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Prospects and Challenges of Small Hydropower Development in Jordan

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Abstract

Jordan's energy balance is largely dominated by combustible fuels. However, the country is well endowed with solar, wind and oil shale resources, in addition to large and small-scale hydropower projects. Based on available data and the current analysis, it is believed that there are at least 6-10 candidate sites in the western part of Jordan and 2-3 locations in the eastern plateau, which could be developed as small hydro plants, with a combined potential of more than 33 MW. At present, only two sites, namely King Talal Dam and Aqaba Thermal Power Plant, have been developed to be operational from 1980's. A major barrier to starting small scale hydro power projects is an understanding of how much the scheme will cost. This paper provides also an overview of the setbacks that inhibit the smooth investment and operation of small hydropower plants in Jordan. It is estimated that installing small hydropower schemes on the most promising existing dams will generate more than 200 GWh/year of electric energy without effecting the natural environment. In addition, there are another few sites, still under study, that may be developed in the future as small hydro plants.

Keywords: Small hydropower; Pumped storage; Power generation; Renewable energy; GHG emission; Jordan

1. The Problem

Despite being adjacent to oil-rich countries, Jordan has no significant fossil resources of its own. In 2010, Jordan produced 136.4 thousand tons of oil equivalent (ktoe) of natural gas and 1.2 ktoe of crude oil, while it consumed 3,440.7 ktoe of crude oil and 2,288.7 ktoe of natural gas, which clearly illustrates that Jordan is heavily dependent on oil imports to fulfill its domestic energy needs in the transport, industrial, domestic heating, and power sectors [1]. The 2003 Iraq invasion disrupted Jordan's primary oil supply route from its eastern neighbor, which prior to the war provided the Kingdom with highly discounted crude oil via the road truck route. Since late 2003, an alternative supply from the regional market at international prices has been established; Saudi Arabia is now Jordan's primary source of imported oil, with Kuwait and the United Arab Emirates following. The completion of the first phase of the Arab Gas Pipeline in 2003 was an important milestone in reducing dependence on refined products and crude oil, allowing Egyptian natural gas to reach various power plants in Jordan, thereby reducing the local cost of power production [2]. However, and after the recent political developments in Egypt, there were several cuts and major shortages in gas supplies due to terrorist attacks against the main pipeline in the Sinai Peninsula. Supply has been cut for more than 120 days during the last year, and total gas quantities received by Jordan were less than 20% of that agreed upon [3]. But the Egyptian government agreed to substitute for the lost quantities of natural gas over a period of three years starting from 2013 depending on the technical situation at their side. However, the Government of Egypt insisted on amending the favorable pricing agreement between the two countries under which Jordan received natural gas for less than half the international market price. During the past 2-3 years, the national power generation level was critical, and sometimes felled short behind the national demand, especially during the summer season [4]. In the near future, Jordan will remain a net importer of oil and natural gas from the Arab neighboring countries, especially Saudi Arabia and Kuwait as well as electricity from Egypt, to meet peak-load and sometimes part of base-load. Thus, the current situation presents an ideal environment for development of renewables including hydropower sources, particularly small hydropower (SHP) sources whose financial and technical demands can be met by small investors from within or without the country with relative ease.

The Government of Jordan plans to promote the continued development of the country's overall energy sector to best enable it to accommodate changing market conditions, and in particular, the rapidly growing local demand for electricity and refined petroleum products. One of the primary objectives of Jordan's Energy Master Plan is to further increase private sector investment in the development of the energy sector over the next 20 years [5]. The plan was approved by the Council of Ministers in December 2004, and its 2007 updated version calls for an estimated investment of US$ 13 to 17 billion from 2007 to 2020, which would be financed by the private sector across

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the downstream, electricity, natural gas, oil shale, and renewable energy. Implementation of the plan is expected to stimulate further growth in the Jordanian economy and will create a number of investment opportunities which will be structured to encourage and promote private sector participation. The plan aims to reduce the reliance on imported products from the current level of approximately 96%, with a goal for renewable energy meeting 10% of energy demand by 2020 and nuclear energy providing a significant portion of new electricity capacity by 2035. It also addresses the required investment cost from the private sector and reforms needed within the energy sector for improved market competition. As a part of this plan, Temporary Law #3 of 2010, The Renewable Energy and Energy Efficiency Law (REEL), was released in early 2010 to define Jordan's plans to introduce renewable energy generation to the local sector [6]. Primary objectives of the REEL include: (i) increasing the contribution of renewable energy to the total energy mix in Jordan; and (ii) promoting and exploiting renewable energy for environmental protection and sustainable development purposes. Rules and regulations to guide implementation of the REEL are still under development. The Government of Jordan, with the assistance of donors such as USAID, USTDA, and the World Bank, is currently in the process of further defining the required regulation and technical considerations, and is identifying potential funding sources to enable the development of these assets.

