DOI: http://dx.doi.org/10.32571/ijct.1549692 **E-ISSN: 2602-277X**

International Journal of Chemistry and Technology

http://dergipark.org.tr/ijct

Research Article

Assessment of Greenhouse Gases Emissions from Dam Reservoirs: the Case of Tuzluca Dam

Çağrı AKGÜN[1]*, Salim Serkan NAS[2]

[1]*Igdir Vocational School of Higher Education, Igdir University, 76000 , Igdir, Turkey*

[2]*Civil Engineering Department, Gumushane University, 29100, Gumushane, Turkey*

Received: 13 September 2024; Revised: 7 November 2024; Accepted: 14 Novmber 2024

*****Corresponding author e-mail: cağri.akgun@igdir.edu.tr

Citation: Akgün, Ç.; Nas, S. *Int. J. Chem. Technol.* **2024**, 8(2), 170-179.

ABSTRACT

It is a known fact that large dam projects built to serve important purposes such as electricity generation, irrigation drinking water supply, and flood control cause greenhouse gases emissions due to the areas they flood. In this study, the greenhouse gases emission impacts of the Tuzluca Dam and Hydroelectric Power Plant (HPP) project, planned to be constructed in the Iğdır province of Turkey, were evaluated. Analyses conducted using the G-res tool, developed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Hydropower Association (IHA), estimated that the Tuzluca Dam and HPP project will emit 2,228 tCO_2e of greenhouse gases annually once the dam begins to hold water. In accordance with the guidelines of the Intergovernmental Panel on Climate Change (IPCC), it is predicted that when emissions occurring before the dam and during its construction are included, the net greenhouse gases emissions of the project will be -902 gCO_2e per square meter annually. The results obtained from this study were found to be consistent with similar studies in the literature.

Keywords: Carbon footprint, G-res tool, greenhouse gases emissions, reservoirs of dam

1. INTRODUCTION

The need for water, which has emerged since the beginning of humanity, has led mankind to various pursuits in terms of finding, storing, and utilizing water resources. Dam reservoirs, created by closing off the valley sides on a river, have been used since ancient times to meet the need for water.[1,2]

It is known that dams provide numerous benefits to humanity, such as flood control, water supply, irrigation, hydroelectric power generation, transportation, fisheries, and recreational services. However, research has shown that in addition to these benefits, dams also create several environmental problems. These negative impacts during the construction and operation phases of dams can be summarized as the deterioration of water quality and river ecosystems, endangering local wildlife, damaging vegetation, displacing people, increasing GHG emissions, and contributing to air pollution.[3,4,5,6,7,8]

Today, the primary cause of global warming, which is considered one of humanity's biggest problems, is shown as anthropogenic greenhouse gas (GHG) emissions, and it is estimated that dam reservoirs constitute 1.3% of global GHG emissions.[9,10,11] Since dam reservoirs are already formed by anthropogenic effects on an ecosystem, they emit higher levels of greenhouse gases compared to naturally formed water bodies.[11,12,13]

The amount of greenhouse gas emissions from dam reservoirs may vary from region to region depending on factors such as the age of the dam, reservoir area, water

DOI: http://dx.doi.org/10.32571/ijct.1549692 E-ISSN: 2602-277X

height, water residence time, amount of underwater vegetation, soil carbon content and global average horizontal radiance.[14,15,16,17]

GHG emissions from dam reservoirs generally occur in four different ways. These are surface diffusion, where CO_2 and CH_4 gases are released into the atmosphere as a result of the decomposition of organic matter underwater and rising to the surface of the water; Bubbling emission, which develops especially in shallow areas of the reservoir and where organic matter decays and CH_4 gas is released into the atmosphere in the form of bubbles; Degassing emission, where sudden pressure changes in water passing through turbines and weirs causes the release of dissolved CO_2 and CH_4 gases into the atmosphere, Downstream emission, where CO_2 and CH_4 gases formed in that region are released into the atmosphere as the water passing through the weirs mixes with the downstream side. In addition to all these, construction equipment and transportation vehicles used intensively during the construction process of a dam also cause CO_2 emissions.[16,18,19,20,21,22]

