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Research Article

Nexus Evaluation of Combined Cycle Power Plants based on Water, Energy, and Carbon

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Abstract
Power generation, water consumption, and carbon emissions from power plants are intertwined. Most power generation technologies require water to cool steam turbines. The amount of water required for different types of power generation technologies varies in different power plants. The electricity sector is also one of the most important sources of greenhouse gas emissions worldwide and the main source of carbon emissions from fuel consumption in gas turbines and boilers. This study aimed to investigate the water, energy, and carbon nexus in the combined cycle power plants of Iran to identify the relationship between power generation, water consumption for electricity generation, and greenhouse gas emissions and ultimately improve the conditions, leading to the protection of the environment. In this study, first, the carbon and water footprints were assessed by LCA, and then, the water-energy nexus was modeled using the REWSS model (Regional Energy and Water Supply Scenarios). The Sankey diagram was then used to show the relationships and the current values for the power generation in the combined cycle power plants. Calculations of water, energy and carbon nexus have been done for 9 power plants and National scale. According to the results Damavand Power Plant had the highest power generation and the lowest WFL (0.068×10^{-9}). The opposite was observed in Khoy Power Plant with the lowest power generation and the highest WFL (0.43×10^{-9}).
Keywords: carbon and water footprint, combined cycle power plant, REWSS, Sankey diagram, water–energy–carbon nexus

Introduction

High consumption of fossil fuels in recent years has led to an increase in greenhouse gas emissions (GHGs). The GHG-induced climate change affects the flow of surface and groundwater. The analysis of integrated systems provides a correct understanding of the interconnections between

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energy, water, carbon, climate, agriculture, ecosystems, economy, and society. Healthy ecosystems, along with clean energy and water are the three basic needs of any community (Padash et al., 2021; Padash and Ghatari, 2020). Water and energy nexus are mutually interconnected. As the demand for water and energy increases, the relationship between the two will be strained in the coming years. Both water and energy are among the basic human rights and economic goods (Padash and Ghatari, 2020; Padash et al., 2019). It is important to address water and energy issues, such as population growth, climate change, and the resulting droughts as they complicate the management of energy and water systems.

Increasing demand for local resources, increasing the scale and types of pollution and climate change, altering climate patterns, and increasing the likelihood of droughts, floods, and natural disasters have made the water crisis as a risk of the current and future generations. By 2035, global primary energy demand will increase by 40% compared to 2010. Water and energy saving will remain one of the most important fields of sustainable development worldwide. Energy saving can reduce the pressure on water resources. Water needed for power generation can be stored or reused. Increasing water efficiency can reduce the amount of energy used for transportation, heat generation, and water treatment. Due to growing concerns about water and energy security around the world, deep investigation of the relationship between water and energy sources, known as Water and Energy Nexus (WEN), has gained much attention in recent years. The WEN analysis is believed to support better water and energy planning and help understand the potential policy and technology options. The WEN is expected to assist policymakers in the conservation and sustainability of water and energy (Faruqui, 2003; Dai et al., 2018).

Public awareness of water scarcity in Iran has increased significantly in recent years (Madani et al., 2016). Declining water levels in various lakes and wetlands such as Lake Urmia are often discussed. More than 90% of the annual water harvest in Iran is used by the agricultural sector for irrigation and livestock uses. The main water consumer in Iran, which is mostly affected by water stress, is the agriculture sector (Ashraf et al., 2019).

Accordingly, the nexus between water and agriculture in Iran is controversial and has already been widely discussed. The share of water consumption in the energy sector is much lower than in agriculture.

However, the current water shortage in Iran stems from electricity generation. In the near future, as water resources become less accessible, energy security and water allocation aspects will become more important (Terrapon-Pfaff et al., 2018).

