14th INTERNATIONAL 100% RENEWABLE ENERGY CONFERENCE

IRENEC

IRENEC 2024

PROCEEDINGS

17-19 APRIL 2024

RENEWABLE ENERGY ASSOCIATION

EUROSOLAR Türkiye

Editors

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Publishing Date 09 December 2024

ISBN 978-605-62511-4-6

Tanay Sıdkı Uyar

Conference Chair,
IRENEC 2024

Dear Participants,

In our journey of promoting 100% Renewable Energy, we have arrived the 14th stop where we shall again share our research results and other achievements.

Every day we are discovering and practicing the good quality of renewable energies. The genie is out of the bottle. It is time to use the good quality of human beings to guide this opportunity effectively to the destination. The qualities of human beings can play its role if the individuals and countries talk together and define problems correctly and find solutions that can be implemented.

Renewable energy resources at each corner of the atmosphere are ready to be converted to electricity and process heat locally when needed. Kinetic energy of the moving air, chemical energy stored in biomass, heat and light of the sun and geothermal resources are available all over our planet earth free of charge. As the main energy source of living space on earth, sun and its derivatives were available before, are available today and will be available in the future.

Global support provided for the renewable energy made the market penetration of renewables possible. Today wind and solar energy became the cheapest way of producing electricity in many parts of the World.
Cities and countries who are trying to reach 100% renewable energy mix are working on preparing the infrastructure necessary to be able to supply more renewable energy for industry, transportation and buildings by smart grids and renewable energy storage systems.

Since renewable energy is available at every corner of our atmosphere, Community Power (the involvement of the local people individually or through their cooperatives and municipalities in the decision-making process and ownership of their energy production facilities) is becoming the most effective approach for transition to 100% renewable energy future.

During IRENEC 2024 we shall share and learn from the global experiences on difficulties, barriers, opportunities and solutions for transition to 100 % renewable energy societies and make our contribution to Global Transition to 100% Renewable Energy.

Best Regards,

Tanay Sıdkı Uyar

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Full Research Papers

Energy Sharing in Citizens Communities

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Abstract. *A fossil free society will not only change the generation of energy to 100% renewable energy, but also the use of energy. Therefore, every person will be involved in the change individually. Energy sharing in citizens communities will thus become an important aspect in a fossil free society.*
The publication will give examples for the realisation of such projects. It discusses the problems of a neighbourhood energy sharing scheme. Furthermore, it shows, which effort is necessary to manage an energy sharing communities using the example of a community battery store in a climate protecting settlement. The effort is much dependent on what people consider as "fair" for the sharing of energy. The role of administration and legislation to trigger citizen's activities will be discussed as well.

Keywords: energy sharing, renewable energy, communal storage.

1 Involvements of citizens

The energy transition towards a fossil free energy use is something, where everybody is involved. In Germany in 2019, the majority of renewable energy owners were citizens with 53.6%, which include private persons (30.2%), farmers (10.2%) and crafts and trades (13.2%) [1]. This results in the energy transition generating significantly lower cost for the energy users, because typically based on own experiences private investors are satisfied with lower profits compared to institutional investors, as illustrated in **Fig. 1**. While the investments are needed anyhow, the expenditure for the profits can be significantly lowered with expectations of private persons.

Investment in renewable energies does not only pay back to the individual investors, but a whole region may benefit from it. As an example, the region Rhein-Hunsrück-Kreis in Germany had spent 290 Million Euros on energy imports. After changing the energy structure to renewable energy generation to more than 100% the region could generate a profit of 44.175 Million Euros in 2017 [2].

Therefore, the involvement of citizens remains very important and this contribution shows two examples to stimulate citizens involvement into energy transition. The first shows a proposal for neighbourhood energy sharing and the problems that may appear. The second example shows the use of a mutual battery storage for a climate friendly settlement and discusses possible business cases.

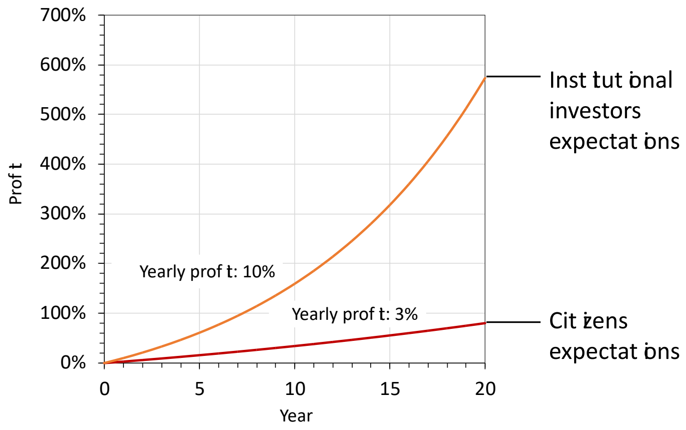

Fig. 1. Expected profit for institutional investors compared to private citizens.

2 Neighbourhood energy sharing

One possibility to involve citizens in energy generation is energy sharing. While energy sharing over a larger distance appears abstract to most people, sharing self generated energy with neighbours is something many can imagine. The idea would be to deliver excess generated energy, e.g. by a photovoltaic (PV) system on the own roof, with neighbours, who do not have the possibility to generate their own energy.

A technical amateurs may think of straightforward solution, which is simply a power cord connecting the neighboured households as illustrated in fig. 2. However, this is a dangerous solution, because the circulating currents may appear, which can not be controlled and possibly exceed limits. In addition, the power flowing through the energy counters is not defined and thus no suitable energy counting is possible.

Therefore, the only technical solution is to share energy over the power grid, which connects the households. This is usually a public grid and therefore public rules apply. This however raises legal aspects. The challenge here is a fair energy counting, which takes into account the acquired energy from the neighbour. The different modes are explained in the following paragraphs.

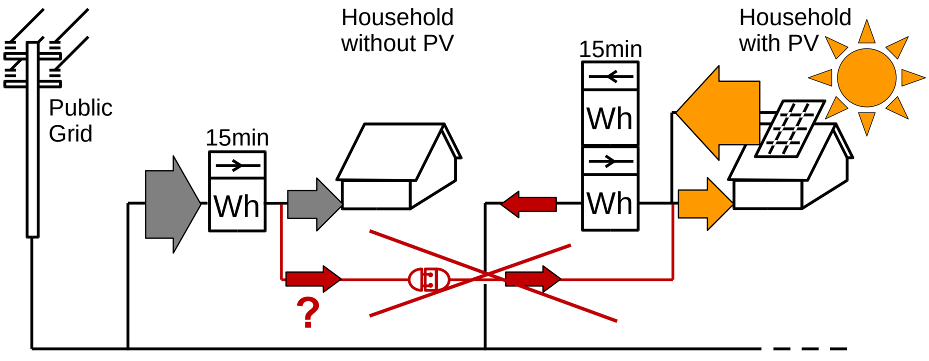

Fig. 2. Energy sharing with a power cord. Take care: This leads to uncontrollable current flow!

Fig. 3. illustrates the case on a sunny day, where the generated PV power is sufficient to supply the own and the neighboured household. In this case the total consumed power by the household without PV is delivered from its neighbour. Therefore, then the power consumption must not be charged to the usual energy supplier. Furthermore, in this case only a fraction of the excess power of the PV owner is finally fed into the public grid. Then the PV owner has to get compensation for fed-in PV energy. And finally, the two household need to know, how much power is shared to establish a fair financial compensation.

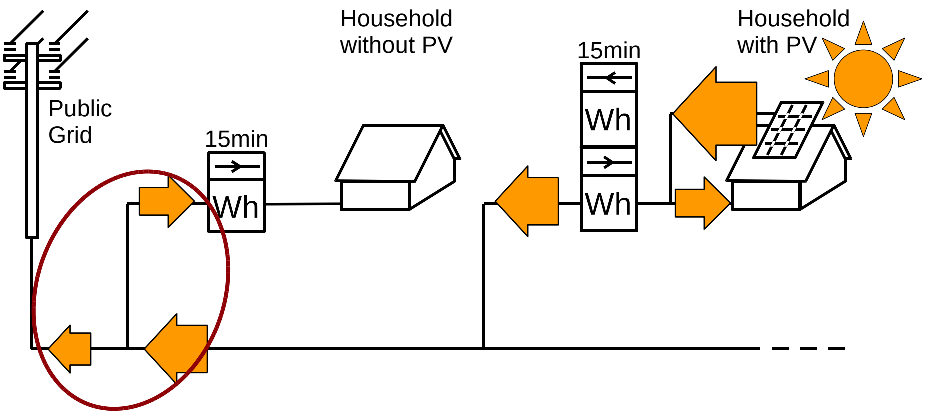

Fig. 3. Energy sharing over the power grid at a sunny day.

An even more complex case is a cloudy day as shown in fig. 4. Here a case is illustrated, when the generated PV power is not sufficient to supply both households completely. Instead, the household without PV gets a mixture of a little excess PV power from the neighbour and in addition the remaining power from the public grid. This shows that the neighbour's PV cannot be the only source of power, and also that one cannot easily switch completely from one to the other source. Instead, two power sources must be billed at the same time.

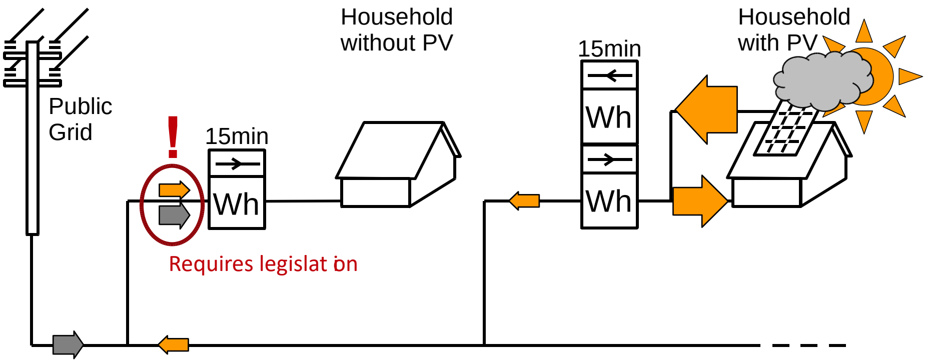

Fig. 4. Energy sharing over the power grid at a cloudy day.

If there is only little or no PV generation, as e.g. during night, all households must be supplied by the public grid (see fig. 5). This is the conventional case and is handled by energy providers already now.

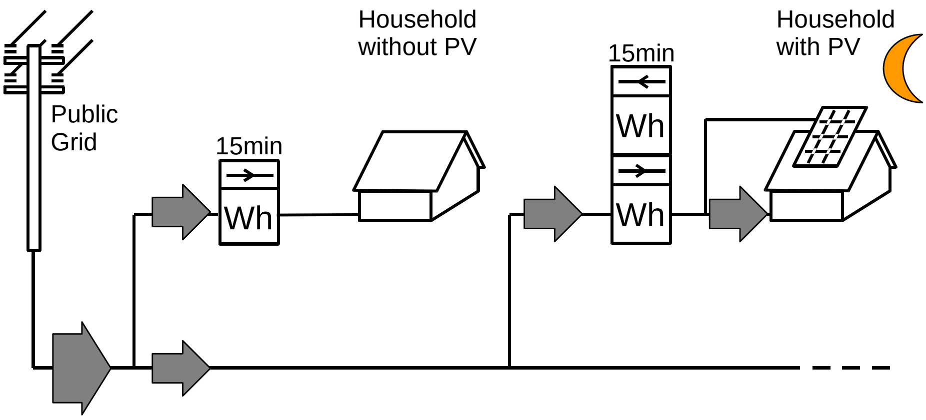

Fig. 5. Energy sharing over the power grid at night.

The above shown examples illustrate that neighbourhood energy sharing is basically a commercial issue. Neighbourhood energy sharing would not change the physical power flow on the lines. But this commercial aspect would have some additional benefit: It would be considered as “fair” to many users. It would possibly even trigger additional PV installation, because many people would be more willing to deliver excess energy by their additional PV system go well known neighbours instead to an anonymous power provider. It would also improve acceptance by those who are not able to install an own PV system, if they could commercially benefit from their neighbours PV.

The examples also made clear that it requires appropriate organization and legislation. It can be solved only with a sophisticated measuring system like smart meter systems. It requires timely energy counting in both directions at every household,, e.g.

in 15 min time slots. Then, a balance can be calculated taking the meter readings into account. The calculation can sort out the power flows as illustrated in the previous figures.

It is obvious that such tasks cannot be done by normal consumers. Therefore, it is proposed by SFV (Solarenergie Förderverein Deutschland e.V., Solar Energy Promotion Association Germany) [3] that power providers should be obliged to this task. This includes

- billing with multiple suppliers,
- considering excess PV energy
- using individual power profiles
- 15 min energy counting and billing

The energy sharing should be limited to the neighbourhood. The related distance has jet to be defined, either by air distance or by the power grid.

There are several legal aspects to be considered:

At the moment, multiple suppliers are not foreseen by legislation. This would be the first step to be changed. This would also require a complete redesign of the billing systems of energy providers, which actually do not have the option of multiple suppliers.

As a further aspect, this would deeply change the way how the balancing group equalisation (in German: Bilanzkreisausgleich) is done for power grids with private households. Today, it is done with standard load profiles, which are scaled to the last year's energy consumptions. This does not require real time or 15 min balancing, and it allows an easy prediction of the future consumption. Changing to multiple supplies with much less predictable use of the neighbour's PV power would require a complete new setup of the whole system for balancing group equalisation.

Even worse, fed-in PV power by households is usually treated a EEG-energy and is related to a special balancing group, where it is also treated with standard feed-in profiles [4]. Neighbourhood energy sharing would therefore require a change also in the EEG-energy balancing group equalisation. In fact, the local energy exchange would require balancing locally power from one balancing group to the other.

Concluding, introducing neighbourhood energy sharing in Germany would require a change in legislation and a remarkable effort for the power supplier to change their billing and power balancing systems. However, EU legislation already demands such a provision.

3 Community Battery

3.1 Use case

A further option for energy sharing are settlements with mutual energy use. Here, a n example for a climate friendly settlement is shown, which is going to use a common community battery storage. Each of the houses in the settlement have photovoltaic (PV) systems on their roofs. There is one connection to the public grid for the whole settlement. From there the power grid is non-public. The primary function of the battery storage is to enhance the autarky of the settlement from the public grid by storing excess PV energy and providing it, when there is less PV generation. This improves the use of "green" energy from the PV, while import of grid power always include "grey" energy from fossil based power generation.

In a previous publication [5] it could be shown that a mutual storage requires less capacity than individual storages in each household. Fig 6. shows the main results. Details are explained in the paper. The figure shows that the advantage for a common storage appears for battery sizes, where the energy capacity is less than the daily energy consumption. About halve of the daily energy consumption would be a typical case for the dimensioning of such a battery storage. As an example indicated in the figure a typical grade of autarky of about 70% requires 24% smaller size of a common battery storage compared to individual batteries in each household. The reduction appears, because in the mutual power grid generated PV power can be exchanged between households, which avoids the need for storing and the need for receiving energy from the public grid.

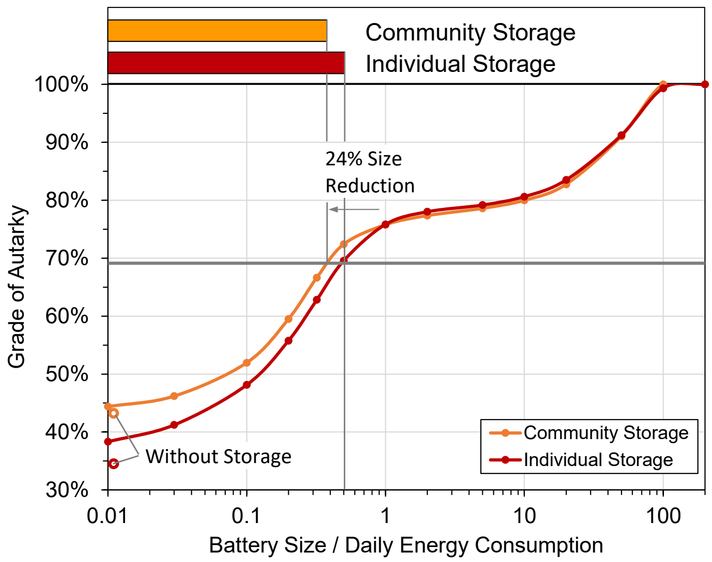

Fig. 6. Grade of autarky for the settlement with a community storage compared to average grade of autarky of the households with individual battery storages. Both storages have the same accumulated capacity.

3.2 Fairness

An important aspect for energy sharing is how fair the involved people consider the commercial aspect. Especially such a community as in the climate friendly settlement offers the choice for different models. The aspect, how fairness is achieved, influences to a great extend the effort, which is needed for billing and measuring. This will be explained in the following paragraphs.

Commercial Fairness: Most people consider commercial fairness as most fair when giving and receiving things. As an example, one can find this principle "Buy for what you get – Get what you pay for" in a market hall. Here, the energy exchanged is the considered as individual property of each involved person. It requires an individual measurement of each fraction of energy and a tracking, who got which energy from where. This requires a high effort for billing. A concept like this has been tested in a real life project involving a communal storage [6].

Such a concept requires a high effort for measurement and billing. Fig.7. illustrates the technical needs. There are real-time measurement devices necessary in order to control the power converters according to the actual need. The measurement devices must be reliably connected with suitable bandwidth. Because the connection for the control is time-critical and because of the reliability a public data network like internet is not suitable. Instead it requires a proprietary communication solution. To track each energy package billing requires a 15 min metering. Since the billing is not time critical, public data networks can be used. However, in a public network data security must be considered. Upcoming smart meter infrastructure would be suited for it.