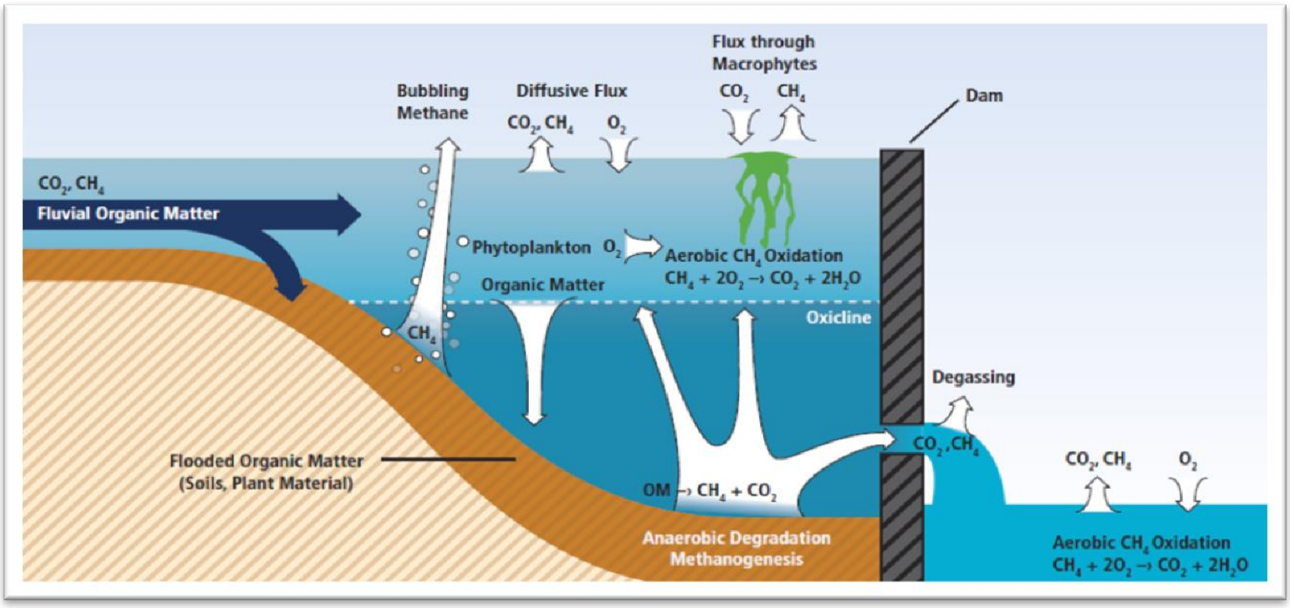

Figure 1. GHG emissions from dam reservoirs.[23,24]

The GHG emissions caused by dam reservoirs and their clear impact on global warming have prompted researchers to study this area. In a study conducted by Fearnside[25], the GHG impact of the Tucuruí Dam, one of the largest reservoir dams on the Amazon River, was analyzed. The research indicated that in 1990, this dam released between 7.0 and 10.1 million tons of carbon equivalent CO_2 into the atmosphere. It was emphasized that this emission level was higher than the annual fossil fuel-related emissions of São Paulo, Brazil's largest metropolis, highlighting the significant impact of dam reservoirs in terms of emissions.

In their study, Tremblay and Bastien[26], calculated the net GHG emissions of the Eastmain-1 reservoir, located in Quebec, Canada, with a reservoir area of 603 km² and an installed capacity of 480 MWh. More than 750 emission measurements were taken before and after the dam's construction, and the results were evaluated. Measurements taken immediately after the reservoir began holding water indicated that CO_2 emissions were eight times higher compared to the pre-impoundment period. However, measurements taken two years later showed that this value had significantly decreased. Similarly, when comparing CH_4 emissions, measurements taken one year after the reservoir began holding water showed a threefold increase compared to previous periods, while by the second year, this value had approached the pre- impoundment measurement levels.

Kemenes et al.[27], investigated the CO_2 emissions of the Balbina Dam, located in the Amazon Basin, with a reservoir area of 1170 km². Emission data were collected from 14 different measurement points between 2004 and 2006. It was determined that a total of 2,531 $GgCO_2e$ emissions occurred annually, including diffusive emissions, degassing emissions, and downstream emissions. It was noted that 97% of this total emission originated directly from the dam reservoir.

Kumar and Sharma[28], calculated the GHG emission of Tehri Dam, which has a reservoir area of 52 km^2 and an installed power of 2400 MWh on Bhagirathi River in India, using GHG Risk Assessment Tool (GRAT).

DOI: http://dx.doi.org/10.32571/ijct.1549692 E-ISSN: 2602-277X

GRAT was developed by United Nations Educational, Scientific and Cultural Organization (UNESCO) and International Hydrological Association (IHA) to estimate the GHG emission of reservoirs. According to the estimates made with the model, it was stated that 790 mg/m^2 CO_2 and 64 mg/m^2 CH_4 emissions will occur daily from Tehri Reservoir in 2011 and the emission level will decrease by 2015.

Jiang et al.[29],estimated the GHG emissions of 4 different dam reservoirs in China using the G-res tool developed by the International Hydrological Association (IHA). It was stated in the study that as the life of the dams increases, the average emissions decrease and 70% of the emissions that will occur are due to dam construction. It was also emphasized that the hydroelectric power plants in question emit approximately 100 times less compared to the average emissions of coal-fired power plants in China.

Ion and Ene[22], estimated the annual GHG emissions of the Stânca-Costesti Dam with a reservoir area of 59 km^2 on the Prut River using the G-res tool. Within the scope of the study, the emissions from the pre-dam period were also evaluated and it was calculated that the dam in question emitted a net GHG emission of -5 g/m^2 CO_2 equivalent per year.

Vuta et al.[30], calculated the net GHG emission amount of the Vitaru Dam with an installed capacity of 220 MW located on the Arges River in Romania. In the analyses carried out using the G-res tool, an annual net emission of -2293 tons of CO_2 equivalent was determined. In addition, while an average emission intensity of 30 g CO_2 equivalent per kWh was calculated for a 10-year period, it was stated that this value would decrease to an average of 3.02 g/kWh CO_2 equivalent in a 100-year period.

Min et al.[31], estimated the net GHG emission of 7 dam reservoirs in South Korea using the G-res tool. The total net GHG emission for these dams was calculated as 128.64 tons of CO_2 equivalent per year. Within the scope of the study, the emission values occurring after the dam were classified according to the emission type. Accordingly, the annual average for the 7 dams; CO_2 diffusive emission is determined as 133 g/m^2, CH_4 diffusive emission is determined as 65 g/m^2 (CO_2 equivalent), degassing emission is determined as 30 g/m^2 CO_2 equivalent and bubbling emission is determined as 14 g/m^2 CO_2 equivalent.

