Renewable and Sustainable Energy Reviews 75 (2017) 476–489

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

An overview of research and energy evolution for small hydropower in Europe

Francisco Manzano-Agugliaro[a,b,*], Myriam Taher[a], Antonio Zapata-Sierra[a,b], Adel Juaidi[a], Francisco G. Montoya[a]

[a] Department of Engineering, Universidad de Almeria, 04120 Almeria, Spain
[b] CIAMBITAL(Research Center on Agricultural and Food Biotechnology), CeiA3 University of Almeria, 04120 Almeria, Spain

ARTICLE INFO

Keywords:
Small hydropower
Hydroelectric
Policy
Assessment
Models
Renewable energy

ABSTRACT

Europe has a large tradition of Small Hydropower stations (SHP); these proliferate wherever there was an adequate supply of moving water and a need for electricity. As electricity demand grew many of these plants were abandoned. Today with the rising price of energy, SHP can be a solution to help rural electrification, furthermore SHPs do not consume the water that drives the turbines. The advantage of this technology is extremely robust and systems can last for 50 years or more with little maintenance. This paper summarizes an overview of SHP Hydropower in Europe. Hydropower on a small scale, or micro-hydro, is one of the most cost effective energy technologies to be considered for rural electrification in less developed countries. Europe is a market leader of SHP technology. Optimal turbine designs are available and new technical developments offer automated operation of SHP. The present role of SHP in Europe in the development of renewable energy sources is discussed through this paper. The main producers of SHP electricity in Europe are Italy, France, Spain, Germany and Sweden. On the other hand, 10 European countries are ranked based on the total numbers of SHPs: Germany (7,512), Italy (2,427), France (1,935), Sweden (1,901), Spain (1,047), Poland (722), Romania (274), Portugal (155) and UK (120). The research shows that there is a considerable scope for development and optimization of this technology. This opens new perspectives because it has a huge, as yet untapped potential in most areas of Europe and can make a significant contribution to future energy needs.

1. Introduction

Hydroelectric energy is a continuously renewable electrical energy source, it is non-pulling, It has no fuel cost and is advantageous for its low operation and maintenance. Hydropower is that generated by the movement of water bodies. The water flows via channel or penstock to a waterwheel or turbine where it strikes the bucket of the wheel, causing the shaft of the waterwheel or turbine to rotate. When generating electricity, the rotating shaft, which is connected to an alternator or generator, converts the motion of the shaft into electrical energy. Hydroelectric plants are more cost effective compared to other types because; although its construction cost is higher, once put into operation have some operating costs and relatively low maintenance provided that the average year rainfall conditions are favorable [1]. The inherent technical, economic, and environmental benefits of hydroelectric power make it an important contributor to the future world energy mix, particularly in the developing countries [2]. The hydropower is the leading source of renewable energy, providing more than 97% of all electricity generated by renewable sources [3] Village-scale hydro-electric programmes exist in many developing countries throughout the world [4]. Technically feasible hydropower estimated at nearly 15,000 TWh/year still exists in the world today, mostly in countries where increased power supplies from clean and renewable sources are most urgently needed to progress social and economic development [2]. As far as Europe is concerned, technical potential in Europe in terms of annual generation hydroelectric energy is 1,021 TWh/year and the Technical potential installed capacity was 338 TWh/year in 2009 [5]. Countries with the largest production hydroelectric energy during the years 1995–2011 were: Norway (an average of 120 TWh, which accounts for 21.81% for Europe and 3.54% for the world), Sweden (66 TWh on average, which represents 12.03% for Europe and 1.95% worldwide) and France (61 TWh on average, 11.08% for Europe and 1.80% for the world) [6]. Europe has developed 75% of hydropower potential, whereas Africa has only developed 7%

* Corresponding author at: CIAMBITAL (Research Center on Agricultural and Food Biotechnology), CeiA3 University of Almeria, 04120 Almeria, Spain.
E-mail addresses: fmanzano@ual.es (F. Manzano-Agugliaro), myriamtaher@yahoo.es (M. Taher), ajzapata@ual.es (A. Zapata-Sierra), adel_juaidi@yahoo.com (A. Juaidi), pagilm@ual.es (F.G. Montoya).

http://dx.doi.org/10.1016/j.rser.2016.11.013
Received 26 May 2015; Received in revised form 31 October 2016; Accepted 1 November 2016
Available online 10 November 2016

Table 1
Detail of Small-scale hydropower classification by installed capacity (MW) in some countries and organizations.

Installed capacity (MW)	Countries	Organizations
≤10	France, Norway, South Africa, Czech Republic, Spain, Italy	International Energy Agency, World Commission on Dams, ESHA (European Small Hydropower Association), IEA Small Hydro
≤15	Sweden, UK	
≤20	EU	
≤25	India	
≤30	Brazil	
≤50	New Zealand, Philippines	
≤100	USA	

[7].

In this article, SHP refers to hydraulic power plants with less than 10 MW installed power, which is commonly called “Small Hydropower” in a majority of institutions or international agencies. However, in some countries like China or India this value increases to 25 MW [8]. Table 1 shows a brief detail of Small-scale hydropower classification by installed capacity (MW) in some countries and organizations. International organizations generally opt for 10 MW as the limit for SHP. Small hydroelectric plants have individual capacities of 10 MW or less [9], and very small 5 kW [10].

The contribution of SHP to the worldwide electrical capacity is more of a similar scale to the other renewable energy sources (1–2% of total capacity) amounting to about 47 GW (53%) of this capacity in developing countries [11]. We have to take into account that hydropower technology is regarded as the most mature of all considered RESs [12]. In electric power generation, small SHPs have special importance thanks to their low administrative, executive costs, and short construction time compared to large power plants [13]. Small Hydropower electricity supplies electricity for over 13 million households in Europe, which contributes to 29 million tones of CO_2 avoidance annually [14].

The principal objective of this work is to study the evolution of the produced by small hydropower in Europe and the major field of investigation. Concretely, it brings deeper analysis on Dam and penstock, turbines, pumps and generators, control strategies and costs, socials aspects and environmental issues.

2. Small hydropower energy production in Europe

In this review, we have to understand Gross Installed Capacity as the maximum electric output that the whole of facilities can produce and Gross electricity generation as the amount of electricity that the facilities have produced over a specific period of time, usually one year.

The vast majority of installed SHP capacity (81.5%) in Europe is concentrated in 6 countries. According to the number of facilities installed, this is lead by Germany (7,512), followed by Austria (2,589) and Italy (2,427) as shown in Fig. 1. These largest EU producers of electricity from SHPs in recent years are Italy (2,751 GWh); accounting for about 21% of the total SHP installed capacity, followed by Spain (15.5%), Germany (14%), Austria (9.4%), Sweden (7.7%) and France (7.5%) [15] as shown in Fig. 1, data extracted from [14] in year 2010 (last year with full data for all analyzed countries).

2.1. United Kingdom

The negation of fuel costs, technology efficiency, low operating and maintenance costs and reduced environmental impact, contribute to make hydropower an attractive option [16]. Hydropower currently provides only 1.5% in the UK [17]. Micro-hydro is one of the most environmentally benign energy technologies available. The technology is extremely robust and systems can last for 50 years or more with little maintenance [18]. For 2002, the UK has 100 MW of small hydro capacity operating from approximately 120 facilities [8]. Fig. 2 shows the evolution of the installed SHP from 2007 to 2011, the total installed capacity and the electricity generation in the United Kingdom. So, the total number of power plants in UK increased through the period 2007–2011, the total of SHPs in 2007 (86 SHPs) and for year 2011 (183 SHPs). The Gross Installed Capacity was increased slightly in the same period (2007–2011), the maximum Gross Installed Capacity equals 218 (MW) in 2011. In addition, the maximum Gross electricity generation scores 697 (GWh/year) in 2011.

2.2. Portugal

As shown in Fig. 3, the total number of power plants in Portugal increased slightly through the period 2007–2011: the total of SHPs was 137 in 2007 and 157 for year 2011. The Gross Installed Capacity was increased slightly in the same period (2007–2011), the maximum Gross Installed Capacity equals 453 MW) in 2011. In addition, the maximum Gross electricity generation equals 1,605 (GWh/year) in 2010.

The hydropower capacity is foreseen, to be about 7,000 MW increasing the hydropower generating capacity potential from 46–70%, in Portugal for the year 2020. Promotion and development of small hydropower aim to increase by 50% the actual capacity [19]. The number of SHPs has increased from 137 in 2007 with an installed capacity of 399 MW to 157 plants in 2011 with an installed capacity of 453 MW [14].

2.3. Italy

The total number of SHP in Italy increased through the period 2007–2011, being the total of SHPs in 2007 about 1,835 and 2,601 for year 2011. The Gross Installed Capacity was increased slightly in the same period (2007–2011), the maximum Gross Installed Capacity equals 2,896 MW in 2011. Also, the maximum Gross electricity generation equals 10,958 GWh/year in 2010 (see Fig. 4).

In Italy, the potential energy production by SHP plants is expected to be 12,000 GWh/year by 2020 [14]. Italy is one of the largest producer of hydroelectric power in Europe in terms of reference to SHP. It increased since 2007 where it generated about 4,000 GWh to 10,958 GWh generated in 2011 with 2,601 SHPs.

2.4. Germany

The total number of power plants in Germany increased slightly through the period 2007–2011, the total of SHPs in 2007 was 7,503 and the total of SHPs in 2011 was 7,512 as Fig. 5 shows. Germany, since 2007–2011 has scarcely increased the number of SHP, been 7,512 in 2009 and 7,516 in 2011, with 1,723 MW installed that produced 8,352 GW/h/year in this year [14].

2.5. France

The history of hydropower is linked to France because the first hydropower plant was successfully built in this country around 1880 [20]. Hydropower is the second source of electric power generation in France [21]. In France, the total number of power plants increased slightly through the period 2007–2010, as shown in Fig. 6. The total of SHPs were 1,825 in 2007 and 1,935 for year 2010. France is one of the largest producer of hydroelectric power in Europe in terms of SHP and refers generating 6,820 GWh in 2010, but suffering a significant decline in 2009 for both installed capacity and electricity generation. The maximum Gross Installed Capacity equals 2,110 MW in year 2010 and