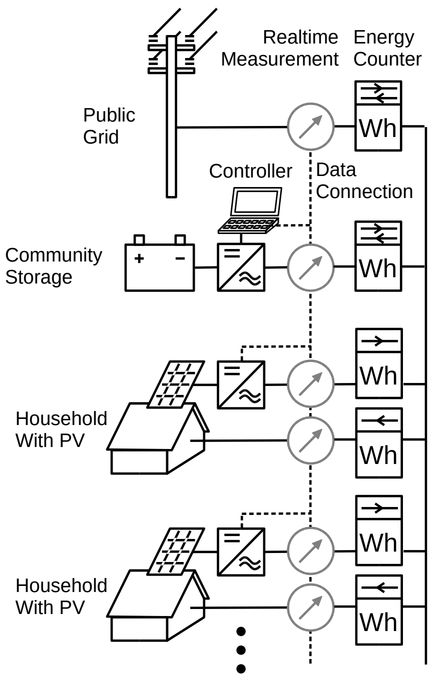

Fig. 7. Measurement setup for a community storage including real-time measurements to allow individual billing.

Social fairness: In families or groups of friends sharing can be obtained without keeping track of each transition. In such a case of "social fairness" the involved people agree that each person gets what is needed and consider this as fair. Property is treated as mutual property.

Transferred to the energy community all generated and consumed energy is treated as mutual. The no internal tracking of the energy flow is necessary. This makes the measuring setup very simple, as shown in Fig. 8. Only on common meter and one real-time sensor are necessary at the point of connection to the public grid. The common meter is necessary for the billing with the public energy supplier once a year. The current sensor is needed for the control of the battery converter.

While this is the most simple measuring arrangement, it requires trust between the participants. Since a settlement is installed for many years, trust between participants can change, e.g. because of unforeseen events, change of participants or change of individual needs. Therefore, such an arrangement is not highly recommended, even the technical solution would be most simple. This may also be the reason why no publication on such an arrangement could be found.

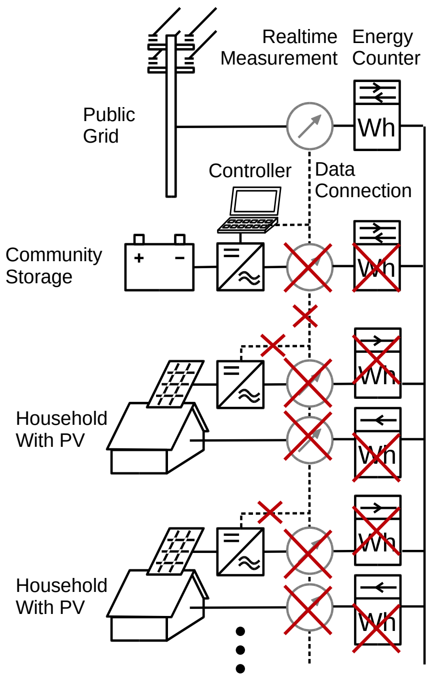

Fig. 8. Measurement setup for a community storage with only mutual energy metering.

Trusted Authority: To find a compromise between these solutions, a "trusted authority" might be introduced. This authority may supervise the use of energy. This may reduce the complexity of the measuring system maintaining fairness tog all participants. As a drawback, additional costs apply to pay the authority.

As a practical use case, a contractor can represent such a trusted authority. The following organisational aspects would be considered: The contractor own the community storage, the local power grid and the PV systems on the roofs of the individual buildings. The contractor provides the energy for a fixed, average electricity cost to each household. Because PV power is cheaper than power from the public grid the contractor is able to offer a cheaper electricity price. In addition, in Germany some additional fees may be reduced or omitted in a closed private power grid, which adds additional cost advantages.

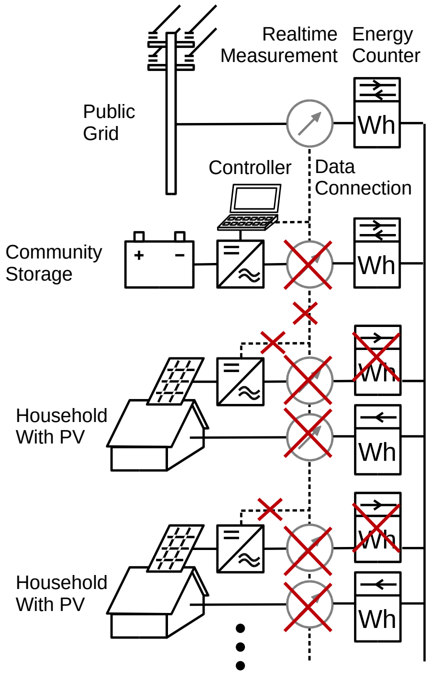

Fig. 9. Measurement setup for a community storage with operation by a trusted authority.

As technical aspects, the required measurements become much simpler compared to the case of individual trading (see fig. 9). Because the contractor owns the PV systems, an individual real-time control of each PV converter is not necessary, such that only one real-time sensor must be introduced at the common point of connection to the public power grid. Billing can be once a year (as long as no time-dependent tariffs are used) which makes it cheap and metering simple. A data connection is not needed, except to make the reading of the meters easier.

As a further aspect, a contractor can use additional modes to operate the battery to gain additional profit. As an example, in winter, when PV generation is low, the storage can be used to buy energy from the public grid, when it is cheapest. It could also provide grid services like balancing power or care for a capping of power transmission on the line.

Therefore, installing a contractor to manage the communal storage is our proposal for the case of a climate friendly settlement [7].

4 Conclusion

Involvement and empowering citizens to use renewable energy helps speeding up the energy transition towards climate neutral energy use. It enhances acceptance, thus leading to less time consuming objections, and it reduces the overall costs.

One way to involve people is by allowing them to share their energy. This must be simple and fair. An energy sharing scheme using the public power grid would increase acceptance and even installations of additional PV generation, but would require a change of legislation and a significant modification billing systems of energy providers.

It is shown that the way of how fairness is achieved influences the effort for measurement and billing for a communal storage in a climate neutral settlement. The operation by a contractor has been shown the best solution to achieve a fair but low effort energy sharing.

5 Acknowledgements

The author would like to thank Susanne Jung and the team of SFV for the discussions and the proposal of a neighbourhood energy sharing scheme.

The work on a communal storage for a climate friendly settlement was made available by project funding of Deutsche Bundesstiftung Umwelt (DBU), Förderzeichen 3871/01-25.

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Renewable Energy Approach in Energy Planning of Erzurum Province

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Abstract. The use of fossil resources has disturbed the natural balance of the world and caused environmental pollution. The most important precautionary measure to eliminate these negative effects is to increase the use of renewable energy resources that do not harm the environment instead of fossil energy resources. In this context, this study aims to prepare a roadmap for the use of 100% renewable energy to meet the electricity needs of Erzurum province. For this purpose, different scenarios for the transition to renewable energy were prepared using the EnergyPLAN program, an energy simulation program. In the program, the program was first verified using the current energy data of Erzurum for the year 2021 and a reference scenario was created with this data. Subsequently, various alternative scenarios were prepared in 5-year periods, starting from 2025 until the use of fossil resources is reduced to zero. The demand for electrical energy required to create these scenarios was generated using the Artificial Neural Networks model. First, the network was trained using historical data and it was found that the trained network made predictions with an accuracy of 98%. Then the demand for electrical energy was estimated for the scenarios. The results of the scenarios show that use of fossil resources will decrease to zero in 2045. At the same time, it was found that the amount of CO2, which was 0.07 million tons in the reference year 2021, was found to be 0.05 million tons, 0.03 million tons, 0.02 million tons, 0.01 million tons and 0.00 million tons 2025, 2030, 2035, 2040 and 2045, respectively.

Keywords: 100% renewable energy, CO_2 emissions, EnergyPLAN.

1 Introduction

It is of great importance to make the best use of renewable energy resources in order to meet the increasing energy demand in our country, to reduce dependence on foreign energy resources and to enable environmentally friendly production. In our country, various renewable energy resources have the potential to be utilized to add value to the economy. The fact that this potential is not fully utilized puts pressure on the country's economy and has a negative impact on the ecosystem, especially air pollution and climate change [1].

In recent years, all countries in the world have increased their investment in renewable energy sources to solve these problems. There are some obstacles that we need to overcome in the transition to renewable energy, such as energy security, environmental impact, efficiency and sustainability. To overcome these problems, strategies should be developed at national and local levels, taking into account many political, socio-economic and technological parameters [2]. There are many studies that have been conducted at national and local levels in the context of transition to renewable energy systems. Some of these studies are: Bačeković et al.[3] compared two models for the development of a 100% renewable energy system, using the Croatiaan capital Zagreb as an example. The first model is based on the smart energy system model, where each energy sector is developed independently, while in the second model the different sectors are interconnected to increase efficiency. The scenarios created were modeled in the EnergyPLAN software. In their study, Menapace et al.[4] presented a method for modeling 100% renewable energy systems for the city of Bozen-Bolzano, which aims to optimize the use of biomass and the energy exchange with the national system, taking into account the electricity import and export balance. Cabrera et al. [5] modeled the entire energy system of the island of Gran Canaria. They proposed several smart strategies for renewable energy, following a cross-sectoral approach for the electricity, heating/cooling, desalination, transportation and gas sectors. In their study, Bamisile et al. [6], , developed three decarbonization models for net zero emissions in the electricity, industry and transport sectors for 2030 and 2050 in the Chinese province of Sichuan. In building the model, the goverment's proposed pathway was presented as a renewable energy model and the reduction of carbon emissions was observed by analyzing three innovation approaches. Luca et al. [7] presented in their study the feasibility assessmet of a new strategy to make the Italian city of Altavilla Silentina exclusively dependent on renewable energy sources by 2030. In addition to the assessment of CO_2 emissions, an analysis of actual energy consumption was also carried out. In their study, Arévalo et al. [8] carried out a techno-economic analysis of 100% renewable energy sources in the Galapagos Islands. Using EneryPLAN software, they proposed a feasibility study for a hybrid renewable energy system to power the islands for decades until 2050. In their study, Luo et al.[9] investigated the feasibility of a deep decarbonization of the energy system in Sichuan, one of the leading provinces in China's economic growth, by 2050. Three pathways powered by imported electricity, biomass and natural gas were developed and simulated using the EnergyPLAN model.

Under the guidance of these studies, the first step is to develop a comprehensive methodology for the utilisation of renewable energy resources for electrical energy in Erzurum province In contrast to studies mentioned the above, this study seeks an answer to the question, "When (after how many years) will fully renewable resources be used to meet the demand for electrical energy ?" In this context, the potential energy situation in Erzurum Province was first examined and then a roadmap for the use of renewable energy was prepared.

As can be seen in Figure 1, the installed capacity in Erzurum province is distributed as follows: 78.56% hydropower, 16.86% solar energy, 2.16% biomass, 1.58% imported coal and 0.83% natural gas.

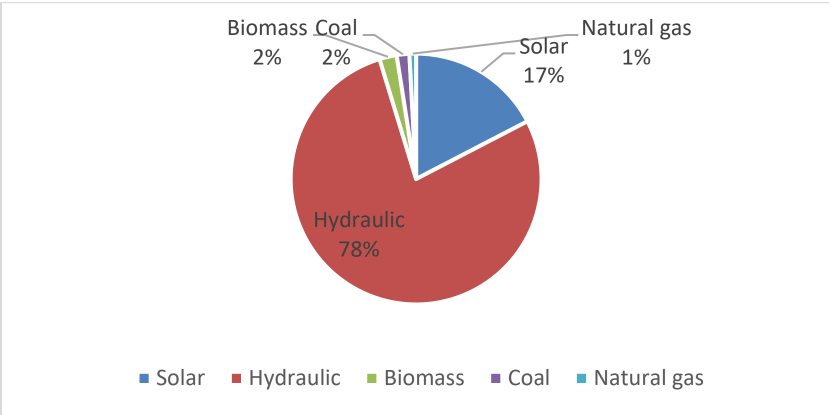

Fig. 1. Installed power distribution in Erzurum province

2 Method and case study

The EnergyPLAN program was used to model the energy system of Erzurum province and to analyze its environmental and economic impacts. EnergyPLAN is an with a energy supply optimization approach developed bottom-up approach. It is also a simulation model in which many technical and economic exogenous variables are used [24].

EnergyPLAN is a Delphi-based input/output simulation model software that covers the electricity, heating, cooling, industry and transportation sectors. It simulates the operation of the energy system on an hourly basis. Since EnergyPLAN is a software created with a model based on carbon-free energy production, renewable energy sources are preferred in the software selection.

For the conversion of Erzurum province to renewable energy, a reference energy model was first created and then alternative scenarios were developed based on this model. The reference energy model is an energy system that exists in 2021. In 2021, all approved energy system data was obtained and entered into the EnergyPLAN software. The installed electricity capacity of Erzurum province by resource is shown in Table 1.

Table 1. Installed electricity capacity of the province of Erzurum by resources

Source	Total installed power (Mwe)
River	335,45
Waste heat	5,5
Dammed	464
Biomass	14,88
Solar	107,79
Imported coal	5,4
Total	933,02

Table 1 shows that the renewable energy source with the highest installed capacity in Erzurum province is the river, while the energy source with the lowest installed capacity appears to be biomass.

The installed electricity capacities and hourly electricity production data by resource in 2021, shown in Table 1, were taken from ARAS EDAS. The hourly electricity generation data was uploaded to the EnergyPLAN software as a separate text file for each resource. The text files are created with 8784 lines vertically, which corresponds to the number of hours in a year. The data was loaded, the program was run, and the results were compared with the real data. During the comparison, it was found that the program works with high accuracy. After this process, alternative scenarios were created. The demand for electrical energy required to create these scenarios was determined using the Artificial Neural Networks model. The demand resulting from the scenarios to be created on an annual basis is shown in Figure 2.

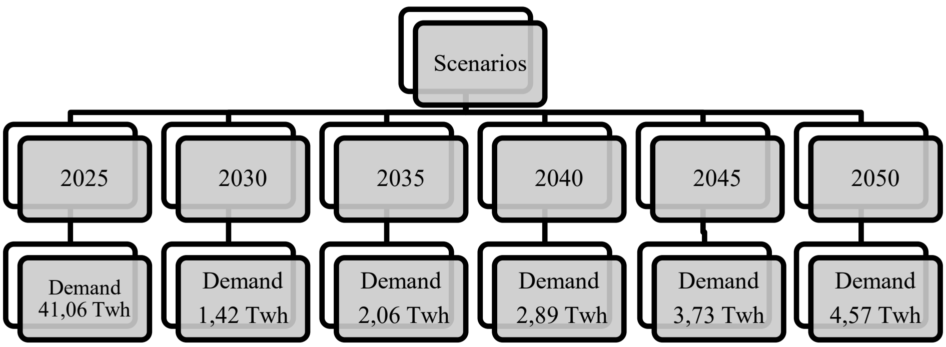

Fig. 2. Demand forecasts by year

In order to meet the requirements specified in Figure 2, the use of renewable energy resources instead of fossil resources was gradually increased, and the year in which CO2 emissions would fall to zero was sought. To this end, the following assumptions were made in the study.

1. The incremental increase method was used.
2. After the 2021 reference scenario, the use of renewable energy resources to meet demand increased in 5-year periods, starting with the year 2025.
3. The amount of renewable energy for 2025 has been increased by 25% compared to 2021.
4. The amount of renewable energy for 2030 has been increased by 25% compared to 2025.
5. The amount of renewable energy for 2035 has been increased by 30% compared to 2030.
6. The amount of renewable energy for 2040 has been increased by 35% compared to 2035.
7. The amount of renewable energy for 2045 has been increased by 35% compared to 2040.

The results of the scenario obtained in line with the above assumptions are as follows:

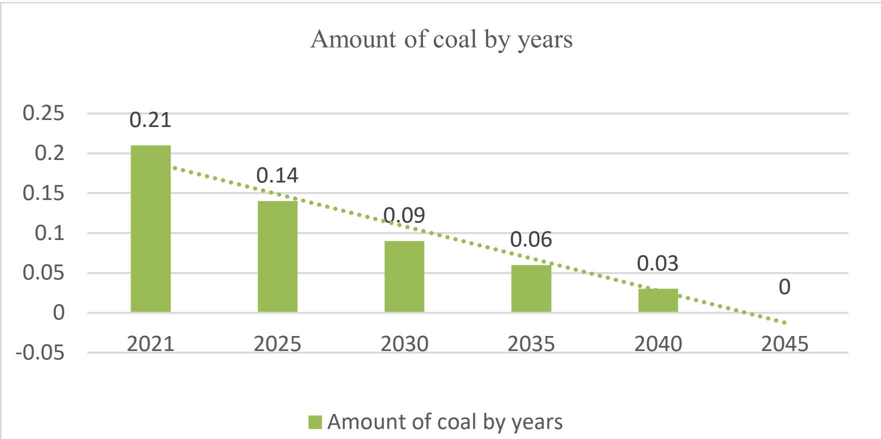

Fig. 3. Amount of coal by years

A look at Figure 3 shows that the amount of coal used decreases over the years and that this value, which is 0.21 in 2021, will be zero in 2045.

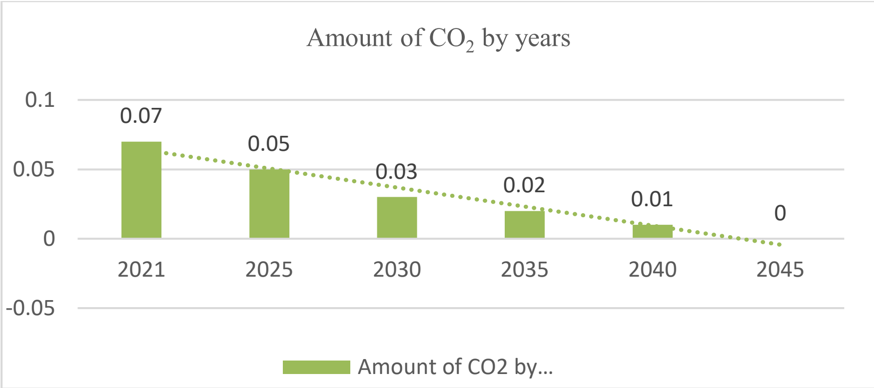

Fig. 4. Amount of CO_2 by years

A look at Figure 4 shows that CO2 levels have also fallen over the years. This value, which was 0.07 mt in 2021, fell to 0 mt by 2045.

