

## **Development of hydropower energy in two adjacent basins (northeast of turkey)**

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### **ABSTRACT**

The main objective in doing the present study is to investigate the sustainable development of hydropower plants in two adjacent basins being located in northeast of Turkey, which are the Çoruh river basin being the least problem river of Turkey in respect to international cooperation as compared with Turkey's other trans-boundary waters and the Eastern Black Sea Basin (EBSB) having great advantages from the view point of small hydropower potential or hydropower potential without storage among 25 hydrological basins in Turkey. The contribution of the hydropower energy potential in these basins to reconstruction of Turkey electricity structure is investigated and a comparison in between is carried out. Finally, it is found that the EBSB will be corresponded from 8.3% and 10.3% of nowadays total electricity energy production and net electricity consumption of Turkey, while Çoruh river basin will provide 7.40% and 9.19% of total electric generation and electricity consumption of Turkey, respectively, after all hydropower projects within these basins are commissioned. In other words, one-fifth of Turkey's electricity consumption will be met from northeast of Turkey. For this reason, development studies and investments in the hydropower sector should be encouraged and supported and projects within these basins should be put into operation as soon as possible.

### **INTRODUCTION**

The electricity division of the energy sector is considered to be a key player in the accumulation of wealth and also a significant component in the economical development [1]. This makes energy resources extremely significant for energy countries in the world [2, 3]. Turkey is an energy-importing country. In order to be less dependent on other countries, Turkey needs to use its sustainable sources. From this point of view, hydropower is a very attractive choice, since it is economical, sustainable, and environmentally friendly and it is a publically familiar source of energy in Turkey [4].

This study examines the sustainable development of hydropower plants in two adjacent basins being located in northeast of Turkey. The contribution of the hydropower energy potential in these basins to reconstruction of Turkey electricity structure is investigated and discussed.

### **TURKEY'S HYDROPOWER POTENTIAL AND ITS USAGE**

Because of social and economic development of Turkey, the demand for energy and particularly for electricity is growing rapidly. The main indigenous energy resources are hydro and lignite. Turkey has no big oil and gas reserves. Almost all oil and natural gas is imported, as is high quality coal [2, 3]. In Turkey, electricity is produced by thermal power plants, consuming coal, lignite, natural gas, fuel oil and geothermal energy, and hydropower plants. There is no nuclear power in Turkey as yet [5]. Turkey also has a large potential for renewable energies. By the year 2030, Turkey is planning to

exploit two-thirds of its hydropower potential between renewable energy sources, aiming to increase hydro-production to about 140.0 TWh/yr [6,7].

In the determination of hydroelectric energy potential gross potential, technical potential and economical potential are the important conceptions. Briefly, the gross potential shows the hydroelectric energy production upper limit of a river basin, a potential that is made up by the existing height and average flow rate. Gross hydroelectric energy potential of Turkey, which is a function of topography and hydrology, is about 433.0 TWh/yr that is equal to 1.1% of the total hydropower potential of the world and 13.8% of European hydropower potential [8,9]. Technical potential shows the upper limit of the hydroelectric energy production of a river basin. Excluding the inevitable losses, this represents the hydroelectric energy production limit that is technically feasible. Technical hydroelectric energy potential in Turkey is estimated as 216.0 TWh/yr. Economical hydroelectric potential is the total hydroelectric energy from a river basin that can be technically developed and is economically coherent. In other words, the economical hydroelectric energy potential shows the hydraulic resources with economical feasibility [10]. Nowadays, economical potential of Turkey is almost 140 TWh/yr. The tax deductions and subsidy policies for green energy in the European Union will contribute to efforts aimed at increasing the economically viable potential of hydroelectricity [11].