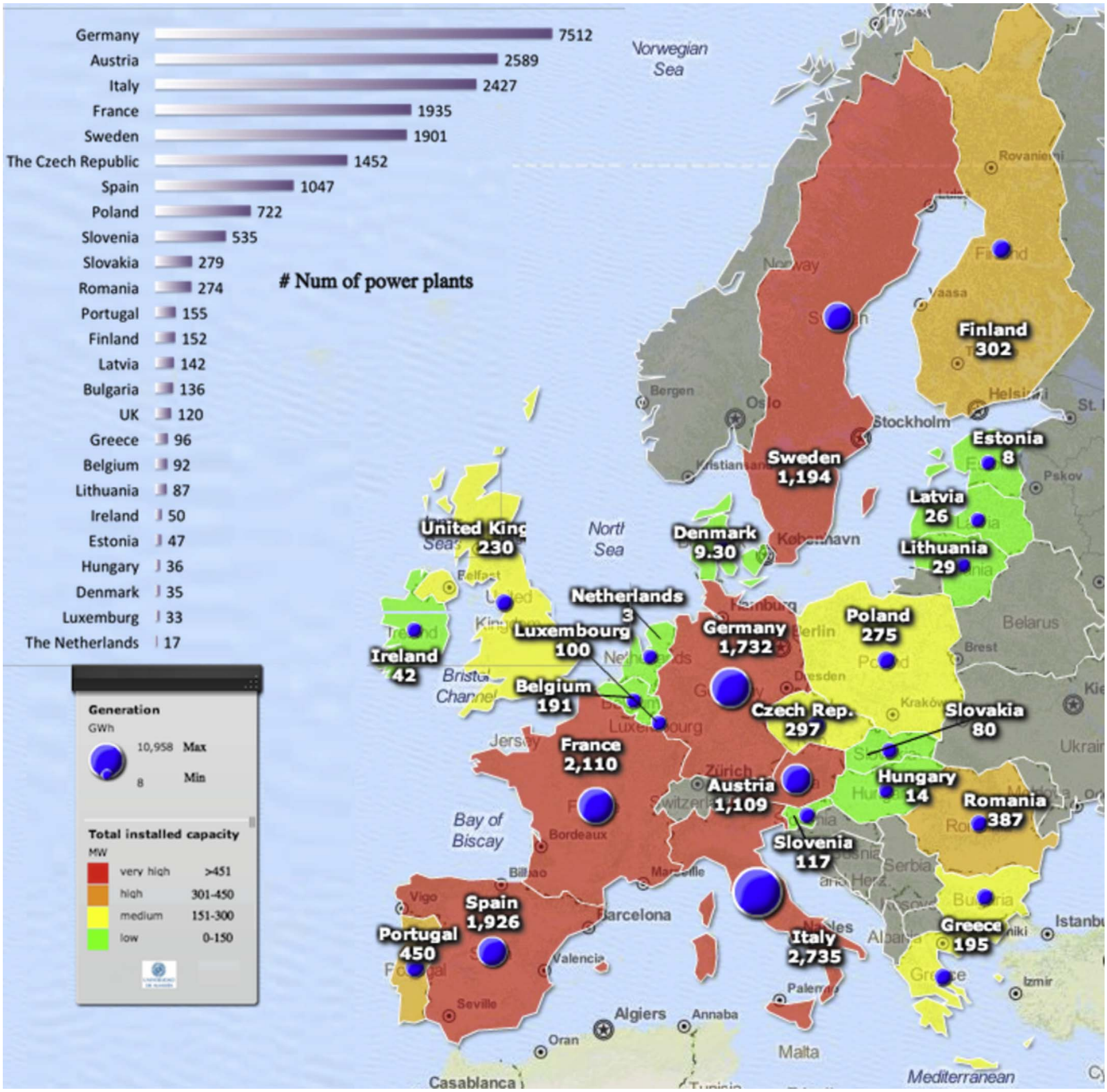

Fig. 1. Map of 25 top European Countries of total installed capacity SHP, total generation energy SHP and number of SHPs. (2010).

the maximum Gross electricity generation equals 7,000 GWh /year in 2008.

2.6. Poland

The number of SHP has increased from 681 in 2007 to 739 in 2011; this means a ratio of almost 12 new SHP a year, as shown in Fig. 7. The maximum Gross Installed Capacity equals 281 MW in 2011 and the maximum Gross electricity generation equals 1,035 GWh/year in 2010. But the Normalized Electricity Generation was 958 GWh in 2011. The summary in this period, the Gross installed capacity has increased 7.2% and the Normalized Electricity Generation has increased 7.8%. Hydropower storage facilities are generally divided into two main categories: hydropower with a reservoir or conventional (pure) hydro and a pumped (Hydro energy) storage plant (PSP). [22] presents and analyzes pumped storage plants, layouts and a clear methodology for determining the renewable electricity generation from mixed pumped storage plants (PSPs) operating all over the EU. In Poland, among 6 PSP in 2011, only 3 of them barely operate in the pumping regime, and 98.8% of their generation in the period 2007–2011 could be counted as renewable [22]. In summary, it can be seen that the installed capacity has been increasing but nevertheless electricity generation has remained stable.

2.7. Romania

Romanian National Renewable Energy Action Plan (NREAP) has promoted the use of energy from renewable sources in accordance with

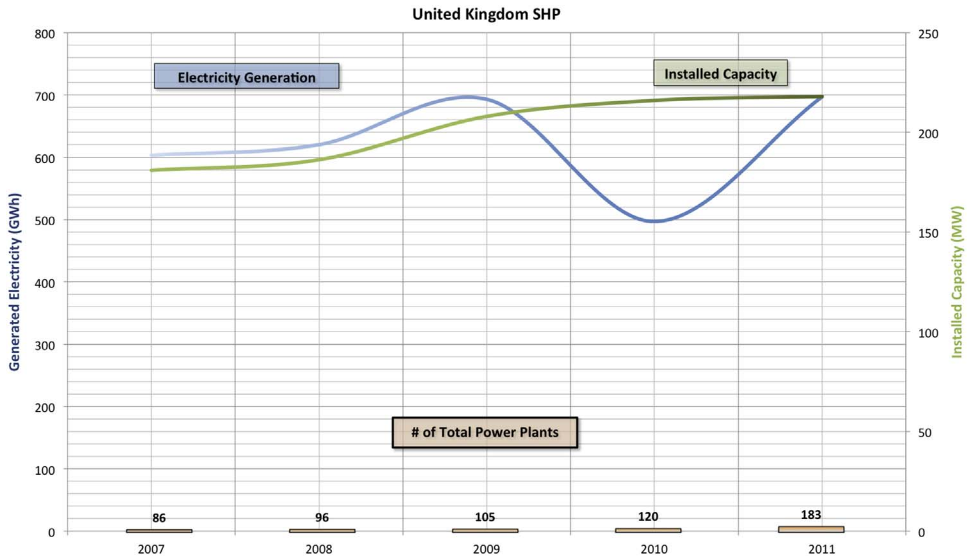

Fig. 2. Installed capacity, electricity generation and SHP in United Kingdom.

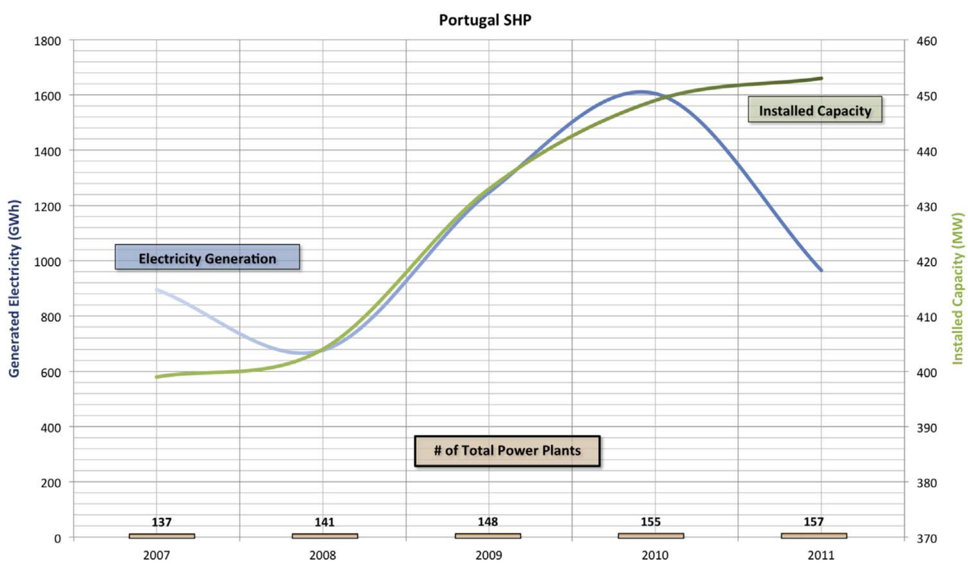

Fig. 3. Installed capacity, electricity generation and SHP in Portugal.

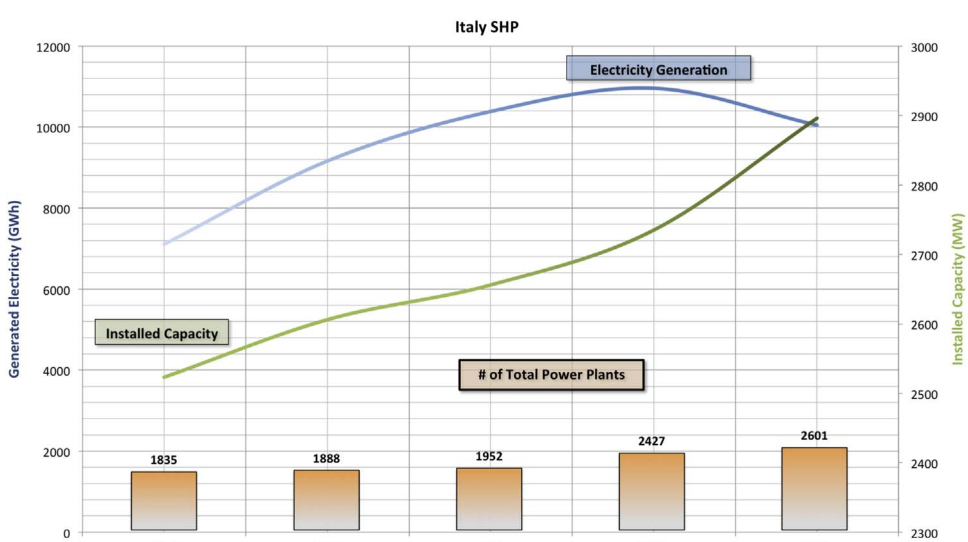

Fig. 4. Installed capacity, electricity generation and SHP in Italy.

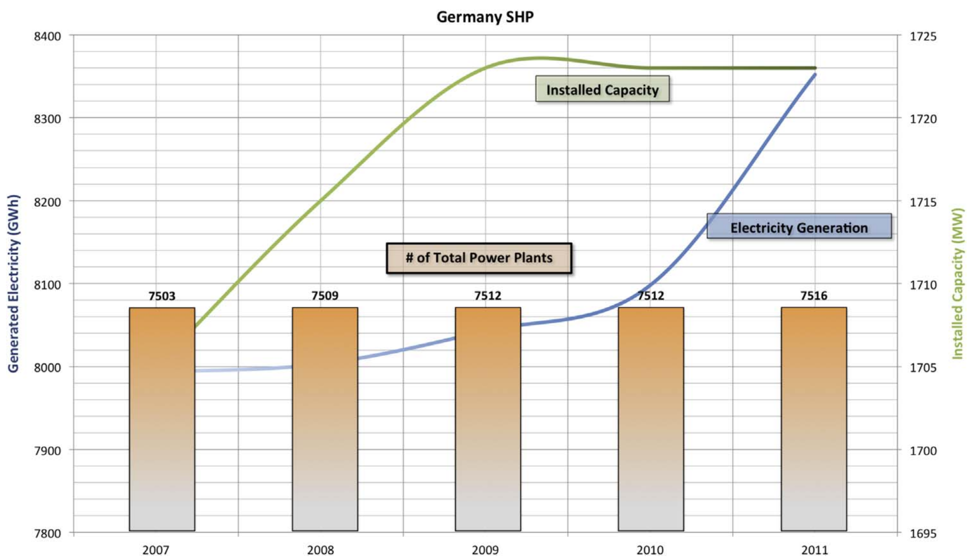

Fig. 5. Installed capacity, electricity generation and SHP in Germany.

the Directive 2009/28/EC of the European Parliament [23]. In 2007 the hydro electric energy production was representative with 15.7%, and in 2013 were 30.0% in hydropower (www.transelectrica.ro. The number of SHP in Romania has increased of 236 in 2007 to 305 in 2011. The Gross electricity generation has remained stable around 600 GWh/year in this period, as shown in Fig. 8. The maximum Gross Installed Capacity equals 433 MW in year 2011 and the maximum Gross electricity generation equals 774 GWh/year in 2009.