According to the latest studies, power plants account for approximately 35% of the GHG emissions in Iran, which is in fact the largest share of emissions (Terrapon-Pfaff et al., 2018). Water plays an important role in the production of electricity in Iran so that more than 80% of the water in the electricity industry is consumed by the power plants. It may be argued that water is as important as fuel for the plants. Due to the current water crisis in Iran and the location of the country in a hot and arid region, it would be of utmost importance to pay attention to the nexus of water and energy in the power plants (Motevali and Koloor, 2017). In addition, while Iran is not an industrial country, it is ranked 7th in the world in GHG emissions. The fact is that thermal power plants in the country have a high share of GHG emissions. The interconnection of power plants and carbon emissions is very important (Ghorbani et al., 2020). Accordingly, the policy of the Ministry of Energy in recent years has shifted its policy on the development of combined cycle power plants (Energy Balance Sheet of Iran, 2016). The present study was an attempt to show the importance of water, energy, and carbon nexus in the combined cycle power plants in Iran. The study first determined the analysis scope by the life cycle assessment (LCA). The system boundary of the LCA was of the gate-to-gate type and set within the site of the power plants. By identifying the fuel consumption sources, emission factors, and global warming potential, the carbon footprint was assessed. After collecting the water consumption data (demin) of the combined cycle power plants, the water footprint was calculated. The REWSS was used to model the water-energy nexus. The REWSS model for new resources or areas for the state scale is about changes in the effects of using or removing specific resources. REWSS makes it possible to quantitatively evaluate policy questions on environmental sustainability. The water, energy, and carbon nexus were then investigated by the Sankey diagram.

Studies show that the issue of the nexus between water, energy and carbon has not been addressed at the national level so far, and only cases regarding the impact of electricity generation on carbon emissions have been addressed. At the international level, more attention has been paid to the technical and engineering aspects of the nexus, and rarely the environmental aspects of the issue have been studied (Lin et al., 2016).

Water is used in the energy production industry by the following sectors:

• Many conversion processes require water to stay cool. An example of this type of application is the water used by condensers in the open cycle cooling systems.

• Many conversion processes use water as a feedstock. This type of application can refer to the water used in the main cycle of the steam power plant and the water needed for chemical reactions and solutions.

• Water is needed in the process of producing and extracting energy and in some cases in the process of extracting oil (Siddiqi and Anadon, 2016). All these applications have a direct impact on the virtual water index of the material and energy production industries. There are also other factors that indirectly affect the index. The amount of water used to produce the energy needed by the upstream industries or to manufacture the required equipment and machinery are examples of these indirect links.

Water, Energy, and Carbon nexus in electricity generation industries

Electricity generation, water, and carbon emissions are highly interdependent. The water in the Rankine Vapor Cycle boiler of the Rankine is converted to steam in steam power plants at a temperature of approximately 500 ° C and a pressure of 170 bar where the steam generates electricity by rotating the turbine. The steam in the condenser then turns into water to re-enter the power cycle. The steam, as a working fluid, moves inside the plant in a closed cycle and is cooled by an open- or closed-loop cooling system. The formation of sludge in the steam cycle causes part of the water to drain out of the cycle. In addition, some steam is usually lost due to leakage. The major amount of water harvested and consumed in the power industry is in the cooling system of power plants. The higher the thermal efficiency of the power plant, less need for cooling and therefore less harvest and consumption. The different types of cooling systems include once-through, wet, dry, and pool systems. Despite a higher water consumption in a wet cooling system, the amount of water withdrawal in the wet cooling system is far less than the once-through. In a pool cooling system, despite the low water withdrawal, water consumption is even higher than the wet cooling system due to surface evaporation. In cooling systems such as wet and pool cooling towers, large volumes of water are lost as steam Higgins and Najm, 2020). To meet the growing demand for electricity and replace existing obsolete power plants, in the Ministry of Energy's policy plans have proposed to increase the efficiency of the combined cycle power plants. Increasing the efficiency of power plants also reduces the demand for cooling. With the increase in the number of combined cycle power plants in Iran's power generation industry, the amount of water needed for cooling will decrease. To increase the capacity of fossil fuel power plants, combined cycle power plants with higher efficiency, lower cost, and less water consumption have been proposed. It is necessary to gradually replace the old power plants, which are usually inefficient and have high water consumption and carbon emissions (Karbassi et al., 2017).