This study aims to estimate the net GHG emission amount to be generated by Tuzluca Dam to be built in Iğdır province of Turkey and to make a carbon footprint assessment of the project. Unlike the studies in the literature, the assessment of the emission effects of a dam in the planning phase rather than a dam that has been constructed will provide important ideas to decision makers regarding the environmental feasibility of the project.

2. MATERIAL AND METHODS

In the study, where the emission values that may occur before the dam and during the dam construction process are also taken into account, the G-res model developed by UNESCO/IHA was used for calculations.

2.1. GHG Reservoir (G-res) Tool

G-res Tool was developed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Hydrological Association (IHA) to estimate GHG emissions of dam reservoirs by considering the relevant basin, reservoir, dam characteristics and environmental factors. The tool works as a statistical model developed on field measurement data carried out in 223 dam reservoirs around the world.[29,31,32,]

The G-res Tool can classify the GHG emissions that dam reservoirs will generate into four categories according to their emission patterns and reveal the GHG impacts of the investigated dam reservoir over a 100-year period. The tool operates as an online platform accessible from https://www.grestool.org/. In addition, the G-res tool can estimate the net GHG emission amount in accordance with the Intergovernmental Panel on Climate Change (IPCC) guidelines, taking into account the emission values before the dam was built.[17,30,31,32]

The most accurate approach to determining the GHG impacts of dam reservoirs is considered to be the calculation of net GHG emissions, which also takes into account natural emissions in the reservoir area before the dam is constructed.[9,29,32,33] In this study, the net GHG emission value was obtained with the following approach using the G-res tool;

Net GHG footprint = - [Pre-impoundment carbon balance of the reservoir area before reservoir creation] + [Post-impoundment carbon balance of the reservoir] + [GHG due to construction] (1)

2.2. Study Area

Tuzluca Dam, planned to be built in Tuzluca district of Iğdır Province, located in the easternmost part of Turkey, was selected as the study area. The tender for the dam, which has been in the planning phase for many years, was made in 2024 and its work has started. The location map of the dam project to be built on the Aras River on the Turkey-Armenia border is given in **Figure 2** below.

DOI: http://dx.doi.org/10.32571/ijct.1549692 E-ISSN: 2602-277X

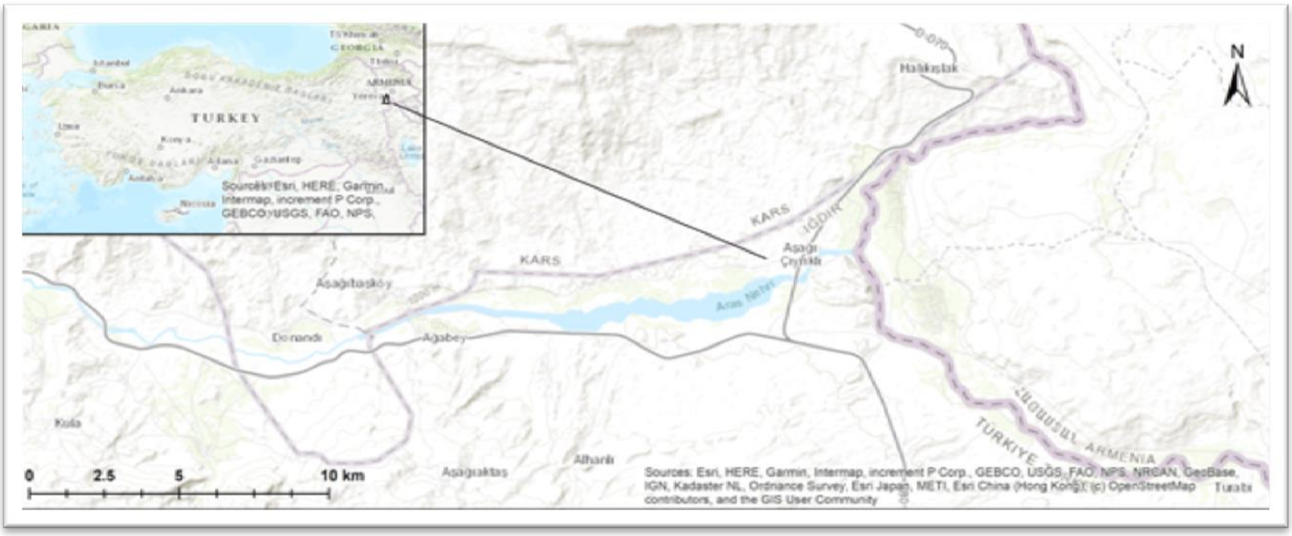

Figure 2. Location map of Tuzluca Dam.

Tuzluca Dam is planned to be a rockfill type, 45 m high and have a reservoir volume of 265 million m^3. In addition, the dam, which will have a 20 MW installed power plant, is planned to produce 117.10 GWh of electricity annually. In addition to hydroelectric energy production, Tuzluca Dam will also meet the irrigation water needs of Iğdır province, which has fertile soil. With the dam's impoundment, three villages will remain under the reservoir waters.[34,35]

2.3. Data Input for G-res Tool

G-res tool offers a practical, effective and reliable approach to assess GHG emissions of large water projects and does this using advanced modeling techniques on robust data.[17] In this respect, the input data that needs to be reliable has been obtained through the dam environmental impact assessment (EIA) report, planning report and remote access sources. The data for Tuzluca Dam and HEPP project to be used in G-res Tool is summarized in Table 1 below.

Table 1. Tuzluca Dam information for G-res tool.