2.8. Austria

Austria has increased the total number of power plants through the period 2007–2011, the total of SHPs in 2007 was 2354 and 2993 for year 2011, as shown in Fig. 9. The Gross Installed Capacity was increased slightly in the same period (2007–2011), the maximum Gross Installed Capacity equals 1,284 MW in 2011. In addition, the maximum Gross electricity generation equals 5,778 GWh/year in 2011. It can be seen that the installed capacity and electricity have been increasing in parallel; this is a good example of this resource optimization.

2.9. Czech Republic

The early twentieth century the Czech territory was at the top of Europe in terms of using hydropower and thanks to specific hydrologic conditions, the hydraulic propulsion was widespread [24]. The total number of power plants in Czech Republic increased slightly through the period 2007–2011. The total SHPs installed in 2007 were 1,405 and for year 2011 were 1,475 (Fig. 10). The Gross Installed Capacity was increased in the period 2007–2011, but the Gross electricity generation can be considered stable for this period. The maximum Gross Installed Capacity equals 297 MW in the years 2010 and 2011, and the maximum Gross electricity generation equals 1,159 GWh/year 2010.

2.10. Slovenia

In Slovenia, the number of power plants in Slovenia increased slightly through the period 2007–2011, so, the total number of SHPs was 456 in 2007 and 471 in year 2011 (Fig. 11). The Gross Installed Capacity was increased slightly in the period 2007–2011. The max-

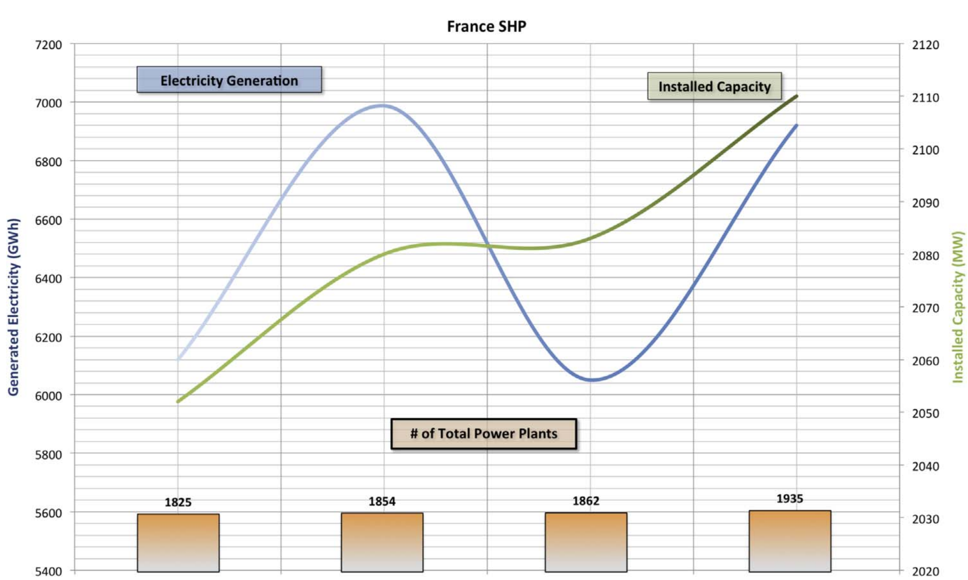

Fig. 6. Installed capacity, electricity generation and SHP in France.

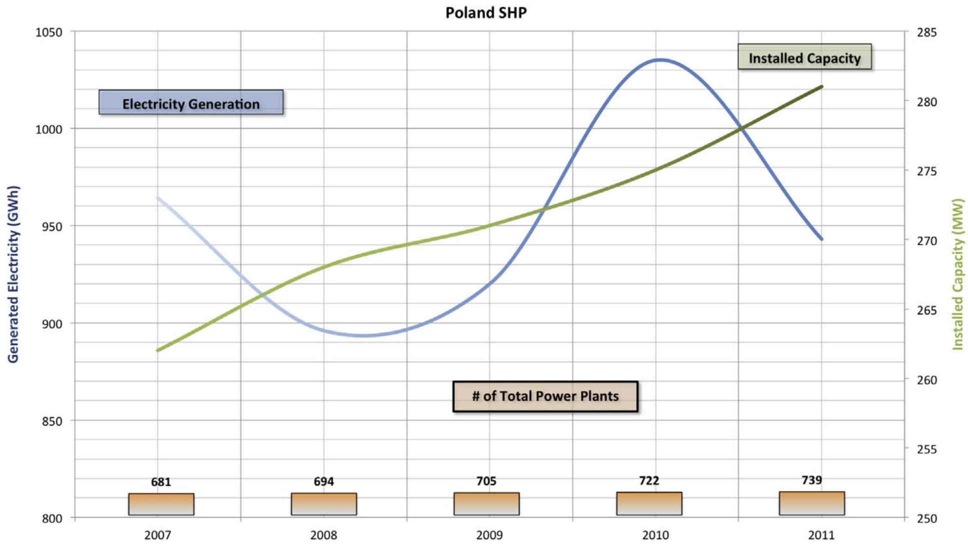

Fig. 7. Installed capacity, electricity generation and SHP in Poland.

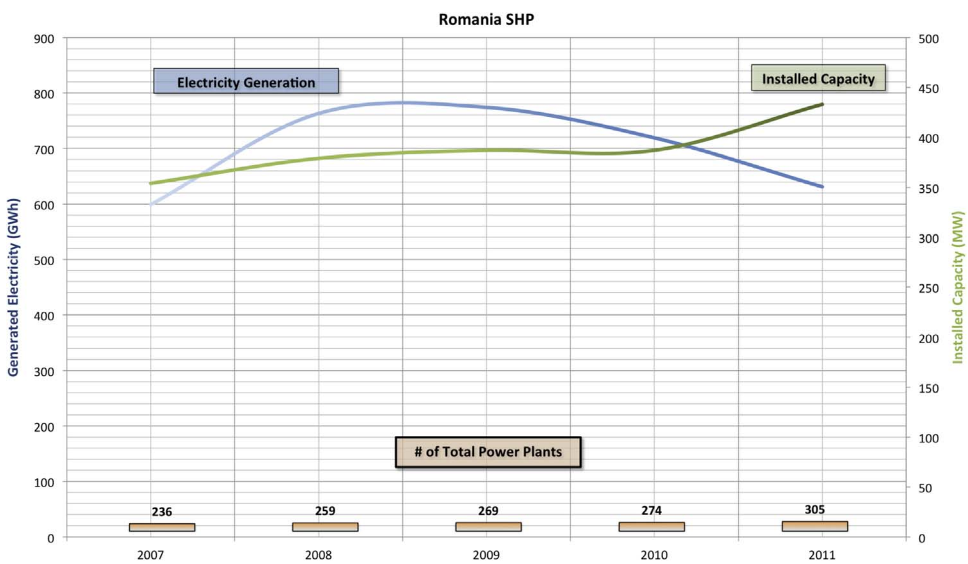

Fig. 8. Installed capacity, electricity generation and SHP in Romania.

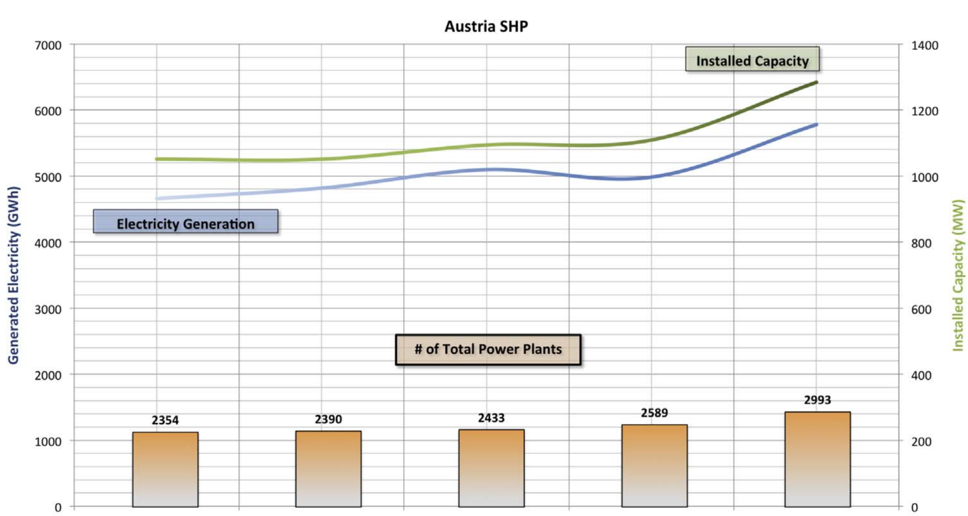

Fig. 9. Installed capacity, electricity generation and SHP in Austria.

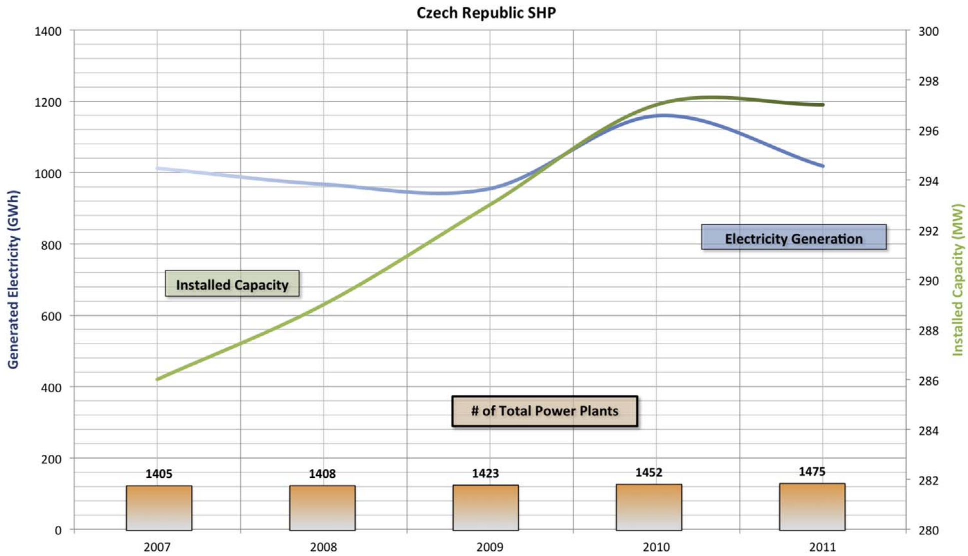

Fig. 10. Installed capacity, electricity generation and SHP in Czech Republic.

imum Gross Installed Capacity equals 118 MW in 2011 and the maximum Gross electricity generation equals 587 GWh/year in 2009. Slovenia is still far away from meeting its renewable energy targets. The most significant RES for electricity production is still hydro power, which in part relies on a large amount of old, small hydro power plants. Their renovation as well as the installation of additional new units is a principal part of Slovenian strategy for use of renewable energy sources [25].