Literature Review

Ahmadi et al. (2020) in a research entitled "The economic synergies of modelling the renewable energy-water nexus towards sustainability" investigates the role of the water-energy-nexus in transition plans to achieve a future system with a higher share of renewable energy and lower excess water extraction. The results showed that planning the water and energy sectors as endogenous parts of one integrated system brings potential synergies. The levelized cost of variable renewable energy decreased by 20% and the levelized cost of desalinated water dropped 4%. Zhang et al. (2020) in a study entitled "Integrating emerging and existing renewable energy technologies into a community-scale microgrid in an energy-water nexus for resilience improvement" presents a novel planning strategy, along with an integrated system design of microgrids (MGs), to help realize sustainable energy supply patterns in a decentralized manner for improving community resilience and environmental sustainability. It is indicative that the system design of MG in an energy-water nexus will improve the reliability of energy supplies and strengthen community resilience, thereby increasing overall economic benefits in the long run. Behboudi et al. (2017) studied on The Nexus of Renewable Energy -Sustainable Development Environmental Quality in Iran: Bayesian VAR Approach. In this study investigates the dynamic interrelationship between sustainable development, renewable and non-renewable energies and environment nexus by applying Bayesian vector autoregression (BVAR) and impulse response functions in Iran with an annual data frequency for the time span of 1980-2013. In this study, the impact of the use of renewable and non-renewable energy with the main focus on sustainable development and CO2 has been investigated. The results showed that the effect of non-renewable energy consumption on air pollution is more than renewable energy consumption (Behboudi et al., 2017). Li studied on A review of the energy carbon–water nexus: Concepts, research focuses, mechanisms, and methodologies. Integrated models, such as computable general equilibrium- based models and input–output (IO)- based hybrid life cycle assessment models, should be used to assess the broad socioeconomic impacts of ECW- related measures in future, in order to inspire policymakers to design and implement effective measures for integrated ECW management (Li et al., 2020). Jangjoo et al. (2019) studied on Nexus Assessment of Water, Food and Health in the 19th District of Tehran. The purpose of this research is to provide a network model that can be used to determine the state of the hazards caused by Irrigation of land with untreated municipal wastewater. Methods of this study include the stages: knowledge of the study area, quantitative and qualitative assessment of surface water of the ministry of the earth, determination of stability indicators and interlinkages matrices, evaluation of interveners, comparison of interventions and management solutions (Jangjoo et al., 2019). Leivas et al studied on develops an integrated index (IWECN) that combines life cycle assessment (LCA) and linear programming (LP). In this study, Nexus of water, energy and climate change were evaluated (Leivas et al., 2020). Wang et al studied-on Water-energy-carbon nexus. The scale of this study was steel company. Integrated material and energy flow and water footprint models were developed to assess the nexus. Economy, energy-saving, water-saving, and carbon-reduction potential, of 31 energy-saving technologies (ESTs) were evaluated by the water-CO2 energy conservation supply curve model. This study highlights the need for policy development and production planning through the perspective of a water-energy-carbon nexus (Wang et al., 2020). Ding et al Studied on industrial water-energy nexus in China by proposing an interactive meta-frontier network DEA approach. This study examines the relationship between hydropower in water use efficiency and industrial energy in industrial production processes and evaluates the scale of wastewater treatment in China from 2011 to 2015. The results show that although eastern and central regions have high industrial production efficiency, most regions have relatively low wastewater treatment efficiency. In addition, the nexus degree of eastern region maintains a relatively high level and shows a stable improvement, while the rest two regions perform relatively worse (Ding et al., 2020). Higgins and Najm (2020) studied on An Organizing Principle for the Water-Energy-Food Nexus. They present an organizing roadmap for a conceptual and mathematical representation of the nexus **(**Higgins and Najm, 2020). Hamidov and Helming (2020) studied on Sustainability Considerations in Water–Energy–Food Nexus Research in Irrigated Agriculture. Results showed that the WEF nexus is indeed very relevant in irrigated agriculture (Hamidov and Helming, 2020). Fazeli et al. (2021) studied on Design and Optimization of Smart Central Heating Units for Homes; Energy and Environment Nexus. In this paper, a smart CHU has been designed and implemented, using an innovative intelligent network with the aim of optimizing burner performance in a 2250 square meter residential building. Furthermore, carbon monoxide (CO) emission and fuel consumption were analyzed and reduced simultaneously. The use of software and hardware elements in the design has reduced the working hours of the burner and improved its performance according to the required heat capacity at different times of the day. This study further indicates how intelligent control can significantly lower the pollution and optimize energy consumption (Fazeli et al., 2021).

