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Review Article

Concentrated Solar Power Plants with Molten Salt Storage: Economic Aspects and Perspectives in the European Union

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Concentrated solar power plants belong to the category of clean sources of renewable energy. The paper discusses the possibilities for the use of molten salts as storage in modern CSP plants. Besides increasing efficiency, it may also shift their area of application: thanks to increased controllability, they may now be used not only to cover baseload but also as more agile, dispatchable generators. Both technological and economic aspects are presented, with focus on the European energy sector and EU legislation. General characteristics for CSP plants, especially with molten salt storage, are discussed. Perspectives for their development, first of all in economic aspects, are considered.

1. Introduction

The European energy sector is going through a transformation caused by the commitments to reduce CO_2 emission, the increasing penetration of renewable sources (RES) [1], and the need for reliable and reasonably priced energy supplies. The new structure of the European energy sector has been described in the "Energy Union" project, executed by the European Commission in 2015 [2]. It combines the European energy policy with the guidelines of the climate policy related to emission reduction and decarbonisation of the energy sector, as well as with the implementation of the Internal Energy Market (IEM) [3]. It is also a foundation for a future-proof and low-emission energy system with significant RES penetration and flexible supply and demand of the energy market. The European concept of the energy market gives special attention to energy efficiency [4, 5] and supply management. It emphasises the role of the European Networks of Transmission System Operators for Electricity (ENTSO-E) and the Agency for the Cooperation of Energy Regulators (ACER), as well as the need for cooperation between the member states. It also focuses on the issue of market liquidity and demand management and points out the role of demand aggregates [6]. The demand for energy in the EU has been decreasing since 2006 [7]. However, the growing percentage of renewable sources in energy generation, especially those whose operation is not continuous and predictable, necessitates the storage of energy. Storage solutions [8–10] will therefore play an important role in many sectors of the economy (sustaining intermittent production, electric vehicles, defence, etc.) and will have a strategic meaning for Europe and its industry [11].

Recent years have seen an increase in the percentage of energy from renewable energy sources (RES), particularly from biomass combustion and wind farms [12], and a drop in fossil fuel energy generation [13]. Large-scale development of renewable energy is a strategic challenge [14]. While it is true that it will help reduce the use of fossil fuels, it does require big storage capacity (installations allowing long-term energy storage, not just until the next day but rather until the next season). Storage is an issue of prime importance to the transformation of the power industry into one that is largely based on renewable energy sources.

Electrical energy stimulates the economic and civilisational development of the world. The level and dynamics of electricity used in individual countries or regions depend mainly on the population, the economic and civilisational development, and the structure and efficiency of energy use [15]. The main determinants of the electric energy demand are economic development measured through Gross Domestic Product (GDP) dynamics, the level of energy consumption per capita, and changes in the energy efficiency in consecutive periods. Historical data confirms that economic growth is often connected with an increase in energy demand, but the correlation between GDP increase and the demand for energy in individual countries may become weaker in the future because economies are heading toward solutions which are more energy-efficient. A steady increase in energy consumption is observed in stable periods, and the energy consumption drops coincide with the 1989-1992 and 2009 economic crises.

Management and control of energy transmission and distribution at an industrial scale has its own specificity. On the one hand, power demand is significantly variable. On the other hand, currently, possibilities of electrical energy storage are strongly limited; thus, means of storing large volumes of energy in other forms have been studied intensively. Such solutions enable us to control the energy supply and optimise the economic aspects of power plant operations and energy market parameters.

This paper analyses molten salt power plants as energy reservoirs that enable us to achieve the specified goals regarding flexible energy control and storage. The topic is crucial because, at the present stage of power industry development, molten salt power plants are pioneering solutions promoted mainly in Spain and the US. Molten salt reservoirs have high storage efficiency (above 90%), but the efficiency of the energy transformation from heat to electricity is much lower at about 50%, which is a significant disadvantage. The presented studies have been conducted in the framework of the PreFlexMS European Project.

