size and each produces electricity independently, which means that hundreds or thousands of them would need to be co-located to create a large-scale plant. By contrast, other CSP designs can have capacities covering a very wide range, starting as low as 1 MW. The optimal size of troughs, LFR and towers, typically from 100 MW to 250 MW, depends on the efficiency of the power block [2].

4. CSP INVESTMENT

To reduce costs through economies of scale, the size of CSP projects is increasing. While plants in Spain have been limited to 50 MW because of regulatory restrictions, new projects in the United States and elsewhere are in the 150–500 MW range and even larger. Increasing size helps to reduce costs through economies of scale, but appropriate plant size also depends on technology [19]. Some projects are also integrating dry cooling solutions that significantly reduce water demand, an advancement that is important in the arid, sunny regions where CSP offers the greatest potential [19].

CSP prices have declined significantly in recent years, for systems with and without thermal storage [20] as shown in Table 5. Although subject to changes in commodity prices, the major components of CSP facilities (including aluminum, concrete, glass, and steel) are generally not in tight supply [21]. The economic valuation of CSP plants with storage has been discussed more frequently in recent years. From a technical point about CSP plants, García et al. [23] developed a detailed model to show the technical flows of energy and to facilitate the prediction of the electrical output of a CSP storage plant. Morin [24] developed an optimization tool for CSP plants based on the levelized cost of electricity (LCOE). Table 5 shows a summary of the CSP technologies and its characteristics and costs.

Parabolic trough is the most mature technology, and it continues to dominate the market, representing about 95% of facilities in operation at the end of 2011, and 75% of plants under construction by mid-2012. Towers/central receivers are becoming more common and accounted for 18% of plants under construction by mid-year, followed by Fresnel (6%) and parabolic dish technologies, which are still under development. Status of CSP Technologies of the countries is increasing gradually. Spain continued to lead the world for both deployment and total capacity of CSP, adding 950 MW to increase operating capacity by 95% to a total of 1,950 MW. As in the global market, parabolic trough technology dominates in Spain, but 2012 saw completion of the world's first commercial Fresnel plant.

The world's first hybrid CSP - biomass plant also came on line. However, policy changes in 2012 and early 2013 including a moratorium on new construction, retroactive feed-in tariff changes, and a tax on all electricity producers pose new challenges to Spain's industry.

