Small hydropower for renewable energy and water efficiency in Turkey

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Abstract. Because of social and economic development, the demand for energy and particularly for electricity is growing rapidly in Turkey. The main indigenous energy resources are hydro and lignite. Turkey has no big oil and gas reserves. Almost all oil natural gas (NG) and high quality coal are imported. It has a large potential for renewable energies. Hydroelectricity is well established as one of the principal energy-producing technologies around world, providing some 20 % of the world's electricity. In the developing countries, the proportion rises to around 40-50%. The capacity of large hydroelectric schemes can be several times that of a conventional power station. They are highly efficient, reliable, and long lasting. Turkey has an abundant hydropower potential to be used for generation of electricity and must increase hydropower production in the near future. For these reasons, hydropower and especially small hydropower are emphasized as Turkey's renewable energy sources. In this paper, to increase production of hydroelectric energy, some streams which are in the different basins in Turkey, have been analysed and some conclusions obtained from this study have been presented.

1 Water resources in Turkey

The annual average precipitation in Turkey is estimated at 643 mm, corresponding to a volume of 500 km^3 (Table 1). The average runoff coefficient is 0.37, and the annual runoff is 186 km^3 (2400 m^3/ha). Subtracting from this figure the estimated water rights of neighbouring countries, minimum stream flow requirements for pollution control, aquatic life and navigation, and topographic and geologic constraints, the annual consumable water potential of 12 km^3 should be added to this, bringing the total annual consumable potential to 107 km^3 [1].

Precipitation differs considerably both from year to year and among the river basins. The annual depth of precipitation is as high as 250 cm in the Eastern Black Sea Region, and as low as 30 cm in some parts of Central Anatolia. Most of the country's water potential

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lies in the south-east (28 %) and the Black Sea region (8 %). Turkey's water resources can be considered in 26 drainage basins.

Table 1. Water resources in Turkey.

Water Resources	**Value**
Mean annual precipitation	642.6 mm
Volume of the mean annual precipitation	501 km^3
Surface Water	
Annual flow	186.05 km^3
Annual run-off coefficient	0.37
Present annual consumption	27.5 km^3
Groundwater	
Annual safe yield	12.2 km^3
Allocated amount	7.6 km^3
Present annual consumption	6.0 km^3

2 General review of hydroelectric power potential

Turkey's geographic location has several advantages for extensive use of most of the renewable energy sources. It is on the humid and warm climatic belt, which includes most of Europe, the near East and western Asia [2]. After 2001, the Turkish government began privatizing some of its electricity generating and distribution networks, and allowing for more private construction and ownership in the sector.

Owing to Turkey's regions, most of which are hilly, it can be possible to develop relatively higher heads without expensive civil engineering works, so that relatively smaller flows are required to develop for the desired power. In these cases, it may be possible to construct a relatively simple diversion structure and to obtain the highest drop by diverting flows at the top of a waterfall.

There are intensive investigations to improve the small and large hydropower development in Turkey and some of small hydropower plants are still under construction in order to put this aim into practice.

Turkey's annual total gross, technically feasible and economically feasible hydropower potentials calculated by General Directorate of State Hydraulics Works (DSI) are 435, 215 and 128 tWh, respectively. 35 % of the economically feasible hydropower, total 45 155 gWh/year is in operation, 8 % (10 129 gWh/year) is under construction and 57 % (72 339 gWh/year) is being designed.

According to findings of a study carried out by Bakir [3], in which a new criterion was developed related to key concept of "the economical feasibility", by taking into consideration some undervalued benefits of hydro plants and some overvalued benefits of thermal power plants; economically feasible hydropower potential goes up 188 tWh/year, with an increase ratio of 47 % compared to DSI value. Turkey's hydropower potential according to DSI and the new developed criteria (by Bakir) together with installed power values are given in Table 2.

Table 2. Turkey's annual hydropower potential according to DSI and Bakir.