2.11. Sweden

Hydropower is historically the most important electric energy source in Sweden [26], so hydro power stands for almost half of the energy production [27]. Sweden increased slightly the number of SHP through the period 2007–2011, so, the total SHPs were 1,813 in 2007 and 1,867 in 2011 (Fig. 12). The Gross Installed Capacity was increased in the same period. The maximum Gross Installed Capacity equals 1,283 MW in 2011 and the maximum Gross electricity generation equals 4,350 GWh /year in 2011. In summary, Sweden has increased almost linearly its installed capacity of SHP since 2007; constantly holding down the next power generated 4,500 GWh, ranking within the top five producers of SHP in Europe. The research has shown that a small hydro power plant can be upgraded yielding an increase in active power by 1 MW [27]. Four relatively big rivers, representing about 17 TWh per year, Vindelälven, Kalix älv, Pite älv, and the Swedish section of Torne-Muonio älv, are unexploited and are protected from future exploitation, except a small hydropower plant in Pite älv [27].

2.12. Spain

The energy crisis of the 1970 s led to a reformulation of the prevailing energy paradigm [28]. Other authors explain that is imperative to reduce existing uncertainties regarding changing environmental regulations and open-ended licensing procedures in order to attract investment capital [29]. Total installed hydropower is 18,682 MW of which 1,974 MW (10.6%) is SHP in Spain [30]. As shown in Fig. 13, the total number of power plants in Spain increased slightly through the period 2007–2008, but there is a drop in 2009, 553 SHPs from 1,250 SHPs in previous year. In addition, the Gross Installed Capacity was increased in the period 2007–2010. The maximum Gross Installed Capacity equals 1,926 MW in 2010, and, the maximum Gross electricity generation equals 4,719 GWh/year in 2010. It can be observed that installed capacity and electricity genera-

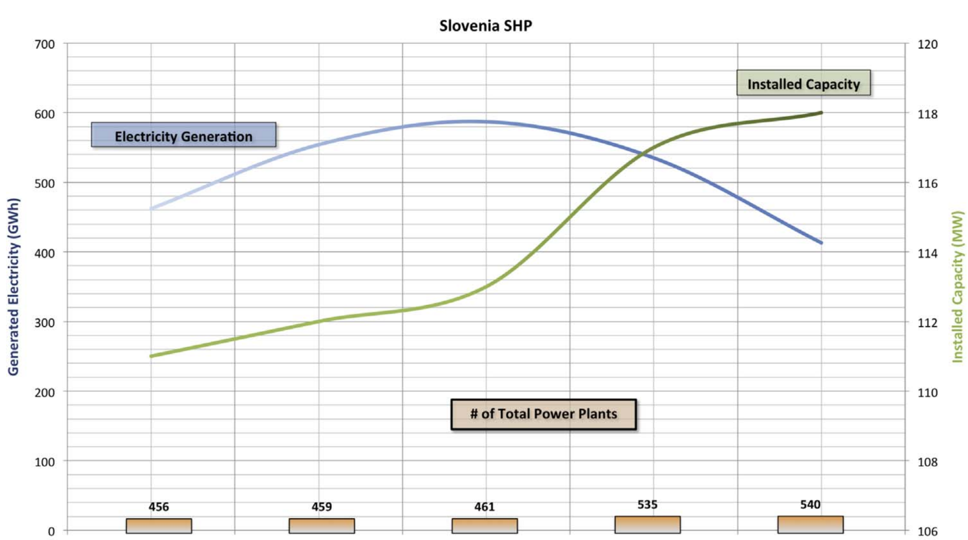

Fig. 11. Installed capacity, electricity generation and SHP in Slovenia.

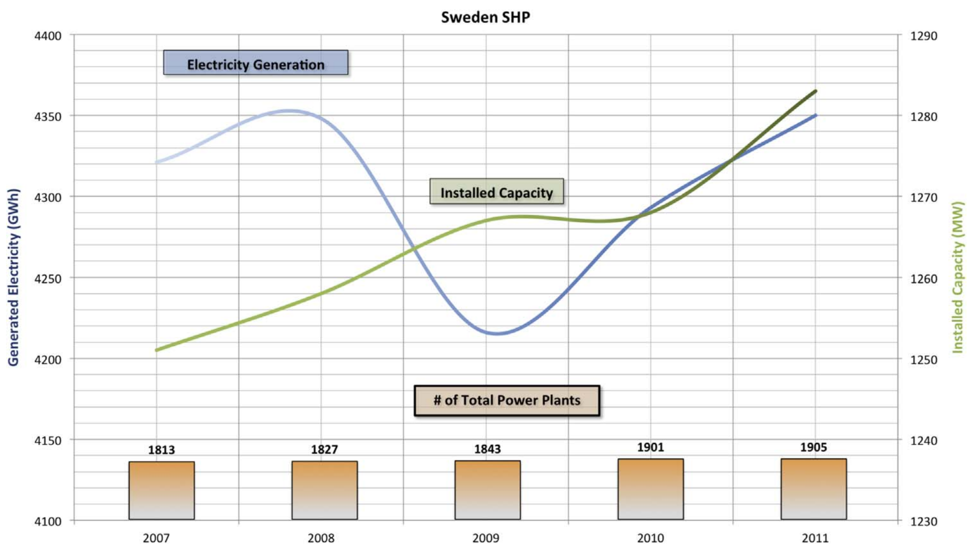

Fig. 12. Installed capacity, electricity generation and SHP in Sweden.

tion have been increasing in parallel from 2009 to 2011.

2.13. Turkey

Development of SHP began in 1902 in Turkey [31] but until 2001 the energy market in Turkey was not liberalized [32], since that year the SHP related engineering research has proliferated, as the European country that provides more articles on this topic. Turkey has a mountainous landscape with an average elevation of 1,132 m that is about three times higher than the Europe's average; this topography favors the formation of high gradient mountain streams which are suitable locations for SHP development [33]. Turkey has an abundant hydropower potential to be used for generation of electricity and must increase hydropower production in the near future [34]. Related to hydroelectric power projects in Turkey, [32] says that there were 1,524 hydroelectric power projects with 22,360 MW installed capacity until January 22nd in 2009. Turkey's hydro electric potential can meet 33–46% of its electric energy demand in 2020 and this potential may easily and economically be developed [34,35]. Small-scale hydropower is underdeveloped, with 90 plants in operation compared with 350 prospective development sites and a total potential production of 33 TWh of electricity per year [36], but [33] reports in its study that 225 small hydro plants with a total capacity of 1,032 MW and 30 mini hydro plants with a total capacity of 159 MW have been planned in Turkey. At present, the total installed capacity of SHPs is 176 MW in 70 locations, with annual generation of 260 GWh [36]. 279 of hydropower plants are between 0–10 MW and their installed capacity is 1,490 MW [37,38].

2.14. Norway

In 1992 Norwegian Water Resources and Energy Directorate made a study on the annual energy potential from up rating and refurbishing hydropower plants, with an installed capacity less than 1,000 kW. The study concluded that approximately 400 GWh could be harnessed by improving old schemes, and approximately another 300 GWh could be produced in new plants. In Norway, the major increase in new hydropower plants was in the period after World War II and until the middle part of the 1980′s. Today, there are 565 hydropower plants with an installed capacity above 1 MW, and mean annual production is about 118 TWh. The capacity is approximately 28,000 MW. The amount of small-hydropower plants is about 44% (http://www.small-hydro.com). The number of existing micro and mini hydropower plants was assumed to be 300, and with an annual production about 300 GWh.

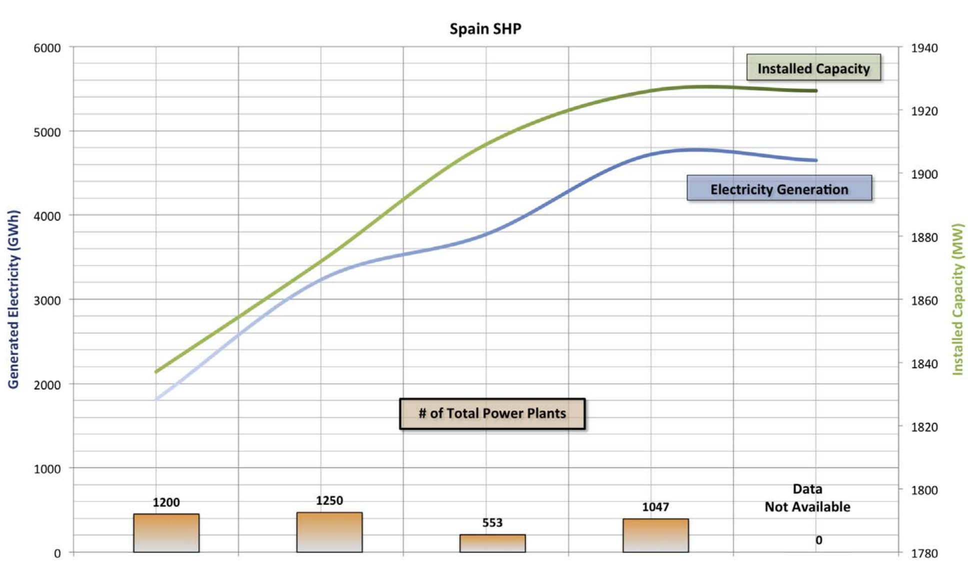

Fig. 13. Installed capacity, electricity generation and SHP in Spain.

During the period with focus on implementing large hydro, most of the micro and mini hydropower plants were closed down. The main reasons for these closing were the developing operation cost and the unreliable electricity production.

3. Small hydropower research in Europe

Between renewable energies, Hydropower is not the most studied as it has a very mature technology [12]. However the Small Hydropower Plants has been undergoing a resurgence of interest, e.g. to consider the irrigation networks role and estimate the hydropower potential of canal systems in Italy [39] or Middle east countries as Syria [40]. Mainly, it is being studied in many countries as a source of energy for rural electrification sections [41,42]. In the following sections an overview of research carried out in Europe is collected related to small hydropower.

3.1. Dam and penstock

Related to engineering field of SHP most of research are related to optimization, most of them related to the tuning criteria consider the elastic water column effects in the penstock [43]. [44] concludes that the analysis of penstock diameter shows that design for less than 10% head loss is likely to give the optimum economic choice. [45] studies the optimal hydroelectric facility for heights less than 2.5 m, as other authors conclude that conventional turbines are the most suitable for these pressures.

[46] studies a simple hydraulic problem in the penstock of a SHP in Valsan (Romania); this penstock was modeled in EPANET software, after the system was implemented, another series of measurements were performed at the site in order to validate it. They developed a system for detection and location of a breakdown, however it works accurately only in steady flow conditions of the system. The drive trains for most of the renewable energy systems include a gearbox to increase up to 30 times the speed of turbine shaft to the generator the speed increasers for hydro applications must have an acceptable efficiency, reduced overall dimensions, complexity and a reduced technological cost [47]. Most of Small hydropower facilities are “run-of-river”, this is without dam [48], for those inflatable weirs for dams can be useful in shp projects [49].