As can be seen from Figures 3 and 4, CO_2 emissions and the use of fossil resources are directly proportional. Depending on the decreasing amount of coal, the emission values also decrease. In the study, to meet the demand resulting from the projections the use of coal was reduced over the years and the use of renewable energy resources increased, and so that in 2045, the demand is only covered by renewable energy sources. This has shown that CO_2 emissions could be reduced to zero, making it possible to switch to 100% renewable energy.

3 Conclusion

The aim of the study is to draw up a roadmap for the use of 100% renewable energy to meet the electricity needs of the province of Erzurum. Accordingly, the amount of CO_2 emissions caused by energy use should be reduced to zero. For this purpose, various alternative scenarios were created to fulfill the demand forecasts made with the help of artificial neural networks. The results of the scenarios show that in 2045, fossil resources will no longer be used for electrical energy consumption, and only renewable energy resources will be sufficient to meet demand. The amount of CO_2 produced by the use of fossil resources has, therefore, fallen to zero. This shows that the goal of transitioning to 100% renewable energy has been positively achieved.

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Investigation of the Parameters Affecting the Performance of Reversible Solid Oxide Cells

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Abstract. Solutions to the economic and climatic constraints of renewable energy sources such as wind and solar can be produced using reversible solid oxide cell technologies. Reversible Solid Oxide Cells (RSOCs) are systems that can produce both energy and fuel. By integrating RSOCs into renewable energy systems, energy storage can be achieved. Storing energy produced during low-demand periods and producing and storing fuel during high-demand periods provides flexibility to renewable energy sources. RSOC operates in two modes: fuel cell and electrolyzer. In the fuel cell mode, fuels such as hydrogen, natural gas, biofuels, or synthesis gas enter the system from the fuel electrode, while oxygen enters from the oxygen electrode, releasing water and electrical energy. In the electrolyzer mode, electricity and water enter the system from the fuel electrode, releasing hydrogen and oxygen. In this study, a model for RSOC has been developed to determine the performance of a YSZ electrolyte-supported planar reversible solid oxide cell under different operating conditions. Electrochemical modeling of a cell with an active area of 16 cm^2 was performed using computer software. The electrolyte of the cell consists of YSZ (Yitria Stabilized Zirconia), the fuel electrode consists of porous Ni-YSZ (Nickel), and the oxygen electrode consists of porous LSM-YSZ (Lanthanum Strantium Manganet). Reversible solid oxide cells typically operate at temperatures between 500°C and 1000°C. In this study, the relationship between the performance of RSOC and pressure and temperature is examined. The effects of polarizations occurring in the three-phase region on the cell performance of RSOC have been investigated, and a parametric analysis has been conducted. It was observed that increasing pressure and temperature improve cell performance in RSOC systems.

Keywords: Reversible Solid Oxide Cell, Electrochemical Model, Performance Analysis.

1 Introduction

Increasing demand for renewable energy sources worldwide is proportional to population growth. Turning to alternative energy sources in the coming years has become logical in the face of potential energy crises. Renewable energy sources such as wind and solar have climate and economic constraints [1]. Therefore, storing generated energy enables overcoming the limitations of renewable energy sources.

Reversible solid oxide cells (RSOCs) are systems that can produce both energy and fuel, providing flexibility to systems by offering solutions to the limitations of renewable energy sources. Integrating RSOCs into renewable energy sources allows for energy storage. These cells operate in two different modes: fuel cell mode and electrolyzer mode, at temperatures between 500°C and 1000°C. In fuel cell mode, fuel (such as hydrogen, natural gas, biofuels, or synthesis gas) enters the system from the fuel electrode, while oxygen enters from the oxygen electrode, producing water and electricity. In electrolyzer mode, electricity and water enter the system from the fuel electrode, producing hydrogen and oxygen.

In RSOC systems, the type of fuel and the ratio of gas mixtures play an important role in determining cell performance. Increasing the proportion of hydrogen in a hydrogen and steam mixture (H_2/H_2O) improves cell performance in fuel cell mode but decreases it in electrolysis mode. Similarly, increasing the proportion of steam has the opposite effect [2]. Compared to hydrocarbon fuels (such as CH_4, CO, H_2, CO_2, H_2O), hydrogen (H_2/H_2O) performs better in RSOC systems [3]. The kinetics of reactions occurring in RSOCs significantly affect cell performance. Reaction rate, fuel utilization ratio, temperature, and pressure parameters are crucial factors in cell kinetics.

In many studies, an electrochemical model has been developed for RSOC, and I-V curves have been generated for model characterization. However, detailed data on the polarizations occurring in the triple-phase region of RSOC has not been provided. In this study, an electrochemical model was created and proposed using computer software. In this electrochemical model, the relationship between polarizations and pressure and temperature has been examined, and parametric analysis has been conducted.

2 Mathematical Model

As shown in Fig.1., a mathematical model has been developed for the electrochemical behavior of RSOC. The cell is a planar cell with an active area of 16 cm^2, consisting of YSZ (Yttria Stabilized Zirconia) electrolyte, porous Ni-YSZ (Nickel) fuel electrode, and porous LSM-YSZ (Lanthanum Strontium Manganite) oxygen electrode. For better performance of the cell, it is assumed that the fuel composition is 50% H_2/H_2O and the oxidant is pure oxygen. The parameters used for the electrochemical model of RSOC are obtained from similar studies in the literature and presented in Table 1.

In many studies in the literature, cell performance analysis based on fuel utilization rates, state of charge, and flow rates is available. In this study, the effect of changes in fuel utilization (UF) rates on cell performance due to variations in temperature and pressure has been investigated.

$$UF = \frac{n_{consumed}}{n_{entered}} = 60000 \frac{i}{nF} \frac{RT}{P_{fuel} V_{fuel} \%x} \tag{1}$$

Where i is the current (A), F is Faraday's constant (96485 C/mol), n is the number of electrons, P_{fuel} is the pressure (Pa), V_{fuel} is the fuel flow rate (l/min), $\%x$ is the percentage of hydrogen molar ratio in the fuel, T temperature (K), and R is the gas constant (8.3145 J/(mol·K). The 60000 constant comes from the conversion from the liter/min flow rate used in the model to m^3/s (1 liter/min = 1/60000 m^3/s). The relationship between the pressure and temperature of the cell has been investigated using the partial pressures of the exhaust gases from the cell, according to mass balance. Calculations are conducted based on the ideal gas law.

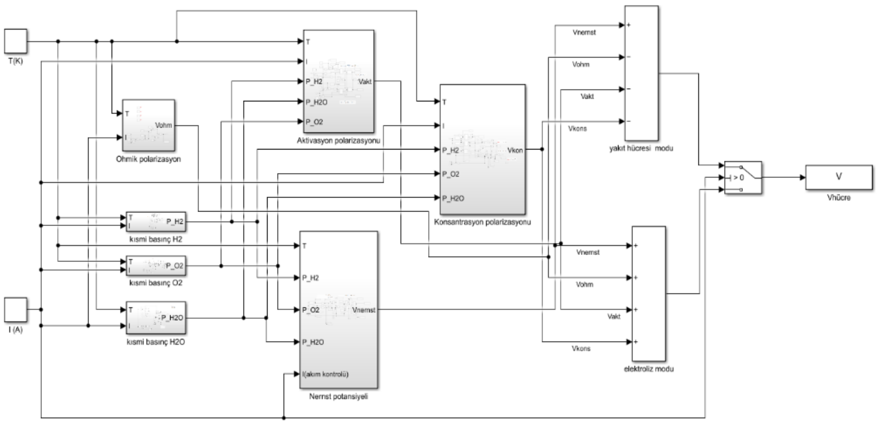

Fig. 1. RSOC electrochemical model

When operating in fuel cell mode, the RSOC is exothermic and produces power. In electrolysis mode, it is endothermic and utilizes electrical energy. In this study, the RSOC system operates in electrolysis mode to produce and store fuel (H_2), effectively converting heat into fuel. The cathode catalyst captures hydrogen from water, while the oxygen ion obtained from water crosses over to the cathode side of the electrolyte, where O_2 is obtained. When transitioning to fuel cell mode, the stored fuel is converted into electrical energy and heat. The reactions occurring in the RSOC are represented in Equations 2, 3, 4, and 5. These equations determine the operating principles of the RSOC and illustrate the chemical reactions occurring between the electrolysis and fuel cell modes.

Fuel cell mode

$$H_2 + 0.5O_2 \rightarrow H_2O + 2e^- \tag{2}$$

$$0.5O_2 + 2e^- \rightarrow O^{2-} \tag{3}$$

Electrolysis mode

$$\rightarrow \quad H_2O + 2e^- \quad H_2 + O^{2-} \tag{4}$$

$$\rightarrow \quad O^{2-} \quad 0.5O_2 + 2e- \tag{5}$$

The operating voltage (V_{cell}) of a single fuel cell is a combination of the Nernst potential and other polarizations, and it differs between the fuel cell mode and the electrolysis mode [4]. In the fuel cell mode, the operating voltage of the cell is determined by subtracting ohmic losses, activation losses, and concentration losses from the Nernst potential. In the electrolysis mode, these losses are summed up. This expression is represented by the following Equations.

$$V_{Cell,fuel\ cell} = V_{Nernst} - V_{Ohm} - V_{Act} - V_{Conc} \tag{6}$$

$$V_{Cell,\mathrm{electrolysis}} = V_{Nernst} + V_{Nernst} + V_{Ohm} + V_{Act} + V_{Conc} \tag{7}$$

Table 1. Parameters used for the RSOC electrochemical model.

Parameter	Unit	Value
$\sigma_{0.el}$	333.3	$\Omega^{-1}.cm^{-1}$
$r_{ohmic,c}$	0,057	$\Omega.cm^2$
δ_{FE}	20	µm
δ_{OE}	20	µm
δ_{el}	15	µm
$E_{act,el}$	85.634	J/mol
$E_{act,YE}$	110	kJ/mol
$E_{act,OE}$	120	kJ/mol
γ_{FE}	1.34E+06	A/cm^2
γ_{OE}	2.05E+05	A/cm^2
r_{por}	1.00E-06	µ
porosity (ε)	0.36	
tortuosity(τ)	5	

2.1 Nernst Potential

The Nernst potential is assumed to be equal to the open circuit voltage. The Nernst potential, or open circuit voltage, represents the cell potential without considering the losses in the cell. To calculate the Nernst potential, it is necessary to determine the molar distributions of gases at the inlet or exhaust of the cell. For the fuel cell mode, the Nernst potential is determined by Equation 8.

$$V_{N,\ Fuel\ Cell} = E_0 - \frac{RT}{nF} ln \frac{P_{H2O}}{P_{H2}\, P_{O2}^{1/2}} \quad (8)$$

where E_0 is the standard potential. The standard potential is expressed as follows:

$$E_0 = -\frac{\Delta g}{nF} \quad (9)$$

Δg is the Gibbs free energy. The Gibbs free energy depends on the bulk temperature and the bulk concentration of reactants and products [5].
For the electrolysis mode, the Nernst potential is calculated using Equation 10.

$$V_{N,\ electrolysis} = E_0 + \frac{RT}{nF} ln \frac{P_{H2}\, P_{O2}^{1/2}}{P_{H2o}} \quad (10)$$

2.2 Ohmic Polarization

Ohmic polarization is the resistance that occurs across the electrolyte, electrodes, and interconnects against the movement of electrons and ions throughout the cell. Ohmic polarizations arise not only from the transport of electric charge but also from the flow of O^2 ions through the electrolyte layer [2].

$$V_{ohm} = J\,(\frac{\delta_{el}}{\sigma_{el}} + r_{ohm,c}) = J(r_{ohm,el} + r_{ohm,c}) \quad (11)$$

where δ_{el} is the the electrolyte thickness, σ_{el} is the ionic conductivity of the electrolyte, $r_{ohm,el}$ is the ohmic resistance of the electrolyte, and $r_{ohmic,c}$ is the resistance of the interconnect material.

$$\sigma_{el} = \sigma_{0,el}\, exp\,(\frac{-E_{act,el}}{R.T}) \quad (12)$$

where $\sigma_{0,el}$ is the pre exponential factor and $E_{act,el}$ is the activation energy.

2.3 Activation Polarization

Activation polarization indicates the potential of the energy barrier that needs to be overcome by the fuel and oxygen electrodes. When calculating activation polarization in a cell, polarizations on both the fuel and oxygen electrode sides are calculated.

$$V_{act} = V_{act,FE} + V_{act,OE} \quad (13)$$

At low and moderate operating temperatures, activation polarization has a significant effect on the existing voltage drop. With an increase in temperature, the effect of activation polarization decreases [6]. The relationship between current density (j) and activation polarization (V_{act}) is described by the Butler-Volmer equation. The Butler-Volmer equation, containing empirical expressions, is expressed as follows to calculate the activation voltage.

$$j = j_0 \left[exp \left(\frac{\beta nF}{RT} V_{act}\right) - exp \left(-\frac{(1-\beta)nF}{RT} V_{act}\right)\right] \quad (14)$$

Where j_0 is the exchange current density, and β is the transfer coefficient. The transfer coefficient is generally accepted as 0.5 in the literature. Since the Butler-Volmer equation does not fully solve the activation polarization, the Tafel equation or the voltage relationship corresponding to the linear current is used. To determine whether the polarization is low or high, the expression $(FV_{act}) / nRT$ is used.

$$\frac{FV_{akt}}{nRT} < 1 \text{ ise } V_{act,low} = \frac{RTj}{nFj0} \quad (15)$$

$$\frac{FV_{akt}}{nRT} > 1 \text{ ise } V_{act,high} = \frac{RTj}{nF\beta} \ln\left(\frac{j}{j0}\right) \quad (16)$$

The subscript i refers to the relevant electrode. The variable current density represents the reaction rate at open-circuit voltage and is associated with parameters of the membrane-electrode assembly structure such as reaction zone density and catalyst activity [7]. The variable current densities for the fuel electrode and the oxygen electrode are determined by Equations 17.

$$j_{0,FE} = \gamma_{FE}\left(\frac{P_{H2}}{P_0}\right)\left(\frac{P_{H20}}{P_0}\right) exp\left(\frac{-E_{akt,FE}}{RT}\right) \quad (17)$$

$$j_{0,OE} = \gamma_{OE}\left(\frac{P_{O2}}{P_0}\right) exp\left(\frac{-E_{akt,OE}}{RT}\right) \quad (18)$$

γ_{YE} and γ_{OE} are the exponential factors for the fuel and oxygen electrodes, respectively. E_{act} is the activation energy, and P_0 is the ambient pressure. In the literature, the activation energy for the fuel electrode is found to be between 100-140 kJ/mol, and for the oxygen electrode, it ranges between 117-160 kJ/mol [8].

2.4 Concentration Polarization

Concentration polarization arises from losses due to the diffusion of reactants and products during the reaction at porous electrodes. It is determined by considering Fick's law to determine the reactant mole fractions in the active region.

$$V_{conc} = V_{conc,FE} + V_{conc,OE} \quad (19)$$

$$V_{conc,FE} = \frac{RT}{nF} ln \left(\frac{1+(j/j_{L,H2O})}{1-(j/j_{L,H2})}\right) \quad (20)$$

$$V_{conc,OE} = \frac{RT}{nF} \, ln \, (\frac{1}{1-(j/j_{L,O2})}) \tag{21}$$

J_Li is the limiting current density of gaseous diffusion at the respective electrode. The limiting current densities for gas types are determined by Equations 11, 12, and 13.

$$J_{L,O2} = \frac{nFP_{O2}D_{OE,eff}}{RT\delta_{OE}} \tag{22}$$

$$J_{L,H2} = \frac{nFP_{H2}D_{FE,eff}}{RT\delta_{FE}} \tag{23}$$

$$J_{L,H2O} = \frac{nFP_{H2O}D_{FE,eff}}{RT\delta_{FE}} \tag{24}$$

δ is the thickness of the corresponding electrode. $D_{YE,eff}$ ($D_{YE,eff}$ = $D_{eff,H2\text{-}H2O}$) and $D_{OE,eff}$ ($D_{OE,eff}$ = $D_{eff,O2\text{-}N2}$) are the effective gas diffusion factors in the fuel electrode and oxygen electrode, respectively. When pure oxygen is supplied to the oxygen electrode, the binary diffusion coefficient for nitrogen is not calculated (see Eq. 26). The effective gas diffusion factors are expressed as follows using Knudsen diffusion and binary diffusion coefficients.

$$\frac{1}{D_{eff,YE}} = \frac{\varepsilon}{\tau} \, (\frac{1}{D_{H2,k}} + \frac{1}{D_{H2-H2O}}) \tag{25}$$

$$\frac{1}{D_{eff,OE}} = \frac{\varepsilon}{\tau} \, (\frac{1}{D_{O2,k}}) \tag{26}$$

where ε is the porosity of the electrode, and τ is the tortuosity of the electrode. $D_{H2\text{-}H2O}$ is the binary diffusion coefficient of H_2 in the H_2-H_2O mixture. The binary diffusion coefficient is calculated with Equation 27.

$$D_{H2\text{-}H2O} = \frac{0{,}00143T^{1.75}}{M_{H2-H2O}^{1/2}\,(\upsilon_{H2}^{1/3} - \upsilon_{H2O}^{1/3})^2 P} \tag{27}$$

P represents the operating pressure of the cell, and υ represents the specific Fuller diffusion volumes of the gas species. The specific Fuller diffusion volume values for gas species are expressed in the literature as υ_{H2}=7.07, υ_{O2}=16.60, and υ_{H2O}=12.70 [9]. $M_{H2\text{-}H2O}$ is the molecular weight of the gaseous components, calculated with the following Equation.

$$M_{H2\text{-}H2O} = 2 \, (\frac{1}{M_{H2}} + \frac{1}{M_{H2O}})^{-1} \tag{28}$$

Knudsen diffusion coefficients are determined by the following Equations.

$$D_{H2,k} = 97 r_{por,H2} \sqrt{\frac{T}{M_{H2}}} \tag{29}$$

$$D_{O2,k} = 97 r_{por,O2} \sqrt{\frac{T}{M_{O2}}} \tag{30}$$

Where r_{por} is the pore radius of the electrode.

3 Model Validation

The performance of RSOCs is correlated with the selected material properties. Information on exchange current density, as well as limiting current densities, ohmic polarization, activation polarization, and concentration polarization plots, is generally not provided in the literature. Therefore, I-V plots have been used to validate the model. The validation of the model has been conducted using the operating conditions and cell parameters from the literature study [2].