The electricity demand of in Jordan is growing rapidly at high rates, of about 7% during the last two decades, and expected to continue in the near future since the social and economic structure is still developing. Several attempts have been made by the consecutive governments to enhance the utilization of indigenous natural sources and to promote the utilization of renewable energy resources, including hydro power, in order to increase electricity production, which will help decreasing dependence on foreign energy supplies. Recently the Government of Jordan through the Ministry of Energy and Mineral Resources (MEMR) announced for interested investors in renewable energy power generation projects to submit an expression of interest before July 28, 2011, on the basis of build, own and operate (BOO). Investors were invited to express interest in developing only one type of renewable energy source and technology in this round. Received proposals were evaluated in late April 2012 and 34 companies selected as qualified investors based on financial position and experience in raising sufficient debt participation and substantial equity participation for power projects, technical capability and past experience in similar projects. MEMR is in the process of preparing memorandum of understanding (MOU) with these companies on individual basis to conduct the needed detailed feasibility studies and submit proposals, including the financial terms, to MEMR within next 24-36 months [7].

Jordan will face major challenges in trying to meet the growing energy and especially electricity, while, concurrently, developing the energy sector in a way that ensures reducing the adverse impacts on the economy, the environment and social life. Fast depleting fossils fuels and their environmental effects forces to look towards renewable sources for sustainable development. Among all renewable sources, SHP is one of the promising sources for sustainable water and energy development. The geography of Jordan supports the development of small hydro plants to enhance power generation from renewable sources. SHP development is also necessary for proper utilization of available limited water resources. The present study has been carried out as a preliminary attempt to highlight the potential of SHP plants in Jordan.

This paper is structured as follows: section 2 introduces the basic concept and technology of SHP; section 3 serves as background and reviews SHP systems. In section 4, the adopted methodology is presented and basic assumptions employed in the current investigation. A detailed argument of the potential of SHP plants and estimated installed power for most promising sites are discussed in section 5, while the following section 6 concludes main findings of his study.

2. What is Small Hydropower?

Small hydropower is a key element for sustainable development due to the following reasons [8-11]:

- SHP is a renewable source of energy: small hydropower meets the definition of renewable because it uses the energy of flowing water repeatedly generates electricity without fear of depletion.
- SHP is a cost effective and sustainable source of energy: simple and less expensive construction work and in expensive equipment are required to establish and operate small hydropower projects. The cost of electricity generation is inflation free. Also, the gestation period is short and the schemes give financial returns quickly.
- Proper utilization of water resources: various streams and rivers can safely provide energy to run a small hydro electric plant. No big water storage is required in such projects which prevents resettlement and rehabilitation of the population.
- SHP aids in conserving scarce fossil fuels: no fossil fuels and other petroleum products are required in small hydro electric project. SHP replaces the fossil-fired generation of electricity.
- Clean and non-polluting source: SHP projects are known for low carbon energy production. Small hydro is a pollution free source for electricity generation and environmental problems like GHG emissions, acid rain are not associated with it. The development of small hydro has low effect on the environment. In SHP, no big storage is formed and rehabilitation of population is not required as in case of large hydropower projects.
- Development of rural and remote areas: in remote and hilly areas, sources for development of small hydro are found in abundance. SHP development provides electricity, transportation, communication links and economy to such rural areas.
- Other uses: SHP also gives additional benefits along with power generation such as irrigation, water supply, flood prevention, fisheries and tourism.

In general, SHP schemes are classified into two main types: (i) utilizing small discharges but high heads, and (ii) utilizing large discharges but low heads. Such features have strong influence on the nature of the power station for a specific site. In high head units the discharges being small, the physical size of the plant required is also small. In the second type, as the flow rates are relatively high, the size of the generating unit and the power station is consequently quite big. Also for the latter type, proper arrangements for entry of water and its discharge are required to be made. The SHP development of the first type is usually used in mountainous regions and characterized by relatively very simple features. The civil works involved comprise a small structure to divert the flow of the water stream/river, and generally the 'run of river' water-falls is utilized. The power is generally consumed near the site of generation, but could be connected to a transmission network. In the second type, as the heads available are rather low and discharges have to be comparatively larger to be economically viable, their development can only take place on small rivers, irrigation outlets, canal falls, etc., and the power output is generally connected to the national grid via a transmission line. Another scheme that could be included here is the pumped storage, which aims to store electric energy in the form of hydraulic potential energy. Pumping typically takes place mainly during off-peak periods, when electricity demand is low and electricity prices are low. Generation takes place during peak periods, when electricity system demand is high. Pumping and generating generally follow a daily cycle but weekly or even seasonal cycling is also possible with larger plants. The benefits of such schemes to the electrical system operations are well documented in textbooks and journals [12-16]. Its flexible generation can provide both up and down regulation in the power system while its quick start capabilities make it suitable for black starts and provision of spinning and standing reserve. In terms of operational characteristics and flexibility, a gas turbine peaking plant such as open cycle gas turbine offer some similar power system operation services, but at a higher capital cost [17].