3.2. Turbines, pumps and generators

The main technologies used in an hydropower facility consist on: dammed reservoir, run of river, pumped storage, in stream technology and new technology gravitational vortex [50]. In this regard, in Europe, the research is focused on the main elements of electromechanical equipment that are: turbines, pumps and generators. Basically, there are two types of turbines: impulse turbines and reaction turbines. There are several types of impulse turbines: Turgo, Pelton and cross flow turbines. However, most reaction turbines are of axial flow turbine (Kaplan turbine) type. Reaction turbines have a better performance in low head and high flow sites compared to impulse turbines [51].

[52] renders in small-scale laboratory dam which adds a siphon turbine and a generator, this model allows a conceptual design without the need for computationally intensive co-optimization of components, optimizing speed and pressure parameters. [53] studies a mathematical model in which it disclose the use of a small siphon to remove air from the premises (Which is pumped independently) and increases the production of hydroelectric stations. [54] presents a kinetic hydropower for small channels, the device extracts energy from a flow of water using an elongated vertical axis turbine, where a series of sails are mounted between two belts at the top and bottom of the device, rotating in the horizontal plane. In Italy, Montanari in 2003 [55] investigates the curves of two types of pumps. The pumps (Michell-Banki) and the propeller pumps are analyzed with few variables in order to know the most economical configuration for small hydroelectric, concluding that is better to use a propeller turbine if the course of water is of sufficiently regular nature, whereas the (Michell-Banki) turbine is the preferred choice for torrential water courses. [56] in 2013, demonstrates in his article as a hydraulic auger used flow rates up to 5 m s^{-3} and heads up to 10 m, this equipment works by gravity with water producing torque on a transmission driving a generator connected to the auger in order to produce electricity it can get the same result from production of energy with a (Michell-Banki) turbine. In Germany, [57] investigates the use of a class of Doubly-Fed Induction Generators for the energy conversion process in SHS. Their simulation studies of a 600 kW induction generator shows that up to 6% gain in efficiency can be achieved. [58] presents also a new concept of a SHP with a Permanent Magnet Synchronous Generator (PMSG). The PMSG used in the proposed solution leads to a significantly better system performance over a wider operating range than conventional systems that use a gearbox and an induction generator. In Romania, [59] analyzes the influence of introducing a speed increaser between a Turgo turbine and the generator in a SHP. The generator is tested on experimental stands in order to find the mechanical characteristics and using (Matlab - Simulink) software; it guarantees the good functioning of the physical prototype of small hydropower plant in certain conditions. Focused on engineering research for SHP, [60] proposes a novel model design for SHP using linear and nonlinear turbine model without surge tank effects. This would be very useful as alternative controller for load frequency control in an isolated SHP. [61] proposes a parametric design-optimization procedure which consists of parametric geometry modeling, computational fluid dynamics analysis and structural verification for Francis type turbine. [62] studies how to minimize water hammer in networks of pipes of a hydroelectric plant through a computer program. This program was used to solve nonlinear partial differential equations of transient flow, proving that the risk of overpressure in hydroelectric facilities could be minimized. Related to this issue, [63] studies the water hammer in hydroelectric power plants, modeling a rigid and elastic water column, resulting in an optimum degree of inclination of the tank which minimizes water hammer. The water hammer is expected to occur due to sudden stoppage of pumps, therefore, the research on a pumped discharge line with joint use of protective devices against water hammer are issues to be investigated [64].

3.3. Control strategies and costs

In 2013, [65] investigates the power production that SHPs need for the proper operation of the Power System, for preparing bid offers in the electricity markets, and for the maintenance scheduling of these power plants. The Power System Operator needs to know in advance the variability in the hydro power production, especially if this production can experience significant ramps (increase or decrease greater than the 40% of the rated power) in very short periods (less than half an hour). These production ramps are due to the tariff schemes used in the electric energy production. On the other hand, the bid offers to the electricity market, from other producers, can depend on the intermittency in the SHPs production. The new statistical model proposed in his investigation, this uses forecasted precipitation values obtained with meteorological models, and utilizes them in the forecasting of the hourly average power production in SHPs. One of the main innovations in the model developed is the representation of the available hydraulic resource, by using an original index, that is, the hydrological power potential, HPP, which includes the inertia of the hydro-resource. This approach allows the modeling of the electric power production, with increases in the periods with precipitation, and decreases in dry periods. In Italy, [66] with seven technical and economic parameters were evaluated (the turbine type, the machine dimensions, the annual energy production, the maximum installation height to avoid cavitation inception, the machine cost...etc.) they developed a model based on the available flow that allows you to choose the optimum turbine. In Germany, [67] analyzes the appropriateness use of water wheels to exploit low pressures of water results as an effective solution with these optimal cost, properly designed overshot wheels having an efficiency of 85% and undershot wheels of approximately 75% for $0.2 < \frac{Q}{Q_{max}} < 1.0$. This makes this type of energy converter suitable for the exploitation of highly variable flows. In a subsequent investigation, [68] concludes that this efficiency could be 87% modeled after the waterfall. In Poland, [69] studies the concept of a energy conversion system for application in a SHP, where the RMS voltage and the frequency of the PM generator can change about $\pm 30\%$ with respect to nominal values since the hydro-set operates with variable speed; they proposed an original algorithm of control strategy for power electronic unit was used to adjust generated energy to the required parameters of the three-phase grid. In Romania, [70] studies how standard pumps can be used in hydro systems when installing or upgrading small hydropower plants and it shows that pumps operating backwards could compete with turbines, they are easy to find, for a large domain of head and discharge and the cost is low comparing to that of a turbine, allowing reduced investment costs for small hydropower plants or hydropower plants with low power output. Related to the engineering research in Spain, [71] develops different equations through which you can get the cost of modernization, renovation or new construction of a small hydroelectric no need to develop a complete project, the result of study will allow us to obtain quite approximate costs for the refurbishment of old hydropower plants, or the construction of new ones and [65] develops a novel short-term forecasting model for the next seven days (Named H4C) for hourly average electric power production of SHPs. In 2005, [72] presents planning models for hydraulic energy systems by means of a new computational tool based on a Geographic Information System (GIS). The developed software tool is flexible, appropriate for studying different scenarios, and can analyze geographically the economic competitiveness of a small hydraulic energy system compared with that of other generation systems. Turkey [3] studies the price offered for electro mechanic equipment is 385 eur/kW; this price also includes inlet valve, turbine (Francis Type), and electrical equipment, automatic control system, warning system, mounting, test and test operation. He concluded that Hydroelectricity could be produced for an average of 0.85 cents per kWh. [33] discusses the current situation of SHP plants in terms of government policy, economical aspects and environmental impacts taking EU policy into account. They conclude that investment and operating costs are in favor of SHP development in Turkey as having the lowest costs among European countries (300–1000 €/kW) as investment cost and 0.01 eur/kWh as operating cost, a little more expensive than a few years earlier studied [3].

The use of a multi-objective optimization model to maximize total hydropower production [73], while limiting negative impacts on river connectivity was studied in UK [74]. Thus, the development of small hydropower installations in Wales was examined to establish the economic and community benefits of such schemes [75]. Due to the infrastructure-related water flow dynamics of Dutch rivers, existing constructions such as weirs make opportunities for small hydropower facilities, due that they improve the water availability and allow control the water flow [76]. Small hydro power plants are characterized by investment costs that cannot be properly estimated, for that, a new approach based on power, net head and design flow rate was developed in Italy [77].

3.4. Social aspects

Many SHP articles wrote in UK are related to rural electrification or small town and sometimes in needy areas in developing countries [78]. Hydroelectricity can be an important contributor to meeting future energy needs, notably in developing countries where two billion people have no electricity supply [29]. [44] in 2009 concludes that mini hydroelectric power is the cheapest option in terms of energy production for rural electrification. Micro hydro scheme provides 25 kW of electrical power which serves almost 130 families [79]. In Portugal, [19] showed that the technical feasibility of the hydropower addition to the Coimbra dam-bridge; maintain its use as multi-purpose plant. The electricity produced is more than enough to supply the fleet of electric mini-buses and trolleys, allowing for the future expansion of this fleet. In addition to electricity production, the research in Austria [24] shows that SHPs help to optimize drinking water treatment process because it aids to aeration of water after it goes through the turbine and it has another benefit that is better mixing of additive with treated water after its distribution in the whole space of the contact tank.

The importance for energy policy for electricity sector in Turkey was studied using an integrated life cycle sustainability assessment and how tensions between different aspects can be reconciled to identify win-win solutions considering environmental, economic and social aspect [80]. These three spheres of sustainability (environmental, social and economic) were also studied to assess the best solutions for enhancing the production of renewable energy in the Alps, also considering small hydropower [81]. In South East Europe, this is for 9% of Europe's total population, achieving 100% renewable energy system also promises to be financially beneficial. Additionally, energy efficiency measures will play an important role in the transition to the zero-carbon energy society [82].

3.5. Environmental issues

Pinho et al. [83] investigates a review mechanisms EIA (Environmental Impact Assessment) and concludes that multidisciplinary teams in EIA studies, better understanding of the technical complexities of the projects under analysis with engineers, architects and project designers in EIA teams, availability of project specific EIA guidance, are all aspects that may prove decisive to an effective improvement of the quality of EIA reports. In Germany, [84] studies the installation a small reservoir of water equipped with a Dive turbine and a gate which determines the amount and degree of impact of falling water, which allows the sediment cleanup and disposal of fish by reducing the mortality of these. This is suitable in dams height to between 2 and 10 m, located in a river with an average discharge higher than 3 m s^{-1}. One of the main research related to small-scale hydroelectric power stations in France was the study of advantages and drawbacks of each type of fish pass, with reference to the requirements of migratory species and the site-specific constraints [21]. This study was applied in several countries such as Canada [85], Portugal [86], UK [87], Sweden [88] or Australia [89]. One of the main research done in Austria related to hydropower was related to ecology; how water entering the proglacial river from a hydropower storage reservoir caused significant increases in water temperature during both late summer and early winter and it is well known that Water temperature has a direct influence on the metabolism of many aquatic organisms and additionally affects freshwater ecosystems [90]. [91] provides a characterization of the water quality status in a river stretch around a SHP plant on river Lérez, northwest Spain, for four years after its construction the SHP plant caused an adverse effect in the ecosystem with respect of the physicochemical parameters and biological quality of the water (Temperature, Dissolved Oxygen and pH). However, this was a transitory situation and, within two years, both physicochemical parameters and the biological quality of the water achieved conditions that are ecologically compatible. [92] studies the ability of hydropower plants to quickly respond to short-term changes in electricity demand. So, associated to reservoirs with enough storage capacity, are usually operated to supply variable power during periods of peak demand. This provides operational flexibility to the electric grid and avoids to some extent the power level variations in thermal plants. However, these fluctuations in water levels associated to peaking operation can cause considerable ecological damage to downstream river ecosystems. [36] shows that Turkey's rate of energy-related carbon emissions growth, with emissions climbing from 57 million tons in 2000 to almost 210 million tons in 2020. [93] highlights the advantages of Hydroelectric for environment against other energies, because he reported that hydroelectric plants generally have small emissions of CO_2 and CH_4 due to reservoir emissions, and emit without SO_2, NO_X, particular materials, or other pollutants associated with combustion. Small hydropower in Norway [94] investigates how investments in renewable electricity production are affected by climate policy uncertainty which translates uncertainty into investment risk and [95] analyzes how market power might affect the allocation of production between seasons (Summer and Winter) in a hydropower system with reservoir constraints and inflow uncertainty.