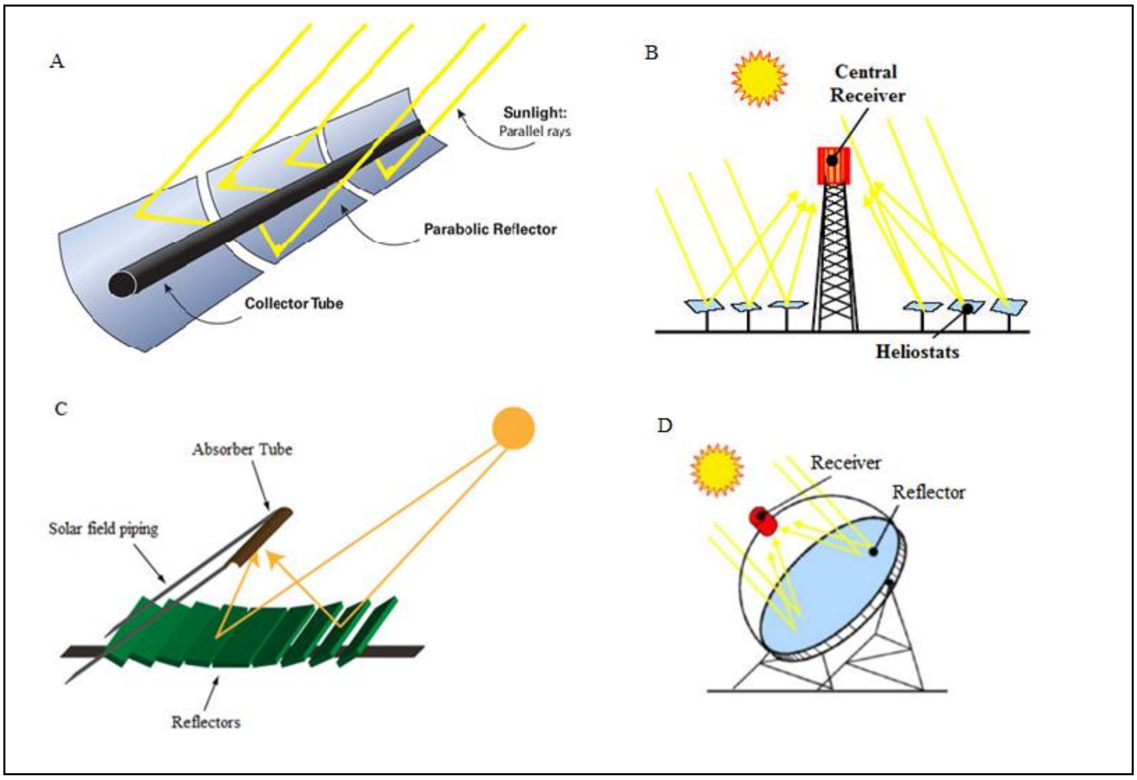

Figure 4. Basic concept of four CSP families: A) parabolic trough B) central receiver C) lineer frensel D) parabolic dish.

Table 5. Status of CSP Technologies: characteristics and costs.

Technology	Typical Characteristics	Capital Costs (USD/kW)	Typical Energy Costs (LCOE-U.S.cents/kWh)
Power Generation			
Concentrating solar thermal power	Types: parabolic trough, Fresnel, tower, dish Plant size:50-250 MW (trough); 20-250 MW(tower); 10-100 MW (Fresnel) Capacity factor: 20-40% (no storage); 35-75% (with storage)	Trough, no storage: 4,000-7,300 (OECD); 3,100-4,050 (non-OECD) Trough, 6 hours storage: 7,100-9,800 Tower, 6-15 hours storage: 6,300-10,500	Trough and Fresnel: 19-38 (no storage); 17-37 (6 h. Storage) Tower: 20-29 (6-7 hours storage); 12-15 (12-15 hours storage)

The United States remained the second largest market in terms of total capacity, ending the year with 507 MW in operation. As in 2011, no new capacity came on line, but just over 1,300 MW was under construction at the close of 2012, all due to begin operation in the next two years. By year's end, the Ivanpah facility under construction in California's Mojave Desert was 75% complete; once on line, this 392 MW power tower plant will be the world's largest CSP facility and is expected to provide enough electricity for 140,000 U.S. homes. The Solana plant (280 MW), which was 80% constructed by year's end, will be the world's biggest parabolic trough plant upon completion. Elsewhere, more than 100 MW of capacity was operating at year's end, with most of this in North Africa. Some relatively small projects came on line in 2012: Australia added 9 MW to its Liddell Power Station, where solar thermal feeds a coal-fired power plant, and Chile became home to the first CSP plant in South America, a 10 MW facility to provide process heat for a mining company. Other countries with existing CSP that did not add capacity in 2012 include Algeria (25 MW), Egypt (20 MW), and Morocco (20 MW) all with solar fields included in hybrid solar-gas plants and Thailand (5 MW). Several additional countries had small pilot plants in operation, including China, France, Germany, India, Israel, Italy, and South Korea. The United Arab Emirates (UAE) joined the list of countries with CSP in March 2013, when Shams 1 (100 MW) the first full-size pure CSP plant in the Middle East-North Africa (MENA) region began operation.

Interest in CSP is on the rise, particularly in developing countries, with investment spreading across Africa, the Middle East, Asia, and Latin America. One of the most active markets in 2012 was South Africa, where construction began on a 50 MW solar power tower and a 100 MW trough plant. Namibia announced plans for a CSP plant by 2015. Several development banks committed funds for projects planned in the MENA region, where ambitious targets could result in more than 1 GW of new capacity in North Africa in the next few years for domestic use and export. Saudi Arabia and the United Arab Emirates plan to install CSP to meet rapidly growing energy demand and reserve more oil for export, and Jordan is evaluating possible projects; in early 2013, Saudi Arabia launched a competitive bidding process that includes significant CSP capacity.

India planned to complete 500 MW by the end of 2013, but only one-third might be ready on time and some projects have been cancelled; phase two of the National Solar Mission has been delayed. In Australia, a 44 MW plant is under construction to feed steam to an existing coal facility. Many other countries, including Argentina, Chile and Mexico in Latin America, several countries in Europe, Israel, and China have projects under construction or have indicated intentions to install CSP plants.