Internationally, the methodology of studies on water-energy nexus can be divided into qualitative and quantitative methods. Combined life cycle analysis, indexing, comparing, and sampling are the four main qualitative methods to describe energy dependence on water. Different mathematical models and calculation of input/output tables are the main measurement methods for calculating the degree of energy dependence on water in the production process. Mathematical models are used to evaluate the consequences of energy use on water transfer and consumption and to determine the degree of energy dependence on water in the power generation process and vice versa. Too much water is consumed in power plants when burning different types of fuels such as coal, oil, natural gas, etc.

The plants harvest the water they need from rivers and lakes and use it in the cooling processes before returning it back to the original source. In this study, REWSS model was used to evaluate the nexus between water and energy and calculate their degree of interdependence.

Productivity Analysis and Simulation/Optimization Models (Types of Optimization Models): Mathematical techniques are used to express optimization problems, exploration techniques such as the genetic algorithm, annealing simulation, particle optimization, and the integrated techniques for the optimization of water and energy consumption. In the field of water and energy nexus, the optimization techniques are separately applied on each of those segments intended for nexus problems. The formulation of optimization problems depends on the features of the system and is a function of the purpose and the operating environment. Optimization techniques are used in water systems. The supply-side of the nexus can broadly be divided into the mathematical and heuristic techniques.

Material and Methods

Although water, energy and carbon nexus methods are diverse, there is no unique method for nexus assessment of water, energy, and carbon in combined cycle power plants and existing methods are not specific for such an assessment. In this research, it has been tried to evaluate water, energy and carbon nexus according to the existing methods and the use of combined methods.

Method structure:

1. Study and identification of existing models of water, energy and carbon nexus.
2. Investigating the status of power plants based on capacity, geographical location and age.
3. Calculation of water and carbon footprint of combined cycle power plants in defined scenarios.
4. Calculate the entanglement of water consumption, electricity generation and carbon emissions.
5. Show the relationship between water consumption, power generation and carbon emissions using the Sanky flow chart.

Method of selecting the sample combined cycle power plant

According to Iran's policies for the development and construction of more combined cycle power plants, the names of all active combined cycle power plants were listed from the power generation reports of Tavanir Company in 2018. A total number of 26 cases were identified, namely Sarv (Chadormelo), Abadan, Fars, Shariati, Rajaei, Montazer Ghaem, the Shohadaye Pirouz-e Behbahan, Parand, Shobad, Zavareh, Khoy, Neishabour, Guilan, Samangan, Shirkuh, Shirvan, Kerman, Yazd, Taban Yazd, Shahid Salimi, Qom, Sanandaj, Kazerun, and Pareh Sar. In addition, important parameters in selecting the sample power plant were also determined from Tavanir reports, including, climatic conditions, geographical location, model and type of turbine, power generation rate, nominal capacity, year of operation, type of fuel consumed, amount of fuel consumption, and type of cooling systems. Then, the power plants were classified based on the mentioned parameters and according to the similarity with each other.

Finally, according to the parameters of climatic conditions, year of operation, type of cooling system, and type of fuel consumed, which had a greater impact on the results, 9 power plants were selected in three categories. The power plants of Guilan, Fars, and Khoy were classified under the first category, Yazd, Kerman, and Damavand under the second, and Zavareh, Chadormelo, and Shirkuh under the third.

Determining the research time horizon

Library studies were conducted to determine the time horizon of the research. Given that similar studies were considered in external studies had considered the time horizons of 20-30 years (Hamidov and Helming, 2020) and information related to the forecast of electricity demand in 2040 was available and based on the BAU scenario, the time period of the present study was set from 2017 to 2040. There are various reasons for the increase in electricity demand, some of which are related to climate change in the region. For example, rising temperatures can lead to increased electricity demand for cooling. In turn, the growing demand for electricity increases the demand for water in the electricity sector. Unconventional water supply through seawater desalination techniques, or wastewater reuse methods is expected to stimulate the power shortages in the water sector. All of these different driving forces increase the electricity demand, and this in turn increases the demand for water to generate electricity. These dependencies are likely to lead to new dynamics in Iran's energy and water nexus (Higgins and Najm, 2020; Azadi et al., 2017; Newell et al., 2019).

Carbon footprint from the perspective of LCA

The LCA was implemented based on the gate-to-gate approach and for the climate change impact category. Emission sources in combined cycle power plants are fuel consumption in gas turbines and boilers. Accordingly, the amount of greenhouse gas (GHG) emissions was calculated based on the amount of fuel consumed for natural gas and diesel in table 1 (Kaur-Sidhu et al., 2020).

