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The effect of hydroelectric power plants on the carbon emission: An example of Gokcekaya dam, Turkey

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ABSTRACT

In recent years, as a result of the rapid increase in population and industrial development, the need for energy has increased. Many investments are made especially for electrical energy which is an inevitable requirement for the industry. Most of these investments are made by using fossil resources in countries' lands. Fossil sources are known to be consumable as well as too poisonous gases they give to the atmosphere during energy production. This situation causes global climate change. To prevent climate change, the carbon emitted to the atmosphere has to be brought under a certain control mechanism. In this context, the first Kyoto Protocol and then Paris Climate Agreement was signed. Under these agreements, countries will be responsible for the level of their greenhouse gases in the atmosphere. This situation led to the carbon trade among countries. This situation accelerated the transition of countries from fossil sources to renewable energy sources. In this study, the effect of hydroelectric power plants, one of the renewable energy sources, on carbon emissions was investigated. According to the results, based on fossil sources of 408,533.57 tCO_2 per year from Turkey Gökçekaya dam has been shown to reduce the carbon footprint.

1. Introduction

One of the results of the developing industry with the rapidly increasing world population is the increase of the energy needed. Today, 76% of global energy demand is met by oil, natural gas, and coal [1]. It is estimated that 70% of the total world energy demand will continue to be met by fossil fuels in 2050 in line with the current level of technology and the forecasts made [2]. However, the fact that fossil resources can be consumed and polluted the environment has revealed the importance of renewable clean energy sources in recent years. Renewable energy resources (hydraulic, geothermal, solar, wind, biomass, wave, etc.), being domestic resources in countries' energy policies, contributing to energy supply security, being clean, reducing emissions in the fight against global warming, contributing to eliminating environmental concerns and Protocol is of great importance due to its economic value bearing features within the mechanisms. The use of renewable energy sources to shift to a low-carbon economy is becoming more and more widespread worldwide [3–7]. In particular, the carbon dioxide gas produced by coal and oil-derived power plants to meet the required energy accumulates in the atmosphere and has negative effects on the climate. This causes global climate change.

Many studies have been carried out in recent years on climate change. Leng et al. [8] used bias-corrected daily outputs from state of the art climate models as inputs for a calibrated hydrologic model configured over the whole of continental China to assess the potential impacts of future climate change on drought characteristics in different domains of the hydrological cycle in China. Clifton et al. [9] described processes in the Blue Mountains of Oregon, historical trends in hydrologic parameters (snowpack, peak streamflow, low streamflow, and stream temperatures), and projected effects of climate change on these hydrologic parameters. Christensen et al. [10] investigated the effects of climate change on the hydrology and water resources of the Colorado River Basin by comparing simulated hydrologic and water resources scenarios derived from downscaled climate simulations of the U.S. Department of Energy/National Center for Atmospheric Research Parallel Climate Model (PCM). In addition, many studies have been conducted examining the effects of global climate change on water

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Nomenclature

Acronyms

PCM	Parallel Climate Model
INDC	Intended National Contribution Declaration
PV	Photovoltaic
USD	United States Dollar
GHG	Greenhouse Gas
SIMAHPP	Simulation and Evaluation of Feasibility of Hydroelectric Projects
HEPP	Hydroelectric Power Plant
N	North
E	East
EGC	Electricity Generation Corporation
NPV	Net Present Value
IRR	Internal Rate of Return
CSO	Civil Society Organization
VER	Voluntary Emission Reduction

Units

%	Percentage
kWh	Kilowatt-hours
g	Gram
GWh	Gigawatt-hours
CO_2-eq	Carbon dioxide equivalent
MWh	Megawatt-hours
kg	Kilogram
$	American Dollars
m^3/s	Cubic meters per second

resources [11–13]. Temiz [14] examined the effects of global climate change on humanity from different perspectives. In his study, which aims to highlight different approaches to how climate change will affect humanity soon. When all these studies are examined, it is seen that climate change increases the frequency of extraordinary meteorological events and causes countries to experience socio-economic problems. As the carbon dioxide gases accumulated in the atmosphere increase global warming, the hydrological system of nature is disrupted. Events such as extremities in precipitation regimes, melting of snow and glaciers, increasing evaporation, changes in soil moisture indicate that the hydrological cycle has been affected in recent years [15–21].