Basin	**Gross Pot. (gWh)**	**Potential According to DSI**		**Potential Acc. to Bakir**	
		Econ. Feasib. Pot. (gWh)	**Installed Power (mW)**	**Econ. Feasib. Pot. (gWh)**	**Installed Power (mW)**
Firat (Euphrates)	84 122	39 375	10 345	46 267	12 176
Dicle (Tigris)	48 706	17 375	5 416	24 353	7 610
Eastern Black Sea	48 478	11 474	3 257	24 239	6 925
Eastern Meditt.	27 445	5 216	1 490	10 978	3 137
Antalya	23 079	5 355	1 537	9 232	2 638
Coruh	22 601	10 933	3 361	12 431	3 825
Ceyhan	22 163	4 825	1 515	8 865	2 860
Seyhan	20 875	7 853	2 146	9 394	2 609
Kizilirmak	19 552	6 555	2 245	7 821	2 697
Yesilirmak	18 685	5 494	1 350	8 408	2 213
Western Black Sea	17 914	2 257	669	7 166	2 108
Western Meditt.	13 595	2 628	723	5 438	1 511
Aras	13 114	2 372	631	5 246	1 418
Sakarya	11 335	2 461	1 175	3 967	1 984
Susurluk	10 573	1 662	544	2 643	881
Others (Total)	30 744	1 788	546	1 721	507
Total	432 981	127 623	36 950	188 169	55 099

3 Prediction of Turkey's long term electric energy demand

A demand prediction model, called "Model for Assessment of Energy Demand" (MAED) was used to predict Turkey's long term electric energy demand. This model, prepared by International Atom Energy Agency (IAEA), is a simulation model which evaluate mid and long term energy demands. MAED evaluates future energy needs based on mediumto long term scenarios of socioeconomic, technological and demographic development in a country or region.

The electric energy demand varies according to various parameters. The main parameters to affect the energy demand are: Gross National Product (GNP); population and demographic variations; development in housing, industry, agriculture and transportation sectors; income per capita; climatic conditions; employment, technological development, etc.

Three kinds of planning scenario were applied in the model and MAED Model was executed for three scenarios and Turkey's annual electric energy demand values were predicted from 2004 to 2020. According to the results of the study, Turkey's annual electric energy demand in 2020 is predicted between 407 to 571 tWh [4].

4 Small hydropower in Turkey

The development of hydro-electricity in the 20th century was usually associated with the building of large dams. Hundreds of massive barriers of concrete, rock and earth were placed across river valleys world-wide to create huge artificial lakes. While they created a major, reliable power supply, plus irrigation and flood control benefits, the dams necessarily flooded large areas of fertile land and displaced many thousands of local inhabitants. In many cases, rapid silting up of the dam has since reduced its productivity and lifetime. There are also numerous environmental problems that can result from such major interference with river flows [5].

Small, mini and micro hydro plants (usually defined as plants less than 10 mW, 2 mW and 100kW, respectively) play a key role in many countries for rural electrification. Small-scale hydro is mainly 'run of river,' so does not involve the construction of large dams and reservoirs. Small hydro currently contributes over 40 gW of world capacity. The global small hydro potential is believed to be in excess of 100 gW. The industry believes that small hydro will have a strong resurgence in Europe in the next 10 years, after 20 years of decline [5].

The distribution of the hydro power plants that are under design level is presented in Table 3 according to their hydro capacity [7]. As can be seen, 30.34 % of all of the annual energy will be generated by SHP. There is 80 installed SHP in Turkey 5 % of which with medium head and 95 % with high head [6]. Being generally a mountainous country, Turkey's SHP potential is high. There is installed 80 SHP with 177 mW capacity. However, the remaining economically feasible potential is nearly 22 000 gWh/year [7].

Table 3. Distribution of under design hydropower plants according to their hydro capacity.

Classification	Number of HEPP	Total Capacity (mW)	Total Annual Energy (gWh)	Percentage of Total Annual Energy
<5 MW	139	312	1 568	2.17
5 to 10 MW	79	548	2 135	2.95
10 to 50 MW	186	4 595	18 244	25.22
50 to 100 MW	54	3 824	13 524	18.70
100 to 250 MW	36	5 527	18 179	25.13
250 to 500 MW	11	3 500	11 657	16.11
500 to 1000 MW	3	1 791	3 199	4.42
>1000 MW	1	1 200	3 833	5.30
TOTAL	**509**	**21 297**	**72 339**	**100**

5 Focus on the eastern Black Sea region

Among 26 hydrological basins in Turkey, the Eastern Black Sea Basin (EBSB) has great advantages from the view point of SHP potential. Because, the annual average precipitation is the highest in the country going up to 2329 mm in Rize Province. Also, the basin covers sharp valleys and there are a lot of steep streams with considerable discharges and heads.