The CO_2, CH_4, and N_2O emissions were estimated by multiplying the amount of consumed fuel by the emission factor (Table 2). Multiplying the obtained number by the GWP of each of the gases, their CO_2 equivalent (Table 3) was calculated by equation 1 (Change, 2014; Dale and Bilec, 2014).

$$\text{Emissions } (CO_2e) = \text{Emission factor of each gas} \times \text{Fuel consumption} \times \text{Global warming potential of the gas} \quad (1)$$

Table 1. Information on the fuel consumed amount and the electricity produced amount by combined cycle power plants (Kaur-Sidhu et al., 2020)

Name of the combined cycle power plant	electricity generation (MkWh)	Fuel consumption (in thousand)	
		Gas oil (L)	Natural gas (m^3)
Guilan	7942	306896	1529226
Fars	5952	8855	1303058
Khoy	2057	97345	371179
Yazd	3827	28449	799637
Kerman	10353	83243	2211243
Damavand	13582	474470	2554614
Zavareh	2837	66332	520858
Chadormelo	2826	3186	597456
Shirkuh	2686	43267	544029
National scale	115079	2491605	24223311

Table 2. Fuel emission factor for the combustion sources (kg/1000m^3) and GWP of GHGs

Fuel Type	N_2O	CH_4	CO_2
Natural gas	3.12	0.059	2133
Gas oil	5.2	0.319	2648
GWP	265	28	1

Water footprint from the LCA perspective

As previously stated, in this study, the LCA was based on the gate-to-gate approach. Accordingly, the affected area, i.e. system boundary, was set as the site of the power plant. The average amount of water consumption in the power generation process of the combined cycle power plants (Demin water) in terms of m^3 and in a period of 5 years (2014-2015) were determined from the detailed statistics reports of Iran's electricity industry (Table 4).

Also, the water consumption intensity in terms of MWh/m^3 was calculated based on the amount of power generation in the base year (2017).

Evaluation of water and energy (electricity) nexus using REWSS model

After reviewing several models of water, energy, and carbon nexus, the REWSS model was selected finally. REWSS is a new model integrates water and energy into a single life-cycle framework and allows different effects to be considered from different sources. Beyond saving the life-cycle effects of each year, the model can determine the additional infrastructure needed to achieve specific goals, incorporate new technologies, and evaluate uncertainty based on known information.

Introduction on REWSS model

REWSS (Regional Energy and Water Resources Scenario Model) is an open-source model developed by Dale and Bilec to calculate the annual environmental impacts of energy and water resources in a given region. The model, which is based on available data and designed for non-specialist use in the context of life-cycle, simulates uncertainty and variability using Monte Carlo methods. It can be used to calculate the effects of GHGs, energy consumption, water consumption, land occupation, and monetary costs. These impact categories are not region-specific in the calculations, are available to all sources, and provide a clear and basic image of the use of resources. In the implementation for a specific region, it is also possible to add more complex impact categories to the model such as environmental toxicity, eutrophication, or human health effects (Change, 2014).

Calculation steps in REWSS

The model uses the data of LCA, current regional infrastructure, and geographic conditions, as well as the information of designed scenarios to calculate the environmental impacts of energy and water supply in a given area.

It consists of three steps: (1) calculating the annual demand for each resource, (2) identifying the construction needed to meet the demand, and (3) combining the two with LCA data to calculate the annual impact in five impact categories.

Table 3. The Carbon footprint calculation results

Name of power plant	CO_2 e(t)		Total CO_2e emissions	Carbon footprint (t/MkWh)
	Gas oil (L)	Natural gas (m^3)		
Guilan	1.236	4528.729	4529.96	0.57
Fars	0.035	6847.114	6847.14	1.15
Khoy	0.391	1099.227	1099.618	0.53
Yazd	0.114	2368.085	2368.19	0.618
Kerman	0.334	6548.488	6548.822	0.632
Damavand	1.913	7565.365	7567.278	0.55
Zavareh	0.266	1542.495	1542.761	0.543
Chadormelo	0.012	1769.335	1769.347	0.626
Shirkuh	0.173	1611.114	1611.287	0.6
National scale	10053.45	71736172.8068	71746226.2568	0.623

Calculation of the water and energy nexus

REWSS is a new model that integrates water and energy into a single life-cycle framework and allows considering different effects from different sources. Beyond saving the life-cycle effects of each year, the model can identify the additional infrastructure needed to achieve the specific goals, incorporate new technologies, and evaluate uncertainty based on the known information.