Due to the rapid increase in climate change in recent years, the need to keep the carbon dioxide gases released into the atmosphere as a reason for this is kept under a control mechanism. For this reason, the Kyoto Protocol came into force as the first international agreement to commit countries to reduce greenhouse gas emissions. According to this protocol, countries will be responsible for keeping a certain level of greenhouse gases recorded in the atmosphere. This situation has given rise to the concept of Pay Carbon Market al among countries. The carbon market is a market established for greenhouse gases and the emission permits allocated to emission sources are purchased and sold. The scientific community has published many studies on the carbon market [22–28]. The emission reduction costs of countries do not occur at the same level as each other. Some countries can reduce greenhouse gases at a lower cost and higher rates than others. A country may sell its emission permits to other countries in need of emission permits by Articles 3 and 17 of the Kyoto Protocol. For this purpose, the country wishing to participate in trade should establish an emission monitoring, distribution, and control system within itself and commit to comply with international standards [29]. Perdan and Azapagic [30] have comprehensively addressed compulsory emissions trading plans in the world. The tendency of the emission trade to expand geographically and sectorally is determined as future developments. According to the article, important technical regulations and different trade systems must be harmonized to realize the expansion and for this; political support and a stable economic environment are needed. As a result, post-Kyoto commitments were not fulfilled and negative environmental policies continued. It is stated that this situation points to an uncertain future for carbon trade. Scientific studies have shown that there are some difficulties in carbon trade. Also, global climate change parameters could not be reduced to the desired level. For this reason, a series of meetings were held in the context of the measures to be taken in response to the increasing global climate change between 2008 and 2012 following the Kyoto Protocol. As a result, the Kyoto Protocol was extended until 2020 and a new climate plan was approved starting in 2020. Unlike the Kyoto Protocol, the Paris Agreement provides for a specific global temperature target. The result of the negotiations was to keep this increase below 2° at the end of the century and to continue efforts to achieve 1.5°. Another difference from the Kyoto Protocol to the Paris Agreement is that it imposes responsibility not only on developed countries but on all countries. The agreement is based on the Intended National Contribution Declaration (INDC), enabling countries to act according to plans that they determine according to their capacities with common but differentiated responsibilities.

1.1. Effect of hydroelectric energy on carbon emission

Hydraulic energy is the most advanced energy source in terms of technological development among renewable energy sources. This type of energy, obtained by converting the potential energy of water into kinetic energy, has the largest share among renewable energy sources As shown in Fig. 1, hydroelectric energy, as a low carbon emission technology, meets about two-thirds of the world's renewable energy production.

Although hydro energy is considered as a renewable energy source, people in many countries oppose these investments due to its environmental effects. Among the most mentioned negative effects of hydroelectric power plants; damage to wildlife habitats and migration routes, influencing precipitation pattern of regional climate, controlled release of water to the river downstream of the dam, the forced migration of people living in settlements under the dam reservoir etc. Despite all these negative effects, hydroelectric power generation is the cheapest way to generate electricity today. According to 2019 data, costs per kWh; 0.047 USD for hydroelectric power plants, 0.068 USD for solar energy, 0.053 USD for onshore wind, 0.115 USD for offshore wind, 0.073 USD for geothermal, 0.066 USD for bioenergy [32]. It is also known that solar and wind energy, which is one of the most popular renewable energy sources, cause significant damage to the environment. In addition to high maintenance costs, solar energy systems can cause soil erosion by preventing efficient land use with large land area coverage [33]. In wind energy systems, changes in air pressure caused by rotating turbines are known to cause the death of many birds and bats [33]. When the social, economic and environmental impacts of renewable resources in energy production are evaluated as a whole, it can be said that hydro energy is the most preferred.