As the name implies, SHP is a smaller version of the large hydro schemes. In the open literature, there is no internationally accepted formal definition of small hydro in place as yet, though it is generally taken as a power plant having an average output of about 25 MW or less [8]. Different agencies use different upper limits for micro and mini hydro projects ranging from 0.1 MW to 2 MW for the micro and >2 MW to 50 MW for mini hydro. However, it looks that a ceiling value of 10 MW, which could be sufficient to power 10 thousand houses, or 50-60 thousand inhabitants and a community centre, based on average of 1 kW per house and a typical diversity factor, is becoming more generally accepted for mini hydro projects, especially in the European countries, i.e. The European Small Hydropower Association (ESHA). At the lower end of the scale, technology is available to utilize discharges as small as 200 l/s, heads down to 1 m, and a power output of just 0.001kW with reasonable cost. Some researchers classify very small (<5kW) units as 'pica-hydro'. According to the Indian Ministry of New and Renewable Energy (MNRE), small hydropower stations are classified as shown in Table 1: Similar classification is adopted in the UK and other countries [8,18-20]

The hydro turbines convert water pressure into mechanical shaft power that can be used to drive an electric generator. The power available is proportional to the product of head and flow rate. In a typical SHP scheme, water is taken from the stream/river by diverting it through an intake weir. The weir is a man made structure constructed across the water stream/river, which maintains a continuous flow through the intake. The water passes through a desilting tank in which the water is slowed down sufficiently for suspended particles to settle down before descending to the turbine. In medium or high-head installations, water is carried to the forebay by a canal. In low-head installations, generally, water entering the turbine directly from the weir. A pressure pipe, known as a penstock, conveys the water from the forebay to the turbine. All installations need to have a valve or gate at the top of the penstock to control the flow. The hydraulic efficiency of water turbines is high with an average of about 90% [21-23].

Table 1: Classification of small hydro power plants according to capacity & head.

Capacity (kW)	Head (m)
Micro, up to 100	Ultra low, less than 3
Mini, between 101 and 1000	Low, more than 3 up to 40
Small, more than 1000 up to 25000	Medium/high, more than 40

3. Background

Initially, hydropower was specifically used in water wheels for lifting water up from the water source, e.g. river, to a water supply network, irrigation, mills and other mechanical applications. But during the last century it became an efficient source for power generation, and the development of hydropower was usually associated with building large dams. Large number of massive barriers of concrete, rock and earth were placed across river valleys, world-wide, to create huge manmade water reservoirs. While these created a steady power supply in addition to irrigation and flood control benefits. But dams, in most cases, flooded large areas of fertile land and displaced millions of local inhabitants. In many cases rapid silting up of the dam has reduced its productivity and lifetime. There are also numerous environmental problems that can result from such major interference with stream/river flows. However, at present the exploitation of large hydro sources is mainly saturated, especially in developed countries. Further construction of large hydropower plants is often burdened with the unacceptable high investments, and/or undesirable environmental consequences. Hence, in recent years, a wide interest and activity is directed towards the utilization of energy potentials of small streams, and building SHP plants, as well as towards other natural hydropower sources, such as sea waves [24].

The small hydro energy generation is environment friendly and it is very useful for generating electricity in rural and urban areas: it is certainly the most mature application of renewable technologies. Approximately 22% of the world's power generation comes from hydropower installations, many of which are SHP plants

[25]. There is no international consensus on the definition of small hydropower. However, a capacity of up to 10 MW total is becoming the generally accepted norm in different countries [12-15]. SHP plants have found an extensive application in electricity production both in EU, USA and other countries, and deserve a special attention regarding its huge economically feasible potential. Such resource has been harnessed for more than 100 years in most of EU countries. China and India also achieved a considerable success in SHP development [8-11,26]. In China, which is the leading country worldwide in terms using SHP units, about 19 thousand micro-hydropower plants with a total installed capacity of 687 MW and a slightly higher similar number of mini-hydropower plants with a total installed capacity of 7171 MW were constructed between 1994 and 2004 [11]. Moreover, small hydropower could be harnessed at several hydraulic structures where power generation is not the main aim of the use of water [27]. These hydraulic structures are: water supply dams, irrigation canals, wastewater treatment plants, weirs, and water cooling systems in thermal power plants. For example, In Switzerland, 80 SHP plants were installed on the municipal water supply systems of the country [28]. The advantages of these systems compared to a stream/river-type hydropower plants could be summarized as follows: (i) all civil works are present which will reduce the investment cost 50%, (ii) it has a capacity factor about 85% which provides two times higher annual energy with the same installed capacity of a stream/river-type hydropower plant (iii) the generated electricity will be used in the water treatment plant and the excess electricity will be sold to the grid, (iv) there is no land acquisition and operating cost.