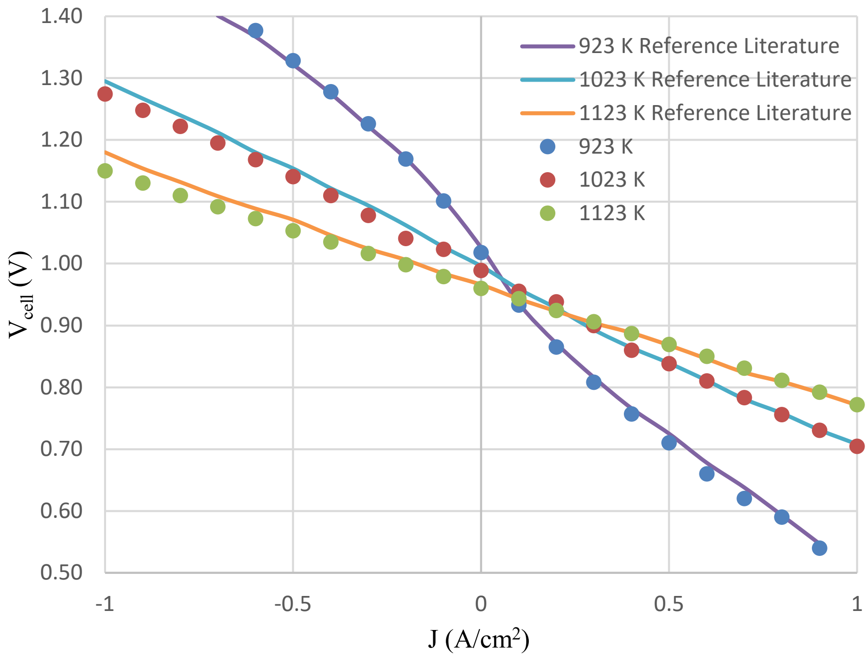

Fig. 2. Validation of the RSOC model with the literature model [2].

In this section, the electrochemical relationships of RSOC model have been explained. The results of the proposed model have been compared with the literature [2] findings in Fig. 2. The validation of the model has been conducted at operating pressures of 1 bar and temperatures of 650 °C-750°C-850°C with current densities ranging from -1 A/cm^2 to 1 A/cm^2. It has been observed and confirmed that there is consistency between the model and the literature results.

4 Results

In this section, parametric analysis has been conducted to examine the effect of operating temperature and pressure on cell performance and polarizations. The parameters of the cell subjected to parametric analysis are presented in Table 1. Parametric analysis is being performed at operating temperatures of 1073 K, 1173 K, and 1273 K to investigate the effect of temperature. Additionally, parametric analysis is being conducted at operating pressures of 1 bar, 3 bar and 5 bar to examine the effect of pressure.

4.1 Effect of Temperature

The performance of the solid oxide cell model had been investigated at different operating temperatures with selected cell parameters. Operating temperature significantly affects reaction kinetics and Nernst potential. Parametric analysis is conducted for operating conditions ranging from 1073 K to 1273 K and 1 bar pressure. The relationship between the cell's current and temperature is shown in Fig. 3. As the current increases, the cell voltage decreases. This is because as the current density increases, the ohmic, activation, and concentration potentials also increase. In the electrolyzer mode, it is desirable for the cell voltage to be low, whereas in the fuel cell mode, it is desired for the cell voltage to be high.

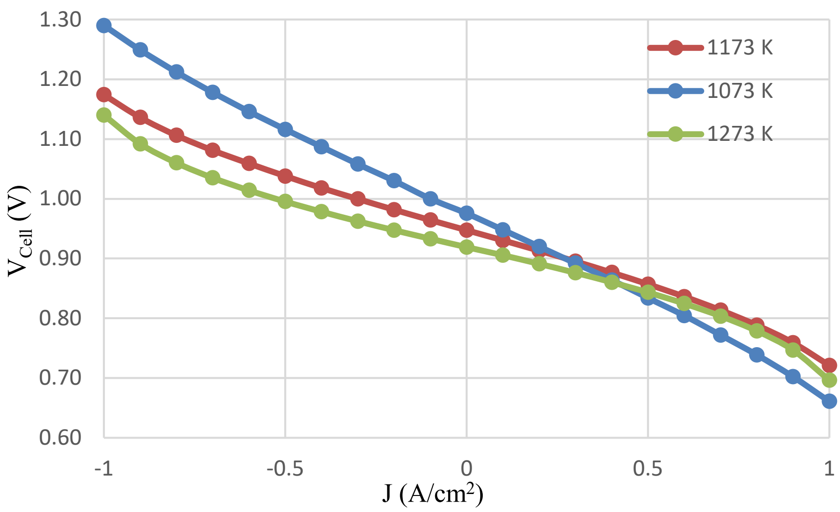

Fig. 3. The effect of temperature on RSOC performance.

The effect of temperature on ohmic polarization is shown in Fig. 4. It can be observed that as the temperature increases, ohmic polarization decreases. The selected material properties have a significant impact on reaction kinetics. Particularly, the thicknesses of the electrolyte and electrodes affect cell performance significantly. As the layer thicknesses in the cell decrease, the ionic resistance encountered by the cell decreases. However, this compromises the mechanical strength of the cell. While the reference cell has an electrolyte thickness of 12.5 µm, the thickness of the cell selected in the model is 15 µm. Despite increasing the cell temperature improving cell performance, the performance of the cell decreases in the fuel cell mode at 1273 K temperature due to the thickness of the electrolyte.

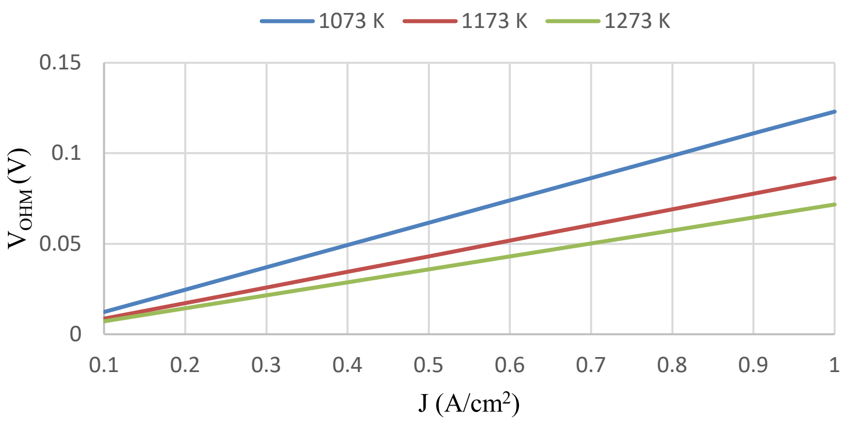

Fig. 4. The effect of temperature on ohmic polarization.

The relationship between temperature and activation polarization is shown in Fig.5. As the cell temperature increases, the increase in the exchange current density (J_0) leads to a decrease in the activation potential. This is attributed to the enhanced mobility of charges passing through the ionic conductors in electrochemical reactions. The reason for the increase in activation potential as the current density increases is the need for a higher energy increment to overcome the potential in electrode reactions.

The relationship between temperature and concentration polarization is shown in Fig.6. An increase in temperature leads to an undesired increase in concentration polarization. This increase is due to the decrease in limiting current density (J_L) as the gas density decreases with increasing temperature. However, the decrease in ohmic and activation losses with temperature helps to balance concentration losses. The thickness of the cell layers also affects the diffusion properties of the cell linearly. As seen in Fig.3., the cell exhibited the best performance at a temperature of 1173 K in both electrolysis and fuel cell modes.

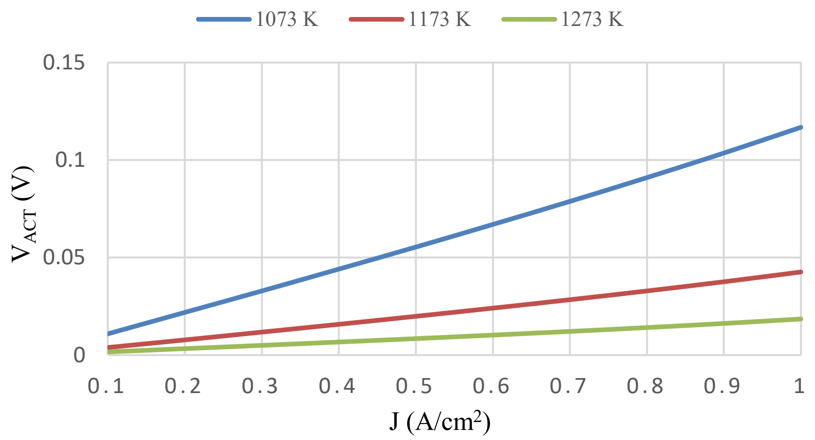

Fig. 5. The effect of temperature on activation polarization.

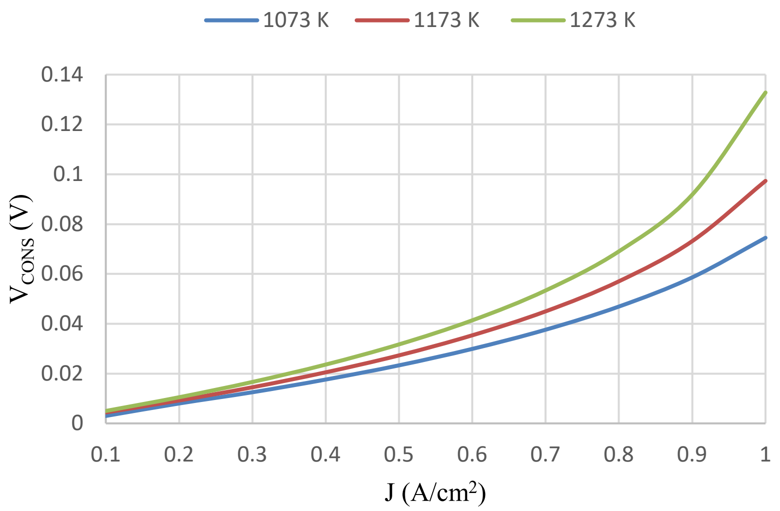

Fig. 6. The effect of temperature on concentration polarization.

4.2 Effect of Pressure

Since RSOC exhibited its best performance at 1173 K, parametric analysis for pressure had been conducted at this temperature. Due to reported difficulties and leakages in cell integrity at high pressures in experimental studies, parametric analysis was conducted for pressures of 1 bar, 3 bar and 5 bar [10]. The effect of pressure on RSOC performance is shown in Fig.7. Although the decrease in Nernst voltage with increasing pressure may be considered a disadvantage, it has been observed to improve cell performance in both electrolysis and fuel cell modes.

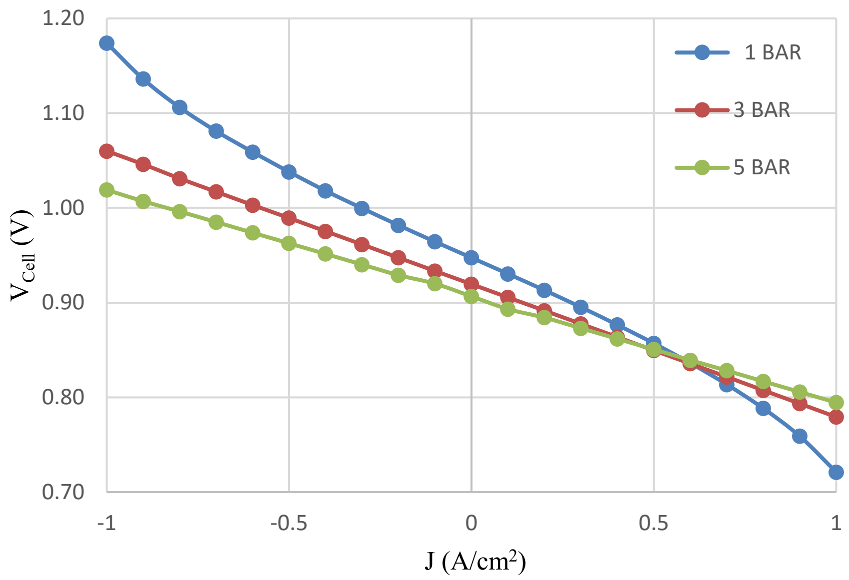

Fig. 7. The effect of pressure on RSOC performance.

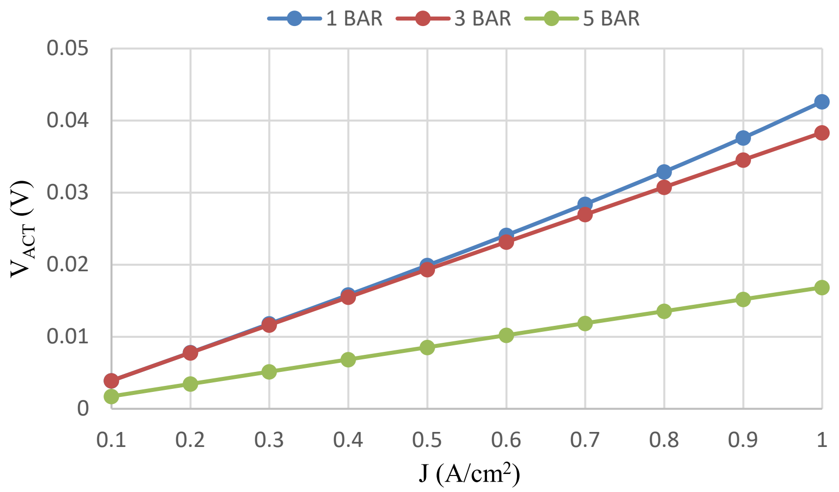

Fig. 8. The effect of pressure on activation polarization.

The effect of pressure on activation and concentration polarization is shown in Fig.8 and in Fig.9. An increase in pressure has led to a decrease in both activation and concentration polarizations. The increase in pressure has raised both the exchange current density and the limiting current density, resulting in reduced activation and concentration polarizations, thus improving cell performance.

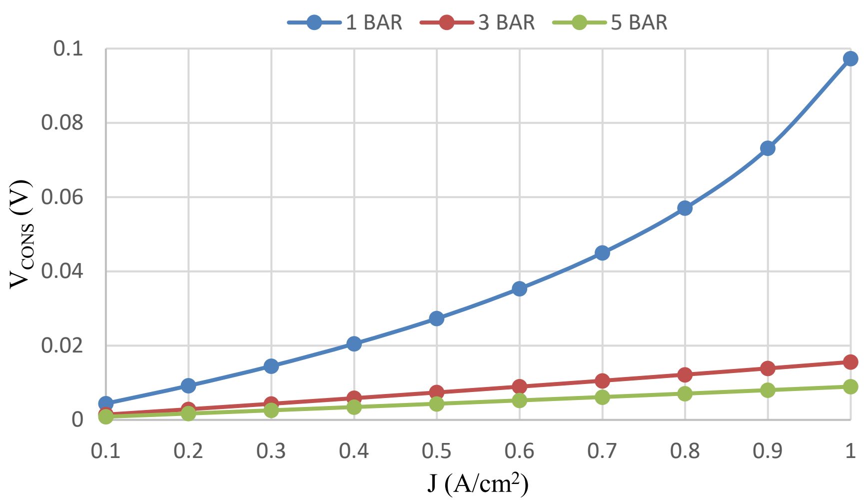

Fig. 9. The effect of pressure on concentration polarization.

5 Conclusions

In this study, the concentrations of exhaust gases are calculated based on changes in current, temperature, and pressure, and the effect of pressure and temperature on cell performance is being investigated. Parametric analyses had been conducted using computer software and validated. It has been observed that increasing temperature and pressure led to an increase in fuel utilization rate and improved reaction kinetics. While an increase in temperature led to an increase in concentration polarization, a decrease in activation and ohmic polarizations resulted in improved cell performance. The effect of pressure, on the other hand, reduced both activation and concentration polarizations. When modeling a cell, optimizing the thicknesses of the electrolyte and electrodes is one of the most critical design parameters. These parameters are important for the cell's performance, durability, and cost-effectiveness.

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Examining Türkiye in the Context of Renewable Energy in European Region

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Abstract. This study aims to examine the growing role and position of Türkiye within the European renewable energy market. Europe remains one of the leading regions in the global transition to renewable energy. European countries have made significant progress in reducing their dependence on fossil fuels, and Türkiye has gained increasing attention for its strategic location between Asia and Europe, as well as its vast renewable energy potential. Growing concerns about energy security across Europe, particularly in the context of geopolitical tensions, have made diversification of energy sources a critical issue. At the same time, the increasing urgency of environmental issues such as climate change has further accelerated the demand for clean energy solutions. This study focuses on the development of Türkiye's renewable energy sector, particularly wind and solar, and how these advances have increased the country's strategic importance within the European energy market. It also examines Türkiye's potential to become a key player in the broader European energy transition, helping to address energy security concerns while supporting Europe's goals of reducing carbon emissions and promoting sustainability.

Keywords: Türkiye energy profile, renewable energy, Europe energy market

1 Introduction

The energy transition represents a shift from fossil fuels to alternative clean energy sources. This transition has been on the global agenda for many years and is becoming an increasingly prominent topic. While numerous countries and regions are involved in this transition, the European region, with its high energy demand, stands out as a critical area. Europe's industrialization and dense population contribute to its significant energy consumption and dependency [1, 2]. External energy dependence frequently raises concerns, especially in terms of energy security. The Russia-Ukraine war has heightened these concerns, highlighting the challenges posed by such reliance. In parallel, climate change has garnered as much attention as energy security. Given that fossil fuels are a major contributor to environmental degradation [3], the energy sector has faced increasing criticism. The 2015 Paris Agreement accelerated efforts to find solutions to climate change [4], positioning renewable energy sources as a key means of mitigating both energy security risks and environmental problems.