Hydropower projects ensure that countries are protected from the negative impacts of climate change (flood and drought) within

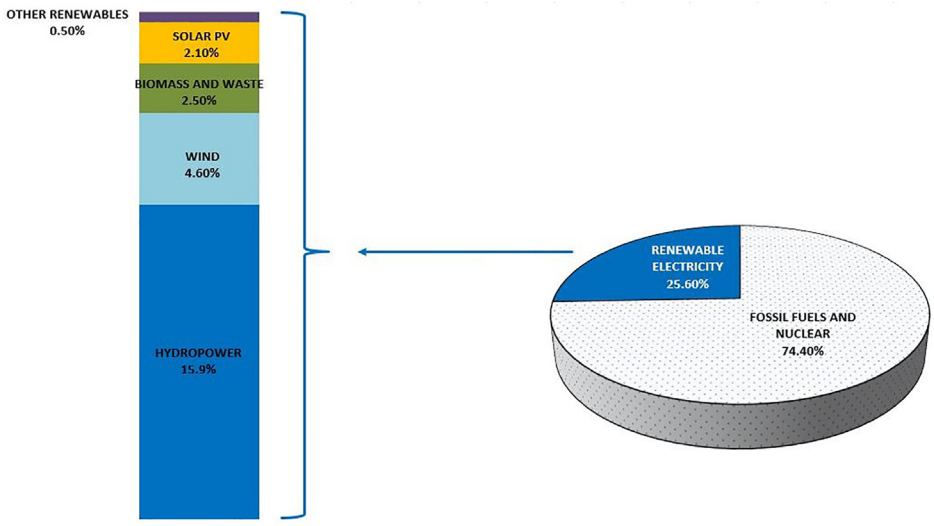

Fig. 1. The position of hydropower in renewable energy [31].

the framework of the Paris Agreement and sustainable development objectives. Hydroelectric power is known to have the lowest greenhouse gas (GHG) emissions per kilowatt-hour compared to other energy sources [34]. The average life cycle carbon equivalent density of a coal power plant is 820 gCO_2-eq/kWh, while a hydroelectric power plant is said to be 18.5 gCO_2-eq/kWh [31]. This shows that hydroelectric power plants reduce greenhouse gas emissions by 97.7% compared to coal power plants. Hydropower reduces greenhouse gas emissions by 96.2% per kilowatt-hour of natural gas, 92% by biomass, 61.5% by solar PV, and 51.3% by geothermal. Wind energy provides a 40.5% advantage in greenhouse gas emissions compared to hydroelectric power. Utilizing water compared to fossil fuel such as coal in energy production means preventing 148 million tonnes of particles, 62 million tonnes of sulfur dioxide and 8 million tonnes of nitrogen oxide released into the atmosphere [31]. As a result, global climate change has increased the efforts in the field of renewable energy resources [35–37]. Especially researches on hydro and solar energy have been reported to be more than other renewable energy sources [38].

In this study, to determine the emission emissions of hydroelectric power plants compared to other fossil fuel-fired power plants, it is aimed to make analysis using Simulation and Evaluation of Feasibility of Hydroelectric Projects (SIMAHPP) software over a sample dam.

2. Study region and methodology

2.1. Features of the study region

In this study, located in the province of Eskisehir in Turkey Gökçekaya Dam and Hydroelectric Power Plant (HEPP), it was examined. The dam is located on the Sakarya River in the Gökçekaya locality of the Alpu District of Eskişehir at latitude 40° 1′59.76″ N and longitude 31° 0′58.43″ E coordinates (Fig. 2).

Publicly owned Electricity Generation Inc. (EGC) operated by the power plant installed capacity of 278.40 MW. In Turkey's Eskisehir is the largest power plant. With an average 421 GWh of electricity generation, the facility can meet all the electrical energy needs of 127,243 people in their daily lives (housing, industry, subway transportation, government offices, environmental lighting, etc.) [39].

As shown in Fig. 3, the Gökçekaya dam produces an average of

Fig. 2. Location of Gökçekaya dam.

421 GWh per year. Borders in the last 14 years in Eskisehir found that the energy consumption of approximately% 22.26's if Turkey meets the 0.22's%. In this study, it is aimed to put forward the carbon emissions that occur in obtaining such a power plant from consumable fossil sources.