2. Motivations

The EU environmental and climate objectives require the European countries to introduce changes concerning power generation. Instruments supporting the renewable power industry in the form of subsidies and privileged access to energy infrastructure change the energy mix of the European Union [13]. Unfortunately, the development of renewable technologies such as wind and photovoltaic power plants is not coupled with an increase in the energy storage capacity or activities which optimise the operation of power systems. Depending on needs and limitations, energy can be stored in different forms (electric energy, gas, hydrogen, heat and cold, and mechanical storage) in the vicinity of energy production facilities, in energy systems, or close to the place where it is to be consumed. Although there are numerous solutions, it seems that the possibilities to introduce new elements are still limited. Moreover, due to their high costs, the new, more flexible technologies such as lithium-ion batteries or power-to-gas transformation do not seem ready for large-scale use.

The situation in the energy market makes the entities which aim to cover the deficiencies in wind and photovoltaic generation or cater for peak consumption ineffective. Increased green energy supply causes the conventional energy sources with high generation costs to lose profitability. However, even unprofitable generating entities are crucial to energy security because 90% of wind or solar energy require full backup. Energy deficits in times of slowdowns in renewable generation can be observed in many EU countries. These problems are intensified by unplanned transborder flow of energy from the RES of neighbouring countries. The ongoing changes bring hazards for the safety and stability of power systems [16]. Hence, the issue of energy storage is discussed in many EU countries, including Poland.

The biggest challenge hampering the economic optimisation of power generators of any type is the lack of ability to react to sudden changes in demand. Depending on the technology, the following factors contribute to this state:

(i) Unpredictability and little controllability of factors affecting the generation (such as the weather)

(ii) Lack of headroom with regard to power generator capabilities (as it is unfeasible to deploy generators with much power reserve)

(iii) Lack of agility with regard to controlling the power generation process (usually reflected by long startup and shutdown times) [17]

The approaches used to remedy these problems may include the following:

(i) Deployment of energy storage devices to bridge the temporal gap between generation and consumption of energy

(ii) Implementation of modern technologies to improve the agility by reducing startup and shutdown times

(iii) Utilization of prediction and simulation methods both to assess the requirements for power generation and storage capacity during the design phase and to optimise the dispatch plan during operation

3. Molten Salt Power Plants

3.1. General Characteristics. A concentrated solar power plant (see Figure 1 for details) converts solar energy to electricity. It is based on focusing solar energy from a large area onto a small receiver using concentrators such as mirrors or lenses. Light is converted to heat which, in turn, drives steam and power generators to provide electricity.

Various technologies are in use regarding each of the steps of light-electricity conversion. A solar field is composed of reflectors concentrating light onto a receiver. They are usually equipped with trackers which follow the sun position to maximise the amount of harvested energy. The receiver can be integrated with the reflectors (which is the case with

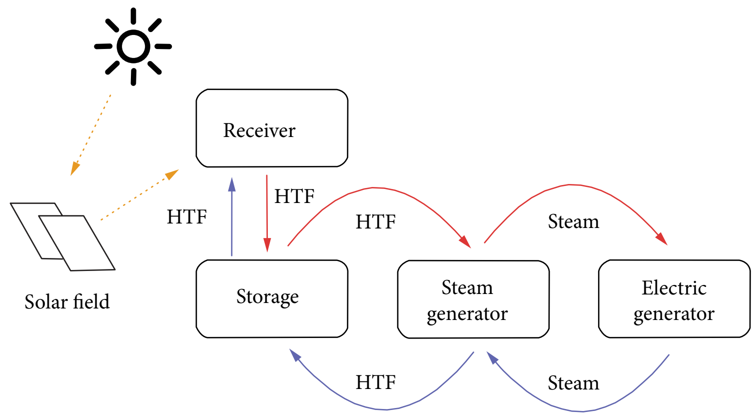

Figure 1: Functional schema of a concentrated solar power (CSP) plant.

parabolic trough, enclosed trough, and Fresnel plants), or it can stand alone (e.g., in solar towers). The latter approach seems to be the most promising [18]. The receiver distributes the gathered heat with the use of a heat transfer fluid (HTF). Energy storage is introduced in order to smooth power output. It also lets us release energy in a timed and controlled manner, especially if none is being generated. Therefore, it enables prolonged, after-sunset operations. Next, the HTF is delivered to the steam generator. Finally, the steam reaches an electric generator which produces electricity.

Molten salt CSPs seem to be the most promising regarding both economic and technical factors. In such a plant, molten salt is used as the HTF, hence the name. The technology was developed in the 90s by the Sandia National Laboratories [18]. Molten salt is more economically viable than other HTFs, such as mineral oil [19, 20].