Within the region Turkey and Iran have good potential of hydropower. In Turkey the estimated total hydropower potential is about 433 TWh that accounts for almost 1.1% of the total hydropower potential of the world and approximately 14% of the European hydropower potential. But only 130 TWh of the total hydroelectric potential of Turkey can be used economically. In 2007 almost 18% of total annual electricity production in Turkey, which is equal to 35TWh/yr, i.e. about 27% of economical hydropower potential, was provided by hydropower plants. By the commissioning of new hydropower plants, which are under construction, 43% of the economically usable potential of the country would be exploited [20,29]. Recently the Iranian government embarked upon a joint venture with the Chinese government for establishing micro hydro plants, a number of which are at present operating at different points of the country and work is still going on to install more SHP units [30].

Although it is reported in the open literature that Asia leads the world as the biggest small hydropower generating continent, still the gap is large between available resources and the existing SHP projects. For example, India has SHP of about 15,000 MW, which is considered only a tenth of it has been tapped so far. Indonesia has an estimated SHP of 500 MW but only 5 MW has been installed and just 1 MW is being actually used. Bangladesh has a SHP of close to 10,000 MW but almost zero utilization. Other countries, including the world's fastest growing economics, India and Brazil, are putting in place increasingly ambitious plans to tap their SHP. Alongside wind energy, SHP is the fastest growing renewable energy option for electricity supplies in Canada. The European Union's new member states have only about a tenth of small hydro capacity compared to the old EU-15 nations, but plans are afoot to increase it substantially [8,9,11,18,20].

The increase in prices of fossil fuels and their impact on the environment has made hydropower a more important and attractive energy source. Of all the renewable sources of energy, water seems the best choice, and small hydropower development seems the most cost-effective and reliable energy technology to be considered for providing clean electricity generation. In particular, the key advantages that small hydro has over other renewable sources, such as wind, biomass and solar power are:

- High efficiency of between 70 and 90 %, by far the best of all energy technologies.
- High capacity factor of about 50 %, compared with 10% for solar and 30% for wind.
- High level of predictability, varying with annual rainfall patterns.
- Slow rate of change; the output power varies only gradually from day to day, but not from second to second.
- It is a long-lasting and robust technology; systems can readily be engineered to last for 50 years or more.
- It can be integrated with fishing, drinking and irrigation water projects, in order to share the costs between different beneficiaries.

Jordan has some good geographical locations with small and big potential of water resources, but small hydro development is an important step for conservation of water resources and sustainable development in the country. The possibilities and scope of enhancement of SHP in Jordan was attempted to explore in the present study. This article introduces the potential of hydropower in Jordan from the following aspects: potential, economy, environment and society as well as assesses their existing problems, and then demonstrates that Jordan must accelerate the development of such resources and other renewable projects in order to realize the sustainable development of economy, environment and society.

4. Methodology

The traditional approach in electric power generation is to have centralized plants distributing electricity through an extensive transmission and distribution networks. Distributed generation provides electric power at a site closer to the customer, eliminating the unnecessary transmission and distribution losses and costs. In addition, it can reduce emissions resulting from fossil fuel combustion, defer capital cost, and reduce maintenance and investments. The decision to develop a hydropower project is usually made on economic grounds, but other factors such as environmental, cultural and physical characteristics of the site and the costs and availability of technological and engineering solutions are also important. While the capital costs of a hydro plant installation is high, operating and maintenance costs are low, which means that a large proportion of the project's overall budget will be spent at the development stage. It is therefore important to balance the cost installation against the magnitude and speed of energy output (and its value) to evaluate whether the project is worth pursuing, and if so, to plan the subsequent budget. The viability of each hydro project is site-specific and dependent on the local characteristics. The amount of the power produced depends on water flow, hydraulic head and the efficiency of the employed device, but it should be remembered that the flow will vary through the year and hence the generated power and efficiency will change in response to this variation.