While renewable energy finds its uses in different parts of the world, Europe is one of the regions that started the energy transition the earliest. Germany's transition to clean energy, which started in the 1970s, stands out as an important example [5]. However, since this transformation is not at a level to meet the high energy demand, dependence on fossil fuels is an ongoing process. In this context, it is important for Europe to contribute to the energy transition ecosystem of the countries in and around the region in order to realize its sustainable energy targets. Türkiye, with its strategic location and significant renewable energy potential, is an increasingly vital player in this ecosystem. With its growing industry and population, Türkiye’s energy demand is also on the rise [6]. Although it started its energy transition later than some, Türkiye is becoming a critical player in the field of clean energy, particularly given its abundant renewable energy resources [7].

This study emphasizes Türkiye’s importance to the European region in the context of renewable energy. It explores the current state of Türkiye's energy sector within the European energy market, focusing on its contributions to energy security and its role in helping Europe achieve its sustainable energy goals.

2 Market Structure of the Energy Sector in Europe

Europe constitutes a significant region within the global energy market, characterized by a complex and multi-layered structure. [8]. Europe’s energy consumption is particularly high, driven by its advanced industrial sectors and large urban areas. Industrialization has led to substantial energy requirements in sectors such as heavy industry, production, and technological development. Additionally, Europe’s high population density further elevates energy demand. Urban infrastructure, including homes, workplaces, and public transport systems, demands significant energy to maintain. The combination of industrialization and population density positions Europe as a global leader in energy consumption [9, 10]. Figure 1 demonstrates the comparative total energy consumption of the European region over time, highlighting the region’s increasing energy needs.

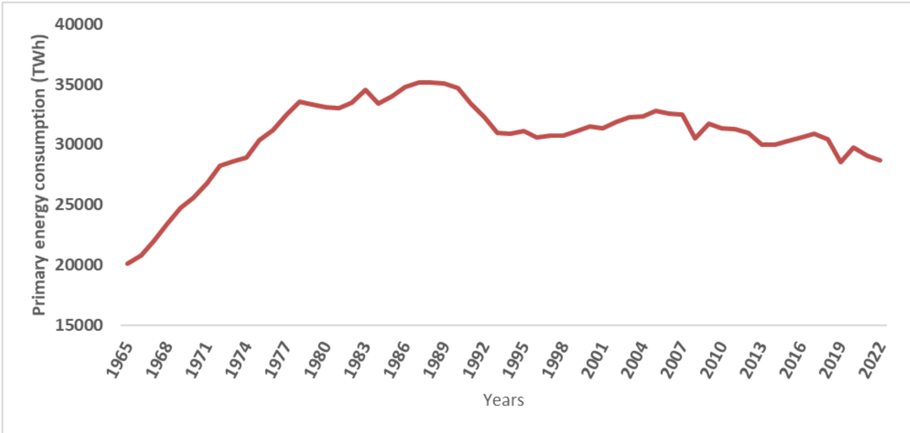

Figure 1. Primary Energy Consumption in Europe (TWh) [11]

From 1965 to 2022, energy consumption in the European region increased from approximately 19 TWh to 29 TWh. The energy sector in Europe is complex, characterized by diverse energy sources and significant external dependencies. Natural gas plays a critical role in Europe's energy production, with Russia historically being its largest supplier. However, recent political and economic developments have underscored the need for Europe to diversify its energy sources and move toward more sustainable options. Reducing external dependence, particularly on fossil fuels such as natural gas and oil, is essential for ensuring energy security. In Europe, natural gas, oil, and coal remain significant components of energy consumption, with oil being especially critical for transportation and industrial processes [12]. Table 1 presents the distribution of energy sources used in the European region. Despite a diverse energy mix, fossil fuel use remains dominant. Given that Europe is not a major producer of fossil fuels, this dependency presents significant challenges. In this context, renewable energy sources emerge as a crucial alternative.

Table 1. Energy Consumption by Source in Europe (2022) [13]

Energy Source	%
Other renewables	2,43
Biofuels	0,84
Solar	2,13
Wind	4,78
Hydropower	6,37
Nuclear	8,5
Gas	30,62
Coal	11,25
Oil	33,07

While Europe's renewable energy transition spans a long period of time, it can also be assessed in the context of both energy security concerns and the 2015 Paris Agreement. Reading through these two main themes provides insight into the diversity and urgency of Europe's energy transition.

The Paris Agreement of 2015 is a globally recognized accord that aims to address the challenges of global warming and climate change [14]. In order to fulfill the obligations set forth in the agreement, the European region, which is a principal party to the agreement, is modifying its energy production and consumption patterns and pursuing a more comprehensive energy transition. This transition signifies a shift from conventional to renewable energy sources and aligns with the objective of sustainable energy. As part of this transition, the European region is allocating resources to renewable energy sources, particularly wind and solar energy. These investments and transition efforts should be regarded not only as an acknowledgment of the 2015 Paris Agreement but also as a foundation for Europe's long-term climate policy[15].

Along with high energy demand, the European region has to cope with the significant challenges of energy dependence. The most prominent one is the issue of energy security. The disruption of energy transportation between supplying and demanding countries can cause irreversible damage to Europe in many different ways. One of the most prominent examples in this context is the war between Russia and Ukraine and its effects. The fact that Russia is an important and major fossil fuel supplier for Europe has maximized energy security concerns [16]. Energy dependence represents a major risk for the European region but also demonstrates the urgency of the energy transition. Ensuring the transition to clean energy and increasing the share of renewable energy in the energy used helps to ensure energy security. While many different countries in the European region, including Türkiye, have policies and practices within the scope of energy transition, Germany stands out as one of the leading countries with its investments in the 1970s [5, 17]. Over time, many different countries have initiated their own energy transformation, and with the 2015 Paris Agreement, this transformation has spread to more areas.

2.1 Current Status of Türkiye's Renewable Energy Sector

Türkiye's geographical location renders it a strategic player in the global energy market, as well as in numerous other domains. As a bridge between Asia and Europe, it has a critical role in the European energy sector. Apart from this role, the country has a diversified energy portfolio to meet the energy demand of its developing industry and dense population. Within this portfolio, renewable energy sources are also important. The development of Türkiye's energy sector and the diversification of its energy portfolio are critical for ensuring energy security and achieving sustainability goals [6, 7, 18]. With its growing structure, the Türkiye energy sector helps the country to maximize its strategic position both locally and globally [6, 19]. The change in Türkiye's energy consumption over the years, which constitutes one of the important markets in the European energy region, is shown in Figure 2. As can be seen from the figure, there has been an almost continuous increase in consumption since 2000. This increase can be attributed to different reasons, but developing industry and dense population can be shown as the main reasons for the increase in energy.

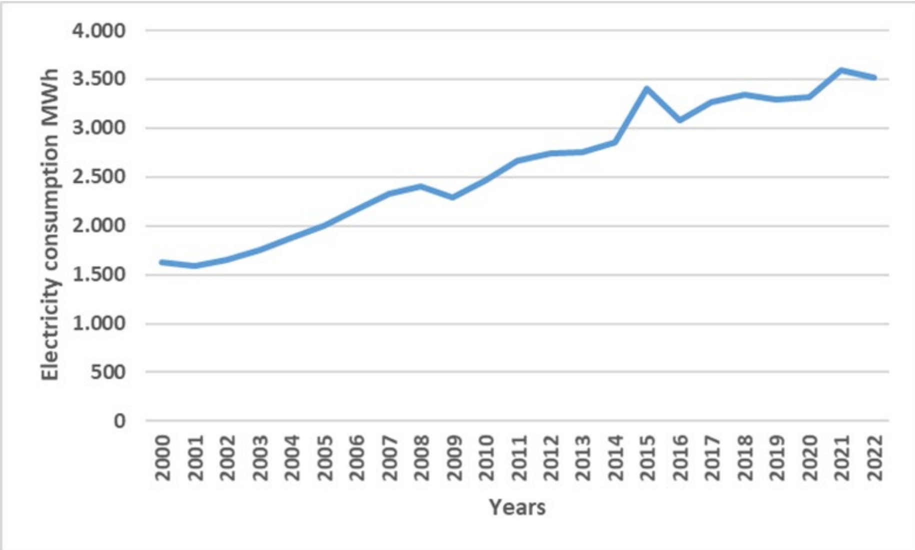

Figure 2. Electricity consumption, Republic of Türkiye, 2000-2022 [20]

With Türkiye's growing energy demand, the question of how to meet this need has become increasingly critical. While Türkiye meets part of its energy demand domestically, it remains heavily reliant on foreign imports, particularly for fossil fuels [21]. To meet its rising energy consumption, Türkiye has steadily increased domestic energy production. Figure 3 illustrates the change in Türkiye’s energy production over the years, showing a significant increase since the 1980s.

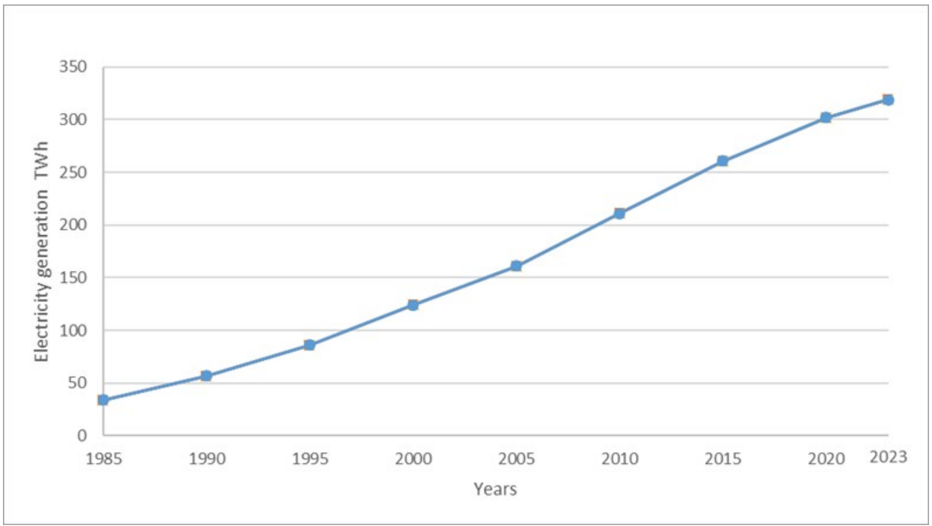

Figure 3. Per capita electricity generation-Türkiye [22]

Although Türkiye has significantly increased its annual energy production, it still faces a trade deficit. The risks of dependence on external energy sources have accelerated Türkiye's shift towards renewable energy [23,24,25]. Since becoming a party to the Paris Agreement in 2015, Türkiye has notably increased its investments in clean energy, particularly wind and solar. This strategic shift aims to reduce carbon emissions, enhance energy security, and lower dependence on imported fuels. These objectives align with global sustainability goals and Türkiye's international climate commitments.

Figure 4 illustrates the development of energy production from renewable, nuclear, and fossil fuel sources in Türkiye and Europe between 1985 and 2022. The graph shows a consistent and significant increase in electricity production from fossil fuels in Türkiye. However, recent years have seen a notable rise in electricity generation from renewable sources. Figure 4 clearly highlights Türkiye's transition towards renewables to diversify its energy mix, reduce environmental impacts, and meet its growing energy demands.

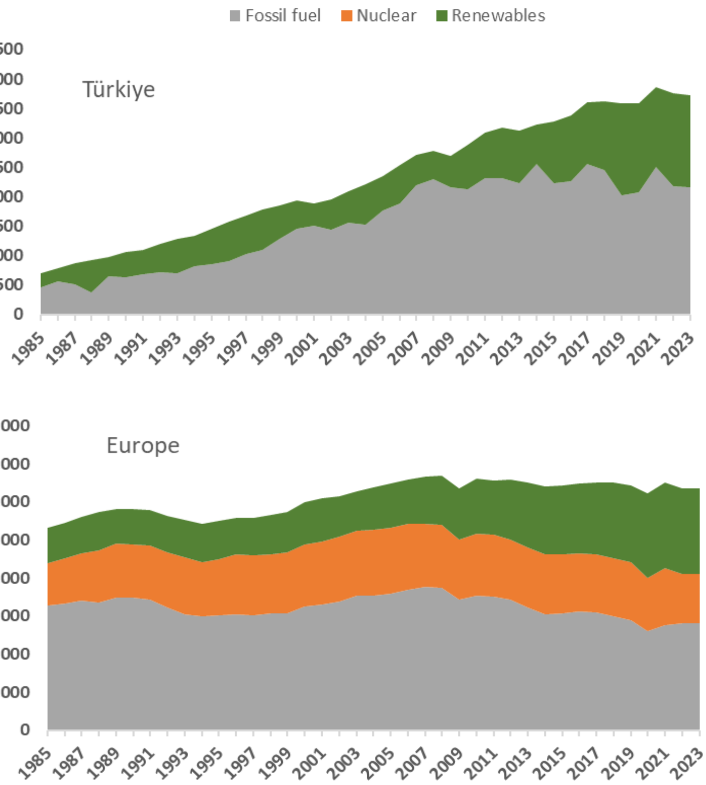

Figure 4. Electricity production from fossil fuels, nuclear and renewables (Türkiye and Europe) [26]

3 The Significance of Türkiye in the European Renewable Energy Sector

Türkiye's geographical location and strategic advantages, coupled with its high potential in renewable energy, underscore its importance to the European region. The growth and maturation of Türkiye's energy sector further strengthen its position as a major player in Europe. As a bridge between Asia and Europe, and with significant potential in wind and solar energy, Türkiye is poised to play a key role in the energy transition [19, 27, 28]. These factors position Türkiye as a crucial partner in Europe's pursuit of energy security and sustainability.

Energy security is one of the most prominent and debated issues within the broader energy sector. The uninterrupted flow of energy from producing to consuming countries is vital, and the Russia-Ukraine war has exacerbated these concerns [16]. The war has brought energy security to the forefront, making it one of the most urgent challenges. The transition to renewable energy has become inevitable, and Türkiye's renewable energy sector can accelerate this transformation. Cooperation between countries, shared resources, and the exploration of new regions can create an ecosystem that offers diverse alternatives. This could be a foundational pillar for supporting energy security in Europe.

In addition to energy security, environmental concerns are equally pressing. As fossil fuel usage increases, so do environmental risks. Renewable energy, as one of the most viable alternatives to mitigate these concerns, contributes not only locally but also regionally and globally. Türkiye's renewable energy sector can play a pivotal role in helping Europe achieve its sustainable energy goals.

4 Conclusion

As the Türkiye energy sector continues to expand, it is taking on a more prominent role within the broader European energy market. Incentives and investments in the renewable energy industry not only bolster infrastructure but also contribute to a more diverse and resilient energy mix. Sustained investments in the sector will further enhance Türkiye’s role in renewable energy within the European region. Given its substantial wind and solar energy potential, Türkiye is positioned to be a key player in Europe’s long-term energy strategy.

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Impact of Thermo-physical Properties of Windows on the Reduction of Greenhouse Gas Emissions Towards 2030 Sustainable Development Goals

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Abstract. Today, it is of great importance to design buildings based on both zero-carbon and high thermal comfort principles, focusing on passive system strategies associated with given climatic region. Allowing a dynamic interaction between the building and the environment, the building envelope plays a crucial role in terms of heat gain and loss in buildings. Accordingly, thermo-physical properties of building materials are among the crucial factors that should inform design decisions in both new and existing buildings to decrease greenhouse gas emissions. Improving building standards to keep up with the Goal 13, i.e., "Take urgent action to combat climate change and its impacts" of the 2030 Sustainable Development Goals would help reducing greenhouse gas emissions. The present study investigated the reference thermo-physical property (U-value) of windows provided in the TS825 Thermal Insulation Requirements for Buildings standard vis-a-vis three distinct thermo-physical categories (U-value, SHGC, and T-vis) with an aim to recommend optimal window options to reduce CO_2 emissions originated from residential buildings in Turkey. Energy performances of various window types were investigated for a sample residential building located in the 2nd degree day region of TS825 standard, using the DesignBuilder building energy simulation tool. Following the performance tests, three window options, W07, W17, and W19, which featured low-e and polymer glazing types with 16mm air-filled. W07 (U-value: 1.89 W/m^2.K, SHGC: 0.40, T-vis: 0.61), W17 (U-value: 1.37 W/m^2.K, SHGC: 0.47, T-vis: 0.59), and W19 (U-value: 1.29 W/m^2.K, SHGC: 0.35, T-vis: 0.47) ensured reductions of 10.45%, 9.81%, and 19.56% respectively, in the annual CO_2 emissions of the sample building in Istanbul.

Keywords: Greenhouse Gas Emission, Sustainable Development Goals, Window Glazing.

1 Introduction

The “TS825: Thermal Insulation Requirements for Buildings” is a national standard that was included in the zoning regulation by Republic of Turkey Ministry of Environment, Urbanization and Climate Change in 1985. The purpose of this standard was to save energy by limiting the amount of heating energy used by buildings in Turkey and to determine a standard method for the calculation of the net heating energy demand. The revised version of this standard dated 2008 is still in use today. The standard divided Turkey into four separate climatic regions as seen in Table 1, based on the average monthly outdoor temperature and average monthly solar radiation intensity for use in the calculations of net energy demand. Accordingly, the lower limits of overall heat transfer coefficients (U-values) of building constructions (exterior walls, floors, roofs, and windows) were determined for each climatic region [1].

Table 1. The lower limits of U-values for the construction materials by climatic regions in Turkey [2].

Degree-Day Regions	U_D (W/m^2K)	U_T (W/m^2K)	U_t (W/m^2K)	U_P (W/m^2K)
1. Region	0,70	0,45	0,70	2,4
2. Region	0,60	0,40	0,60	2,4
3. Region	0,50	0,30	0,45	2,4
4. Region	0,40	0,25	0,40	2,4

The meanings of the U-values provided in Table 1 are given below.

- U_D: The overall heat transfer coefficient of the external wall
- U_T: The overall heat transfer coefficient of the roof
- U_t: The overall heat transfer coefficient of the floor/slab
- U_P: The overall heat transfer coefficient of the window

As seen in Table 1, the U-values of the external wall, roof, and floor vary by region; nevertheless, it is noteworthy that the U-values of the windows remain constant. The standard prescribes the reference U-value for windows as 2.4 W/m^2K. Nevertheless, the fact that the U-value of the envelope components, such as windows, where heat losses and gains are very high throughout the year, varies by the degree-day region, can significantly reduce the annual greenhouse gas (GHG) emissions by increasing the energy conservation of buildings in Turkey.