Information	**Value**
Catchment	
Catchment area	7437 km^2
Population	75000
Annual runoff	58.86 m^3/s
Precipitation	254 mm
Reservoir	
Country	Turkey
Climate zone	Temperate
Longitude of dam	43.38
Latitude of dam	40.07
Reservoir area	16.52 km^2
Reservoir volume	0.265 km^3
Water Level	995 m
Maximum depth	45 m
Mean depth	16.04 m
Water intake depth	25 m
River Length before impoundment	12.8 km
Soil carbon content under impounded area	4.22 kg/m^2
Annual wind speed at 10 m	3.25 m/sn
Water residence time	3 yrs

DOI: http://dx.doi.org/10.32571/ijct.1549692 **E-ISSN: 2602-277X**

Reservoir mean global horizontal radiance	4.34 kWh/m^2/d
Mean annual air temperature	7.71 °C
Land cover in the reservoir area	Pre-impoundment
Bare areas	%35
Croplands	%52
Grassland	%8
Water bodies	%3
Settlements	%2
Power generation	20 MW
Yearly electricity generation	117.10 GWh
Construction	
Material excavated for construction	5549254 m^3
All concrete brought to site for construction	92873 m^3
All steel brought to site for construction	5549 t

The basin area around the dam was determined as a result of the basin analysis performed using ArcGIS 10.8 software using DEM data. The carbon content of the soil under the reservoir area was obtained from the Soil Information System of the Ministry of Agriculture and Forestry of the Republic of Turkey. The wind speed value at a height of 10 m in the reservoir area was obtained from the US National Aeronautics and Space Administration(NASA)https://power.larc.nasa.gov/data-access-viewer/ address. The reservoir mean global horizontal radiance value was taken from the Global Solar Atlas https://globalsolaratlas.info/map address, which is a map-based online platform that provides information about solar resources and photovoltaic power potential. The characteristic data belonging to the Tuzluca Dam project, from the information summarized in Table 1, were taken from the EIA and planning reports of the dam.[34,35]

3. RESULTS AND DISCUSSION

It is known that the biomass under water plays an important role in GHG emissions caused by dam reservoirs. Many studies have shown that especially dam reservoirs in tropical regions emit more GHG due to the dense vegetation under them and high water temperatures.[12,14,15,25,36,37,38] In order to estimate the GHG emissions to be generated by the Tuzluca Dam and HEPP project, the basin, reservoir, land cover, environmental parameters and dam characteristics of the dam region were obtained from reliable sources and entered into the G-res tool model.

The GHG emission values of the Tuzluca Dam and HEPP project before and after the dam are presented as G-res tool output images in Figure 3.

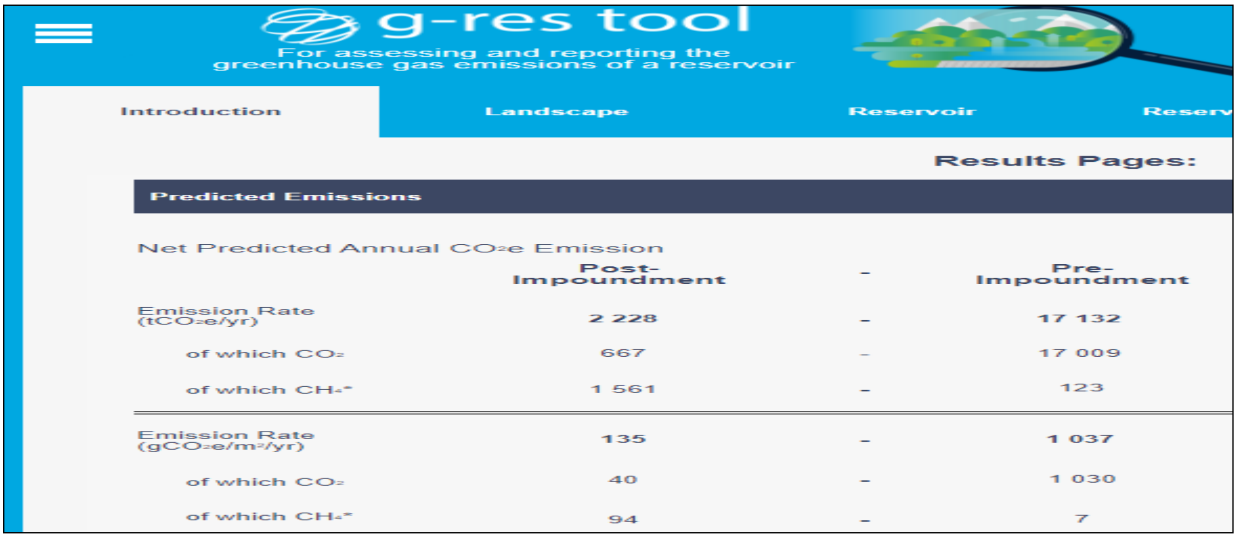

Figure 3.The GHG emission values of the Tuzluca Dam and HEPP project before and after the dam.

When Figure 3 is examined, it is seen that before the construction of Tuzluca Dam, annual greenhouse gas emissions in the reservoir area were approximately 17,132 tons of CO_2 equivalent, and this value was calculated as 1,037 grams per square meter. This high emission level is due to the fact that the land in the

DOI: http://dx.doi.org/10.32571/ijct.1549692 E-ISSN: 2602-277X

region is in agricultural use; since agricultural lands cause CO_2 emissions from soil and vegetation. However, after the dam started holding water, annual emissions decreased significantly, falling to approximately 2,228 tons of CO_2 equivalent (135 grams per square meter). This decrease can be attributed to the transition from agricultural activity to a reservoir area covered with water; since soil respiration and organic matter decomposition are at lower levels in flooded areas compared to actively cultivated agricultural lands. This change shows that the transformation of land use from agriculture to a water body can lead to a significant reduction in greenhouse gas emissions in certain cases.