After the necessary investigations, it was decided that the system boundaries should be the same as the site of the power plants. The inputs of the system were the amount of fuel and water consumed and its output was the amount of GHG emissions. As one of the steps of the REWSS model, it was necessary to calculate the required water and electricity nexus. The GHG emissions and water consumption rate were calculated from the perspective of LCA and using carbon and water footprints. The percentage of water used for electricity generation (WfL) was obtained from Equation 2:

$$WFL = \frac{I_{t,Elec}^{Wat}}{D_{t,Wat}} \quad (2)$$

Where, *WFL*= Percentage of water used to generate electricity, $I_{t,Elec}^{Wat}$= Intensity of water used to generate electricity in the year *t*, $D_{t,Wat}$=Water demand in the year *t*.

One of the goals of the REWSS model is to put water and energy in a similar framework for calculating the effects. The nexus between these two sources is calculated based on their relative demand for each other.

REWSS is used as a method to calculate the effects and uncertainties. In terms of uncertainty, REWSS depends on the existing LCA data and if unavailable, the impact assessment will be either incomplete or very undesirable. REWSS is a key tool in bridging the gap between environmental impacts and regional sustainability based on physical resources that the results are presented in Table 5.

Result and discussion

As mentioned before, 9 combined cycle power plants have been selected. Water and carbon footprint have been calculated for 9 power plants and national scale. In order to describe the nexus of water, energy and carbon for power plants, Sankey diagram have been used. It is necessary to mention that combining the REWSS, footprint calculation and Sankey diagram have been used in this research.
Water footprint, carbon footprint and WFL, were calculated according to the formulas defined in the previous section as follows:

Flow plotting by the Sankey Diagram

The research output is finally displayed using a Sanky diagram. The Sankey diagram can be used to show the relationships and values of the currents required in combined cycle power plants to generate electricity.

Sankey diagrams are a special type of flow diagram in which the width of the arrows is in proportion to the number of flows. The Sankey diagrams in this research was drawn using the amounts of water consumption, power generation, and GHG emissions (Fig 1). Then a separate diagram was drawn using thermal efficiency values and water and carbon footprints (Fig 2).

Table 4. Water footprint calculations

Combined cycle power plants name	Electricity generation (Mwh)	Average amount of water consumed (m^3)	Water footprint (Mwh/L)	Water intensity (Mwh/m^3)
Guilan	7942000	275000	34.62	0.034
Fars	5952000	230388	38.7	0.038
Khoy	2057000	87600	42.58	0.042
Yazd	3827000	172572	45.09	0.045
Kerman	10353000	242652	23.43	0.023
Damavand	13582000	911916	67.14	0.067
Zavareh	2837000	53786	18.95	0.018
Chadormelo	2826000	91400	32.34	0.032
Shirkuh	2686000	150146	55.9	0.055
National scale	115079000	112742000	980	0.98

Table 5. Calculated WFLs

Name of the power plant	WFL
Guilan	$10^{-9}\times0.11$
Fars	$10^{-9}\times0.15$
Khoy	$10^{-9}\times0.43$
Yazd	$10^{-9}\times0.24$
Kerman	$10^{-9}\times0.09$
Damavand	$10^{-9}\times0.068$
Zavareh	$10^{-9}\times0.33$
Chadormelo	$10^{-9}\times0.33$
Shirkuh	$10^{-9}\times0.33$
National scale	$10^{-9}\times3$
combined cycle power plants	$10^{-8}\times1$

Levis et al study develops an integrated index (IWECN) that combines life cycle assessment (LCA) and linear programming (LP) to assess energetic, water and climate systems, enabling the identification of those products with minors energetic and water intensity and climate change. The goal and scope of this study was the assessment of the energy and water consumption as the main resource’s consumption, as well as the quantification of CO_2 emissions as the main environmental burden. while in the present paper, water and carbon footprints are examined from a life cycle assessment perspective, and energy is considered from a production perspective at Nexus. The article by Wang et al. Discusses energy and water savings that reduce carbon emissions. But the current article discusses the water and carbon footprint in energy production, and in the article compared, Integrated material and energy flow and water footprint models were developed to assess the nexus. Economy, energy-saving, water-saving, and carbon-reduction potential, of 31 energy-saving technologies (ESTs) were evaluated by the water-CO_2 energy conservation supply curve model but in this study, REWSS model used for evaluating water-energy- carbon nexus. Higgins and Najm studied on an Organizing Principle for the Water-Energy-Food Nexus.