4.1. Investment by Technology

In 2012, solar power was the leading sector by far in terms of money committed; at USD 140.4 billion, solar accounted for more than 57% of total new investment in renewable energy. Wind power was second with USD 80,3 billion, representing almost 33%. The remaining 10% of total new investment was made up of bio-power and waste-to-energy (USD 8,6 billion), small-scale hydropower (<50 MW) (USD 7.8 billion), biofuels (USD 5 billion), geothermal power (USD 2 billion), and ocean energy (USD 0.3 billion). With the exception of small-scale hydropower and ocean energy, investment in 2012 declined relative to 2011 in all renewable sectors tracked by Bloomberg New Energy Finance (BNEF) as shown in Figure 5. Approximately 96% of investment in the solar sector went to solar PV (USD 135,1), with the remaining share going to concentrating solar thermal power (CSP) (USD 5,3 billion). Solar investment dropped in 2012, due primarily to a slump in financing of CSP projects in Spain and the United States (down USD 14 billion from 2011), as well as to sharply lower PV system prices.

Solar power investment continued to be dominated by developed economies, which together accounted for 63% of the total (down from 80% in 2011). Germany, the United States, Japan, and Italy were four of the five largest investors in solar

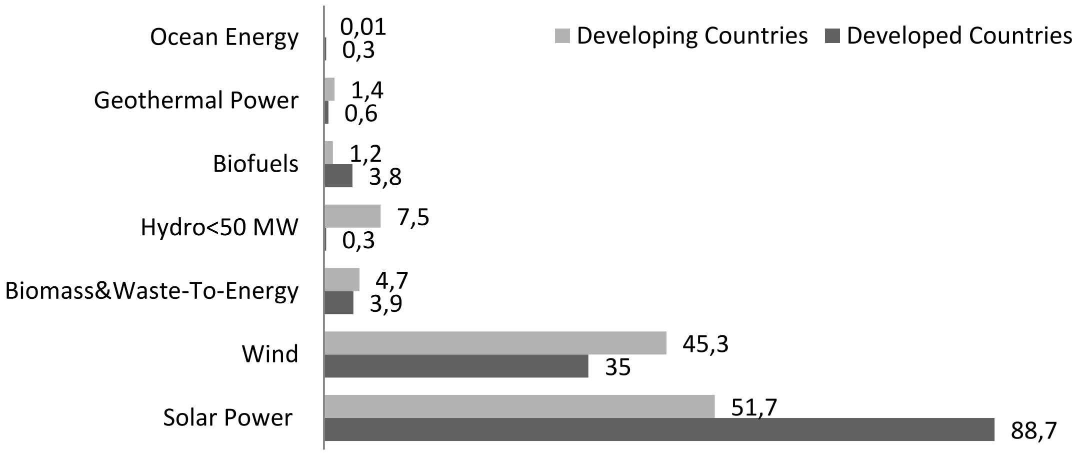

Figure 5. Global new investment in renewable energy by technology, developed and developing countries, 2012 [17].

power capacity in 2012. Even so, China accounted for the largest share, at 22% of global investment. The USD 31,3 billion that China invested in 2012 was up sharply from USD 17.8 billion in 2011. Overall, solar power investment in developing countries rocketed up 72% to USD 51.7 billion, while investment in developed markets fell 31% to USD 88,7 billion.

Aside from solar energy, developed countries maintained a lead only in biofuels and the embryonic sector of ocean energy. In all other technologies including wind power, small-scale hydro, biomass and waste-to-energy, and geothermal power developing economies were at the forefront. This represents a dramatic break from previous years; in 2011, developing countries were the major investors only in small-scale hydropower.

Detailed statistics are not available for solar water heating technologies or large hydropower projects over 50 MW in size. It is estimated that about 55 GWth of solar collector capacity was added during 2012, with about 80% of this capacity installed in China. The value of this investment is hard to estimate, given the wide range of prices paid for different solar collector technologies, but it is likely to have exceeded USD 10 billion.

Investment in large hydropower projects of more than 50 MW continued to be significant in 2012, exceeding all other renewable energy sectors except wind and solar power. Translating capacity additions into asset finance dollars per year is not straightforward because the average project takes four years to build, but it is estimated that asset financing for large hydro projects commissioned in 2012 totalled at least USD 33 billion over a fifth of the USD 148,5 billion value of asset finance excluding large hydro.