In recent years, the extent of global warming has dramatically increased due to the unconscious use of non-renewable energy sources such as natural gas, coal, and oil, and now it is a fundamental environmental problem across the world, jeopardizing human life. This, triggered efforts to combat global warming on a global scale [3]. Accordingly, the world leaders set 17 global Sustainable Development Goals (SDGs) in 2015, which included the problem of climate change associated with CO_2 emissions as one of the three essential goals (inequality, injustice, and climate change) to be achieved by 2030. Although the SDGs set by the European Union (EU) for countries with different levels of development are designed as achievable targets for governments, incentives for businesses and users to use renewable energy sources should be further increased, especially in order to achieve the aforementioned targets. Renewable energy sources have become increasingly important in recent years due to their continuous availability in nature, lack of reserve problems, and the fact that their use is not associated with an increase in carbon emissions, which also contributes to environmental protection. Additionally, the use of renewable energy sources has the advantages of reducing the country's energy dependency, ensuring energy supply security, diversifying energy sources, and reducing dependence on energy imports for the national economy. Therefore, the use of renewable energy resources is of utmost importance for the world's nations to achieve the Goal 13 (Climate Action) of the SDGs. It is aimed that the targets stipulated in the “Climate Action” article are achieved by the United Nations by 2030. The objective is to prevent global warming and consequent climate changes by raising public awareness about reducing the use of fossil fuels [4]. The sub-targets set within the scope of this goal are as follows:

- 13.1. The target is to increase the number of countries that have strategies in place to reduce the hazards associated with the intensive use of fossil fuels at the national and local level by raising awareness in countries with regard to the adverse outcomes of climatic change.
- 13.2. The goal is to raise awareness on climate change adaptation and mitigation [4].

Upon a review of the sub-targets above, it is evident that the reduction of GHG emissions and the resulting climatic change effects are directly associated with a reduction of thermal losses/gains from building windows, and consequently, the reduction of carbon emissions. In this study, a sample building model for Istanbul, which is located in the 2nd degree-day region by the TS825 standard, was developed using the DesignBuilder building simulation tool. The thermo-physical properties of the window in the standard, namely the U-value, solar heat gain coefficient (SHGC), and visible light transmittance (T-vis), were re-classified, and recommendations were made as regards the most suitable window types to reduce GHG emissions based on the climatic characteristics of the region, where the sample building was located.

2 Method

For the purposes of the present study, a sample residential building located in the city of Istanbul, which was classified in the 2^{nd} degree-day region by the TS825 standard, with the highest population in Turkey was modeled using the DesignBuilder building simulation tool. In the second step of the study, 20 windows with different thermo-physical properties were tested to see the impact on the energy performance of the sample building, using the window U-value reference in the TS825 standard. In this study, thermo-physical properties such SHGC and T-vis were also considered in addition to the U-value of the window glass, and the sample sizes of the window glasses in the study were increased. For the final part of the study, the annual GHG emission levels due to electricity and natural gas consumption were calculated for the case, where the recommended windows were used in the sample building. The calculation results were analyzed to identify the optimal window types that would contribute to the reduction of GHG emissions associated with windows in residential buildings in Istanbul.

The amount of GHG emissions from electricity use was calculated with reference to the Turkish Ministry of Energy and Natural Resources' Information Form on Emission Factors for Electricity Generation and Electricity Consumption Point Emission Factors for Turkey published on August 8, 2022 [5]. The GHG emission factor associated with electricity use of buildings is 0.481 tCO_2/MWh, representing the amount of total GHG emissions in CO_2 emitted per unit of electricity consumption. The Turkish Emission Inventory published by the Ministry of Energy and Natural Resources in April 2023 was taken as reference for the inclusion of the GHG emission factor from natural gas in the calculations [6]. This inventory prescribed the natural gas emission factor as 55.46 tons/TJ. To convert the unit of this value to tCO_2/MWh, it was first necessary to convert 1 TJ to kWh (1 TJ =277777.78 kWh). As a result, the GHG emission factor from natural gas was calculated as 0.2 tCO_2/MWh.

Upon the calculations within the scope of this study, the optimum window type was determined with an aim to improve the thermo-physical properties of the windows specified in the TS825 standard for Istanbul, as well as to reduce the CO_2 emissions from the windows of residential buildings in Istanbul. Accordingly, it was aimed for Turkey to approach its 2030 target for Istanbul province within the framework of Goal 13 of the SDGs on Climate Action.

3 Energy Performance Modeling of the Sample Building

In this part of the study, a 2-story residential building with a length of 10 m and a width of 5 m was modeled using the DesignBuilder simulation tool. DesignBuilder is a building simulation tool developed in the United Kingdom, which provides a user-friendly interface to model the energy performance of a wide range of building types. The tool utilizes the EnergyPlus simulation engine to perform comprehensive energy analyses. The accuracy of these building simulation tools has been validated through a number of independent research studies [7]. Both of these tools are based on a detailed dynamic methodology stated in the European standard EN 13790: Energy performance of buildings -Calculation of energy use for space heating and cooling [8].

The ground and first floor were set to 50 m^2 each, and the building had a total area of 100 m^2. The building energy model incorporates occupant density, lighting, and equipment data sourced from the ASHRAE 90.1 standard [9]. Figure 1 shows the energy model visualization of the sample building.

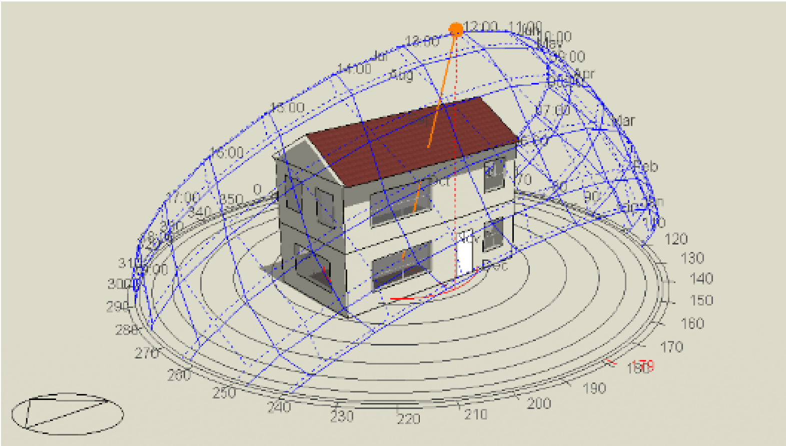

Figure 1. DesignBuilder model view of the sample building.

TS825 standard was taken into consideration in modeling the exterior wall, floor, roof, and window materials of the sample building. Furthermore, the assumed SHGC and T-vis thermo-physical properties of the sample building windows in this study are given in Table 2. It was assumed that the window to wall ratio of the modeled sample building was 30% and all the proposed window types were double glazed with wooden frames.

The version of the TS825 standard as published in 2008 is still valid and only the U-value was defined for windows in this version. In this study, 20 different window types were selected to test their effect on the energy performance and GHG emissions of the sample building and their thermo-physical properties (U-value, SHGC and T-vis) are given in Table 3. The window defined with the code “RW” in the table is the reference window that provides the window U-value in TS825 standard. The other windows identified with the code “W” are the other windows proposed in this study since their U-value is better than the RW window.

Table 2. Thermo-physical properties of the air-filled double-glazed window (glass + wooden frame) types proposed for the sample building.

Recommended Windows	Glazing Type	Thickness of External Glass [mm]	Air Gap [mm]	Thickness of Internal Glass [mm]	U-value [W/m^{2}K]	SGHC	T-vis
RW	Clear	13.60	16	13.60	2.390	0.494	0.659
W01	Low-e	6.35	16	13.60	2.382	0.160	0.100
W02	Low-e	3.06	16	3.85	2.264	0.350	0.395
W03	Low-e	3.06	16	7.03	2.233	0.394	0.414
W04	Low-e	2.18	16	2.18	2.144	0.684	0.713
W05	Polymer	12.12	16	12.12	2.131	0.519	0.255
W06	Low-e	3.08	16	3.08	1.963	0.686	0.645
W07	Low-e	3.06	16	3.06	1.886	0.400	0.608
W08	Low-e	5.88	16	5.88	1.850	0.535	0.802
W09	Polymer	19.61	16	19.61	1.826	0.665	0.528
W10	Low-e	6.00	16	6.00	1.813	0.187	0.192
W11	Low-e	11.65	16	11.65	1.803	0.241	0.319
W12	Low-e	6.00	16	6.00	1.802	0.227	0.233
W13	Low-e	5.88	16	13.60	1.682	0.557	0.726
W14	Polymer	26.48	16	26.48	1.617	0.630	0.438
W15	Low-e	6.00	16	6.00	1.559	0.587	0.666
W16	Polymer	14.90	16	14.90	1.493	0.500	0.617
W17	Polymer	2.74	16	2.74	1.372	0.471	0.591
W18	Low-e	5.92	16	5.92	1.366	0.525	0.683
W19	Polymer	2.74	16	2.74	1.291	0.353	0.474
W20	Polymer	48.91	16	48.91	1.237	0.511	0.295

In this study, the proposed window glasses were selected from clear glass, low-e coated glass, and polymer glass materials. Table 2 also includes a categorization of the proposed glasses according by material properties. Clear glass has low reflectivity due to its low iron content, which allows 90% of sunlight to pass through [10]. Low-e coating is a microscopically almost invisible thin layer of metallic or metal oxide applied directly to the surface of the glass panel. With this thin layer, the U-value of the window is reduced and thus daylight transmittance and solar heat gains can be managed [11]. Polymer glasses have higher transparency, higher heat capacity, higher impact, and chemical resistance compared to other types of glass. Therefore, they can be preferred over clear glass and low-e coated glass types [12].

4 Results

The DesignBuilder simulation tool was used to test the effect of the RW window on the energy performance of the sample building and the annual heating and subsequently, the cooling energy requirement of the sample building was determined under Istanbul climate conditions. Based on the simulation results, the annual heating and cooling requirement of the building was 5390 kWh and 2430.79 kWh, respectively, where the total annual energy requirement of the building was 7820.79 kWh. The effect of all windows between W01 and W20 on the performance of the sample building was then simulated and the annual heating and cooling needs of the sample building due to these windows are given in Figure 2. As can be seen from the figure, the annual heating and cooling loads of the sample building varied dramatically depending on the thermo-physical properties of the windowpanes. Since the lighting and interior equipment in the building were not affected by the window selection, there was no change in the loads of these systems.

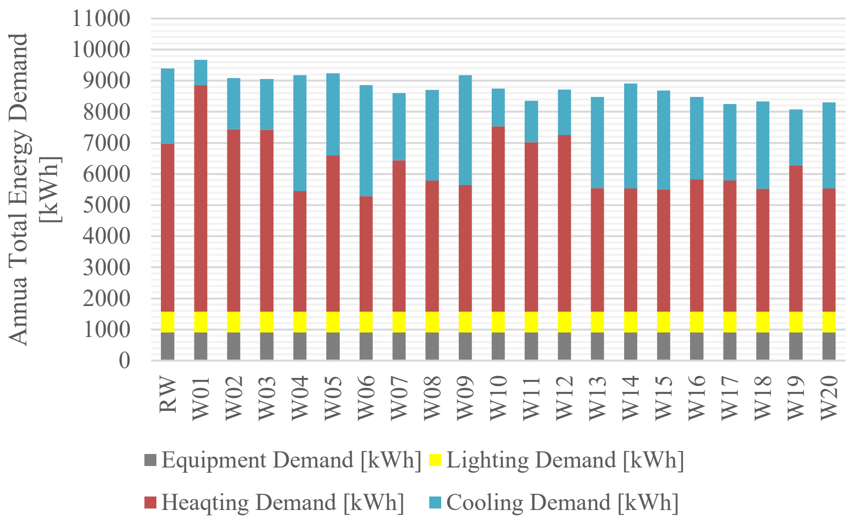

Figure 2. Change in annual heating and cooling needs of the sample building depending on the recommended window type.

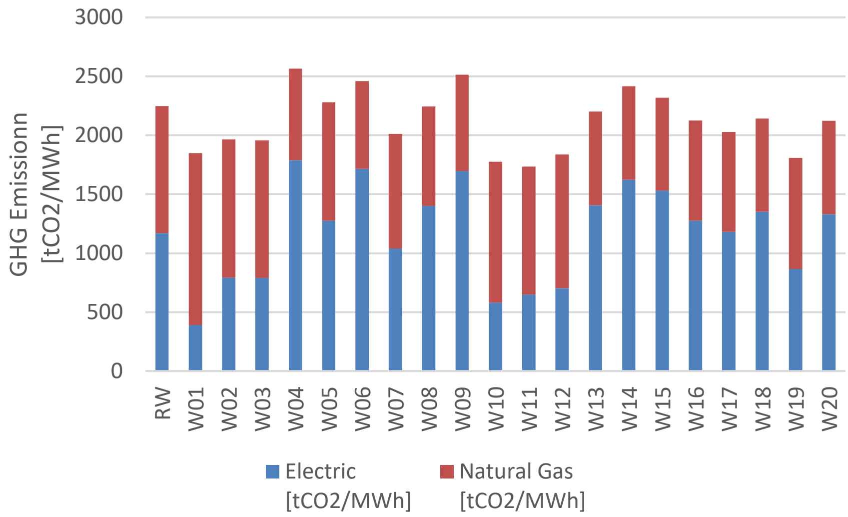

Figure 3. Change in the annual GHG emission amount of the sample building depending on the proposed window type.

Upon a review of the figure, it was clearly seen that reducing the U-value in the windows was not sufficient to increase the energy conservation of the building and that the SHGC ratio was largely effective in changing the building loads. Compared to the RW window, the decrease in the SHGC ratio of the other windows increased the natural gas demand for heating the sample residential building and reduced the electricity demand for cooling. A decrease in this ratio reverses the situation. Other windows, with a U-value lower than RW but a SHGC ratio close to RW, reduced the building's need for natural gas for heating. The T-vis ratios of the recommended window glasses did not have a direct effect on the energy performance of the building. Nevertheless, it was concluded that if this ratio was lower, it would reduce the amount of daylight let in, thus increasing users' need for artificial lighting systems, which would be associated with a significant increase in electricity consumption. As a result of the tests, W17 and W19 windows showed the most striking performance among double-glazed windows with a 16 mm air gap. Both windows were made of polymer material and reduced the total annual energy need of the building the most.

Then, within the scope of Goal 13 of SDGs, the effect of all window types recommended for the sample building on the GHG emissions of the building was calculated as explained in the method of the study, and the optimum window types that reduced GHG emissions were determined among these windows. Pursuant to Goal 13, climate action article, of the SDGs, annual CO_2 emissions from electricity and natural gas due to the choice of window type of the sample building were calculated in line with the data retrieved from the Ministry of Energy and Natural Resources of the Republic of Turkey for Istanbul as located in 2nd degree day zone stated in TS825 standard, and the results are given in Figure 3. As seen in Figure 3, window types W01, W02, W03, W10, W11, W12, and W13 performed better compared to other windows in reducing total annual GHG emissions. This was due to the fact that the GHG emission factor associated with electricity consumption in buildings in Turkey was higher compared to the GHG emission factor due to natural gas. These windows significantly reduced the cooling loads of the building and saved a lot of electricity compared to other windows. Therefore, the use of these windows significantly reduced GHG emissions as a result of cooling, greatly reducing the total amount of emissions. Nevertheless, the SHGC and T-vis ratios of these window types were very low, causing the interior spaces of the building to benefit from sunlight at a lower rate compared to the RW. In addition to adverse effects on the visual comfort of building users, this increased the annual electricity use by significantly increasing the need for artificial lighting systems. Therefore, although they reduced the total GHG emissions, this did not make them an optimal window type for the Istanbul climatic zone. An analysis of Figure 3 suggested that W07, W17 and W19 window types had the highest performance in terms of both thermo-physical properties and the reduction of the total annual GHG emissions of the building within the scope of Goal 13 of the SDGs compared to the RW and the recommended window types. However, although window W19 performed better in reducing the total annual GHG emissions compared to W07 and W17, the lower SHGC and T-vis ratio of this window caused the interior spaces to benefit less from natural light compared to the other two windows. This may cause users in the building to prefer windows W07 and W17, which have higher light transmittance.

5 Conclusion

This study aimed to reduce the CO_2 emissions from windows of residential buildings in Istanbul, which is classified in the 2nd degree day zone by the TS825 standard within the scope of Goal 13 of the SDGs. Accordingly, 20 different window types were selected considering 3 different thermo-physical properties of windows (U-value, SHGC and T-vis) and a sample building model was developed using the DesignBuilder simulation tool and the effect of the selected window types on the annual CO_2 emissions of the building was tested.

Considering the test results, W01, W02, W03, W07, W10, W11, W12, W13, W17, and W19 window types showed better performance compared to other window types. However, considering the user comfort in the building, W07, W17 and W19 window types gave the optimum results in reducing the total annual CO_2 emissions. Although window W19 had the highest performance in reducing CO_2 emissions from both electricity and natural gas, windows W07 and W17 with higher daylight penetration, might be preferable for users as they increased visual comfort and contributed to reducing the need for artificial lighting.

In the next study, the sample set will be expanded by including different gas types and glass gap thicknesses to be used for windows in the tests, and more comprehensive research is planned to investigate the effects of windows not only on the annual energy needs and carbon emissions of the building but also on the annual energy costs of the building.

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Comparative Analyses between Mainstream and Alternative Media in Turkey on Climate Crises

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Abstract. The transformation of the media in Turkey began in the 1990s with global neoliberal policies. This led to changes in the ownership structure of the media and brought about ideological and structural differences in news discourse. However, with the widespread use of new media in journalism, new platforms have been discovered. These platforms called alternative media, constitute a resource for journalists who have difficulty making their voices heard in the mainstream media. On the other hand, issues that cannot be discussed in the mainstream media find more coverage in alternative media. The climate issue receives more coverage in alternative media. Based on this premise, this study analyzes the coverage of the climate crisis by alternative and mainstream media in Turkey. The news on the landslide accident that occurred in İliç district of Erzincan on February 13, 2024 was analyzed in both mainstream and alternative media through discourse analysis method.