In this work, a preliminary analysis of the potential sites was undertaken for the western highland region in Jordan, including site visits, scheme layouts, and scheme costing as well as economic evaluation. Based on limited data for the studied sites, a flow duration curve was produced for each site using a tailor made computer program, specially developed for this purpose. After the average flow and head were estimated, then the scheme capacity, for each site, was projected. The capacity (power, kW) is computed using the following basic model.

$$\text{Power (kW)} = \eta_t \rho_w g Q h \eta_g \quad (1)$$

ηt the hydraulic efficiency of the turbine (%)
γw the specific weight of water (9.81 kN/m^3)
Q the discharge rate (m3/s)
H the head of water acting on the turbine (m)
ηg the efficiency of the electric generator (%)

The annual power generation E (kWh/year) of a hydropower plant is obtained from

$$E = P\, t \quad (2)$$

t is the operation of hours through a year

The design head of the power plant was selected as the average water level of the reservoir for a specific site. The actual electric energy generation cost is about 0.15 US $/kWh in Jordan for the year 2011; this value was used in determining the economic benefit of the hydropower plant [7]. Several studies have been carried out to analyze the costs of hydro plant development depending on the hydraulic characteristics of a given site. Due to diversification in layout/configuration of SHP plants, a number of cost equations were developed to suit the site conditions. It was found that number of contributions exists for determining the installation cost using the head and capacity as cost influencing parameter. Similarly different optimization approaches have been used and implemented to obtain the optimum investment required for installation of the plant [31-34]. It is observed that for the optimization of investment, different methods have been used carried out simple techniques; however it is recommended to use evolutionary algorithm and other new techniques for the optimization of investment. But in this study, the relationship between the overall costs of the SHP project and the hydraulic characteristics of a site is given by the following empirical models [34]:

For heads between 2-30 m

$$C\text{ (US\$)} = 37{,}500\ (kW/h^{0.35})^{0.65} \quad (3)$$

and for heads between 30-200 m

$$C\text{ (US\$)} = 67{,}000\ (kW/h^{0.30})^{0.60} \quad (4)$$

It is worth mentioning here that no high heads, e. g. waterfalls, are available in Jordan, and thus the empirical for high heads, Equation 4, will not be used in the current study. A computer based costing package was developed and used to estimate the capacity, annual power generation, avoided GHG emissions and total cost of each scheme excluding the transmission cost for each of the studied sites, in Jordan. The basic assumptions employed in this investigation are (i) average operating time 6000 hrs/yr, (ii) average hydraulic head for all existing dams will be taken as 15 m, and about 10 m for the proposed new dams, and (iii) turbine hydraulic efficiency is 80 %, regardless of the type of turbine, and electric generator efficiency is 90 %.

As stated previously energy and development are closely intertwined and increasing fossil fuel-based power generation contributes significantly to environmental problems on national and international levels. The power sub-sector, in Jordan, is facing problems of high electricity demand as well as regulation on gaseous emissions, in addition to security of fuel supplies, especially the imported natural gas from Egypt. Thus, it is crucial to find sustainable generation methods with high efficiency and availability. Following this criteria there are few possibilities of power generation, in Jordan, such as solar, wind, small hydropower and oil shale based power plants. Hydropower schemes can contribute with a cheap source, as well as to encourage the development of small industries across a wide range of new technologies. The energy of flowing water is a renewable and clean source of electricity. SHP systems allow achieving self-sufficiency by using the best possible scarce natural resource that is the water, as a decentralized and low-cost of energy production. In this paper the prospects of SHP, in Jordan, are presented and evaluated.

5. Potential of Small Hydro in Jordan

In Jordan, hydropower sources are limited due to the fact that the surface water resources, such as rivers and falls, are almost negligible. However, currently there are two SHP schemes. The first one is King Talal dam spanning the river Zarqa, with a rated electricity-generating capacity of about 5 MW. The other scheme is at the Aqaba thermal power station, where the hydro-turbine utilizing the available head of returning cooling seawater with a capacity of 5 MW [35]. The total amount of electricity generated, in 2010, by hydro-units was about 61 GWh, i.e. less than 0.5% of the total national electricity generation [36]. Such low ratio of utilization could be attributed to many reasons, but the most important being lacks both financial and technical capacity to develop its own conventional hydroelectricity potential. However, there is a great possibility to generate electricity, using hydropower stations, by exploiting the elevation difference between the Red and Dead Seas. The latter is the lowest region on earth with water-surface of 400 m below normal sea level. If seawater is allowed to follow from the Gulf of Aqaba into the Dead Sea through a canal/pipeline system at predetermined rates, it will produce electricity from hydropower stations and potable water from seawater desalination plants. While, this project is expected to help in establishing new economic activities, such as tourism and agriculture, it ensures supply of large amounts of highly needed electricity and water as well as the renewal of the Dead Sea water by making up the evaporated water. The latter will dictate the amount of electricity generated annually. Preliminary pre-feasibility reports showed that it is possible to build hydropower stations with a total capacity of about 800 MW, or more [37]. But the required capital investment is extremely high due to the long canal, i.e. about 200 km, and necessary infrastructure.