This article outlines the four essential nexus framework and lays the grounds for establishing a nexus mathematical framework. In addition to the differences in Nexus parameters, it does not calculate it and only presents conceptual models. Fazeli et al (2021) studied-on Design and Optimization of Smart Central Heating Units for Homes; Energy and Environment Nexus.

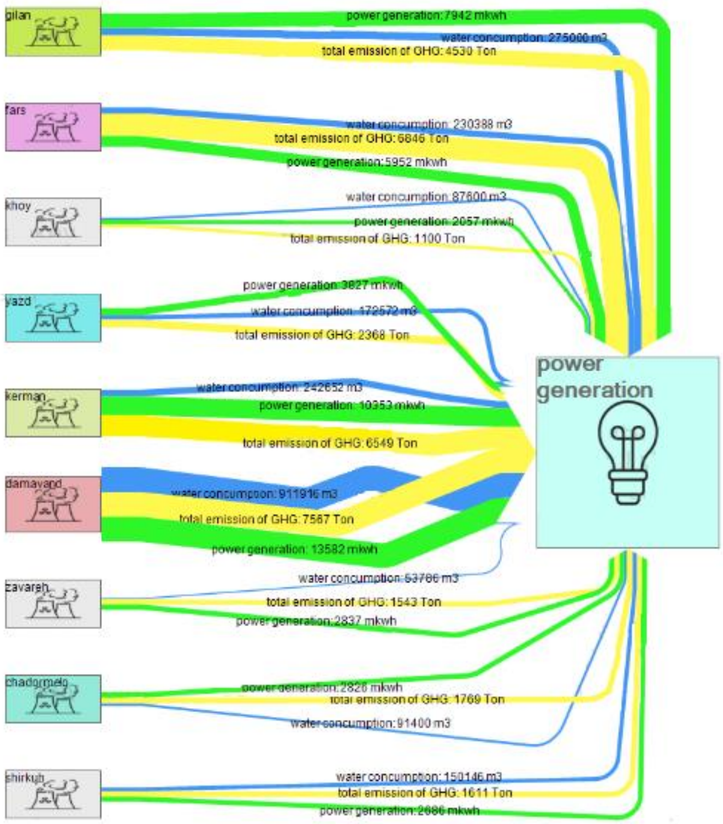

Figure 1. Sankey Diagram of Water consumption-power (electricity) generation-Total emission of GHG Nexus

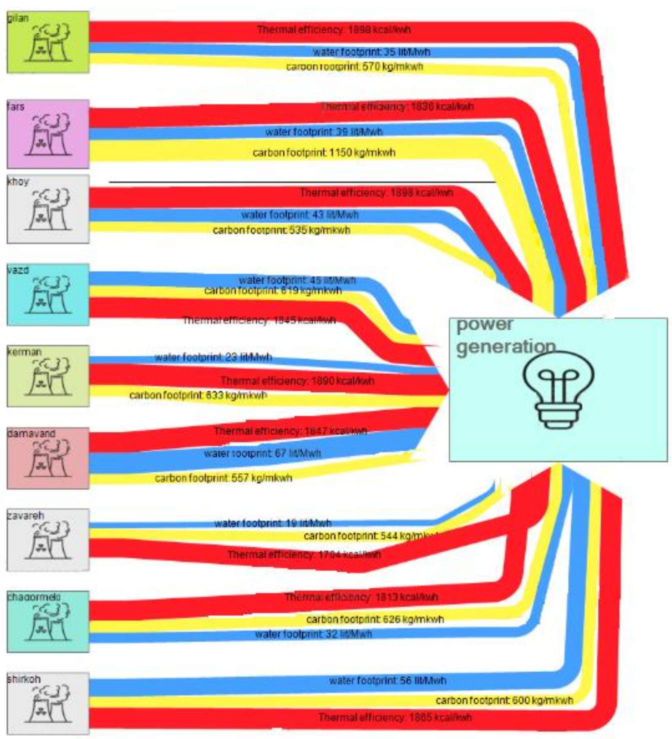

Figure 2. Sankey diagram of Water Footprint-Thermal Efficiency-Carbon Footprint Nexus.