Facilities based on Small hydropower have become especially attractive to lawmakers and developers alike because they use low-impact designs that have minimal cost and environmental impact compared to conventional hydropower ones [96]. Unfortunately, there are a lot of studies against the river flow regulation in Europe. E.g. Salmonid rivers in Austria are considerably regulated by small hydropower facilities, resulting in potential declines of the spawning habitats of salmonids [97]. Thus, small hydropower development in Europe has been hindered by regulations to address environmental concerns.

4. Results comparison

Table 2 summarizes de data of EU-25 for year 2010. The table is ordered first by Total installed capacity (MW). It can be observed that there are a group of countries with more than 1000 MW of SHP installed, with very different structure due the numbers of facilities (power plants). Thus, if one pay attention to the average of installed capacity by power plant, it is observed that Portugal leads with 2.9 MW by power plant, followed by Greece 2.03 MW and Finland 1.99 MW . Related to the efficiency, this is the average of Generation by facility, this is also lead by Portugal 8.84 GWh , followed this time by Finland and after 8.64 GWh by Greece 7.64 GWh .

Another important Issue is the employment; this is leaded by France with 12,000, and followed by UK 4,526 and Italy 3,000. If this is studied by the average of the facilities of each country, this is leaded by UK 37 employment in average by facility, followed by Hungary 13 and Netherland 11.

5. Conslusions

This paper summarized an overview of small hydropower and its research trends in Europe in order to prompt renewable resources, environmental and sustainability practices. Small hydropower is an option for rural electrification with the advantage to quickly respond to short-term changes in electricity demand in rural areas. The main producers of SHP electricity in Europe are Italy, France, Spain, Germany and Sweden. However, this is not the order of these countries as SHP research relates. The research leads that the ranking in Europe is as follows: Turkey, followed by UK and Portugal, these are countries with curiously little impact in terms of energy generated SHP. Related to the engineering research of small hydropower in Europe, the main research is developed by these countries: Turkey, UK, Portugal, Italy, Germany, Poland, Romania, Spain, and Norway. As for the electrical energy generated by the force of flaming water, technology used is still based on traditional turbines, robust and durable. Although hydropower technology is regarded as one of the most mature technology among all considered RESs, the research has focused on adapting the various types of turbines and facilities to the type of head and flow for optimum performance-cost production with low maintenance and high durability. Researchers mainly focus their efforts on improving returns covering areas such as reducing water hammer, to improve the performance of intermittent production due to rainfall and varying the voltage or frequency generator to improve the energy conversion. As a main conclusion, it is highlighted that small hydropower depends

Table 2
Comparison of SHP in EU-25 for year 2010.

Country	Total installed capacity (MW)	Generation (GWh)	Number of power plants	Mean (total installed/n)	Mean (generation/n)	Potential (GWh)*	Number of companies	Employment	Civil works (estimation)	Employment/N
Romania	387	719	274	1.41	2.62	1380	n/a	n/a	n/a	n/a
Slovakia	80	303	279	0.29	1.09	344	135	n/a	n/a	n/a
The Czech Republic	297	1159	1452	0.20	0.80	1153	640	n/a	n/a	n/a
UK	230	750	120	1.92	6.25	2353	226	4526	200	37.72
Hungary	14	67	36	0.39	1.86	58	11	476	n/a	13.22
The Netherlands	3	8	17	0.18	0.47	29	10	195	10	11.47
Portugal	450	1370	155	2.90	8.84	1908	305	1745	450	11.26
France	2110	6920	1935	1.09	3.58	4200	3000	12000	55	6.20
Bulgaria	263	630	136	1.93	4.63	919	15	695	450	5.11
Greece	195	753	96	2.03	7.84	5773	70	443	n/a	4.61
Slovenia	117	435	535	0.22	0.81	447	27	2325	25	4.35
Poland	275	1036	722	0.38	1.43	1928	380	2800	330	3.88
Ireland	42	160	50	0.84	3.20	227	31	124	20	2.48
Finland	302	1314	152	1.99	8.64	22	272	370	45	2.43
Latvia	26	69	142	0.18	0.49	226	116	318	10	2.24
Lithuania	29	93	87	0.33	1.07	129	56	140	15	1.61
Spain	1926	4719	1047	1.84	4.51	4757	384	1485	371	1.42
Italy	2735	10958	2427	1.13	4.52	10002	400	3000	n/a	1.24
Luxemburg	34	100	33	1.03	3.03	145	32	30	10	0.91
Estonia	8	30	47	0.17	0.64	42	26	42	10	0.89
Belgium	61	191	92	0.66	2.08	297	15	67	8	0.73
Austria	1109	4983	2589	0.43	1.92	7679	90	1057	257	0.41
Denmark	9.3	28	35	0.27	0.80	0	5	10	0	0.29
Sweden	1194	4571	1901	0.63	2.40	2450	380	520	120	0.27
Germany	1732	8043	7512	0.23	1.07	557	n/a	1900	1000	0.25

largely on already proven and developed technology. The research shows that there is considerable scope for development and optimization of this technology. This opens new perspectives because it has a huge, as yet untapped potential in most areas of Europe and can make a significant contribution to future energy needs.

Acknowledgements

The authors are grateful to CIAMBITAL (Research Center on Agricultural and Food Biotechnology), University of Almeria, for its support.

References

[1] Vilanova MRN, Balestieri JAP. Hydropower recovery in water supply systems: models and case study. Energy Convers Manag 2014;84(0):414–26. http://dx.doi.org/10.1016/j.enconman.2014.04.057, [URL ⟨http://www.sciencedirect.com/science/article/pii/S0196890414003616⟩].
[2] Yuksel O, Kaygusuz K. Small hydropower plants as a new and renewable energy source. Energy Sources B: Econ Plan Policy 2006;1(3):279–90, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-33747166757 & [#38;partnerID=40 & [#38;md5=2ccb91ac639e9e1773f481d015feed69⟩].
[3] Bakis R. Electricity production opportunities from multipurpose dams (case study). Renew Energy 2007;32(10):1723–38, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-33847416711 & [#38;partnerID=40 & [#38;md5=f9c9ff9b835d28e75ec203eaeb557e32⟩].
[4] Smith N. Key factors for the success of village hydro-electric programmes. Renew Energy 1994;5(5–8):1453–60, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-0028666290 & [#38;partnerID=40 & [#38;md5=0d2c3b3574ae69a2fdada22d29171732⟩].
[5] Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Kadner S, Zwickel T, et al. Renewable energy sources and climate change mitigation: special report of the intergovernmental panel on climate change. Cambridge University Press; 2011, [URL ⟨https://books.google.es/books?id=AjP9sVg01zoC⟩].
[6] Zimny J, Michalak P, Bielik S, Szczotka K. Directions in development of hydropower in the world, in europe and poland in the period 1995–2011. Renew Sustain Energy Rev 2013;21:117–30, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84873862104 & [#38;partnerID=40 & [#38;md5=0ef8ded2644727b808a992040e96bdb9⟩].
[7] Altinbilek D, Seelos K, Taylor R. Hydropower's role in delivering sustainability. Energy Environ 2005;16(5):815–24, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-25444440352 & [#38;partnerID=40 & [#38;md5=e70045e9aff27db7908ded77903fd20d⟩].
[8] Paish O. Small hydro power: technology and current status. Renew Sustain Energy Rev 2002;6(6):537–56, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-0036882632 & [#38;partnerID=40 & [#38;md5=9ad91014c4fa406385c99fe7bf770989⟩].
[9] Kaygusuz K. Sustainable development of hydroelectric power. Energy Sources 2002;24(9):803–16, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-0036731855 & [#38;partnerID=40 & [#38;md5=ca18bfc744a42ab43d4c0bc8be4ac4c1⟩].
[10] Gentle C, Smith N, Williams A. Enhancing the cost-effectiveness and sustainability of community pico hydro projects and programmes, Vol. 1, 2003, p. 274–280. URL ⟨http://www.scopus.com/inward/record.url?Eid=2-s2.0-2642563607 & partnerID=40 & md5=6d2e734e45ace2920a4b4bdd0af10f1b⟩
[11] Yuksel I. Development of hydropower: a case study in developing countries. Energy Sources, Part B: Econ, Plan Policy 2007;2(2):113–21, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-34548430101 & [#38;partnerID=40 & [#38;md5=14bdfb4f3a62ffcb77511f00e4597d32⟩].
[12] Manzano-Agugliaro F, Alcayde A, Montoya F, Zapata-Sierra A, Gil C. Scientific production of renewable energies worldwide: an overview. Renew Sustain Energy Rev 2013;18(0):134–43. http://dx.doi.org/10.1016/j.rser.2012.10.020, [URL ⟨http://www.sciencedirect.com/science/article/pii/S136403211200562X⟩].
[13] Hanmandlu M, Goyal H. Proposing a new advanced control technique for micro hydro power plants. Int J Electr Power Energy Syst 2008;30(4):272–82, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-41149095201 & [#38;partnerID=40 & [#38;md5=e3160a0adf9edb437b73ac875bf34feb⟩].
[14] ESHA. (ESHA). accessed on may 2015, 2012. [link]. URL ⟨http://www.esha.be/⟩
[15] Malesios C, Arabatzis G. Small hydropower stations in greece: the local people's attitudes in a mountainous prefecture. Renew Sustain Energy Rev 2010;14(9):X2492–2510, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-77956550083 & [#38;partnerID=40 & [#38;md5=e54209bc258afa1cfa2944c5db473583⟩].
[16] Osborne J. When small is beautiful: boom time for small hydro?. Refocus 2002;3(4):46–8, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-15844380286 & [#38;partnerID=40 & [#38;md5=b13b73f789d17504728d78b5c55a5ce9⟩].
[17] Bartle A, Hallowes G. Hydroelectric power: present role and future prospects. Proc Inst Civ Eng: Civ Eng 2005;158(6):28–31, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-27844565273 & [#38;partnerID=40 & [#38;md5=a8bc485815ab6eedd4c992eb06797ce7⟩].
[18] Paish O. Micro-hydropower: status and prospects. Proc Inst Mech Eng, Part A: J Power Energy 2002;216(1):31–40, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-0036228124 & [#38;partnerID=40 & [#38;md5=1377939d96afd974b7f607e71af4327e⟩].
[19] de Almeida A, Inverno C, Santos L. Integration of renewable energies for trolleybus and mini-bus lines in coimbra. World Electric Vehicle Journal 3 (1). URL ⟨http://www.scopus.com/inward/record.url?Eid=2-s2.0-79953041599 & partnerID=40 & md5=4420f15022586deaed0eff4773d62c57⟩
[20] Pang M, Zhang L, Ulgiati S, Wang C. Ecological impacts of small hydropower in china: insights from an emergy analysis of a case plant. Energy Policy 2015;76:112–22. http://dx.doi.org/10.1016/j.enpol.2014.10.009, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84919471802 & [#38;partnerID=40 & [#38;md5=68b91a4353f1192db492aea7ec86a806⟩].
[21] Larinier M. Fish passage experience at small-scale hydro-electric power plants in france. Hydrobiologia 2008;609(1):97–108. http://dx.doi.org/10.1007/s10750-008-9398-9, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-45749159051 & [#38;partnerID=40 & [#38;md5=4652079215619425c7b1d41e06c80736⟩].
[22] Punys P, Baublys R, Kasiulis E, Vaisvila A, Pelikan B, Steller J. Assessment of renewable electricity generation by pumped storage power plants in eu member states. Renew Sustain Energy Rev 2013;26:190–200, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84879294162 & [#38;partnerID=40 & [#38;md5=48143898d5336185ccd602e64a46c7d7⟩].
[23] Safta C, Marinov A, Dumitran G, Popa B. Clean and sustainable electric energy in romania. WIT Trans Ecol Environ 2013;176:3–15, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84887580597 & [#38;partnerID=40 & [#38;md5=0a66a751676091588dbf8fc96e37fb3d⟩].
[24] Gono R, Novak M, Gono M, Kyncl M. Utilization of small hydropower. 2013, p. 348–351. http://dx.doi.org/10.1109/EEEIC.2013.6737934. URL ⟨http://www.scopus.com/inward/record.url?Eid=2-s2.0-84897730979 & partnerID=40 & md5=d27e7ad5077d7e94e0e792f9b74a4dcc⟩
[25] Stangar U, Kranjcevic E. Renewable energy sources in slovenia: facts and plans. In: Hanjalic K, Van de Krol R, Lekic A, editors. Sustainable energy technologies. Netherlands: Springer; 2008. p. 251–9. http://dx.doi.org/10.1007/978-1-4020-6724-2_14, [URL ⟨http://dx.doi.org/10.1007/978-1-4020-6724-2_14⟩].
[26] Perers R, Lundin U, Leijon M. Development of synchronous generators for swedish hydropower: a review. Renew Sustain Energy Rev 2007;11(5):1008–17. http://dx.doi.org/10.1016/j.rser.2005.07.007, [URL ⟨http://www.sciencedirect.com/science/article/pii/S1364032105000936⟩].
[27] Thorburn K, Leijon M. Case study of upgrading potential for a small hydro power station. Renew Energy 2005;30(7):1091–9. http://dx.doi.org/10.1016/j.renene.2004.08.006, [URL ⟨http://www.sciencedirect.com/science/article/pii/S0960148104003374⟩].
[28] Araujo J, Tato E, Lopez A. The development of renewable energies in galicia 1980–2008, engasa, an outstanding reference of the sector. Rev Galeg- De Econ 2010;19(1):1–23, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-77956954061 & [#38;partnerID=40 & [#38;md5=9e172e8516dbd5e1e3bb2c409eb3f580⟩].
[29] Klimpt J-E, Rivero C, Puranen H, Koch F. Recommendations for sustainable hydroelectric development. Energy Policy 2002;30(14):1305–12, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-0036830730 & [#38;partnerID=40 & [#38;md5=9caa020074e17fdd291b7ee165d26cb5⟩].
[30] Alonso-Tristan C, Gonzalez-Peña D, Diez-Mediavilla M, Rodriguez-Amigo M, Garcia-Calderon T. Small hydropower plants in spain: a case study. Renew Sustain Energy Rev 2011;15(6):2729–35, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-79955501266 & [#38;partnerID=40 & [#38;md5=13c0100c8c103a139dcac109dbe1adaf⟩].
[31] Balat H. A renewable perspective for sustainable energy development in turkey: the case of small hydropower plants. Renew Sustain Energy Rev 2007;11(9):2152–65, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-34250873376 & [#38;partnerID=40 & [#38;md5=ac6742d78db181dfbcf1cdf9ec344269⟩].
[32] Uzlu E, Akpinar A, Komurcu M. Restructuring of turkey's electricity market and the share of hydropower energy: the case of the eastern black sea basin. Renew Energy 2011;36(2):676–88, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-77957354334 & [#38;partnerID=40 & [#38;md5=4c7d29b6b2006961024aa9753a74a289⟩].
[33] Kucukali S, Baris K. Assessment of small hydropower (shp) development in turkey: laws, regulations and eu policy perspective. Energy Policy 2009;37(10):3872–9, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-69949127333 & [#38;partnerID=40 & [#38;md5=ca542a96b4369c78007e9ad8ccd2a459⟩].
[34] Yuksel O, Komurcu M, Yuksel I, Kaygusuz K. The role of hydropower in meeting turkey's electric energy demand. Energy Policy 2006;34(17):3093–103, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-33747186086 & [#38;partnerID=40 & [#38;md5=85850f8994300c2ec63c60ed7dbbcf76⟩].
[35] Yuksel I. Energy production and sustainable energy policies in turkey. Renew Energy 2010;35(7):1469–76, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-77349117988 & [#38;partnerID=40 & [#38;md5=13f739c117f82898c0c7af52b13fd711⟩].
[36] Yuksel I. Global warming and environmental benefits of hydroelectric for sustainable energy in turkey. Renew Sustain Energy Rev 2012;16(6):3816–25, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84860217326 & [#38;partnerID=40 & [#38;md5=2fca0946a1da9b43c67005e7b51b5a9c⟩].
[37] Capik M, Osman Ylmaz A, Cavusoglu I. Hydropower for sustainable energy development in turkey: the small hydropower case of the eastern black sea region. Renew Sustain Energy Rev 2012;16(8):6160–72, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84865490006 & [#38;partnerID=40 &