Keywords: Climate, Media in Turkey, News Coverage.

1 The structure of Media in Turkey

In the late 1980s and early 90s, the strengthening bourgeois class in Turkey supported its influence in the industrial sector with the financial sector and the media started to become the political supporter of this power.

There are some turning points in the Turkish media. These are,

- In 1979, Hürriyet, which was considered the flagship of Turkish media, was sold to Aydın Doğan.
- Establishment of nationwide distribution systems,
- January 24th decisions (non-press capital started to enter this area)
- First private television (MagicBox, Star 1)
- New communication technologies.

In 1993, the first internet connection was established in cooperation with METU. The Internet was adopted in Turkey in a very short time and spread rapidly. This technology, which has made an impact in Turkey and around the world, is an important development, especially in the field of access to and dissemination of information. In addition to its institutional use, the Internet has become more popular as it has been opened to the use of individuals and commercialized. Internet media has created an alternative space to the mainstream. With Internet technologies, a new alternative media has emerged. On these alternative platforms, unspoken issues became news.

Alternative media structures and alternative media actors are different from capitalist mass media. Within this structure, they are characterized as more free in terms of discourse.

Alternative media aims to foster emancipatory social transformation through critical media content. Critical media content, rooted in Marxist critique, challenges capitalist relations and societal contradictions, seeking to negate repressive conditions and envision a society devoid of domination and oppression.

2 News on Climate Crises

There are many different perspectives on the causes of climate change. According to the critical political economy approach, climate change is caused by capitalism's own structural dynamics.

Climate change has been caused by the increasing use of fossil fuels since the late 18th century. In the 1st Mediterranean Assessment Report published in 2020, it was stated that the average sea water level in the Mediterranean has risen by 6 cm in the last 20 years and that It has been stated that the increase may increase from 43 cm to 84 cm in 2100. Since the Mediterranean Basin, where Turkey is located, is one of the areas that will be most affected by climate change, it is important that the public is informed in this area. The most important function of journalism is to inform and raise awareness.

News is great importance in terms of providing information and raising awareness on climate crises. However, the way the mainstream media and alternative media handle the news differs.

3 Methods and Findings

In this research, News on Çöpler gold mine disaster in Erzincan were analyzed. This issue has been analyzed because it is current and its consequences could create major climate problems in the long term.

On February 13, 2024, 9 workers were trapped under a cave-in in the Çöpler gold mine in the İliç district of Erzincan due to a cyanide-soil slide. This environmental accident will cause many problems in the long and short term. The news in the one-week period following the incident is analyzed. NTV, the first news channel in Turkey, and iklimhaber.org, an alternative media platform, were analyzed.

Content analysis method is used. Content analysis has been used in academic research with the widespread use of mass media. The first applications of content analysis were newspapers in the 16th century on the religious and theological messages in newspapers and then the 20th century in the contemporary mass media research.

In content analysis, repeated words and images are important. On the day of the accident, many repeated words were found in the content of the news reports.

On February 13, NTV television covered this accident in İliç with security camera footage. News headline: ‘Landslide at the mine: 9 missing’ Repetition of words in the news content. Pile of soil, Soil mass, 9 missing, In the same day, NTV used many headlines. These are ‘30th hour of the tragedy’, ‘Moments of terror in the landslide’

Television news used a lot of repetitive images. These are earth-moving track footage, photos of missing people.

On February 14, the speaker said, "On the other hand, measurements are being made against an environmental disaster that we don't even want to think about. It was stated that there was no pollution entering the water sources. The statements of the Ministers dealing with this region and also accident were included. Interior Minister Ali Yerlikaya stated that the search for the workers continues. Minister of Energy and Natural Resources Alpaslan Bayraktar said, 'Continuous measurements and samples are being taken. There is nothing to worry about the dams.’

In the second days’ news content that Çöpler mine came to the agenda in 2022 with the news of a cyanide leak. It mentions the fine imposed on the mining company.

There are no information about these crises’ enviromental consequences. Populist discourse from the government and opposition leaders is featured. The news falls to third place in the main news bulletin on February 15. Main points of this news- workers trapped under the cave-in could not be reached. Election news and news about candidates ranked first

On the other hand, İklimhaber.org is a news website that shares the latest developments in climate science, climate policy and climate economics. İklimhaber.org publishes unbiased and data-driven news. In this way, it aims to disseminate accurate and unbiased information by focusing on addressing climate change with its scientific, economic and political dimensions.

This thematic news site has different news tabs. These are, 1,5 degree - campaign link, Coal tales – a site for the conversion coal power plants in Turkey, Politics, Economy, Science, Disasters, Analysis, Reports.

The politics and economy tab is important because these tabs have most news than other tabs. 70% of the political news is about Turkey. Discourses of political parties on climate were reported. In the economy tab, there are news about the effects of climate change on companies and the European Union. İklimhaber included news on the accident in İliç under the politics tab. In these news reports, the discourses of many organizations and individuals whose views are not covered in the mainstream media were included. These are, İstanbul Bar Association, Muğla Environment Platform (MUÇEP), Independent Miners Union, Grand National Assembly – Environment Commission.

4 Conclusion

The landslide and mining accident in the İliç region of Erzincan is an environmental disaster. The consequences of this negligent environmental disaster are contributing negatively to the rapidly advancing climate crisis.

The media should cover climate and environmental issues and raise the awareness of organizations and individuals. The most important task of the media is to provide information. In addition, it is among the duties of the media to mobilize society in a positive way.

As a result of this research, Climate and environmental issues do not get enough coverage, especially in the mainstream media. Even if they do, they do not stay on the agenda long enough to create social awareness and pressure on policy makers.

In natural disasters or disasters caused by human (mining accidents), the media reports only the number of dead and injured. Audiences cannot find any details about the cause of the event or help to solve it in the mainstream media. Mainstream media is insufficient in raising awareness on environmental and climate issues.

Alternative media reports more oppositional news alongside the mainstream media. However, the climate issue attracts attention in alternative media only with news such as accidents, landslides or fires. When the impact of these events fades or subsides, routine news continues to be reported. 53 days later, one of the workers was found dead, and the incident was brought to the media agenda again as a new development emerged.

Effective decision-making on climate change and environmental issues is closely linked to the dissemination of timely and accurate information. However, the quality and quantity of climate change journalism will play a key role in the coming years.

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Comprehensive Inventory Assessment of Ardahan Municipality: Facilitating Sustainable Urban Development and Resource Management

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Abstract. Ardahan inventory report provides a detailed assessment of the tangible and intangible assets within the jurisdiction of the Ardahan Municipality. The report aims to evaluate the current state of the municipality's resources, infrastructure, and services, serving as a foundation for strategic planning, policy-making, and sustainability initiatives. The inventory encompasses a wide range of sectors, including urban infrastructure, transportation networks, public buildings, cultural heritage sites, green spaces, and environmental resources. In addition, it incorporates a thorough evaluation of the municipality's financial assets, human resources, and institutional capacities. Data were collected through a combination of field surveys, geospatial mapping, stakeholder consultations, and the analysis of municipal records. Key findings indicate a need for investment in critical infrastructure renewal, more efficient resource allocation, the integration of sustainable practices, and enhanced community engagement. Recommendations are provided to address issues such as energy efficiency, waste management, water conservation, and public transportation system improvements, fostering resilience against climate change impacts. It calls for a participatory approach involving local communities, businesses, and policymakers in the decision-making process. By documenting the current state of assets and highlighting areas for enhancement, the report serves as an instrumental tool for driving Ardahan's sustainable development agenda forward.

Keywords: Energy Modelling, Reference Energy System, CIRIS, Inventory Report, Greenhouse Gas Emissions.

1 Climate Change and Cities

The relationship between cities and climate change involves a complex set of factors. Urban growth and development can lead to the destruction of natural areas and an increase in greenhouse gas (GHG) emissions. Intensive energy consumption in cities accelerates the release of GHG into the atmosphere due to dependence on fossil fuels [1]. Additionally, the growing population in cities increases the demand for water and energy resources, requiring more resources for infrastructure, transportation, and energy production [2].

The effects of cities on climate change are not limited to emissions alone. Cities are also vulnerable to environmental issues related to climate change, such as air pollution, the urban heat island effect, and flooding [3]. This requires local governments to not only reduce GHG emissions but also be prepared for the effects of climate change [1].

Despite these challenges, cities can also be part of the solution. Local governments play a critical role in combating climate change [4]. Municipalities can reduce GHG emissions by making their infrastructure sustainable and low-carbon, promoting public transportation, implementing energy efficiency measures, and preserving green spaces [1]. Additionally, local governments can lead in building a resilient community against the effects of climate change.

Many cities worldwide are setting goals and taking steps to combat climate change. Collaboration in addressing climate change is essential among local, national, and international actors. Furthermore, the involvement of civil society, businesses, and local communities is crucial in this process [5].

To conclude, the link between cities and climate change is both intricate and of paramount importance. For cities to play an effective role in combating climate change, they need to embrace sustainability, energy efficiency, and green technology practices. Additionally, it is important to promote and support collaboration among cities to contribute to the worldwide initiative to tackle climate change.

1.1 The Current Situation in Türkiye

Turkey is experiencing rapid urbanization and population growth, which aligns with global trends. As of December 31, 2021, the population of Turkey reached over 84.68 million, with a significant proportion residing in urban areas [6]. This demographic shift has major implications for energy consumption, transportation, waste management, and overall GHG emissions.

The growing urban population has led to increased energy demand, primarily met by fossil fuels. Turkey's energy consumption is heavily reliant on imported oil and natural gas, which contributes significantly to GHG emissions [7]. The residential sector, particularly in urban areas, consumes a large portion of this energy for heating, cooling, and electricity. In the past few years, there has been a trend towards expanding the energy mix and incorporating a larger percentage of renewable energy [8]. Wind, solar, and hydroelectric power are being developed, but the transition is gradual. The Energy Market Regulatory Authority (EPDK) reports indicate that efforts are being made to improve energy efficiency and reduce dependency on fossil fuels [9].

Local governments in Turkey are increasingly taking action to address climate change. Many municipalities have developed climate action plans and are participating in international initiatives such as the Covenant of Mayors for Climate & Energy. These plans typically include measures to improve energy efficiency, increase the use of renewable energy, enhance public transportation, and improve waste management. For example, the Metropolitan Municipality of Istanbul has set ambitious goals to reduce its carbon footprint by promoting energy-efficient buildings, expanding green spaces, and investing in renewable energy projects [10]. Similarly, the city of Izmir is focusing on sustainable urban mobility, waste-to-energy projects, and enhancing the resilience of its infrastructure to climate impacts.

Despite these efforts, Turkey faces several challenges in its fight against climate change. The reliance on fossil fuels, rapid urbanization, and industrial activities contribute to high GHG emissions [9]. Furthermore, the country is susceptible to the effects of climate change, including more frequent and intense extreme weather events, rising sea levels, and alterations in precipitation patterns. However, there are also significant opportunities. Turkey's geographic location offers substantial potential for renewable energy development, particularly wind and solar power. The growing awareness and commitment of local governments to sustainability and climate action provide a strong foundation for achieving national and international climate goals [8].

In conclusion, Turkey is actively working to address climate change through various initiatives at both national and local levels. While challenges remain, the concerted efforts of local governments, supported by national policies and international cooperation, are paving the way for a more sustainable and resilient future.

2 Methodology

The Ardahan Municipality GHG Emission Inventory aims to quantify and report greenhouse gas emissions within the municipality. This baseline inventory will support future tracking, strategic planning, and climate action efforts.

2.1 GHG Inventory Tools and CIRIS

GHG inventory tools are essential for organizations, municipalities, and businesses keen on measuring, managing, and reducing their carbon footprints [11]. These tools help systematically collect data, understand emission sources, and track progress over time.

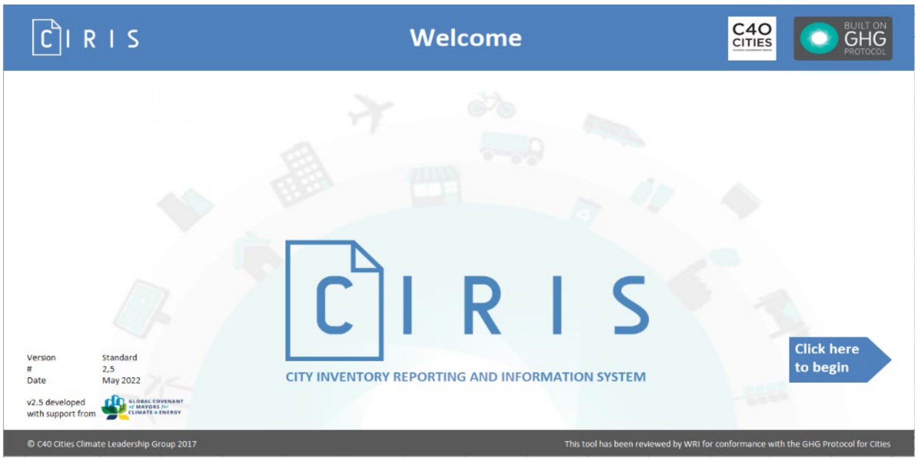


Fig. 1. CIRIS GHG Emission Inventory Tool [11]

Among the numerous options available, the City Inventory Reporting and Information System (CIRIS) shown in Fig. 1 stands out as the optimal choice for municipalities. Developed by the C40 Cities Climate Leadership Group, CIRIS offers several unique advantages. CIRIS is specifically developed for municipalities, ensuring it caters to the unique needs and challenges cities face in managing their emissions [11]. Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) ensuring that the inventory is consistent with globally recognized standards [1]. GHG emissions from GPC City operations are shown in Fig. 2 as categorized into six main sectors and sub-sectors under it [12]. This makes it easier to compare with other cities globally and report to international initiatives. CIRIS offers a user-friendly interface, which simplifies data entry and management. This reduces the workload on municipal staff and enhances efficiency. CIRIS includes a database of regularly updated emission factors, eliminating the need for manual research and ensuring accuracy in calculations. CIRIS goes beyond data collection by providing robust reporting and visualization tools. These tools enable cities to identify key emission sources and model the impact of different reduction strategies [11].

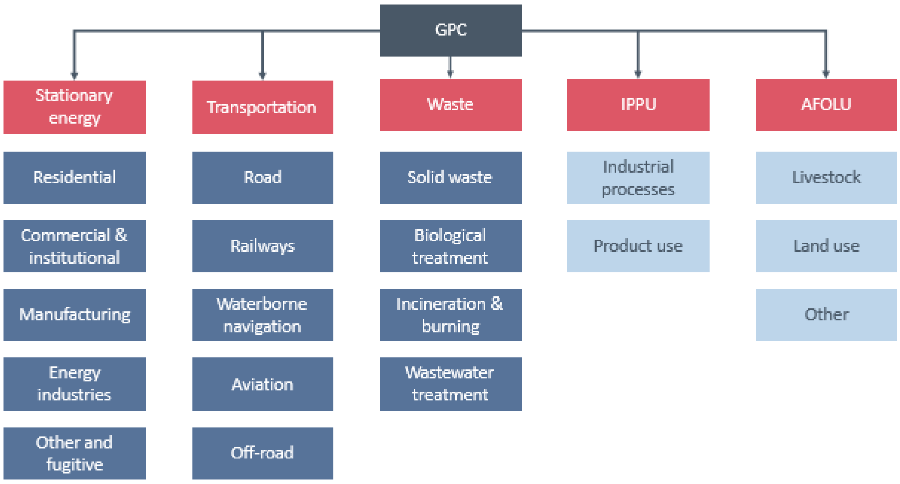


Fig. 2. Sectors and Sub-sectors of City GHG Emissions [12]

In addition to CIRIS, other valuable tools are available such as Clear-Path (developed by ICLEI), carbonn® Climate Registry, and BEACON (developed by C2ES). However, CIRIS's design specifically for municipalities and its alignment with global standards make it a particularly effective choice for GHG inventory calculations.

Thus, CIRIS is recommended for calculating inventory due to its user-friendly design, standardized methodologies, and robust data management capabilities, all of which are tailored to the specific needs of cities.

2.2 Scope and Boundary

The Ardahan Municipality GHG Emission inventory covers emissions for the calendar year 2021, representing the base year for future comparisons. It encompasses all GHG emissions occurring within the administrative boundaries of Ardahan Municipality.

As shown in Fig. 3 GHG emissions are categorized into three different scopes based on their source and the level of direct control an organization has over them [13]. Understanding these scopes is crucial for accurately accounting for and managing GHG emissions.

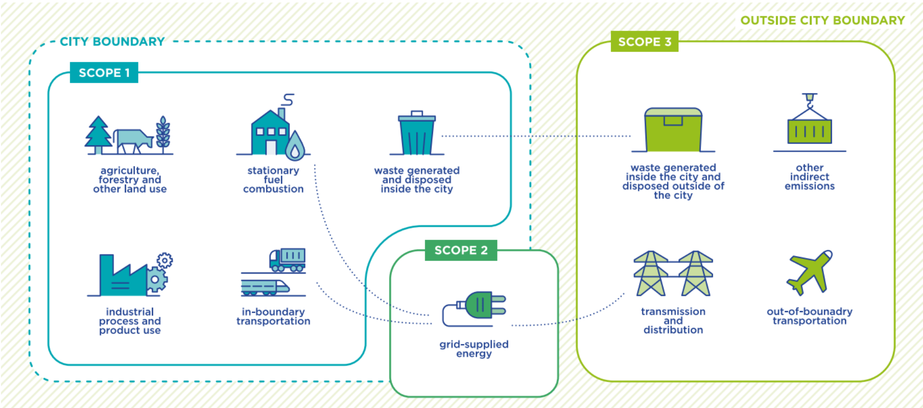


Fig. 3. GPC Scope Framework: sources and boundaries of city GHG emissions [13]

Scope 1 emissions are the most direct, stemming from sources an organization owns or controls [13]. Think of burning fuel for heating in a municipal building or the exhaust from city-owned vehicles. These emissions are generally easier to measure and control since the organization has direct influence over the source [12].