The work in the current study is focused in the western region, i.e. mountains region, of Jordan, where almost all water sources and/or collection systems are located. Both of the Ministry of Energy and Mineral Resources and Ministry of Water and Irrigation should strongly believe that mini-hydro or pumped storage plants and related facilities are considered as energy projects. But there are other important dimensions such as improved agriculture, cultivation, water harvesting and irrigation as well as tourism and recreation activities in the developed areas which would benefit from the additional power generation. Table 2 below summarizes capacities of existing dams, while Table 3 provide the same information for the proposed dams which are under study till now. As can be seen in Table 3 that only the hydro potential of one dam, i.e. King Talal, has been utilized to generate electricity with a rated capacity of 5 MW. It is considered as a SHP scheme.

Table 2: Average flows of existing main dams in Jordan [38].

Name / Location	Average Annual Flow (10^6 m^3/yr)		Hydropower Utilization	
	In	Out	Yes	No
Al Wahdah / Irbid	13.0	5.0		x
Al Arab / Nothern Shuonah	10.0	11.5		x
Sharhabiel / Northern Jordan Valley	5.1	5.8		x
King Talal / Jerash	92.2	92.3	x	
Wadi Shuiaib / Southern Shounah	6.1	6.3		x
Kafrain / Southern Shounah	11.3	11.3		x
Karameh / Southern Shounah	2.1	0.5		x
Tanoor / Jordan Valley	4.1	1.3		x
Waleh / Madaba	6.6	8.7		x
Mojeb / Karak	3.o	16.0		x

At present, all other existing dams are being utilized as storage reservoirs to meet water demand during the long dry summer season. But almost all of these sites are suitable to be upgraded as SHP and/or pumped storage schemes since they are located in hilly areas in the western part of the country, where annual precipitation exceeds 400 mm and may reach 600 mm with some snow in some areas. Evaluating the case of a pumped storage system for each site is very difficult at this stage, since its features and characteristics are site specific, e.g. topography, average annual flow, etc., for each site. Thus, it would be impossible in this study to assess the potential of such schemes, in Jordan, and it is recommended that future work should investigate such possibility and address the feasibility of pumped storage systems as part of the energy management plan in the country. The proposed small dams, under study by the Ministry of Water and Irrigation, listed in Table 3, may represent an opportunity for implementing SHP systems. However, most of these sites are not developed yet, and would take long leading time before seeing the light.

Table 3: Storage capacity for the proposed small dams in Jordan [38].

Name / Location	Proposed Storage Capacity (10^6 m^3)	Status as of Early 2010
Maa'in / Madaba	1.0	Under study
Lajjun / Karak	1.0	Under study
Dalaghah / Tafila	1.0	Under study
Shuthim / Tafila	1.0	Under study
Kufranjah / Ajlun	9.0	Under study
Bin Hammad	5.0	Under study
Wahidi / Maa'n	1.8	Under study
Wadi Karak / Karak	2.1	Updating studies
Bayer / Eastern desert	4.0	Completed
Jafer / Southern desert	0.5	Under construction
Rukban / North eastern desert	2.0	Completed
Khanasree / Mafraq	1.0	Under construction
Ghadaf / Central desert	0.5	Completed

The flows of main small rivers and streams, in Jordan, that may have good potential in terms of hydropower generation are shown in Table 4. These small streams could be developed in the future as SHP projects. However, the final selection of the most promising sites requires detailed and careful assessment for all of the proposed sites before the final decision of developing any of these sites. It should be stressed here that it is not the aim of this paper to design SHP schemes in Jordan; rather it provides a preliminary assessment of the potential for hydropower generation in the studied sites. All of the reported sites are located in rural areas, and thus SHP projects are an ideal energy option for these areas because of its low operational, maintenance and repair costs. Even though the cost per unit electricity from standalone hydropower plants may be higher than that from the national grid, they present a category of energy which could substantially contribute to poverty reduction in rural households. Furthermore, small hydropower development could offer a leading renewable alternative for meeting electricity demand in remote and mountainous parts of Jordan. The advantages and attractiveness of these small hydropower plants are that they can either be stand-alone or in a hybrid combination with other renewable energy sources, such as solar and/or wind farms. The latter, could be integrated with existing dams to form a pumped storage scheme. Further, advantage can be derived from association with other uses of water, e.g. water supply, irrigation, flood control, etc., which are critical to the future economic and socio-economic development of Jordan. SHP plants are not generally affected by the constraints associated with large hydro projects: they are more environmentally and ecologically acceptable. Large scale hydropower development is becoming a challenge due to environmental and socio-economic concerns, and more recently its vulnerability to changing climates. In addition, investment in large hydroelectricity generation requires substantial upfront investment capital.