4.2. Investment Costs

State of the art trough plants, current investment costs are USD 4.2/W to USD 8.4/W depending on labour and land costs, technologies, the amount and distribution of DNI and the amount of storage and the size of the solar field. Plants without storage that benefit from excellent DNI are on the low side of the investment cost range; plants with large storage and a higher load factor but at locations with lower DNI (around 2000 kWh/m^2/year) are on the high side. Investment costs of a 50 MW trough plant with 7-hour storage are given in Figure 6. Figure 6 breaks down investment costs of a trough plant with storage under Spanish skies. These investments costs are slightly higher than those of PV devices, but CSP

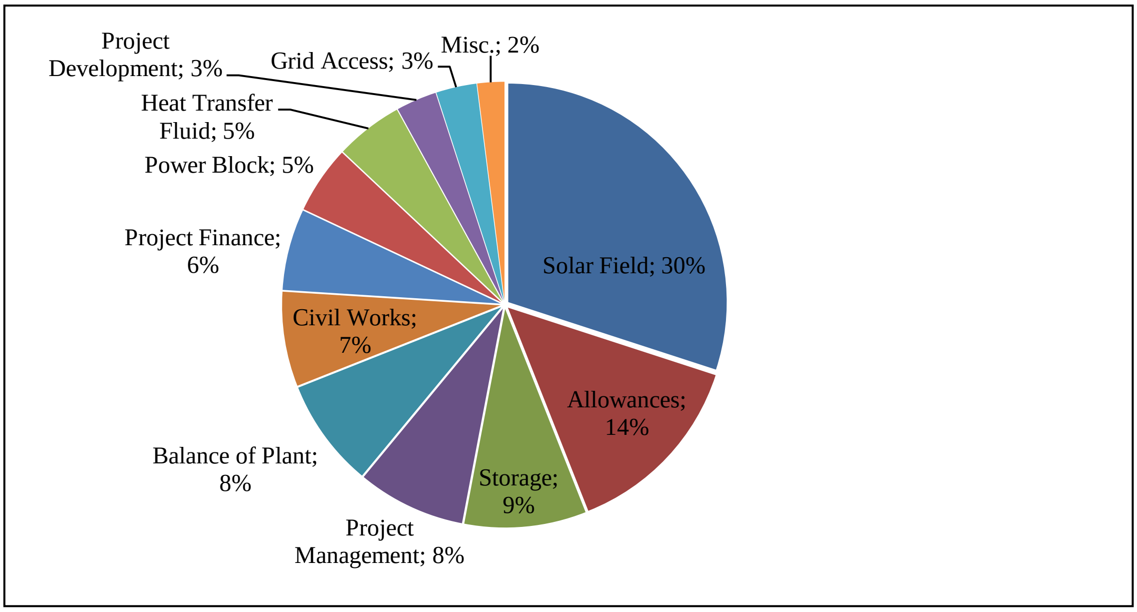

Figure 6. Investment costs of a 50 MW trough plant with 7-hour storage.

plants have a greater energy output per MW capacity. Investment costs per watt are expected to decrease for larger trough plants, going down by 12% when moving from 50 MW to 100 MW, and by about 20% when scaling up to 200 MW. Costs associated with power blocks, balance of plant and grid connection are expected to drop by 20% to 25% as plant capacity doubles. Investment costs are also likely to be driven down by increased competition among technology providers, mass production of components and greater experience in the financial community of investing in CSP projects. Investment costs for trough plants could fall by 10% to 20% if DSG were implemented, which allows higher working temperatures and better efficiencies. Turbine manufacturers will need to develop effective power blocks for the CSP industry. In total, investment costs have the potential to be reduced by 30% to 40% in the next decade. For solar towers, investment costs are more difficult to estimate, but are generally higher than for trough plants. However, increasing efficiency from 15% to 25% will allow a 40% reduction in investment in solar-specific parts of the plants, or 20% of overall investment costs. The recent trend toward numerous mass-produced, small, flat mirrors promises to bring costs down further, as the problems of wind resistance and precision in pointing are resolved using computers.

As the solar tower industry rapidly matures, investment costs could fall by 40% to 75%. The costs of CSP electricity should go down even more. Some experts see a greater potential in developing countries for local fabrication of towers than of troughs, leading to lower costs in emerging economies.

5. CONCLUSIONS

CSP is a technology that is being developed on a global scale. CSP has the advantage of relatively low-cost thermal storage, compared to other renewable technologies and thus has the capability to provide dispatchable power. Concentrating solar power technology has been lately attracting a lot of attention. A sustainable effort is underway to develop its technology. Tough it has been reached the commercial maturity, there are still a lot of activities at different levels to improve its performance. Some experts have expressed concern that the window of opportunity for CSP is closing as solar PV prices continue to fall and utilities become more familiar with PV. However, CSP has a number of attributes that are expected to remain attractive to utilities. These include CSP's ability to provide thermal storage and thus to be dispatchable and to enable an increased share of variable renewables, and its ability to provide low cost steam for existing power plants (hybridisation). In addition, CSP has the potential to provide heating and cooling for industrial processes and desalination.