When the CH_4 gas emissions to be generated by the dam are evaluated within themselves; It was observed that 70% of the total CH_4 emissions were due to bubbling emissions, 29% to diffusive emissions and 1% to degassing emissions. The relevant situation is shown in Figure 4 as the G-res tool output.

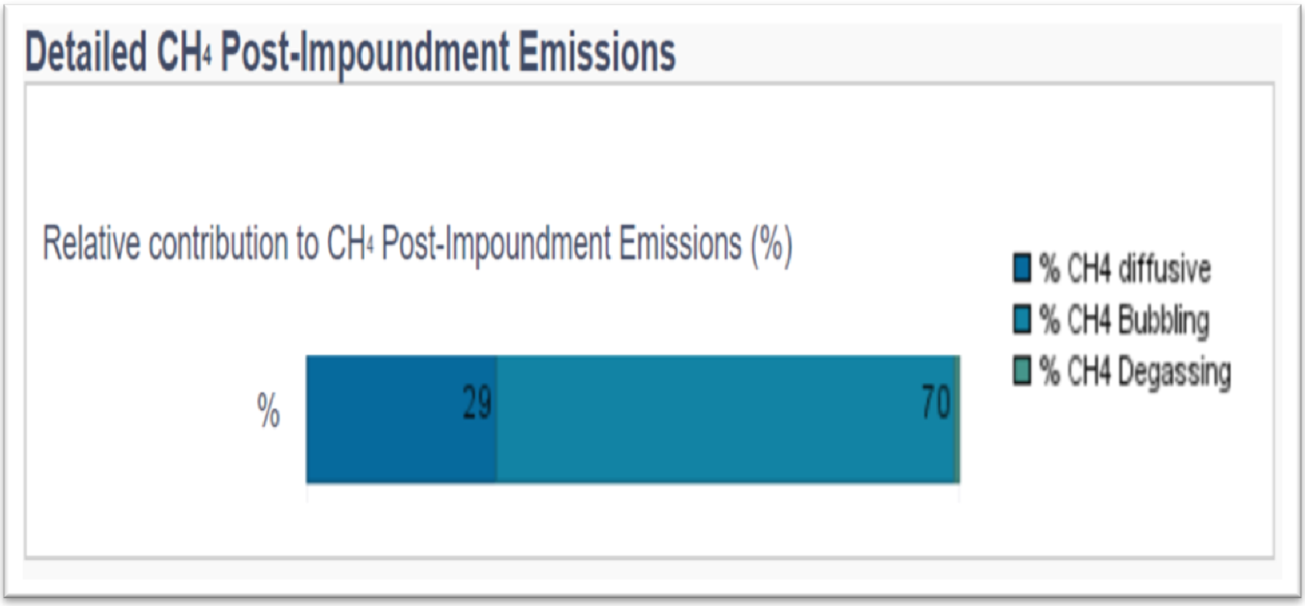

Figure 4. Distribution of CH_4 emissions from Tuzluca Dam and HEPP project.

The GHG emissions that will occur during the construction of the Tuzluca Dam and HEPP project have also been taken into account in the calculation of net GHG emissions. The excavation-filling, concrete and steel amounts specified in the dam project and the estimated transportation distances were entered into the G-res tool model and the GHG emission amount that will occur during the construction process was estimated as 1,661 tCO_2e/yr. The GHG emission values of the Tuzluca Dam and HEPP project before the dam, during the dam construction and after the dam, as well as the net GHG emission value, are presented as G-res tool output images in Figure 5.

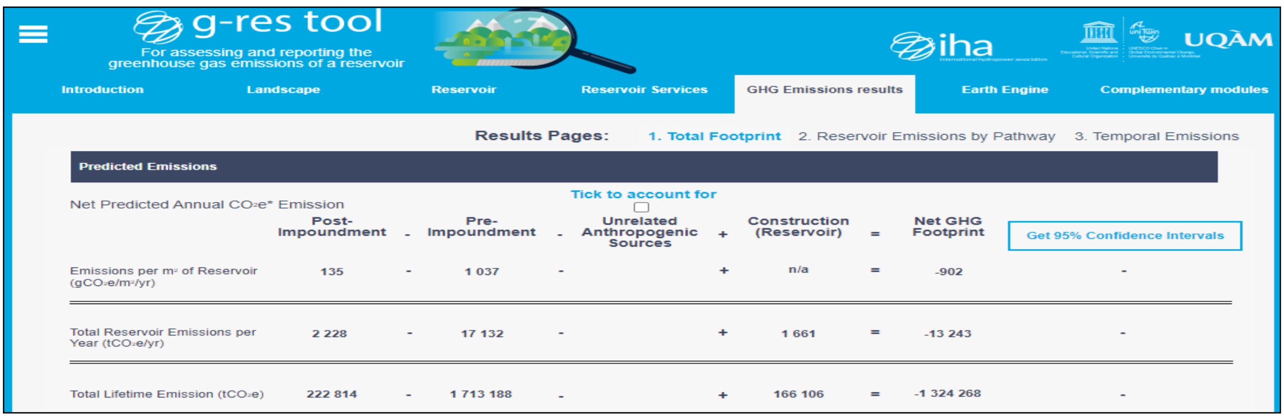

Figure 5. Net GHG emission values of Tuzluca Dam and HEPP project.