Table 4: Average annual flow of main small streams in Jordan [38].

Name / Location	Average Annual Flow Rate (10^6 m^3)
Yarmook / Irbid	32
Mukhaibah / Northern Shounah	32
Zeqlab / Northern Shounah	5
Kufranjah / Ajlun	4
Zerqa / Jerash	82
Wadi Shuiaib / Southern Shounah	6
Wadi Kafrain / Southern Shounah	11
Hussban / Amman	1
Northern Wadis / Northern desert	2
Wadi Hassa / Tafila	25
Wadi Viva / Southern Jordan Valley	4
Wadi Khanzereh / Irbid	2
Bin Hmmad / Karak	8
Wadi Karak / Karak	3
Wadi Thera' / Karak	2

Worldwide, hydropower is still the most efficient way to generate electricity. Modern hydro turbines can convert as much as 90 % of the available energy into electricity while the efficiency of the best fossil fuel plant is only about 50 %, or even less. Additionally, hydropower is an outstanding source to generate electricity in all over the world and will seemingly keep on growing especially in the developing countries. The calculated hydropower potential for the existing small dams and the proposed ones is shown in Tables 5 and 6, respectively. The total potential for the first group is around 33 MW and the annual electricity production may reach 200 GWh, i.e. approximately 1.5 % of the national electricity generation in the year 2010. While the total potential of the second group is much less and estimated at only about 14 MW with possible annual electricity production of about 90 GWh. The annual income due to sales of electrical power would yield US$ 20-30 million and approximately US$ 9-13 million, following the agreed upon feed-in-tariff of between US$ 0.1-0.15 per kWh generated, for the existing and proposed dams, respectively. The expected required investment is relatively high and varies between 1,500 and 2,500 US$ per kW installed, or more in certain cases depending on the specific site. This is considered a high investment when compared with only about 1000 US$ per kW for conventional systems. This is considered as the main obstacle for harnessing the potential of SHP in Jordan. Equally important is the lack of awareness and well to develop such resources among different stakeholders, especially the concerned governmental institutions.

Table 5: Estimated hydropower generation for existing dams.

Name / Location	Estimated Hydropower Potential (kW)	Projected Energy Generation Potential (MWh/yr)
Al Wahdah / Irbid	2,500	15,000
Al Arab / Nothern Shuonah	5,750	34,500
Sharhabiel / Jordan Valley	2,900	17,400
Wadi Shuiaib / Southern Shounah	3,150	18,900
Kafrain / Southern Shounah	5,650	33,900
Karameh / Southern Shounah	250	1,500
Tanoor / Jordan Valley	650	3,900
Waleh / Madaba	4,350	2,6100
Mojeb / Karak	8,000	48,000

Table 6: Projected potential of hydropower generation for proposed dams.

Name / Location	Estimated Hydropower Potential (kW)	Projected Energy Generation Potential (MWh/yr)
Maa'in / Madaba	500	3000
Lajjun / Karak	500	3000
Dalaghah / Tafila	500	3000
Shuthim / Tafila	500	3000
Kufranjah / Ajlun	4500	27000
Bin Hammad	2500	15000
Wahidi / Maa'n	900	5400
Wadi Karak / Karak	1050	6300
Bayer / Eastern desert	2000	12000
Jafer / Southern desert	250	1500
Rukban / North eastern desert	1000	6000
Khanasree / Mafraq	500	3000
Ghadaf / Central desert	250	1500

The obvious benefits of hydropower projects in Jordan, or in any other country where hydropower potential exists, is associated with the generation of electrical power, which has the ability to both assist the sustainable economical development and increase the quality of life. Furthermore, they are labor-intensive during construction, as well as providing long term employment opportunities. Another benefit of exploiting water resources is the environmental concerns, since it is considered as clean and green energy source, releasing no harmful gas emissions as in conventional power stations. With the increasing scarcity of fossil fuel resources, the demand for greenhouse gas reduction and environmental protection all over the world, developing hydropower becomes one of the most important energy strategies. According to statistics, SO2 emissions are about 20 million tons per year, 50% of which are from thermal power [39]. The construction of these projects in Jordan would reduce fuel consumption by about 75 thousand ton/yr of heavy fuel or diesel oil, which costs between US$ 50-60 million, as well as saving at least 2,000 tons of SO2 emissions. In addition, it will help to prevent the discontinuous flow and improve ecosystem as well as reduce floodwater damage in certain locations. Based on the average weighted emission rate from the power sub-sector in Jordan [2], the avoided GHG emission would be between 80,000-100,000 tons for the case of the existing dams and for the proposed dams between 35,000-45,000 tons. Such reduction in GHG emission by using SHP schemes is inevitable and considered as CDM projects, which would yield a net annual income of between US$ 1.2-1.5 million and US$ 0.5-0.7 million for the existing and proposed dams, respectively.