2.2. Methodology

In this study, pre-feasibility analysis of the hydroelectric energy potential of the Gökçekaya Dam was carried out with SIMAHPP 5 Software. SIMAHPP 5 Professional is a pre-feasibility analysis program used to simulate and evaluate hydropower projects using hydraulic, financial and environmental parameters. The software is owned by a private company based on the Windows operating system [40].

SIMAHPP Professional, determine design flow and select appropriate hydro turbines, maximize annual energy production, determine energy revenue, estimate investment, and maintenance costs, determine depreciation rates, optimize operating time in one year, Net Present Value (NPV), It is a multi-option simulator with many aspects, such as the IRR, payback periods and reduction of the project's carbon emissions, as well as the carbon market revenue potential if the planned hydropower project is to be operational [40]. The software can analyze multiple hydroelectric power plant projects. To perform software analysis, the analysis requires 3

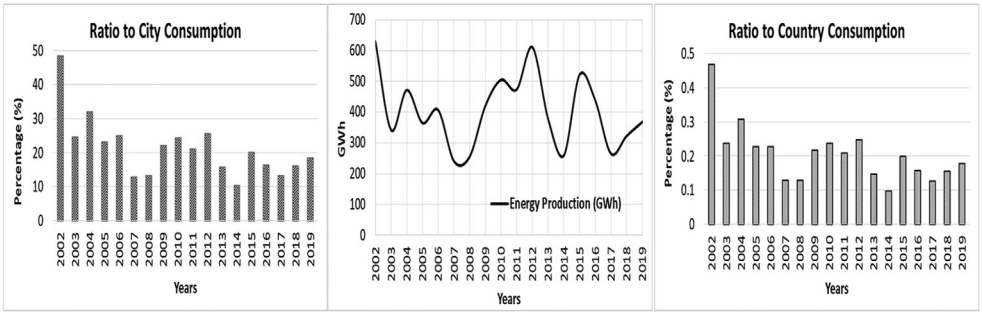

Fig. 3. Annual energy production of the Gökçekaya Dam [39].

different data entries. These parameters are hydraulic, financial and environmental (Fig. 4). The first data entry in the software is hydraulic parameters. These parameters can be entered as daily, monthly or annual flow values coming to the dam site. If the daily flow value will be entered into the software, 365 values, monthly flow values will be entered, 12 flow values, annual flow value will be entered, only 1 flow value should be entered. In this study, the annual flow to the Gökçekaya dam was entered as a hydraulic parameter. Besides, the net height where the water will fall in this section is entered as 100 m for the Gökçekaya dam. Financial parameters are entered as the second data entry in the software. In this section, data such as investment costs per kWh, annual or monthly depreciation plan are entered. This threshold value considering the financial parameters of the countries because it is in Turkey has entered. Finally, in the environmental parameters section, the rates for the carbon emission reduction potential for hydroelectric energy compared to other sources are entered. These rates are entered as 0.5 $kgCO_2$/kWh for natural gas, 0.9 $kgCO_2$/kWh for coal, 0.65 $kgCO_2$/kWh for oil [34]. After entering this data, the analysis is completed.

3. Results and discussions

In this study, the energy produced by Gökçekaya hydroelectric dam is analyzed with SIMAHPP 5 Professional software and its effect on carbon emission is investigated. Calculated data such as the amount of electricity to be generated by the Gökçekaya dam, installed power, turbine design flow, energy production, energy production, investment and repayment period are given in Table 1. According to the results, the total investment cost of the Gökçekaya dam is estimated to be 148×10^6 $. It was also found to have an annual power generation of 597×10^6 kWh at a design flow rate of 77.3 m^3/s. It is known that the dam has 421×10^6 kWh energy production when the actual 14-year operational data are analyzed. Considering that the software neglects energy losses in the analysis, it can be seen that the difference can be considered quite close.