DOI: http://dx.doi.org/10.32571/ijct.1549692 E-ISSN: 2602-277X

When Figure 5 is examined, it is estimated that the Tuzluca Dam and HEPP project will emit -13,243 tCO_2e GHG per year. The total CO_2 footprint of the dam over its 100-year lifespan is determined as -1,324,268 tCO_2e.

The 100-year distribution of GHG emissions to be caused by the Tuzluca Dam and HEPP project is given in Figure 6 below.

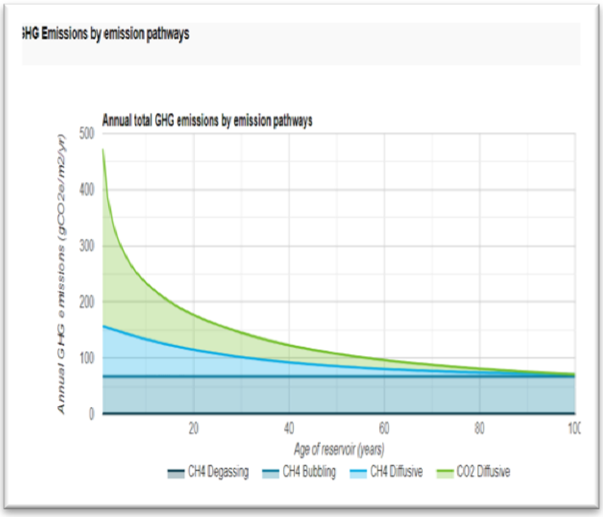

Figure 6. 100-year GHG emission distribution of the Tuzluca Dam and HEPP project.

When Figure 6 is examined, it is seen that the annual GHG emission, which was 470 gCO_2e in the first years of the dam, showed a decreasing trend in the following years. While a faster decrease is observed in the 20-year period, this value is estimated to be 70 gCO_2e in the 100-year period. This is expected and consistent with many studies in the literature.[29,30,33] Because in the first years of the dam reservoir, the organic matter remaining under water decomposes rapidly, causing high amounts of greenhouse gas emissions. However, over time, the amount of this organic matter decreases and the decomposition process slows down, reducing the amount of emissions. In addition, over time, the development of aquatic plants and other organisms and making the organic matter cycle more stable balances the water ecosystem in the reservoir, reducing greenhouse gas emissions in the long term.

GHG emissions from dams may vary from region to region depending on many factors such as climate conditions, dam characteristics, reservoir area, and water residence time. In order to evaluate the compatibility of the study results with the literature, the results were compared with reservoirs where similar studies were conducted in the G-res tool library. The comparison is presented as G-res tool output images in Figure 7.

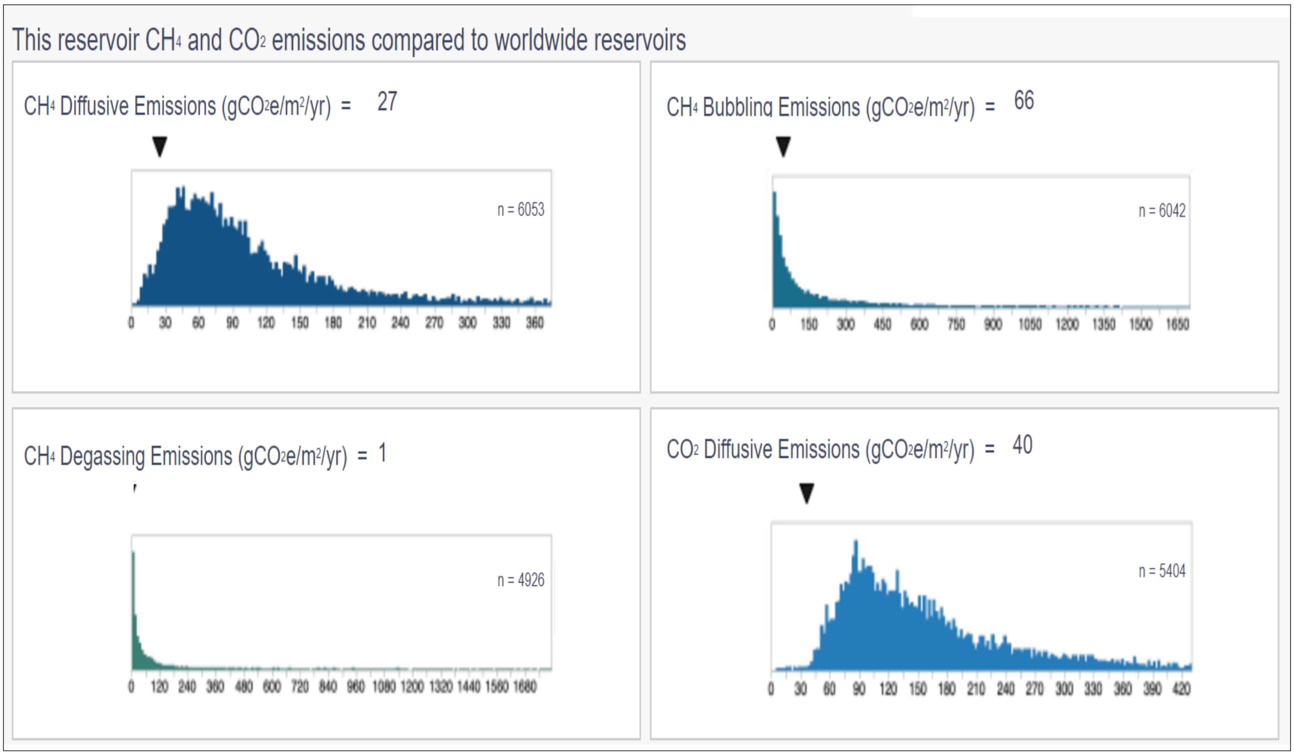

Figure 7. Comparison of GHG emissions of Tuzluca Dam project with other reservoirs.