Although Turkey is not affluent in terms of hydroelectric energy potential, it is ranked in the first quartile within European countries. In terms of developing water resources in Turkey, hydraulic energy generation takes a considerable portion [12]. At present, Turkey has 213 hydroelectric power plants (HPPs) in operation with total installed capacity of 14300 MW generating an average of 50000 GWh/year, which is 35.71% of the economically viable hydroelectric potential. 145 HPPs are currently under construction with 7286 MW of installed capacity to generate an average annual 23770 GWh representing 16.98% of the economically viable potential. In the future, 200 more hydroelectric power plants (excluding 1100 small HPPs planned by private sector) will be constructed to be able to make maximum use of the remaining 66230 GWh/year of economically viable potential. As a result of these works, a total of 558 hydroelectric power plants with 44200 MW and 140000 GWh/yr will tame rivers to harness the economically viable hydropower of Turkey (Table 1) [11].

Table 1 Turkey's economical hydropower potential and its usage

| Status of economically viable potential | Number of hydro-electric plants | Total installed capacity (MW) | Average annual generation (GWh/year) | Ratio (%) |
|---|---------------------------------|-------------------------------|--------------------------------------|-----------|
| In operation                            | 213                             | 14300                         | 50000                                | 36        |
| Under construction                      | 145                             | 7286                          | 23770                                | 17        |
| In program                              | 1300                            | 22614                         | 66230                                | 47        |
| Total potential                         | 1658                            | 44200                         | 140000                               | 100       |

## HYDROPOWER ENERGY IN TWO ADJACENT BASINS (NORTHEAST TURKEY)

### General Characteristics

This study focused on two adjacent basins (Eastern Black Sea and Çoruh River Basins) in the Northeast of Turkey. The EBSB from these basins is located on the north eastern coast of Turkey. The basin is surrounded by the Eastern Black Sea Mountains on the south and Black Sea on the north. The basin starts from Terme stream in the east of Samsun to reaches Georgia boundary. Total basin area is 24077 km<sup>2</sup>, yielding 14.9 km<sup>3</sup> water with an average 19.5 lt/sn/km<sup>2</sup> yield [13]. Nearly 2.5 million people are living in this region. The basin is split by valleys reached from the sea into south zones. The strata of the region are generally made of impermeable or semi permeable volcanic rocks, which prevent the rainfall from percolation and force the water to flow as runoff [14]. The river system of the EBSB had been developed under the effect of the geological properties of the soil, the topography,

the climate and the vegetation mantle and such. A great deal of precipitation in every season, the impermeable soil, and the presence of a mountainside that is covered with a lush vegetation mantle prepare the optimum conditions for comprising the river system. A much branched river system is composed under the effect of all these factors [15] (Figure 1).

The Çoruh River formed Çoruh River Basin, which is other basin examined in this study, rises at Civilikaya Hill, located in the Mescit Mountains at the North of the Erzurum Plateau, and flows through East Anatolia and the East Black Sea Regions of Turkey to finally reach the Black Sea near Batumi in Georgia (Figure 1) [16]. Approximately 91% of the basin's drainage area (21100km<sup>2</sup>) is, however, in Turkey while Georgia's share amounts to 9% only. The principal tributaries of the Çoruh river are the Tortum and Oltu rivers in Turkey, and Adzharis river in Georgia. In total, the Çoruh river is 427km long, 400km of which lies within Turkey's borders. It also forms a short border (3 km) between Turkey and Georgia. Finally, the river flows for 24km through Georgia [17, 18]. The river originates in the western part of the Mescit mountains at a height of over 3000m and lies to the north-west of the Erzurum- Kars Plateau. From these mountains the Çoruh first flows west, then turns east with a sharp bend at the Bayburt Plain and afterwards follows a tectonic hollow which separates the East Black Sea coastal mountain series from the inner mountain range. The Çoruh valley located in the eastern part of İspir, is one of the deepest valleys in Turkey. Having passed the city of Yusufeli and the confluence with the Oltu River, the Çoruh flows north and shapes a mountain landscape with deep canyons. Passing through the cities of Artvin and Borçka, it leaves Turkish territory near the city of Muratlı. Near Batumi, the capital city of the Georgian semi-autonomous province Ajaria, the river empties into the Black Sea through a delta which is largely composed of the alluvium that it has accumulated [17]. The Çoruh basin is one of basins being exposed to the most erosion. The Çoruh river, which is fastest flowing river amongst Turkey's rivers and is accepted between quickest flowing ten rivers of the world, has also the total head of 1420m for energy generation, from the most upstream Laleli Site to the most downstream Muratlı Site close to the Georgian border [12].