[#38;md5=6cf3d43e7bfcffb7d01727d9c82f7665〉].
[38] EEMR. Authority, Electicity market report. Tech rep, accessed on may 2015; 2010.
[39] Butera I, Balestra R. Estimation of the hydropower potential of irrigation networks. Renew Sustain Energy Rev 2015;48:140–51. http://dx.doi.org/10.1016/j.rser.2015.03.046, [URL 〈https://www.scopus.com/inward/record.uri?eid=2-s2.0-84926371023 & [#38;partnerID=40 & [#38;md5=700f728c8b4343944cab658434116771〉].
[40] Bitar Z, Khamis I, Alsaka Z, Jabi S. Pre-feasibility study for construction of mini hydro power plant, Vol. 74; 2015:404–13. http://dx.doi.org/10.1016/j.egypro.2015.07.638 URL 〈https://www.scopus.com/inward/record.uri?Eid=2-s2.0-84948427760 & partnerID=40 & md5=a1342fdaf65157a322db5da40e38e2bb〉
[41] Izadyar N, Ong HC, Chong W, Leong K. Resource assessment of the renewable energy potential for a remote area: a review. Renew Sustain Energy Rev 2016;62:908–23.
[42] Zhang L, Pang M, Wang C, Ulgiati S. Environmental sustainability of small hydropower schemes in tibet: an emergy-based comparative analysis. J Clean Prod 2016;135:97–104.
[43] Sarasúa JI, Pérez-Díaz JI, Wilhelmi JR, ÃÁngel Sánchez-Fernández J. Dynamic response and governor tuning of a long penstock pumped-storage hydropower plant equipped with a pump-turbine and a doubly fed induction generator. Energy Convers Manag 2015;106:151–64. http://dx.doi.org/10.1016/j.enconman.2015.09.030, [URL 〈http://www.sciencedirect.com/science/article/pii/S0196890415008663〉].
[44] Williams A, Simpson R. Pico hydro - reducing technical risks for rural electrification. Renew Energy 2009;34(8):1986–91, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-64549085953 & [#38;partnerID=40 & [#38;md5=7b3a86d8e674811330809f274758bf9d〉].
[45] Senior J, Saenger N, Muller G. New hydropower converters for very low-head differences. J Hydraul Res 2010;48(6):703–14, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-78650430644 & [#38;partnerID=40 & [#38;md5=a01fa12d57fb941cfc8f87db44076f83〉].
[46] Georgescu A, Cosoiu C, Alboiu N, Hlevca D, Tataroiu R, Popescu O. Penstock failure detection system at the Â«valsanÂ» hydro power plant. Vol. 15, 2012. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-84874032511 & partnerID=40 & md5=6fb395a936e46cac80176919490f81c8〉
[47] Jaliu C, Saulescu R, Diaconescu D, Neagoe M. Conceptual design of a chain speed increaser for small hydropower stations. Vol. 6, 2009, p. 321–328. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-82155201833 & partnerID=40 & md5=b2e925cecbc338bfd31d77d5bcb91380〉
[48] Sachdev HS, Akella AK, Kumar N. Analysis and evaluation of small hydropower plants: a bibliographical survey. Renew Sustain Energy Rev 2015;51:1013–22.
[49] Islam S, Kumar A. Inflatable dams for shp projects. Renew Sustain Energy Rev 2016;57:945–52. http://dx.doi.org/10.1016/j.rser.2015.12.115, [cited By 0, URL 〈https://www.scopus.com/inward/record.uri?eid=2-s2.0-84953807203 & [#38;partnerID=40 & [#38;md5=6d6f2913fb13ec795ea532254425b5d1〉].
[50] Elbatran A, Abdel-Hamed M, Yaakob O, Ahmed Y, Arif Ismail M. Hydro power and turbine systems reviews. J Teknol 2015;74(5):83–90, [URL 〈https://www.scopus.com/inward/record.uri?eid=2-s2.0-84930014801 & [#38;partnerID=40 & [#38;md5=24fa775084543429365e689d24565b7c〉].
[51] Elbatran A, Yaakob O, Ahmed YM, Shabara H. Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: a review. Renew Sustain Energy Rev 2015;43:40–50.
[52] Stark B, Ando E, Hartley G. Modelling and performance of a small siphonic hydropower system. Renew Energy 2011;36(9):2451–64, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-79954611136 & [#38;partnerID=40 & [#38;md5=926fcceeb38a4c0ea4cd43cecd109990〉].
[53] Howey D, Pullen K. Hydraulic air pumps for low-head hydropower. Proc Inst Mech Eng, Part A: J Power Energy 2009;223(2):115–25, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-64249160783 & [#38;partnerID=40 & [#38;md5=0eea97d787a2a623cbd0afef56a3204c〉].
[54] Van Arkel R, Owen L, Allison S, Tryfonas T, Winter A, Entwistle R, et al. Design and preliminary testing of a novel concept low depth hydropower device; 2011. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-84855775064 & partnerID=40 & md5=75308feea725e3e5952d55222ee5e291〉
[55] Montanari R. Criteria for the economic planning of a low power hydroelectric plant. Renew Energy 2003;28(13):2129–45, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-0038681897 & [#38;partnerID=40 & [#38;md5=734a92bc9ec0de077c98d23592d23f44〉].
[56] Perillo G. Small hydroelectric plants: the hydraulic auger. WIT Trans Ecol Environ 2013;173:551–62, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-84878179278 & [#38;partnerID=40 & [#38;md5=ad2de3543575d579cdabe74f9792aee0〉].
[57] Okafor F, Hofmann W. Modelling and control of slip power recovery schemes for small hydro power stations. Vol. 2: 2004:1053–1058. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-20744445812 & partnerID=40 & md5=d199dfbf638a35fdbde03098c05e52d0〉
[58] Borkowski D, Wegiel T. Small hydropower plant with integrated turbine-generators working at variable speed. IEEE Trans Energy Convers 2013;28(2):452–9, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-84877920715 & [#38;partnerID=40 & [#38;md5=7701c359362623b5c22f3222a8c643df〉].
[59] Jaliu C, Saulescu R, Diaconescu D, Neagoe M. Conceptual design of a chain speed increaser for small hydropower stations. Vol. 6; 2010:321–328. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-77953741715 & partnerID=40 & md5=eb0581b834458f06693920c819735cc5〉
[60] Ozbay E, Gencoglu M, Load frequency control for small hydro power plants using adaptive fuzzy controller; 2010:4217–4223. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-78751490028 & partnerID=40 & md5=46beb30c6dd8d943c1ff70beadc58eb3〉
[61] Celebioglu K, Okyay G, Yildiz M. Design of a francis turbine for a small hydro power project in turkey. Vol. 3; 2010:483–492. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-79956146272 & partnerID=40 & md5=93dee17ef97730a64bed9a28d486bfc5〉
[62] Calamak M, Bozkus Z. Protective measures against waterhammer in run-of-river hydropower plants. Tek Dergi/Tech J Turk Chamb Civ Eng 2012;23(December):1623–36, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-84873891366 & [#38;partnerID=40 & [#38;md5=b82a7f7ca2f32508d425e3123a0b66bb〉].
[63] Kendir T, Ozdamar A. Numerical and experimental investigation of optimum surge tank forms in hydroelectric power plants. Renew Energy 2013;60:323–31, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-84878907591 & [#38;partnerID=40 & [#38;md5=cac0a3ca8f5d22f73f4217a7ff2baefb〉].
[64] Rezaei V, Calamak M, Bozkus Z. Performance of a pumped discharge line with combined application of protection devices against water hammer. KSCE J Civ Eng 2016:1–8.
[65] Monteiro C, Ramirez-Rosado I, Fernandez-Jimenez L. Short-term forecasting model for electric power production of small-hydro power plants. Renew Energy 2013;50:387–94, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-84864340581 & [#38;partnerID=40 & [#38;md5=e625803bdaa0f5f0963d5b0b90d0f70f〉].
[66] Santolin A, Cavazzini G, Pavesi G, Ardizzon G, Rossetti A. Techno-economical method for the capacity sizing of a small hydropower plant. Energy Convers Manag 2011;52(7):2533–41, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-79952777728 & [#38;partnerID=40 & [#38;md5=6879f1affc4747d39037f9979fc4a7a1〉].
[67] Muller G, Kauppert K. Performance characteristics of water wheels. J Hydraul Res 2004;42(5):451–60, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-7444266740 & [#38;partnerID=40 & [#38;md5=8b24669cdc515ec9d533624511fcf138〉].
[68] Muller G, Becker T. The breast shot water wheel as energy converter for low head differences. WasserWirtschaft 2005;95(6):8–13, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-21344437043 & [#38;partnerID=40 & [#38;md5=50d634563b069f28b8a6289d9d43a649〉].
[69] Sobczyk T, Mazgaj W, Szular Z, Wegiel T. Energy conversion in small water plants with variable speed pm generator. Arch Electr Eng 2011;60(2):159–68, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-82555173745 & [#38;partnerID=40 & [#38;md5=32f0fcc2276a535d3cde97be34b1dcab〉].
[70] Bucur D, Tanase N, Ghergu C, Isbasoiu E. Alternative for small hydraulic turbines, UPB Scientific Bulletin, Series D. Mech Eng 2010;72(1):85–92, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-77951578244 & [#38;partnerID=40 & [#38;md5=65f5747cff15b93149cb4a6079fefabc〉].
[71] Ogayar B, Vidal P, Hernandez J. Analysis of the cost for the refurbishment of small hydropower plants. Renew Energy 2009;34(11):2501–9, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-67149141836 & [#38;partnerID=40 & [#38;md5=5112fb54dbfca13c27b69c89a9f107c2〉].
[72] Ramirez-Rosado I, Zorzano-Santamaria P, Fernandez-Jimenez L, Garcia-Garrido E, Zorzano-Alba E, Lara-Santillan P., et al. Hydropower systems planning in distribution networks based on gis. 2005, p. 268–273. URL 〈http://www.scopus.com/inward/record.url?Eid=2-s2.0-30644463504 & partnerID=40 & md5=7c18907821850531606ce099e4392c7b〉
[73] Banos R, Manzano-Agugliaro F, Montoya F, Gil C, Alcayde A, Gómez J. Optimization methods applied to renewable and sustainable energy: a review. Renew Sustain Energy Rev 2011;15(4):1753–66.
[74] Ioannidou C, OH´anley JR. Eco-friendly location of small hydropower. Eur J Oper Res 2016. http://dx.doi.org/10.1016/j.ejor.2016.06.067, [URL 〈http://www.sciencedirect.com/science/article/pii/S0377221716305264〉].
[75] Bere J, Jones C, Jones S, Munday M. Energy and development in the periphery: a regional perspective on small hydropower projects. Environ Plan C: Gov Policy 2016, [0263774×16662029].
[76] Manders TN, Haffken JI, van der Vleuten EB. Small-scale hydropower in the netherlands: problems and strategies of system builders. Renew Sustain Energy Rev 2016;59:1493–503. http://dx.doi.org/10.1016/j.rser.2015.12.100, [URL 〈http://www.sciencedirect.com/science/article/pii/S1364032115014835〉].
[77] Cavazzini G, Santolin A, Pavesi G, Ardizzon G. Accurate estimation model for small and micro hydropower plants costs in hybrid energy systems modelling. Energy 2016;103:746–57.
[78] Fulford D, Mosley P, Gill E. Recommendations on the use of micro-hydro power in rural development. J Int Dev 2000;12(7):975–83, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-0033675034 & [#38;partnerID=40 & [#38;md5=acd0c102ffdad2fe0af1da39e7849242〉].
[79] Sanchez T. Bringing water power to the poor. Int Water Power Dam Constr 2010;62(7):16–7, [URL 〈http://www.scopus.com/inward/record.url?eid=2-s2.0-78649294873 & [#38;partnerID=40 & [#38;md5=fe7eca7a0e1b502fad0fa5be706d1d03〉].
[80] Atilgan B, Azapagic A. An integrated life cycle sustainability assessment of electricity generation in turkey. Energy Policy 2016;93:168–86. http://dx.doi.org/10.1016/j.enpol.2016.02.055, [URL 〈http://www.sciencedirect.com/science/article/pii/S030142151630091X〉].
[81] Grilli G, De Meo I, Garegnani G, Paletto A. A multi-criteria framework to assess the sustainability of renewable energy development in the alps. J Environ Plan Manag 2016:1–20.
[82] Dominkovic D, Backovic I, Cosic B, KrajaÄic G, Puksec T, Duic N, et al. Zero carbon energy system of south east europe in 2050. Appl Energy 2016. http://