DOI: http://dx.doi.org/10.32571/ijct.1549692 E-ISSN: 2602-277X

When Figure 7. is examined, it is predicted that Tuzluca Dam and HEPP project will produce -902 gCO_2e net GHG emissions per m^2 per year. The mentioned value was compared with reservoirs where similar studies were conducted in the G-res tool library and where negative net emission values were obtained. Graph is presented in Figure 8.

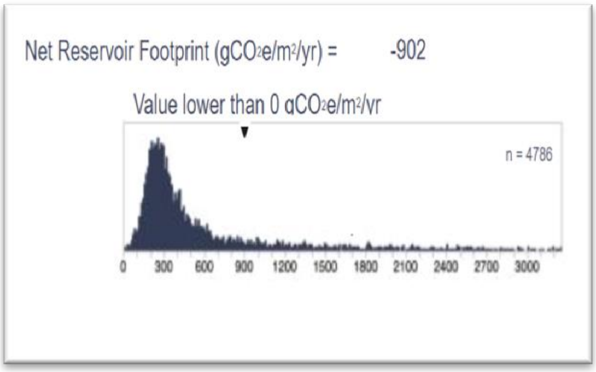

Figure 8. Comparison of net GHG emissions from the Tuzluca Dam Project with other reservoir.

4. CONCLUSION

In this study, the carbon footprint of the Tuzluca Dam and HEPP project to be built in Iğdır province of Turkey was determined with the G-res tool developed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Hydrological Association (IHA). The GHG emissions to be generated by the dam were estimated by presenting the dam characteristics, climatic factors, land cover maps, digital elevation model and information obtained from field studies to the G-res tool model.

Within the scope of the study, it was estimated that there was an annual greenhouse gas emission of 17,132 tons of CO_2 equivalent in the reservoir area before the Tuzluca Dam was built, and that there would be an annual GHG emission of 2228 tCO_2e from the reservoir area after the dam started holding water. The amount of emission that will occur during the construction process of the dam was calculated as 1661 tCO_2e/yr. When all these factors are included, it is predicted that the Tuzluca Dam and HEPP project will produce an annual net GHG emission of -902 gCO_2e per m2. In addition, the project's emission distribution over a period of one hundred years was obtained within the scope of the study. According to this distribution, the annual GHG emission, which is 470 gCO_2e in the first years of the dam, decreases to an annual value of 70 gCO_2e at the end of 100 years. The negative net GHG emission value indicates that there was higher GHG emission in the region before the dam was built. This situation is due to the dense vegetation in the region that will form the reservoir when the dam holds water. We believe that the GHG emission effects of the dam are low and acceptable due to both the negative net emission value and the expectation that the emission effects of the dam will decrease rapidly in 20 years as stated in the findings section. Especially considering that the Tuzluca Dam and HEPP project will meet the irrigation water needs of the region and has an annual electricity generation capacity of 117.10 GWh, it is evaluated that it is in a positive position in terms of benefit-loss.

Cleaning the plant community under the reservoir, which is one of the most important factors in GHG emissions caused by dams, before the construction of the dam is recommended as an emission reducing factor. In addition, as in this study, it is also recommended that the emission effects related to the dam in question be investigated and analyzed with similar methods before the construction of the dam begins, and that the necessary precautions and action plans be prepared.

Conflict of interests

I declares that there is no a conflict of interest with any person, institute, company, etc.

REFERENCES

1.Jansen, R.B. *Advanced dam engineering for design, construction, and rehabilitation*, Van Nostrand Reinhold Pub. New York, **1988.**

2. Berkün, M. *Su Kaynakları Mühendisliği*, Birsen Yayınevi, İstanbul, 2005.

3. Baxter, R.M. *Ann. Rev. Ecol. Syst.* **2005**, 8, 255-83.

4. McCartney, M. *Water Policy*. **2009**, 11(1), 121-139.

5. Fearnside, P.M. *Journal of the Geographical Society of Berlin*. **2015**, 148(1), 14-26.

6. Wu, H., Chen, J., Xu, J., Zeng, G., Sang, L., Liu, Q., Yin, Z., Dai, J., Yin, D., Liang, J., Ye, S. 2019. *Journal of Cleaner Production*. **2019**, 221, 480-489.

7. Zhang, X., Fang, C., Wang, Y., Lou, X., Su, Y., Huang, D. *Sustainability*. **2022**, 14, 5974.

8. Akgün, Ç. and Nas S.S. *Barajların çevresel etkileri, Teknolojideki Güncel Gelişmeler ve Uygulamaları: Çevresel Etkilerden Yapay Zekaya;* Güldal, S.; İksad Pub. Ankara, **2024**; pp 5-22.

9. IPCC Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, **2014**; pp. 659–740, ISBN 978-1-107-66182-0.

DOI: http://dx.doi.org/10.32571/ijct.1549692 E-ISSN: 2602-277X

10. Myhre, G., et al. *Anthropogenic and Natural Radiative Forcing.* In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. Eds., Climate Change **2013**: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, USA, p. 659-708. 2013.