Figure 2 Site location map of study area

## Hydropower Development

The EBSB is one of the richest basins in Turkey from the view point of the hydroelectric energy potential. The total amount of installed capacity and the annual average energy generation of the 292 HPPs (without storage) developed at various project stages by EIE, DSI and the private sector in the EBSB are 4332.42 MW and 15414.24 GWh/yr, respectively. These planned HPPs are at different design level as follows: 38 projects (707.90 MW, 2679.20 GWh/yr) with Signed Water Right Consensus, 155 projects (1550.83 MW, 5323.01 GWh/yr) with feasibility report ready and 94 (1874.30MW, 6715.06 GWh/yr) and 5 (199.39 MW, 696.97 GWh/yr) of these projects are under

construction and in operation, respectively. Also the installed capacity and the annual average energy generation of the dams in this basin are 253 MW and 746 GWh/yr, respectively. Finally, the total installed capacity and the annual average energy generation of the basin are 4585.41 MW and about 16160.24 GWh/yr, respectively (Table 2) [19].

Table 2 Total hydropower potential of the EBSB [19]

| Province  | Status of project            | Number of project | Power (MW) | Energy (GWh/yr) |
|---|------------------------------|-------------------|------------|-----------------|
| Giresun   | In operation                 | 1                 | 31.29      | 99.15           |
|   | Under construction           | 25                | 663.81     | 2208.02         |
|   | Feasibility report ready     | 32                | 423.39     | 1365.25         |
|   | Signed Water Right Consensus | 5                 | 65.81      | 203.68          |
| Gümüşhane   | In operation                 | 1                 | 103.50     | 315.67          |
|   | Under construction           | 5                 | 71.33      | 195.26          |
|   | Feasibility report ready     | 13                | 82.65      | 263.00          |
|   | Signed Water Right Consensus | 2                 | 54.00      | 133.63          |
| Rize  | In operation                 | -                 | -          | -               |
|   | Under construction           | 23                | 610.46     | 2327.56         |
|   | Feasibility report ready     | 29                | 444.67     | 1657.75         |
|   | Signed Water Right Consensus | 5                 | 66.20      | 285.83          |
| Trabzon   | In operation                 | 3                 | 64.60      | 282.15          |
|   | Under construction           | 40                | 429.70     | 1614.79         |
|   | Feasibility report ready     | 48                | 339.11     | 1106.28         |
|   | Signed Water Right Consensus | 10                | 161.24     | 611.33          |
| Ordu  | In operation                 | -                 | -          | -               |
|   | Under construction           | 1                 | 99.00      | 369.42          |
|   | Feasibility report ready     | 20                | 209.89     | 746.57          |
|   | Signed Water Right Consensus | 13                | 242.39     | 909.08          |
| Artvin  | In operation                 | -                 | -          | -               |
|   | Under construction           | -                 | -          | -               |
|   | Feasibility report ready     | 10                | 45.31      | 163.22          |
|   | Signed Water Right Consensus | 3                 | 118.26     | 535.65          |
| Samsun  | In operation                 | -                 | -          | -               |
|   | Under construction           | -                 | -          | -               |
|   | Feasibility report ready     | 3                 | 5.80       | 20.95           |
|   | Signed Water Right Consensus | -                 | -          | -               |
| Atasu Dam   | Under construction           | 1                 | 5.00       | 27.00           |
| Topçam Dam  | Under construction           | 1                 | 60.00      | 199.00          |
| Kürtün Dam  | In operation                 | 1                 | 85.00      | 198.00          |
| Torul Dam   | In operation                 | 1                 | 103.00     | 322.00          |
| Hydro potential which will be made by corporate bodies (private sector) (including Atasu and Topçam Dams) |                              |                   | 4198.02    | 14943.27        |
| In operation hydro potential of EBSB (including Kürtün and Torul Dams)                                    |                              |                   | 387.39     | 1216.97         |
| Total hydro potential of EBSB   |                              |                   | 4585.41    | 16160.24        |