As stated in the national energy strategy, the Government Jordan is committed to increase the sharing ratio of indigenous energy resources, including renewable sources and oil shale, from the current level of less than 0.5 % of the total electricity generation to reach around 10 % from the total installed capacity as outlined in the updated nation energy strategy by the year 2020 [5]. The future development of SHP, including pumped storage, projects would involve different institutions in Jordan, mainly Ministry of Energy and Mineral Resources, Ministry of Water and Irrigation, Jordan Valley Authority, etc., thus, the legal framework and institutional arrangements, e.g. public-private partnership, for the implementation of the identified small hydro projects should be studied and developed soon. Although the SHP projects will focus on power generation from small hydro units and pumped storage schemes, it should address other important issues such as better water management, irrigation, agriculture and possible tourism and recreation activities in the future. But it should be mentioned here that the Government of Jordan has not recognized the important role that mini-hydro plants can play in improving the energy situation in the country and no real effort is paid to develop those sites that have been identified in the current study. Moreover, the absence of targeted incentives for private development of small hydropower is a major barrier. SHP hydro plants are starved of funding, as conventional financiers prefer to fund large scale hydro projects. Thus, The Ministry of Energy and Mineral Resources, Ministry of Water and Irrigation, Electricity Regulatory Commission, etc., should work hard with other concerned institutions on encouraging investors in developing renewable energy projects, including SHP schemes. This will lower the costs of providing electricity as well as increasing security of supplies due to reduced imports of oil and gas as well as pollutant emissions.

The lack of local specialization to undertake feasibility studies for SHP projects, detailed studies that would include design, construction and costing of the schemes to make a meaningful impact on utilization of small hydro sites, contributes to the high costs of procuring the services, and the delays in developing such projects. Waste water treatment plants, e.g. Samra Waste Water Treatment Plant, with electricity as an add-on component are good candidates for multi-purpose projects. Such a multi-purpose project is seen to be more favorable to international financiers than pure electricity supply projects. The present legislations allow for independent power producers (IPPs) to operate in the county, therefore there is no threat to international partners willing to operate SHP plants. One of the main duties of the Ministry of Energy and Mineral Resources and the Electricity Regulatory Commission is to work with other concerned institutions on encouraging investors in developing renewable energy projects, including SHP schemes. This will lower the costs of providing electricity as well as increasing security of supplies due to reduced imports of oil and gas.

To summarize, it can be said that there are candidate sites, i.e. dams and water bodies, which warrant further detailed study and investigation. It is believed that there are at least 6-10 candidate sites in the western part of Jordan and at least 2-3 in the eastern plateau, mainly desert dams, which could be developed as SHP plants. However, further detailed technical and financial studies with certain and clear criteria are required before deciding on any of the presented sites in this study. It may be a good idea that the concerned governmental institutions seek assistance from international donors, such as World Bank, EU, GTZ, JICA, etc., in order to provide technical expertise as well as financial resources needed to develop SHP schemes and other renewable energy projects in Jordan.

6. Conclusion

Jordan is a rapidly growing country regarding its economy and population and therefore has a large and continuously increasing energy demand, and mostly meets its energy demand from imported fossil sources. However apart from petroleum and natural gas, Jordan has vast amounts of various kinds of energy resources, i.e. oil shale, solar and wind, hence it would not need to meet its energy demand through import. In addition, Jordan has a good potential of hydraulic energy but to date only small portion of this significant economical potential was used. In this paper the role of small hydroelectric power, its potential and its present status are investigated in detail for Jordan. The following concluding remarks may be drawn from this research paper:

- Although, Jordan has limited surface water resources, hydropower energy is an important energy source since it is renewable, clean, and less impactful on the environment as well as it is a cheap and domestic energy source.
- The average exploitable potential of the country is estimated at about 33 MW, for the existing dams, therefore, hydropower may possesses sufficient and suitable characteristics which would contribute in maintaining sustainable development through different means: flood control, irrigation, recreation activities as well as supply water for people’s daily life and social life.
- It is apparent that the consecutive government(s) did not recognize the important role that small hydro plants can play in improving the energy situation in the country and no real effort was paid to develop the most promising sites in the country, which have been reported in this study.
- Small hydropower development could offer a leading renewable alternative for meeting electricity demand in remote and mountainous parts of Jordan. The advantages and attractiveness of these small

hydropower plants are that they can either be stand-alone or in a hybrid combination with other renewable energy sources.

Given their high investment costs, the profitability of small hydropower plant projects is a general issue and follows the situation in the local market. But as the future cost of such systems is subject to high uncertainty, this is considered as major barrier that may hinder their utilization in Jordan.

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