11. Deemer, R.,. Harrıson, J., Lı, S., Beaulıeu, J., Delsontro, T., Barros, N., Bezerra-Neto, J., Powers, S., Dos Santos, M., and Vonk, J. *BioScience.* **2016,** 66, 11, 949-964.

12. Fearnside, P. M., *Environment Management.* **1999**, 24(4), 485–495.

13. Yang, L., Lu, F., Zhou, X., Wang, X., Duan, X. Sun, B. *Acta Ecologica Sinica*. **2014**, 34, 204–212.

14. Bastviken, D., Tranvik, L., Downing, J., Crill, P. and Enrich-Prast, A. *Science.* **2011**, 331, 50.

15. Demarty, M. and Bastien, J. *Energy Policy*, **2011**, 39, 4197–4206.

16. Almeida, R.M., Shi, Q., Gomes-Selman, J.M., Wu, X., Xue, Y., Angarita, H., Barros, N., Forsberg, B.R., García-Villacorta, R., Hamilton, S.K., Melack, J.M., Montoya, M., Perez, G., Sethi, S.A., Gomes, C.P., Flecker, A.S. *Nat. Commun*. **2019**, 10, 4281.

17. Gotsiridze, E. Assessment of greenhouse gas emissions from hydropower projects using G-RES tool. Masters Thesis, Norwegian University of Science and Technology Faculty of Engineering, Norway, 2023.

18. Fearnside, P.M. *Climatic Change*. **2004**, 66, 1–8.

19. Farrer, C. Hydroelectric eeservoirs – the carbon dioxide and methane emissions of a “carbon free” energy source. Masters Thesis, Swiss Federal Institute of Technology, Zurich, **2007**.

20. DelSontro, T., Kunz, M., Kempter, T., Weuest, A., Wehrli, B. and Senn D. *Environ. Sci. Technol.* **2011**, 45, 9866–9873.

21. Yang, L., Lu, F., Zhou, X., Wang, X., Duan, X., Sun, B. *Acta Ecologica Sinica*, **2014**, 34, 204 - 212.

22. Ion, V. and Ene, A. *Sustainability.* **2021**, 13, 11621.

23. Guerin, F. Emissions de Gaz a Effet de Serre (CO_2, CH_4) par une Retenue de Barrage Hydroelectrique en Zone Tropicale (Petit-Saut, Guyane Francaise): Experimentation et Modelization. Ph.D. Dissertion, l’Université Paul Sabatier. Toulouse, **2006**.

24. Kumar, A., T. Schei, A. Ahenkorah, R. Caceres Rodriguez, J.-M. Devernay, M. Freitas, D. Hall, Å. Killingtveit, Z. Liu. *Hydropower. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. **2011**, 437-496.

25. Fearnside, P.M. *Water, Air, and Soil Pollution*, **2002**, 133, 69–96.

26. Tremblay, A. and Bastien, J. I*nternationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen*, **2009**, 30, 866-869.

27. Kemenes, A., Forsberg, B.R., Melack, J.M. *Journal Of Geophysıcal Research*, **2011**, 116, G03004.

28. Kumar, A. and Sharma, M.P. *Human And Ecologıcal Risk Assessment,* **2015**, 0, 1-15.

29. Jiang, T., Shen, Z., Liu, Y. and Hou, Y. *Sustainability,* **2018**, 10, 2018.

30. Liana-Ioana Vuta et. Al. IOP Conf. Ser.: *Earth Environ. Sci*. **2023**, 1136, 012061

31. Min, K., Kim, S., Chung, S. *Greenhouse Gas Emissions and Footprint Analysis of Large- Scale Multi-Purpose Dam Reservoirs in Temperate Climates: Case Study from South Korea.* Available at SSRN: https://ssrn.com/abstract=4778125

32. Prairie, Y.T.; Alm, J.; Harby, A.; Mercier-Blais, S.; Nahas, R. *The GHG Reservoir Tool (Gres) Technical documentation v2.1 (2019-08-21).UNESCO/IHA research project on the GHG status of freshwater reservoirs; Joint publication of the UNESCO Chair in Global Environmental Change and the International Hydropower Association:* London, UK, 2017. Available online: https://www.hydropower.org/publications/the-ghg-reservoir-tool-g-res-technical-documentation

33. Dumitran, G., Vuță, L., Neagoe, A., Tică, E. and Popa, B. *Carbon footprint of reservoirs in Bucharest.* E3S Web of Conferences 404, 02001, **2023**.

34. Dolsar ve EİE. *Aşağı Aras Havzası Tuzluca Barajı ve Hidroelektrik Santrali Projesi Yapılabilirlik Raporu*, Elektrik İşleri Etüt İdaresi ve Dolsar Müh. Ltd. Şti., **2004**, Ankara, 298s.

35. AK-TEL. *Aşağı Aras Havzası Tuzluca Barajı ve HES Projesi Nihai Çed Raporu*, AK-TEL Mühendislik Eğt. Tur. Gd. San. Tic. Ltd. Şti., Ankara, 2015, 166s.

DOI: http://dx.doi.org/10.32571/ijct.1549692 **E-ISSN: 2602-277X**

36. Louis, V.L., Kelly, C.A., Duchemın, E., Rudd, J.W.M., Rosenberg D.M. *BioScience,* **2000**, 50, 766–775.

37. Zhao, Y., Nielsen, C. and Elroy, M. *Atmospheric Environment*, **2012**, 59, 214-223.

38. Bansal, S., Chakraborty, M., Katyal, D., Garg, J.K. *Applied Ecology and Environmental Research*, **2015**, 13. 597-613.

.