Currently, molten salt CSP plants are designed as baseload plants, e.g., plants which generate electricity to constantly satisfy minimum demand. Therefore, they replicate the characteristics of nuclear or coal plants. This is due to using energy storage in the form of tanks with heated molten salt. Discharging stored energy, however, does not have to follow the baseload strategy. It can be more dynamic to satisfy a particular demand that is unaccounted for. However, it needs to be stressed that such actions have to be supported by a proven predictive model of the plant itself to identify if such additional dynamic discharge is economically feasible. This is especially important, as only a limited amount of energy can be gathered and successfully stored, depending on insolation. Thus, weather forecasting, indicating the amount of energy that can be harvested, plays a major role in such a case.

While evolving, state-of-the-art CSP technologies have to comply with

(i) dynamic tariffs and the tariff bidding process introduced by regulators

(ii) being a *stable-in-time* power source stimulated by incentives and penalties to match electricity demand from grid operators

(iii) flexibility to adjust plant operations as needed, to react to changing market conditions

Contemporary CSP is mainly limited by two factors:

(i) Plant hardware is designed for baseload operations, having slow ramp-up time

(ii) Simplistic dispatch strategies, accumulating energy during the day and managing storage to ensure delivery at night

The first one makes the plant incapable to respond to demand fluctuations. The second one prevents energy dispatch management, reducing its flexibility. Thus, these factors lead to corresponding challenges that need to be addressed, which are:

(1) to improve the flexibility of a CSP with molten salt energy storage

(2) to improve the predictability and provide not only baseload operations but also on-demand supply driven by market economics

One of the hardware culprits hampering flexibility is the steam generator. It usually consists of four heat exchangers: a preheater, an evaporator with a steam drum, a superheater, and finally a reheater. The preheater heats up feedwater just below the boiling point. The evaporator and the steam drum boil water and separate moisture from steam. The superheater heats up dry steam to superheated conditions, and the reheater reheats the steam exiting the turbine. Currently, there are several kinds of steam generators, including kettle or drum types. They share a common limitation which is a slow ramp-up rate of 2-3 centigrade per minute. It is one of the most limiting factors, preventing using CSP in a flexible manner. Replacing this technology with the once-through approach allows achieving supercritical steam conditions which, coupled with supercritical turbines, is more efficient and increases flexibility. That makes it ideal for CSP applications requiring rapid load changes [17]. In general, a once-through steam generator (OTSG) is characterized by compact design, minimal interconnecting pipework, fast startups, load variations, and efficient part-load operations. Thus, upgrading the steam generator to OTSG addresses challenge #1, mitigating hardware limitations.

Providing on-demand supply, challenge #2, requires applying coupled storage capacity prediction and dispatch optimisation. The storage capacity prediction is solely based on weather forecast. However, depending on the demand, how much thermal energy is stored compared with immediate electricity generation has to be balanced. On the one hand, there is the weather forecast and on the other, the dispatch strategy and optimisations based on current demand and the electricity market. In order to make it work, there is a need for an accurate plant model covering the solar field, receiver, storage, steam generator, and electric generator. It enables decision-making providing the balance, thus making the plant more predictable and capable of reacting to energy market fluctuations. There are several papers that tackle the technological and economic benefits [21–24].

3.2. Economic Specificity. On 27 September 2001, the European Parliament and the Council of the European Union established a directive on the promotion of electricity produced from renewable energy sources [25]. Its main goal is to promote renewable energy sources and create a basis for a future community framework. It was updated in 2009 [26].

The European Union aims to have 20% of consumed electricity coming from renewable sources by 2020. A renewable source is defined as a nonfossil one, which includes wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogases. The directive sets mandatory targets for the member states which range from 10% (Malta) to 49% (Sweden). Furthermore, it also pushes 20% energy savings to be achieved by 2020. It also provides basis for administrative procedures enabling integration of renewable energy sources in buildings, access to an electricity grid, and market cooperation mechanisms.

According to Article 3 of 2009/28/EC (see The European Parliament and the Council [26] for more details) the member states "shall ensure that the share of energy from renewable sources (…) in gross final consumption of 2020 is at least its national overall target." The actual targets are provided as Annex I. In order to achieve these targets, each member state should promote energy savings and energy efficiency.