The Çoruh River is the longest river of the East Black Sea region and is of high economic importance to Turkey because of it is largely undeveloped but has economically exploitable hydropower potential. Initial studies concerning the hydropower production potential in the basin had already been carried out by Turkish authorities in the late 1960s. The Çoruh Basin Master Plan was eventually finished in 1982 and was followed by the Çoruh Basin Development Plan. In the scope of this Development Plan, it is a planned construction of 10 large dams on the main tributary of Çoruh River [20]. Feasibility reports of Laleli Dam and HPP, İspir Dam and HPP, Gullubag Dam and HPP, Aksu Dam and HPP, and Arkun Dam and HPP which are located in Upper Çoruh Basin have been prepared and these projects will be made by corporate bodies (private sector) by the concept of Turkey's Electricity Market Law No. 4628. In this context, license procedures of these projects have

continued. Yusufeli Dam and HPP being one of the two projects taking place in Middle Çoruh Basin is final design report ready. The latter, Artvin Dam and HPP is a project that bilateral agreements will have been signed between countries to further international cooperation in hydropower development. Firms within this project continue license procedure of their project within the scope of Turkey's Electricity Market Law No. 4628. Deriner Dam and HPP is located in Lower Çoruh Basin and this project is under construction. Muratlı and Borçka Dams and HPPs were taken into operation in June 2005 and April 2007, respectively. Feasibility reports of Altıparmak Dam and HPP, Olur Dam and HPP, and Ayvalı Dam and HPP from 5 dam projects which are situated at affluents out of the main tributary of the Çoruh river are ready and license procedures of this projects have also continued by the concept of Turkey's Electricity Market Law No. 4628. Bayram and Bağlık Dams and HPPs which were prepared their feasibility reports are in the scope of intergovernmental bilateral cooperation. Within this scope, any advancement with regard to these projects has been carried out. 22 run of river (without storage) HPPs except for these dam projects have planned; one of these projects is taken into operation and others are being designed. Those are being designed are divided into various sub-groups as follows: 2 HPP projects with feasibility report ready, one project with master plan ready, and 18 HPP projects with preliminary report ready [21]. The planned development will result in a total annual energy production of 10.545TWh with the implementation of 3132.7MW of hydro capacity on the Çoruh river basin.

There are numerous projects in Çoruh river basin planned or developed by private sector except for the Çoruh Basin Development Projects. In this context, 2 hydropower plants (Murgul and Esendal HPPs) developed by corporate bodies within borders of Artvin Province, which have total installed capacity of 5MW and energy generation of 10 GWh/yr, are in operation. Also, in Artvin Province, 58 HPPs have been planned by private sector, which these projects are at different design level as follows: 9 projects (123MW, 418 GWh/yr) with Signed Water Right Consensus, 30 HPPs (432MW, 1509 GWh/yr) with feasibility report ready, 19 projects (99MW, 273 GWh/yr) with preliminary report ready. In Bayburt Province, Bayburt regulator and HPP, which has total installed capacity of 13MW and energy generation of 45.2 GWh/yr, is a project improved by private sector and signed water right consensus. Besides, 3 projects having installed capacity of 18.8MW and energy potential of 67.3 GWh/yr, which are preliminary report ready, will be developed within borders of Bayburt Province. 55 HPPs have been planned by private sector in Erzurum Province. Water Right Consensus of 20 of these projects, which have installed capacity of 320MW (630 GWh/yr) are signed, 21 projects with feasibility report ready and 14 projects with preliminary report ready have energy generation of about 795 GWh/yr and 122 GWh/yr, respectively. Finally, total available hydropower potential of Çoruh river basin reaches 14414 GWh/yr when all these projects planned are taken into consideration (Table 3).