A study is being carried out by EIE to evaluate energy potential of small streams in Turkey. The preliminary results of this study are given in Table 4. The preliminary results of only 8 basins out of 26 basins in Turkey have been obtained yet and the other basins are being studied. As can be seen, 59 projects out of 132 (44.7 %) projects are in EBSB and annual energy of EBSB projects comprises of 886.56 gWh (52.18 %) out of 1698.86 gWh for all of the projects. The potential and potential percentage of SHP projects with various intervals of coefficient of profitability (CP) are also given in Table 4. It is also obvious that, most of (81 %) the projects in EBSB are profitable with CP>1. The profitable projects in EBSB cover 56.4 % of all of the profitable projects discussed in this study [7].

Table 4. Preliminary results of studied SHP projects by EIE.

Basin	**Num. of Project**	**Capacity (mW)**	**Annual Energy Potential (gWh)**	**Potential (Percentage) of Projects According to Coefficient of Profitability (CP)**		
				CP>1	0.7<CP< 1	CP<0.7
East. Black Sea	59	157.75	886.56	718 (81 %)	130 (15 %)	38 (4 %)
Mid Mediter.	20	69.09	278.52	260 (94 %)	10 (3 %)	8 (3 %)
Gediz	7	41.76	166.20	116 (70 %)	27 (16 %)	23 (14 %)
West. Mediter.	9	23.51	111.78	99 (89 %)	8 (7 %)	4 (4 %)
Susurluk	15	23.74	110.55	23 (21 %)	77 (69 %)	11 (10 %)
Wes.Black Sea	15	21.90	108.86	40 (37 %)	47 (43 %)	22 (20 %)
Aegean	5	4.76	20.33	0 (0 %)	14 (67 %)	7 (33 %)
B. Menderes	2	3.38	16.06	16 (100 %)	0 (0 %)	0 (0 %)

According to tables presented by EIE [7], there are 166 projects being studied with capacity of 9 742 MW and annual energy potential of 33 793 gWh. 73 projects with 8 644 MW and 29 375 gWh/year, are planned with various kinds of dams and remaining 93 projects with 1 098 MW and 4 418 GWh/year are planned as “run of river”, without storage and dams. Within the run of water projects, 47 projects (50.5 %) with 149.71 MW (13.6 %) capacity and 768.41 gWh/year (17.3 %) will be made in EBSB. All of these data emphasize the importance of EBSB on the total SHP potential in Turkey.

In addition to the above considerations, it should be emphasized that, there are more SHP potential to be studied in Turkey, and especially in EBSB. In the following, brief results of two case studies, carried out in the EBSB, are summarized. None of these projects are taken into consideration in the calculation Turkey’s hydro power potential and both of them are very economical projects.

One of the projects was carried out in Rize – Ikizdere - Ruzgarli Basin. A feasibility report was prepared [8] for a hydro power plant in which water is being diverted by a weir and no storage dam is necessary. Design flow discharge of the stream is 2.74 m^3/s and net head is 184.5 m, resulting in 4 MW hydropower and 8.8 gWh/year electric energy. This plant will be operated by private sector by build-own-operate (BOO) system.

The other project was carried out in Rize Municipality Domestic Water Facilities. A preliminary report was prepared [9] for a hydro power plant. This is a complicated project, which comprises connecting two streams, generating hydro power energy, water flowing in a pipe, at the downstream of the pipeline again generating hydro power and letting the domestic water to flow where it will be used. It was predicted that totally 20 gWh/year electric energy would be obtained, without creating any negative effects on the quality and quantity of the drinking water. Since most of the facilities are already built, the cost will be less than new-built plants.

Similar to the above two projects, various local projects may be easily and economically developed to improve Turkey’s electric energy potential and therefore the economy. Many of the SHP projects are under investigation and the preliminary reports of some of them are either under preparation or ready. By enlarging SHP potential, the economic status of the rural people, most of whom are unemployed and poor, will be improved by constructing various kinds of structures (weirs, canals, etc) and thus by diminishing unemployment and by providing cheaper electricity for domestic usage (lighting, heating, using electronic apparatus etc.). SHP structures will also diminish deforestation, because nearly all of the rural people have used wood in heating.