It needs to be pointed out that the targets regard gross final consumption. Such a definition makes involvement of all energy market and distribution participants necessary. It includes consumers, prosumers, distribution system operators, transmission system operators, producers, and sellers.

Furthermore, according to Article 4, member states need to formulate national renewable energy action plans which regard the forecast of estimated excess production of energy from renewable sources and the estimated demand for such energy. It allows transferring such energy to other member states to respond to their demand if it cannot be satisfied by domestic production. Similarly, cooperation among member states or member states and other countries on all types of joint projects regarding the production of electricity from renewable energy sources, which may involve private operators, is encouraged.

Table 1: Total installed renewable power (GW), broken down by technology [27].

Technology	Start 2004	2013	2014	2017
Hydropower	715	1,018	1,055	1,114
Biopower	<36	88	93	122
Geothermal power	8.9	12.1	12.8	12.8
Solar PV	2.6	138	177	402
CSP	**0.4**	**3.4**	**4.4**	**4.9**
Wind power	48	319	370	539
Total	800	1,578	1,712	2,195

Member states shall also take appropriate actions, according to Article 16, to develop the transmission and distribution grid infrastructure. This includes intelligent networks and storage facilities. It is to support energy generation from renewable sources as well as its distribution and transmission to obtain interconnection among member states and between member states and other countries. Thus, it mandates focusing on interoperability and the exchange of data, and not only energy, among all involved parties and systems.

While dispatching electricity generation installations, priority must be given to installations using renewable energy sources.

According to the most recent report on renewable energy sources by REN21 [27], the CSP market share remains less significant than that of other renewable technologies but sustains constant growth in recent years, with 2018 seeing the total capacity at 4.9 GW.

An overview of the current trends in installed renewable power is provided in Table 1.

In spite of the growing trends, CSP is in tight competition with PV technologies which, as of 2015, constitute 40 times more installed power.

Fresnel CSP plants range from 10 to 100 MW, while trough and tower installations can provide as much as 250 MW of electrical power. Energy costs of tower CSP plants amount to 0.11-0.145 EUR/kWh, and they grow to 17-38 for trough and Fresnel installations [27]. The efforts in reducing energy costs have mostly focused on increasing plant capacity, with larger plants showing twice as much efficiency [28].

A breakdown of the cost of electricity production (LCOE) for CSP is presented in [29]; it suggests that the CSP technology is not yet competitive in the global renewable energy market. This supports the aforementioned hypothesis that the registered growth is due to local incentives and may only be significant in the short term. Despite that, the International Energy Agency expects CSP to provide over 11% of global electricity by 2050. In the shorter term, the installed capacity is expected to exceed 100 GW by 2020 and 300 GW by 2030 [29].

It needs to be pointed out that it looks optimistic in the light of the data from the same source which states that the

CSP global capacity reached only 11 GW in 2017. On the other hand, increased transmission capacity (deployment of long-distance networks) should further increase the competitiveness of CSP.

An important advantage of CSP, compared to other renewable technologies such as solar photovoltaic (PV) plants, is its flexibility. CSP plants feature short-term heat storage, which allows them to provide more constant output even during periods of cloudy weather or after sunset. Even though this feature is mentioned in the literature, CSP plants are usually analysed with regard to their capacity of competing in baseload operations. As mentioned in Section 3.1, the baseload focus is reflected in the design of current CSP plants.

Application of state-of-the-art operational data analytics and planning algorithms may further increase the flexibility and controllability of CSP plants. CSP technology may prove more competitive if considered not only as an alternative to baseload production by fossil plants but also as a dispatchable source which may provide power on demand. However, this may require a shift in the design methodology, with more stress placed on the energy storage technologies and application of intelligent algorithms both to assess the parameters of plants and to control their operation.