Table 3 Hydropower potential of the Çoruh River Basin [12]

| Province | Status of project            | Number of project | Power (MW) | Energy (GWh/yr) |
|----------|------------------------------|-------------------|------------|-----------------|
| Artvin   | Signed Water Right Consensus | 9                 | 123        | 418             |
|          | In operation                 | 2                 | 5          | 10              |
|          | Feasibility report ready     | 30                | 432        | 1509            |
|          | Preliminary report ready     | 19                | 99         | 273             |
| Bayburt  | Signed Water Right Consensus | 1                 | 13         | 45.2            |
|          | In operation                 | -                 | -          | -               |
|          | Feasibility report ready     | -                 | -          | -               |
|          | Preliminary report ready     | 3                 | 18.8       | 67.3            |
| Erzurum  | Signed Water Right Consensus | 20                | 320.17     | 629.66          |
|          | In operation                 | -                 | -          | -               |
|          | Feasibility report ready     | 21                | 251.2      | 795.2           |

|  |    |                |                 |
|--|----|----------------|-----------------|
| Preliminary report ready   | 14 | 55.01          | 121.54          |
| Hydro potential which will be made by corporate bodies (private sector)                            |    | 1317.18        | 3868.90         |
| Hydro potential within the scope of the Çoruh Basin Development Plan (15 dams and 22 run of river) |    | 3132.70        | 10545.16        |
| <b>Total hydro potential of Çoruh River Basin</b>  |    | <b>4449.88</b> | <b>14414.06</b> |

## RESULTS AND DISCUSSION

The high water power potential of these two basins is a great advantage not only for the region but also for Turkey's economy. When these projects in the basins are completed, the water won't flow idly and the economic income level of the region will be increased. When these projects are completed or while they are under construction, these HPPs and dams and their constructions will provide the possibility of employment and various professional branches will develop in the operational scheme of the new dam and the HPPs. In addition this can also create local employment, have a positive impact on the social cohesion, and contribute to the security of supply. Widespread use of clean and environmentally friendly SHPs in the basins, which will be installed using the region's native resources, has big importance. Thus, it will both contribute to the region's economy and decrease the dependence of the country on foreign resources because the energy requirement will be met.

Turkey's annual total economically feasible hydropower potential calculated by DSI is 140000 GWh/yr. However, according to findings of another study [22], this figure goes up to 188000 GWh/yr, with an increase ratio of 47% compared to DSI value [2]. According to these data, the hydropower potential of the EBSB and Çoruh River Basin will meet 11.54-8.6% and 10.30-7.67% of Turkey's hydropower potential as stated in the DSI and Bakır [22]'s data, respectively. By evaluating these resources, Turkey will provide an important part of its electrical energy demand from its own hydropower resources. When Turkey's hydro potential is taken into consideration, it is understood that an important potential in these basins is realized. When these planned projects are carried out, it is expected to have significantly positive socio-economic impacts primarily on this underdeveloped region and on the affected communities. First of all, these projects will contribute to reducing the energy deficiency (Turkey's energy import is about 81.4% in 2007) being an ever-increasing important problem for Turkey. Finally, the EBSB will be corresponded from 8.3% and 10.3% of nowadays total electricity energy production and net electricity consumption of Turkey, while Çoruh river basin will provide 7.40% and 9.19% of total electric generation and electricity consumption of Turkey, respectively, after all hydropower projects within these basins are commissioned. In other words, total hydropower potential in these basins corresponds 15.70% and 19.49% of total electricity energy production and consumption of Turkey which is equal to 194.8 TWh/yr and 156.9 TWh/yr in 2009, and 85% of Turkey's hydroelectric energy generation being equal to 35.96 TWh/yr in 2009. Finally, it is quite important that these projects which are developed by the private and state sectors are operated as soon as possible since Turkey is an energy-importing country. One-fifth of Turkey's electricity consumption will be met from northeast of Turkey. For this reason, development studies and investments in the hydropower sector should be encouraged and supported and projects within these basins should be put into operation as soon as possible.

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