This study further indicates how intelligent control can significantly lower the pollution and optimize energy consumption. In addition to the differences of this article in Nexus parameters, the study method and case study are different from the current article. Hamidov and Helming studied on Sustainability Considerations in Water–Energy–Food Nexus Research in Irrigated Agriculture. At last, it is necessary to mention that most research are about water energy carbon nexus in large scales and other sectors like water system of a city, other industries, but there is not similar research as this research, so to compare it completely them with this research).

Ding et al Studied on industrial water-energy nexus in China. The perspective of this research is economic and the scale of the study is wastewater treatment systems over a period of 4 years, which is different from the present study. Li studied on A review of the energy carbon–water nexus: Concepts, research focuses, mechanisms, and methodologies. This study is a review study of existing methods and mechanisms for evaluating and calculating Nexus And has not examined a specific case study.

Behboudi et al (2017) studied on The Nexus of Renewable Energy -Sustainable Development Environmental Quality in Iran. The scale is similar to the current research, Iran. But the parameters of Nexus evaluated and the method of study are different from the current research.

Comparison of the present study with similar studies indicates that the cases of study are only combined cycle power plants (gate to gate) and the energy consumption and fuel combustion that leads to greenhouse gas emissions only in terms of fuel consumption Have been tested in boilers and gas turbines.

Regarding water consumption, only process water consumption has been considered. The nexus of water, energy and carbon has also been assessed from an environmental rather than an economic or engineering perspective.

Conclusion

Assessing the water consumption and electricity generation nexus

The water-energy approach is an overall vision of sustainability that seeks to strike a balance between different goals, interests and needs of people, industry and the environment based on the quantification of water-energy relationships through qualitative and quantitative modeling as well as advancing research for integrated modeling. Establish management to present important sustainable development strategies in today's dynamic and complex world.

To assess the water-energy nexus, after collecting water consumption data in the sample power plants, their water footprints were assessed and compared based on the power generation amounts. Then, the water and energy nexus were evaluated using the REWSS model. Then, the WFLs of the combined cycle power plants (which show the percent of water use by the power plants to generate power) were compared with the amount of power generation in the power plants. According to the results Damavand Power Plant had the highest power generation and the lowest WFL. The opposite was observed in Khoy Power Plant with the lowest power generation and the highest WFL.

The results also revealed that Damavand Power Plant has the highest power generation, the highest water consumption, and the highest GHG emissions among the sample power plants (Figure. 1). Compared to Khoy, Chadormelo, and Shirkuh Power Plants, Zavareh has more power generation but less water consumption. This shows that the amount of power generation and water consumption in combined cycle power plants are not always directly related to each other. As figure 2 suggests, Guilan and Khoy Power Plants with the highest thermal efficiency rates had less water footprint than Yazd, Damavand, and Shirkuh Power Plants. Most of the water harvested and consumed in the electricity industry is for the cooling system of power plants. The higher the thermal efficiency of the power plant, the less need for cooling. This would lead to less need for water withdrawals. Thus, in a general conclusion, it can be stated that there is not always a direct and linear relationship between water consumption and power generation in combined cycle power plants.

Assessing GHG emissions and electricity generation nexus

According to the obtained results, Damavand Power Plant has the first rank in power generation, water use, and GHG emissions among the sample power plants. Compared to Khoy, Chadormelo, and Shirkuh Power Plants, Zavareh has more power generation rate but less water consumption (Fig. 1). According to which, it can be concluded that the amount of power generation and water consumption in combined cycle power plants are not always directly related to each other. The results also revealed that Guilan and Khoy Power Plants with the highest thermal efficiency have less water footprints than Yazd, Damavand, and Shirkuh Power Plants. The vast majority of the water withdrawals in the electricity industry is spent on the cooling system of power plants. The higher the thermal efficiency of a power plant, the lower the need for cooling and, therefore, the harvesting and consumption of water. In better words, it can be concluded that there is not always a direct relationship between the amount of power generation and water consumption in combined cycle power plants.

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