6. REFERENCES

1. International Energy Outlook 2013, U.S. Energy Information Administration, DOE/EIA-0484, 2013, www.eia.gov/ieo/.

2. Technology Roadmap Concentrating Solar Power International Energy Agency, OECD/IEA, 2010.

3. Devabhaktuni V., Alam, M., Depuru, SSSR., Green, RC., Nims, Ds., and Near, C., Solar energy: Trends and Enabling Technologies, Renewable and Sustainable Energy Reviews 19 555–564, 2013.

4. Cherubini, F., Bird, ND., Cowie, A. Jungmeier,. Energy- and Greenhouse Gas-Based LCA of Biofuel and Bioenergy Systems: Key Issues, Ranges and Recommendations, Resources, Conservation and Recycling, Vol. 53, ElsevierAmsterdam, pp. 434–447, 2009.

5. NEEDS (New Energy Externalities Developments for Sustainability Project) (2009), Final Outcomes, www.needs-project.org.

6. POST (Parliamentary Office of Science and Technology) (2006), Carbon Footprint of Electricity Generation, Postnote N. 268, www.parliament.uk/documents/post/postpn268 . pdf.

7. World Energy Outlook. Executive Summary; 2012, www.worldenergyout look.org/.

8. An Overview of the Desertec Concept. Red paper, 3rd ed.

9. Himri YY, Malik S, Boudghene Stambouli A, Himri S, Draoui B., Review and Use of the Algerian Renewable Energy for Sustainable Development. Renewable and Sustainable Energy Reviews 2009;13:1584–91.

10. Antonis, T., Tomtsia T, Hatziargyriou ND, Poullikkas A, Malamatenios Ch, Giakoumelos E, et al. Review of Best Practices of Solar Electricity Resources Applications in Selected Middle East and North Africa (MENA) countries. Renewable and Sustainable Energy Reviews 2011;15:2838–49.

11. Abidin Ab, KMZ., Yaaseen, R., and Mariah. AN., Prospective Scenarios for the Full Solar Energy Development in Malaysia. Renewable and Sustainable Energy Reviews 2010;14:3023–31.

12. Manuel, RA., and Eduardo. Z., Concentrating Solar Thermal Power. Energy Conversion (19). LLC: Taylor & Francis Group; 2007.

13. El-Ghonemy AMK. Future Sustainable Water Desalination Technologies for the Saudi Arabia: a review. Renewable and Sustainable Energy Reviews 2012;16:6566-97.

14. Chennan, L., Yogi, G., and Elias, S., Solar Assisted Sea Water Desalination: A Review. Renewable and Sustainable Energy Reviews 2013;19:136–63.

15. www.cspworld.com. (accessed 2013)

16. Behar, O., Khellaf, A., and Mohammedi, K., Review of Studies on Central Receiver Solar Thermal Power Plants, Renewable and Sustainable Energy Reviews 23 (2013) 12-39.

17. Renewables 2013 "Global Status Report" Ren 21 Renewable Energy Policy Network for the 21st century.

18. Power Technologies Energy Data Bank, Fourth Edition, National Renewable Energy Laboratory (NREL), August 2006, NREL/TP-620-39728.

19. Bank Sarasin, Solar Industry: Survival of the Fittest in the Fiercely Competitive Marketplace (Basel, Switzerland: November 2011); Protermosolar, op. cit. note 7.

20. Macknick, J., Newmark, R., and Turchi, C., Water Consumption Impacts of Renewable Technologies: The Case of CSP, presentation at AWRA 2011 Spring Specialty Conference, Baltimore, MD, 18–20 April 2011

21. Morse, F., Abengoa Solar, Washington, DC, personal communication with REN21, March 2013.

22. Hashem, H., "Grid Parity Solar: CSP Gains on

PV," CSP Today, 25 May 2012, at http://social.csptoday.com.

23. Llorente García, I., Álvarez, J. L., and Blanco D., Performance Model for Parabolic Trough Solar Thermal Power Plants with Thermal Storage: Comparison to Operating Plant Data. Solar Energy 85: 2443-2460, 2011.

24. Morin, G., Techno-economic Design Optimization of Solar Thermal Power Plants, Dissertation, University of Braunschweig, Fraunhofer Verlag, 2011.