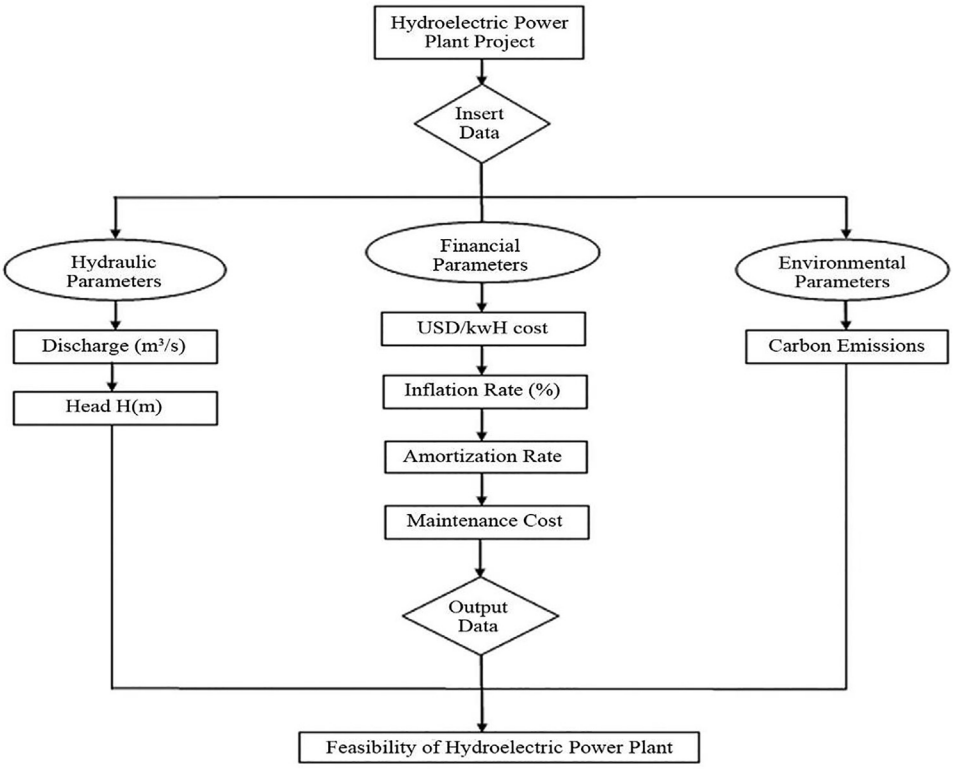

Fig. 4. SIMAHPP 5 Professional flow diagram.

Table 1
Project characteristics of Gökçekaya Hydroelectric Power Plant according to SIMAHPP 5 Professional software.

Project characteristics	Project site
Net head (m)	100.000
Design flow (m^3/s)	77.3
Design time of operation (%)	100
Power production (kW)	68,248.170
Energy production (kWh/year)	597,853,969.200
Energy revenue (USD/year)	32,319,985.575
Emission reduction (tCO_2/year-Coal)	538,068.572
Emission reduction (tCO_2/year-Gas)	298,926.985
Emission reduction (tCO_2/year-Fuel)	388,605.08
Carbon market (USD/year)-Mean	
Investment cost (USD)	148,931,130.274
Investment cost per kW (USD/kW)	2182.200
Investment cost per kWh (USD/kWh)	0.249
O & M Cost (USD/year)	1,787,173.563
NVP: Net Present Value (USD)	221,369,971.377
IRR: Internal Rate of Return (%)	20
Payback period (years)	5
Exchange rate (December 26, 2019) 1 EUR/USD	1.11

Since the annual energy return of the dam is 32×10^6 $, the reimbursement period of its own cost is as short as 5 years. Payback period is an important measure that shows the investment risk in a project [41]. Although the initial investment costs of hydroelectric power plants are high, they can pay off with a short payback period of 6–8 years [42]. The payback period varies depending on the economic conditions of the countries. In the countries such as Turkey which imports 77% of its energy needs, incentives given to hydro energy projects and cheap labor costs ensure that the payback period is below the world average.