4. Perspectives for Molten Salt Power Plants

Electric energy is a unique commodity. The instability of power systems and the complexity of energy storage require constant monitoring of the demand-supply balance [6, 30, 31]. The specificity and uniqueness of the energy market influence the price dynamics not matched by other markets. Electric energy prices are complex, which is why they are not easy to model econometrically. They are highly changeable and can deviate strongly from expected values; there is a seasonality in their daily, weekly, and annual prospects; and they can unexpectedly increase significantly for short periods of time [21, 32–35]. The common causes of this situation are unpredicted demand and supply changes brought by, e.g., the development of low-emission energy sources, sudden and unplanned downtimes in the transfer network, and transfer limitations [36]. The prices of energy on the market are conditioned mainly by production and environmental costs. One of the major price determinants nowadays is the increasing role of climate policy, especially the costs of CO_2 emission certificates. Also, the development of transborder connections raises the level of price sensitivity in neighbouring countries. Prices of energy in the EU follow the trends on other global wholesale markets. Because of the regional and state circumstances, including the level of interconnections and the unfinished technical integration of the EU market, the electric energy prices are not uniform [37]. However, the pan-European Market Coupling (MC) algorithm and the activities to coordinate the European power exchange management structures in the framework of the Price Coupling of Regions (PCR) lead to the implementation of the target model of the European Day-Ahead Market compliant with Regulation (UE) 2015/1222 from 24 July 2015 r. [38]. That will help lift the limitations on wholesale markets in order to fully benefit from flexibility, an increased share of the demand side, and transborder trade. The PCR system enables forwarding of requests and information on transmission capacity between exchanges at the meeting points of individual areas in order to calculate prices for these areas as well as other benchmark prices. It allows an assessment of the potential of transborder transfers between areas for all regions participating in the exchange. According to the decisions on the EU level and with the commission's and ACER's acceptance, the European Day-Ahead Market in the XBID model was successfully launched on 12.06.2018. Marking an important step towards creating a single integrated European intraday market, the go-live with the 10 Local Implementation Projects delivers continuous trading of electricity across the following countries: Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Latvia, Lithuania, Norway, the Netherlands, Portugal, Spain, and Sweden. Most other European countries are due to take part in a second-wave go-live with XBID in 2019.

4.1. Specificity of Energy Markets. Analysing the volume of output of the primary energy in the EU in the period 2004-2016, we observe a negative trend for the majority of energy sources, except for renewables (Table 2).

Primary production of energy in the EU-28 in 2016 dropped by 1.5% compared to 2015 (Table 3). The biggest decrease was observed in the production of fossil fuels (8%), followed by the production of nuclear energy (2.1%) and petroleum-derived products (1.5%). The production of energy from renewable sources, on the other hand, increased by 3%. The most popular sources of renewable energy in EU-28 in 2016 were biomass combustion (63.8%), hydroelectric plants (14.2%), wind power plants (12.3%), solar energy (6.3%), and geothermal energy (3.2%); see Table 4 for more details. Gross inland energy consumption in the EU-28 in 2016 was 1,640.6 Mtoe, and the final energy consumption was on the level of 1,107.8 Mtoe [39]. As for the structure of gross inland energy consumption in 2016, petroleum products held the biggest share (34.6%), followed by gas (23.3%) and solid fossil fuels (14.7%), which means that 71.5% of all energy in the EU-28 was produced from fossil sources (coal, crude oil, and natural gas). The share of nuclear heat and renewable energies accounted for 13.2% each. Gross inland energy consumption in Poland in 2016 was 99.9 Mtoe, and the final energy consumption was on the level of 66.7 Mtoe [39].

The key elements of electric energy supply strategy are price and supply reliability. Legal regulations on the level of the EU as well as individual states are among the factors determining the price of electric energy. They influence the market's daily valuation and create long-term pricing conditions which are mainly connected with the basic premises of the EU climate policy. The policy regulates the models of state energy markets, the security and solidarity mechanisms, and the instruments for the unification of the EU market. Legal solutions of individual states influence the energy pricing as well. All kinds of administrative interventions on the energy market can complicate the operation of energy

Table 2: Total production of primary energy in EU-28 and in Poland, 2004-2014.

Year	EU-28	Poland
2004	930.1	78.5
2005	900.2	78.2
2006	881.6	77.2
2007	856.5	72.0
2008	850.7	70.8
2009	816.0	67.1
2010	831.6	66.9
2011	802.9	67.9
2012	794.3	71.1
2013	789.7	70.5
2014	771.6	66.8

Source: Eurostat (online) (cit.2016-02-17), available: data codes: ten00076. The energy balances (also called energy balance sheets) are expressed in thousands of tonnes of oil equivalent (ktoe). The tonne of oil equivalent is a standardised energy unit defined as a net calorific value of 107 kilocalories (41,868 MJ), which is roughly the net energy equivalent of a tonne of crude oil. Mtoe: million tonnes of oil equivalent.

entities and increase the unpredictability of prices. Also, different sorts of tariffs can make it hard to properly valuate energy and determine market risk. Another factor is the RES and cogeneration support systems, which are promoted for two reasons: they are efficient and help reduce the emission of carbon dioxide and other harmful substances. Lastly, the capacity mechanisms which ensure the right and effective capacity level in entities are independent of atmospheric conditions [40]. They also influence the valuation of energy.