dx.doi.org/10.1016/j.apenergy.2016.03.046, [URL ⟨http://www.sciencedirect.com/science/article/pii/S030626191630366X⟩].
[83] Pinho P, Maia R, Monterroso A. The quality of portuguese environmental impact studies: the case of small hydropower projects. Environ Impact Assess Rev 2007;27(3):189–205, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-33947096525 & [#38;partnerID=40 & [#38;md5=f378d5595d22e18e662bc3375ab0f7ca⟩].
[84] Lucchetti E, Barbier J, Araneo R. Assessment of the technical usable potential of the tum shaft hydro power plant on the aurino river, italy. Renew Energy 2013;60:648–54, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84880145912 & [#38;partnerID=40 & [#38;md5=168061956bec5bfc82e397f30cb8a73e⟩].
[85] A. Baki, D. Zhu, N. Rajaratnam, Turbulence characteristics in a rock-ramp-type sh pass, Journal of Hydraulic Engineering 141 (2). doi:10.1061/(ASCE)HY.1943-7900.0000962. ⟨http://www.scopus.com/inward/record.url?Eid=2-s2.0-84921503137 & partnerID=40 & md5=5d26350315f49a36ff45c6976d0521bd⟩
[86] Santos J, Branco P, Katopodis C, Ferreira T, Pinheiro A. Retrofitting pool-and-weir fishways to improve passage performance of benthic fishes: effect of boulder density and fishway discharge. Ecol Eng 2014;73:335–44. http://dx.doi.org/10.1016/j.ecoleng.2014.09.065, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84907857946 & [#38;partnerID=40 & [#38;md5=2de977e7bdad0fb00bde416f47e82c09⟩].
[87] Bracken L, Bulkeley H, Maynard C. Micro-hydro power in the uk: the role of communities in an emerging energy resource. Energy Policy 2014;68:92–101. http://dx.doi.org/10.1016/j.enpol.2013.12.046, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84896781218 & [#38;partnerID=40 & [#38;md5=0cf41d9214f532ca64018a4d0dfabd8d⟩].
[88] Calles O, Karlsson S, Vezza P, Comoglio C, Tielman J. Success of a low-sloping rack for improving downstream passage of silver eels at a hydroelectric plant. Freshw Biol 2013;58(10):2168–79. http://dx.doi.org/10.1111/fwb.12199, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84883273477 & [#38;partnerID=40 & [#38;md5=4c451a7db31609289a415c4cce0e61e9⟩].
[89] Boys C, Robinson W, Baumgartner L, Rampano B, Lowry M. In uence of approach velocity and mesh size on the entrainment and contact of a lowland river fish assemblage at a screened irrigation pump. PLoS ONE 8 (6). http://dx.doi.org/10.1371/journal.pone.0067026 URL ⟨http://www.scopus.com/inward/record.url?Eid=2-s2.0-84879252087 & partnerID=40 & md5=a3fc488f43fff812714cc6d7254a787f⟩
[90] Dickson NE, Carrivick JL, Brown LE. Flow regulation alters alpine river thermal regimes. J Hydrol 2012;464–465(0):505–16. http://dx.doi.org/10.1016/j.jhydrol.2012.07.044, [URL ⟨http://www.sciencedirect.com/science/article/pii/S0022169412006610⟩].
[91] Valero E. Characterization of the water quality status on a stretch of river lorez around a small hydroelectric power station. Water (Switz) 2012;4(4):815–34, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84878742412 & [#38;partnerID=40 & [#38;md5=da38cf0c6a7bdd1d77ba2482cf8255bf⟩].
[92] Sarasua J, Fraile-Ardanuy J, Perez J, Wilhelmi J, Sanchez J. Control of a run of river small hydro power plant; 2007:672–77. URL ⟨http://www.scopus.com/inward/record.url?Eid=2-s2.0-79951639983 & partnerID=40 & md5=c2efd0f781a9d0b3e9bf4f699f2bee30⟩
[93] Kaygusuz K. Hydropower and the world's energy future. Energy Sources 2004;26(3):215–24, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-1242287850 & [#38;partnerID=40 & [#38;md5=a3d4b8bfd5bbfa8634546144a5b30f8d⟩].
[94] Fleten S-E, Ringen G. New renewable electricity capacity under uncertainty: The potential in norway; 2006. URL ⟨http://www.scopus.com/inward/record.url?Eid=2-s2.0-46149112612 & partnerID=40 & md5=80c60e8d0c40edf00139c13ec8555613⟩
[95] Mathiesen L, Skaar J, Sargard L. Electricity production in a hydro system with a reservoir constraint*. Scand J Econ 2013;115(2):575–94, [URL ⟨http://www.scopus.com/inward/record.url?eid=2-s2.0-84876078274 & [#38;partnerID=40 & [#38;md5=74925fc973b3e725dff5fb1e1d459412⟩].
[96] Krause C, Koziol E, Merrill M. Incorporating small-scale hydropower projects into our energy future. Nat Resour Environ 2016;30(4):3.
[97] Obruca W, Hauer C. Abiotic characterization of brown trout (Salmo trutta f. fario) and rainbow trout (Oncorhynchus mykiss) spawning redds affected by small hydropower plants-case studies from austria. River Research and Applications.