The coronavirus pandemic has once again demonstrated the importance of maintaining the balance between human activities and nature. In this context, the European Green Deal, which basically aims to protect the balance between human and nature, aims to become climate neutral in European Union member countries by 2050 [43–45]. The most important step in achieving this goal is to reduce carbon emissions in energy production. Therefore, the use of renewable energy sources is essential to achieve the green deal goals. The commission, which was established as a requirement of the European Green Deal, focuses on three main headings among the 2030 targets. These are: To reduce greenhouse gas emissions by at least 40% compared to 1990, increase the use of renewable energy by at least 32%, achieve at least 32.5% improvement in energy efficiency [46–48].

Turkey is a candidate country to the European Union yet, therefore remain outside the framework of the European Green Agreement targets [49]. However, concerning about carbon market in Turkey, many voluntary environmental and social responsibility projects operated independently since 2005 without no any legal basis [50]. Voluntary Carbon Markets; It works independently from governments' objectives and policies to combat climate change, ranging from local governments, Civil Society Organizations (CSOs) and individuals. Increased public awareness of climate change and its impacts and a carbon offset makes up a reliable precautionary strategy. Voluntary Emission Reduction (VER) certificate is called. It is designed to reduce and offset these prints by calculating the amounts using the companies required for the greenhouse gas they create for their activities. The value of 95 million tons of CO_2 volume of the voluntary carbon market in 2011 is stated as 576 million $ [50]. When some projects and conditions reductions are examined in voluntary carbon markets in 2018, 8,747,634 tons CO_2/year greenhouse gas reduction is made from 159 hydropower projects required for 2018 [51]. To obtain 597.85 GWh/year energy of a hydroelectric power plant from a coal power plant, the atmosphere requires 538,068.572 tons of CO_2. If gas is used, use 298,926.985 tons of CO_2 and 388,605.08 tons of CO_2 are released into the atmosphere. The value of these fluctuations in the carbon market is an average of 2,479,833 $ per year. This property features a hydroelectric power characteristic and offers an important property to reduce global warming.

4. Conclusions and recommendations

Hydropower is an energy source that provides 16% of the energy produced by the world and approximately 78% of renewable electricity production with its clean, renewable and environmental features. It is a cheap and renewable energy source that can compete with the energy prices of the current market. Even if the initial investment costs seem to be high, it is considered as a feasible energy production project due to its long economic life, low operating and maintenance costs. Population growth and industrialization lead to an increase in energy demand, which in turn leads to an increase in resource use, resulting in a chain of more fossil fuel use. This cycle brings with it carbon dioxide and other greenhouse gases that cause climate change. One of the biggest environmental problems threatening the world is the increase in greenhouse gas and global warming. Turkey, in terms of the devastating consequences of global warming, is among risky countries. In the long run, the use of hydropower sources to support the sustainable economy and reduce environmental impacts will play a key role. Hydroelectric power plants contribute significantly to greenhouse gas reduction and play a critical role in preventing global warming. They serve the purposes of agreements such as Kyoto and Paris by providing the same amount of energy produced as compared to the fossil sources while preventing the amount of CO_2 to be released into the atmosphere.

In this study, in the case of CO_2 emissions produced from Turkey Eskisehir SIMAHPP 5 Professional software by analyzing the energy produced Gökçekaya Hydroelectric Power Plant located in the province of exhaustible energy source produced in the same amount was calculated. When the results are evaluated, it is predicted that if the 597.85 GWh/year energy produced from the Gökçekaya dam is produced from fossil sources such as coal, gas, and oil, it will provide an average carbon emission reduction of 408,533.57 tCO_2/year. The contribution of hydroelectric power plants to the environment in the prevention of global warming is undisputed in this study. When the economic dimension of the study is evaluated, there will be a carbon market value of 2,479,833 $ from the reduction of carbon emission generated by the energy generated from the dam. Although carbon transactions made based on voluntary projects in Turkey and not present an organized market shows improvement in the volume of volunteer projects every year. Therefore, voluntary projects pave the way for the formation of an organized market at some point. To be economical as a provision in the country's carbon emission reductions, the European Union Emissions Trading System, the European Energy Exchange European Climate Exchange, Oslo Stock Exchange, BlueNext, Australian Climate Exchange as we are recommended the establishment of a mandatory market in Turkey.

CRediT authorship contribution statement

Yıldırım Bayazıt: Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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