The energy market is a mechanism which helps ensure the capacity needed to cover the demand for energy and maintain reserves necessary for the security of supplies in advance. The market can take two forms: it is either *centralised*, where the demand prognoses and the production of power are handled by one entity, or *decentralised*, where each consumer or supplier is bound to provide the capacity sufficient to cover peak demand with reserves, simultaneously considering the use of system effects [41]. There are two basic categories of power mechanisms. One uses the volume of power as its criterion, and the other concentrates on the price [42]. The former assumes a particular volume of power necessary to meet the standard. The price is generated in the contracting process. The latter determines the price on the basis of different indexes such as VOLL (Value of Lost Load) or LOLE (Lost of Load Expectation). The price has influence on demand and can also change generation capacities. Volume power mechanisms can have a *selective* or *market* character. *Selective* solutions take the form of bilateral agreements done in a tender procedure. They can also be a strategic reserve, which is encountered in the energy systems of Sweden, Finland, the Netherlands, and Poland. *Market* solutions have features similar to capacity auctions or capacity obligations. The capacity auctions are centralised—there is one market administrator and agreement sides responsible for ensuring capacity. Solutions of this type are used in the USA and Great Britain. Capacity obligations are decentralised instruments. Energy suppliers are bound to reserve capacity for their electricity volume. Guarantees to meet the power demand are in the form of either agreements between the system participants or capacity certificates issued by suppliers or receivers who can reduce demand. This type of solution functions in France. An example of a market based solely on price is the model of capacity payments. The contracting process is based on the price offered by the capacity buyer, which determines the volume that the supplier can offer. Such a solution functions in Spain.

As an example, the Polish energy market is a single-good market with two reserves: strategic and operational. The strategic reserve is maintained by the system operator in order to ensure long-term energy security in case of a malfunction in one or more basic generating units. As the starting of the reserve's blocks takes about 8 to 10 hours, the decision to use it must be made in advance. Contracts for 830 MW for the period 2016-2020 have been concluded. The maximum annual cost of the strategic reserve is 40 million EUR. It still uses old blocks which have not been abandoned yet because PSA (the electricity supply operator) decided they would ensure better security for the expected capacity shortage. The operational reserve is to ensure the system's ability to continuously balance capacity and rapidly recreate regulatory capability. The operational reserve mechanism was introduced in 2014 with a value of 102 million EUR. In 2015, it was reduced to 92 million EUR and then increased to 114 million EUR in 2016. The mechanism allows transferring of surplus capacity from system sources to the reserve. This way, the generating entities are remunerated for their readiness to supply additional power on weekdays between 7 AM and 10 PM. In order to maximise profitability, they can also choose the destination of their surplus, which can be directed to the energy market, the balancing market, or the operational reserve. The introduction of the reserve caused the wholesale prices on the energy market to increase. Other resources available in the Polish energy system are the resources of the demand side of the market and import through interconnections with the power systems of neighbouring countries of 8 GW, including 6.5 GW for the EU. However, so far, they have not been used extensively due to delays in market coupling. In 2014, only 2% of the total annual energy supply originated from imports.

While determining the costs of energy for businesses, the electric energy price is an element of international competitiveness. It varies much among the EU member countries in comparison with the prices of fossil fuels on global markets. The prices of energy in the European Union are regulated by the demand and supply in individual countries, level of excise duty and taxes, geopolitical situation, industry costs, import volume, and environmental circumstances with a particular consideration on weather conditions. The price determinants in a given country can be divided into international and domestic. The former are prices of primary fuels, prices of emission certificates (considering the carbon dioxide emission costs), currency exchange rates, development of transborder connections, and volume of energy import and export. The domestic factors include the economic

Table 3: Primary energy production and share of each fuel to total production in EU-28 and in Poland, 2010-2014 (Mtoe).