6 Cost of small hydropower

Small hydropower, especially the very small and the low-head plants, can normally only compete where allowance are made for the external costs associated with fossil fuels and nuclear power. Small hydropower projects are generally considered to be more environmentally favourable and sustainable than both large hydro and fossil fuel powered plants. So, small-scale hydropower is more economically competitive than small-scale fossil fuel/steam-electrical power.

The capital required for small hydropower plants depends on the effective head, flow rate, geological and geographical features, continuity of water flow, equipment such as turbines and civil engineering works. Making use of existing weirs, dams, storage reservoirs and ponds can significantly reduce both environmental impact and costs. Sites with low heads and high flows require a greater capital outlay, as larger civil engineering works and turbine machinery will be needed to handle the larger flow of water.

Apart from the investment and production costs, the other principal cost element is operation and maintenance, including repairs and insurance, which can account from 1.5-5% of investment costs. Both the production and investment costs differ considerably depending on the plant’s head height.

7 Recommendations for sustainable development of SHP

Looking to the future, there are good reasons to support small hydropower in Europe and worldwide. First and foremost, it is a source of renewable energy, which, if used on a small scale and handled sensitively, has few environmental risks. Increased use will help to reduce CO_2 emissions and help countries to achieve their Kyoto obligations as well as to stave off global warming. Secondly, the depletion of oil and natural gas deposits will lead to higher generation costs for thermal plants, helping to improve the economics of SHP. It will also serve to enhance economic development and living standards, especially in remote areas with limited or no electricity. Rural communities have been able to attract new industries (mostly related to agriculture) owing to their ability to draw power from SHP stations. In countries such as China, India, Turkey and South Africa, rapid SHP development has also boosted the development of local manufacturers to support these hydropower plants. In addition, the ability of SHP to be combined with water infrastructure projects will allow it to become a regular feature in developing countries as they overhaul their irrigation, water supply and sewerage systems [10].

Some recommendations for a sustainable development of hydropower include:

- Governments should establish an equitable, credible and effective environmental assessment process that takes into account both environmental and social concerns, with a predictable and reasonable schedule.
- Developing countries should develop energy policies that clearly set out objectives regarding the development of power generation options, including small hydropower.

- Project designers should apply environmental and social criteria when comparing project alternatives, in order to eliminate unacceptable schemes early in the planning process.
- Project design and operation should be optimised by ensuring the proper management of environmental and social issues through the project cycle.
- Local communities should benefit from a small hydropower project, both in the short and the long-term.

8 Concluding remarks

In this paper, Turkey's water resources, hydroelectric and especially small hydroelectric potential are researched, focusing on the Eastern Black Sea Region. The main conclusions obtained from this study are summarized as follows:

From the viewpoint of energy sources such as petroleum and natural gas reserves, Turkey is not a rich country, but has an abundant hydropower potential to be used for generation of electricity. Turkey must base its energy strategy on developing the whole hydroelectric potential as soon as possible. Turkey's main indigenous energy resources are hydro and almost all oil natural gas and high quality coal are imported.

Therefore, in order to avoid foreign dependency both in sources and funds, Turkey must discover new and renewable energy resources. Turkey's annual total gross, technically feasible and economically feasible hydropower potentials calculated by DSI are 435, 215 and 128 tWh, respectively. However, according to findings of another study, in which a new criterion is developed related to key concept of the economic feasibility, economically feasible hydropower potential goes up 188 tWh/year, with an increase ratio of 47 % compared to DSI value.

Small hydropower represents an alternative to fossil fuel generation, and doesn't contribute to either greenhouse gas emissions or other atmospheric pollutants. However, developing the remaining hydropower potential offers many challenges and pressures from some environmental action groups over its impact has tended to increase over time. Moreover, in the context of the restructuring of the electricity sector, markets may favour more polluting and less costly options. On the other hand, small hydropower's main challenges relate to both economics and ecology. Small hydropower can be successfully developed as long as it produces electricity at competitive prices and under conditions that respect the environment.

Small hydropower can provide a positive social and economic contribution to the community through employment creation and good quality of life by contributing to an assured supply of electricity.

Small hydro utilizes a source of energy (water) which is both renewable and abundant throughout the year in many parts of Turkey.

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