Region	Total production (Mtoe)	Solid fuels	Oil (total)	Natural gas	Nuclear energy	Renewable energy	Wastes (none ren.)
2010							
EU-28	831.6	164.0	97.1	159.8	236.6	163.0	11.1
Poland	66.9	55.1	0.7	3.6	0.0	6.9	0.6
2011							
EU-28	802.9	166.6	84.8	141.7	234.0	162.2	13.6
Poland	67.9	55.3	0.7	3.9	0.0	7.4	0.6
2012							
EU-28	794.6	166.1	76.7	133.2	227.7	177.4	13.6
Poland	71.1	57.5	0.7	3.8	0.0	8.5	0.6
2013							
EU-28	790.3	155.8	71.6	131.8	226.3	192.8	12.0
Poland	70.5	56.8	0.9	3.8	0.0	8.5	0.5
2014							
EU-28	771.7	149.3	70.0	118.0	226.1	195.9	12.4
Poland	66.8	53.6	0.9	3.7	0.0	8.1	0.5
2015							
EU-28	766.6	144.9	75.1	107.3	221.5	204.7	13.0
Poland	67.3	53.6	0.9	3.7	0.0	8.6	0.5
2016							
EU-28	755.4	132.2	74.0	107.3	216.8	210.8	14.3
Poland	66.4	52.1	1	3.5	0	9.0	0.8

Source: Eurostat (online) (cit.2016-02-17), available: data codes: ten00076, ten00080, and ten00081.

Table 4: Share of each fuel to total production renewable energy in EU-28, 2013-2014.

Year	Total production (Mtoe)	Biomass & waste	Hydropower	Wind	Solar energy	Geothermal energy
2013	192.0	64.2	16.6	10.5	5.5	3.1
2014	195.8	63.1	16.5	11.1	6.1	3.2
2015	204.7	63.4	14.3	12.6	6.4	3.2
2016	210.8	63.8	14.2	12.3	6.3	3.2

Figures do not sum to 100% due to existence of other fuels. Source: Eurostat (online data codes: nrg_100a and nrg_107a).

Table 5: Comparison of prices for a kilowatt-hour of energy in Euros in the first halves of 2014 and 2015 in EU-28 and in Poland. Half-yearly electricity prices 2014-2018 (semester 1; EUR/kWh).

Region	Electricity prices (EUR/kWh)									
	Households					Industry				
	2014s.1	2015s.1	2016s.1	2017s.1	2018s.1	2014s.1	2015s.1	2016s.1	2017s.1	2018s.1
EU-28	0.203	0.208	0.205	0.204	0.205	0.123	0.121	0.116	0.114	0.114
Poland	0.142	0.144	0.133	0.146	0.141	0.083	0.088	0.081	0.088	0.088

Source: Eurostat (nrg_pc_204 and nrg_pc_205).

growth tempo, domestic energy mix, prices and consumption of fuels, labour costs, energy sector investments, and participation in power exchanges. The result of varying local conditions is a considerable energy price discrepancy in the EU, although the change directions are convergent. Table 5 shows the comparison of electric energy prices in Poland and in EU-28 in the first halves of 2014 and 2018 for medium-sized households and industry receivers.

4.2. Economic Optimisation by Using Molten Salt Power Plants. By its nature, renewable generation is not reliable in terms of energy stability. Thus, prediction and planning plays

Table 6: Storage technology rated power worldwide.

Technology type	Number of installations	Rated power (MW)	%	Without PH (%)
Pumped hydro (PH)	350	180627	95.35	
Thermal (TH)	202	3615	1.91	41.06
Electromechanical (EM)	69	2611	1.38	29.66
Electrochemical (EC)	902	2572	1.36	29.21
Hydrogen (HY)	9	6	<0.01	0.07

a major role in such a case [43–48]. To compensate, an energy storage solution needs to be employed.

It increases the reliability and flexibility of such generation. While storage deployment decreases generation risks, it simultaneously increases maintenance risks, which contribute in more complicated installations.

The main energy storage technologies are pumped hydro, thermal, battery, and flywheel [49, 50]. The participation of different storage technologies as of 2016 is showed in Table 6, based on data from the U.S. Department of Energy Storage Global Energy Storage Database (http://www.energystorageexchange.org). The most power is delivered by pumped hydro, with a global share of over 95%. It is a well-developed and mature technology, with a very high ramp rate. It is also one of the most cost-effective ones. However, there are certain substantial drawbacks, such as geographical limitations and high overall investment cost. There are also environmental impacts regarding the dislocation of substantial amounts of water.

Among the other technologies with widespread use, thermal storage takes the first place. It offers high energy density and, depending on HTF, economic viability while offering high ramp rates. Moreover, it is not limited geographically and it does not influence the environment. Its deployment is on the rise, starting with 0.4 GW in 2007 and reaching 3.6 GW in 2016. Advancing this type of storage, focusing on HTF and CSP, is one of the U.S. Department of Energy (DOE) long-term goals [50].

Besides the economic barriers—mostly high capital costs—there are also other issues related to regulatory policies, market, utility business model, and technology regarding storage deployment [51]. The most significant one is still high technology cost. However, there are identified target goals of lowering the capital cost in 2016 down to 227 EUR/kWh and under 18 cents/kWh/cycle [52]. For long-term goals, it goes down to 136 EUR/kWh and 9 cents/kWh/cycle. There is a significant push from the DOE to increase commercial deployment. For comparison, a 200 MW CSP molten salt plant has an installed cost of energy storage at 30 EUR/kWh [18], while the storage system lifetime is estimated at 30 years.

Since molten salt-based power plants were designed from the ground up for base load generation, they address these storage problems; in particular, certain characteristics of molten salt-based thermal energy storage need to be pointed out [18]. They are as follows:

(i) *High capacity:* molten salt thermal storage capacity can vary significantly from MWh to GWh [17, 18] while still being economically viable. Currently, the world's largest storage now under construction in Nevada is rated at 2.9 GWh

(ii) *High flexibility:* ability to charge and discharge quickly. Flexibility means short startup times and rapid load changes [17]. Current assumptions for the PreFlexMS project (http://preflexms.eu/) indicate load changes at 8%/min (400 kWth/min)

(iii) *High efficiency:* efficiency of such a thermal storage is at 99% [18]. However, power block efficiency varies from 40% to 49% [53]

(iv) *No special location demands or geographical features*

Cost analysis for a plant with gross power output at 165 MW level is presented by Pacheco et al. [17]. Different steam cycles are being investigated. The annual energy produced varies from 721 GWh to 818 GWh, while the leveled cost of energy varies from 10 to 11.2 cents/kWh.

5. Concluding Remarks

Current energy markets are characterized by dynamically changing power demand. Furthermore, they have to comply with strong legal regulations. As a result, market players struggle to provide agile response while optimising technological and economic aspects of energy generation, distribution, and transmission. Particular plants have to plan ahead to maximise profits and minimise risk. Smart grid technology is a key enabler for the required dynamic control and data exchange.

Concentrated solar power plants belong to the category of absolutely clean sources of renewable energy. Therefore, their development matches the EU policy that consists in increase of renewable energy penetration and, on the other hand, tightening of environmental protection regulations. This type of renewable energy, however, cannot be stored directly. Therefore, energy reservoirs for such a generation must be used. Molten salt storage facilities are reliable solutions for this problem. Applying energy reservoirs in the power industry allows us to store energy at the industrial level which results in increasing control abilities at a single power plant level, the grid level, and the system level spanning across multiple countries. Increased control abilities increase stability of the power system and, as a consequence, strongly influences economic aspects. It regards both system management and energy market stability. It should be also mentioned that molten salt reservoirs are conjugate to concentrated solar power harvesting due to the lack of additional energy conversion. Such a solution allows us broader exploitation of solar energy which is one of the few absolutely clean energy sources. This is crucial in the context of protection of the environment.

Moreover, current research in the field of molten salt-based generation aims at shifting its application from the baseload to a more flexible, agile one. This need arises from increasing dynamic characteristics of energy market demand.

Given the extra flexibility provided by using molten salt energy storage and intelligent control, such plants can also be used as supplementing installations for other types of renewable generators, for instance, wind turbine farms.

It should be stressed that the considered topic is connected with the stream of studies that is concerned with the operation possibilities of systems in general. The more autonomous a system is, the more operation possibilities it has. The theory of autonomous systems, strongly referred to as multiagent system theory and game theory, has been developed intensively since the 1960s [54–57], including its economic aspects [58–60]. These topics are planned to be subject to further research.

Conflicts of Interest

The authors declare no conflict of interest.

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