Scope 2 emissions are indirect, coming from the energy an organization buys. The emissions occur at the power plant generating electricity or the facility producing heating or cooling for a city building [13]. Although not directly controlled, organizations can influence these emissions by choosing renewable energy sources or implementing energy efficiency measures.

Scope 3 emissions represent the most complex category, encompassing all other indirect emissions from an organization's activities [12]. This could include emissions from waste disposal, employee commutes, business travel, or even the production of goods and services the organization purchases [13]. Managing Scope 3 requires collaboration with suppliers, promoting sustainable practices within the community, and making responsible choices about procurement and travel.

Effectively addressing climate change requires understanding and managing emissions across all three scopes. While Scope 1 and Scope 2 are more readily managed, Scope 3 often makes up the largest portion of an organization's emissions, making it equally important to address [12]. By carefully examining all three scopes, municipalities and organizations can develop comprehensive strategies to reduce their impact on the planet [13].

When it comes to GHG reporting and management practices, there are varying levels of comprehensiveness as shown in Table 1 [12]. The Basic level involves fundamental GHG reporting and management, focusing on compliance with regulatory requirements and basic reporting, usually concentrating on Scope 1 and Scope 2 emissions. On the other hand, the Basic + level signifies a more advanced approach, incorporating more thorough GHG accounting, including some Scope 3 emissions, and implementing proactive strategies for emissions reduction. This level often involves adopting some best practices in GHG management, even if not yet at the leading industry standard [12].

Understanding these scopes and levels is crucial for organizations aiming to manage their environmental impact effectively and develop robust strategies to reduce GHG emissions across their entire value chain.

Table 1. Summary of differences between BASIC and BASIC+ level reporting [12]

Emission Sources	Scope	Basic	Basic +
Stationary fuel combustion	1	+	+
In-boundary transportation	1	+	+
Grip supplied electricity	2	+	+
Waste and wastewater generated & disposed in the city	3	-	+
Electricity transmission and distribution losses	3	-	+
Out-of-boundary transportation	3	-	+
Industrial Process And Product Use (IPPU)	1	-	+
Agriculture, Foretsry, Land Use (AFOLU)	1	-	+

The Ardahan Municipality GHG Emission inventory is developed using the BASIC level approach as outlined in the GPC. This level focuses on the most significant emission sources and readily available data. The BASIC level prioritizes readily available data and actionability. By focusing on Scope 1 and Scope 2, municipalities can gain a good initial understanding of their main emission sources and begin implementing direct reduction strategies.

3 Ardahan GHG Emission Inventory Report

To prepare the inventory, essential data was collected from various sources within the municipality boundaries, including residential buildings, commercial and institutional buildings, energy production facilities, industrial facilities, solid waste and wastewater treatment facilities, and transportation. Additionally, data on fuel and electricity consumption in agricultural, and forestry were gathered.

3.1 Stationary Energy (GPC I)

In Ardahan, GHG emissions mainly come from stationary sources. Residential heating and cooking rely on natural gas, coal, and biomass. Commercial buildings and industrial facilities primarily use electricity, as there is no natural gas supply for industries.

Residential Buildings (GPC I.1). This covers emissions from heating and cooking in homes. Table 2 shows the quantity and sources of the natural gas, imported coal, locally sourced coal, and dried animal dung which are used for these purposes.

Table 2. Stationary Energy-Residential Buildings Activity Data

Fuel/Energy	Quantity	Source
Natural Gas	21112986.52 m³	EPDK - Electricity Market Sector Report, 2021 [9]
Imported Coal	3000 tons	Provincial Directorate of Environment and Urbanization
Domestic Coal	2650 tons	Provincial Directorate of Environment and Urbanization
Dried Animal Dung	262800 tons	Ardahan Municipality
Electricity Consumption	49181 MWh	EPDK - Electricity Market Sector Report, 2021 [9]
Electricity Transmission and Distribution Losses	9875 MWh	EPDK - Electricity Market Sector Report, 2021 [9]

Commercial and Institutional Buildings and Facilities (GPC I.2). Like residential buildings, emissions from electricity consumption in commercial and institutional buildings and street lighting (Scope 2) are included. However, emissions from transmission and distribution losses are not included in the basic reporting. Data sources and quality assessments for fuel and electricity consumption in these buildings are provided in Table 3.

Table 3. Stationary Energy- Commercial and Institutional Buildings and Facilities Activity Data

Fuel/Energy	Quantity	Source
Electricity Consumption from the Grid	49181 MWh	EPDK - Electricity Market Sector Report, 2021 [9]
Street Lighting Electricity Consumption	14146 MWh	EPDK - Electricity Market Sector Report, 2021 [9]
Electricity Transmission and Distribution Losses	9875 MWh	EPDK - Electricity Market Sector Report, 2021 [9]

Manufacturing Industries and Construction (GPC I.3). In Ardahan, the manufacturing and construction sectors significantly contribute to the local economy, predominantly through small and medium-sized enterprises centered around food production in a 150-hectare organized industrial zone and a 22.8-hectare industrial site. Construction activities include residential, commercial, and infrastructural projects, relying heavily on diesel and gasoline. The primary source of emissions is electricity consumption, with approximately 714 MWh used in 2021 as indicated in table 4 below, as these industrial areas lack natural gas connections. Although data insufficiencies hinder comprehensive emissions tracking, there are opportunities to transition to cleaner energy sources and adopt energy-efficient construction practices.

Table 4. Stationary Energy – Manufacturing Industries and Construction Activity Data

Fuel/Energy	Quantity	Source
Electricity Consumption from the Grid	714 MWh	EPDK - Electricity Market Sector Report, 2021 [9]
Electricity Transmission and Distribution Losses from the Grid	143.37 MWh	EPDK - Electricity Market Sector Report, 2021 [9]

Energy Industries (GPC I.4). The energy industries sector (GPC I.4) in Ardahan has a minimal impact on greenhouse gas emissions. The region does not have any power plants operating on fossil fuels or large-scale hydroelectric facilities. Instead, Ardahan relies on the national grid, as indicated in table 5 below.

Table 5. Stationary Energy – Energy Facilities Sub-Sector Activity Data

Fuel/Energy	Quantity	Source
Liquefied Natural Gas (LNG)	1333 sm^3	EPDK - Natural Gas Market Sector Report, 2021 [14]
Electricity Consumption from the Grid	714 MWh	EPDK - Electricity Market Sector Report, 2021 [14]
Electricity Transmission and Distribution Losses from the Grid	143.37 MWh	EPDK - Electricity Market Sector Report, 2021 [14]

Agriculture, Forestry, and Fishing Activities (GPC I.5). The agriculture, forestry, and fishing activities (GPC I.5) in Ardahan contribute minimally to greenhouse gas emissions. The primary source of emissions in this sector is electricity consumption for various activities. Due to limited data on fuel consumption for agricultural machinery and livestock, the report mainly includes emissions from grid electricity use as shown in table 6. This reflects the traditional and small-scale nature of these activities in the region.

Table 6. Stationary Energy – Agriculture, Forestry, and Fishing Sub-sector Activity Data

Fuel/Energy	Quantity	Source
Electricity Consumption from the Grid	4 MWh	EPDK - Electricity Market Sector Report, 2021 [9]
Electricity Transmission and Distribution Losses from the Grid	0.8 MWh	EPDK - Electricity Market Sector Report, 2021 [9]

3.2 Transportation (GPC II)

The transportation sector in Ardahan contributes significantly to the region's greenhouse gas emissions, primarily through road transportation. The report states that there are a total of 18,911 motor vehicles in Ardahan. Emissions from road transportation are calculated based on fuel consumption data provided by local fuel distributors. Additionally, the Bakü-Tiflis-Kars railway, which passes through the Çıldır district, does not significantly contribute to emissions as it is not extensively used within Ardahan. There are no emissions from maritime or air transportation within the region. In addition, emissions caused by off-road vehicles such as construction vehicles, tractors, and forklifts are included in Road Transportation (GPC II.1) sub-sector emissions since no separate activity data specific to the vehicle type can be obtained.

On Road Transportation (GPC II.1). On-road transportation is the largest energy-consuming sector in Ardahan, with significant GHG emissions resulting from the consumption of fossil fuels such as gasoline, diesel, and LPG. The total amount of fuel consumption is documented in Table 7, which lists the quantities of each fuel type used in 2021. Specifically, the region consumed 2,133.76 tons of gasoline, 36,877.29 tons of diesel, and 1,458.01 tons of LPG. These fuel consumptions contributed to direct emissions of CO2, CH4, and N2O, primarily from vehicles operating within the region. The emissions from this sector are classified under Scope 1, indicating that the fuel used by vehicles was purchased from local distributors within Ardahan.

Table 7. Transportation-On Road Transportation Activity Data

Fuel/Energy	Quantity	Source
Gasoline	2133.76 tons	EPDK - Petroleum Market Report, 2021 [15]
Diesel	36877.289 tons	EPDK - Petroleum Market Report, 2021 [15]
Liquefied Petroleum Gas (LPG)	1458ç011 tons	EPDK - Petroleum Market Report, 2021 [15]
Electricity Transmission and Distribution Losses from the Grid	IE	EPDK - Electricity Market Sector Report, 2021 [9]

Railways (GPC II.2). The railway transportation section in the Ardahan GHG Inventory report focuses on the Bakü-Tiflis-Kars (BTK) railway line, which became operational in 2017. The total length of the BTK railway is 838 km, with 76 km of the line located within Turkey's borders. Notably, 16 km of this section passes through Ardahan's Çıldır district, which also houses the Yukarıcambaz station. However, since the emissions inventory only includes emissions from fuel sold within the region, the limited use of this railway in Ardahan means that it does not significantly contribute to the region's GHG emissions. There is no separate fuel consumption data specifically for railway transportation listed in the report. Only two levels of headings should be numbered. Lower-level headings remain unnumbered; they are formatted as run-in headings.

3.3 Waste (GPC III)

The primary source of emissions within the waste sector is solid waste disposal, which leads to methane release due to the anaerobic decomposition of organic materials in landfills. According to the 2021 data, Ardahan generated substantial amounts of both domestic and industrial waste, though the local waste management infrastructure remains underdeveloped, limiting the capture and treatment of these emissions. Methane emissions, in particular, are calculated using the Methane Commitment method, which assumes that all emissions from waste decomposition occur during the reporting period. Additionally, biological waste treatment processes such as composting and anaerobic digestion also contribute to methane and nitrous oxide emissions. Notably, the region does not employ waste incineration, and thus no emissions from this process were recorded. The report underscores the need for enhanced waste management strategies, particularly in landfill gas capture and waste treatment technologies, to mitigate the sector's impact on GHG emissions.

Solid Waste Disposal (GPC III.1). The Solid Waste Disposal sector (GPC III.1) in the Ardahan GHG Inventory report focuses on emissions generated from the disposal of domestic and industrial solid waste.

Table 8. Waste- Solid Waste Disposal Activity Data

Fuel/Energy	Quantity	Source
Gasoline	2133.76 tons	EPDK - Petroleum Market Report, 2021 [15]
Diesel	36877.289 tons	EPDK - Petroleum Market Report, 2021 [15]
Liquefied Petroleum Gas (LPG)	1458ç011 tons	EPDK - Petroleum Market Report, 2021 [15]
Electricity Transmission and Distribution Losses from the Grid	IE	EPDK - Electricity Market Sector Report, 2021 [9]

According to the report, Table 8 provides an overview of the types and quantities of waste generated in 2021. It notes that 38,115.198 kg of domestic waste and 1,182.6 tons of industrial waste with household characteristics were generated in Ardahan. Additionally, materials like paper, plastic, glass, and metal were also collected, with respective quantities of 37,817 kg, 26,976 kg, 9,220 kg, and 8,157 kg. These waste disposal activities contribute to methane emissions, which are calculated using the 'Methane Commitment' method. This method assumes that all emissions resulting from the decomposition of waste during the reporting period are realized within the same period. The report stresses the importance of improving solid waste management practices to mitigate greenhouse gas emissions in the future. Only two levels of headings should be numbered. Lower-level headings remain unnumbered; they are formatted as run-in headings.

Biological Treatment of Waste Generated in the City (GPC III.2). This process primarily involves anaerobic digestion, where organic waste is decomposed by microorganisms in an oxygen-free environment. Consequently, biogas, consisting of methane (CH4) and carbon dioxide (CO2), is produced. Table 9 specifies that 4,000 tons of solid waste underwent anaerobic digestion. The emissions from this process are crucially included in the overall greenhouse gas emissions tally, highlighting the importance of effective waste management in reducing carbon footprints.

Table 9. Waste- Biological Treatment of Waste Generated in the City Activity Data

Fuel/Energy	Quantity	Source
Anaerobic Digestion	4,000 tons	Ardahan Municipality

Wastewater generated in the City (GPC III.4). This process primarily involves anaerobic digestion, where organic Wastewater treatment can be carried out using either aerated or anaerobic processes. These processes can produce methane, nitrogen oxide, and biogenic carbon dioxide. Biogenic carbon dioxide, which is considered to be of biogenic origin, has not been included in the inventory. The methods presented in the 2006 IPCC Volume 6 - Wastewater Treatment and Discharge, and the National GHG Inventory: 1990-2015 data have been used to calculate the CH4 and N2O emissions resulting from wastewater treatment. The Activity Data listed in Table 10 is used in the wastewater treatment and discharge system emission calculations.

Table 10. Waste- Wastewater generated in the City Activity Data

Fuel/Energy	Quantity	Source
Domestic Wastewater	358,852 tons	Ardahan Municipality

3.4 Industrial Processes And Product Use (IPPU)

The industrial landscape in Ardahan is heavily concentrated in food production, with "Manufacture of food products" representing 68.18% of all enterprises. "Other mining and quarrying" makes up 9.09% of businesses, and "Electricity, gas, steam, and air conditioning supply" comprises 6.82%. Despite having 28 potential industrial subsectors, only six are currently active in Ardahan. The current GHG inventory for Ardahan does not include calculations for emissions from industrial processes and product use (IPPU). This is due to the inventory being prepared at the BASIC level, which does not mandate the reporting of these specific emissions.

3.5 Agriculture, Forestry And Other Land Use (AFOLU)

While Ardahan's economy heavily relies on agriculture and livestock, the current GHG inventory doesn't include detailed emissions from this sector (AFOLU). This is because the inventory was compiled at a BASIC level, which doesn't require such in-depth reporting.

However, it's important to understand the potential sources of emissions within AFOLU in Ardahan. Livestock, a significant part of the local economy, contributes to emissions through enteric fermentation (digestive processes in animals) and manure management. Land use changes, such as deforestation or conversion of grasslands for agriculture, can also release greenhouse gases. Additionally, agricultural activities like applying synthetic fertilizers and lime contribute to emissions.

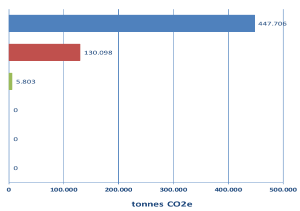
Although not fully quantified in the current inventory, these AFOLU-related activities in Ardahan likely contribute to the region's overall greenhouse gas emissions. Future inventories aiming for a more comprehensive assessment should include detailed data and calculations for AFOLU, providing a clearer picture of Ardahan's environmental impact and informing more targeted mitigation strategies.

4 Results

The 2021 greenhouse gas emission inventory paints a clear picture of Ardahan's emission profile. As shown in fig. 4, Ardahan recorded a total of 583,606 tons of CO2 equivalent (CO2e) emitted, translating to a per capita emission of 6.1 tons of CO2e per person. Delving deeper into the data reveals that the main sources of these emissions are residential buildings, road transportation, and waste disposal.

NAME OF CITY:	Ardahan, Turkey	POPULATION:	94.932
BOUNDARY:	BASIC	LAND AREA (km2):	5.661
INVENTORY YEAR:	2021	GDP (US$ million):	553

tCO2e	BASIC	Scope 1	Scope 2	Scope 3
	Stationary	447.294	411	
	Transportation	130.098		
	Waste	5.776		27
	IPPU			
	AFOLU			
	Other Scope 3			
	TOTAL	583.606		



Intensity indicators	Per capita	Per unit land area (km2)	Per unit GDP (US$m)
Emissions	6,1	103	1.055

Fig. 4. Summary of Ardahan's GHG Inventory for 2021

OVERVIEW (GPC CHAPTER 4.4, TABLE 4.2, PAGE 41)

NAME OF CITY:	Ardahan, Turkey	**POPULATION:**	94.932
LEVEL:	BASIC	**LAND AREA (km2):**	5.661
INVENTORY YEAR:	2021	**GDP (US$ million):**	553

GHG Emissions Source (By Sector)		Total GHGs (metric tonnes CO2e)					
		Scope 1	Scope 2	Scope 3	BASIC	BASIC+	BASIC+ S3
STATIONARY ENERGY	Energy use (all emissions except I.4.4)	447.294	411	78	447.706	447.783	447.783
	Energy generation supplied to the grid (I.4.4)						
TRANSPORTATION	(all II emissions)	130.098			130.098	130.098	130.098
WASTE	Waste generated in the city (III.X.1 and III.X.2)	5.776		27	5.803	5.803	5.803
	Waste generated outside city (III.X.3)						
IPPU	(all IV emissions)						
AFOLU	(all V emissions)						
OTHER SCOPE 3	(all VI emissions)						
TOTAL		583.168	411	105	583.606	583.684	583.684

GPC ref No.	GHG Emissions Source (By Sector and Sub-sector)	Total GHGs (metric tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
I	STATIONARY ENERGY				
I.1	Residential buildings	447.294	24	NE	447.318
I.2	Commercial and institutional buildings and facilities		40	8	47
I.3	Manufacturing industries and construction		346	69	415
I.4.1/2/3	Energy industries			NE	
I.4.4	Energy generation supplied to the grid				
I.5	Agriculture, forestry and fishing activities	NO	2	0	2
I.6	Non-specified sources	NO	NO	NO	
I.7	Fugitive emissions from mining, processing, storage, and transportation of coal	NO			
I.8	Fugitive emissions from oil and natural gas systems	NO			
SUB-TOTAL	(city induced framework only)	447.294	411	78	447.783
II	TRANSPORTATION				
II.1	On-road transportation	130.098		NE	130.098
II.2	Railways	NO	NO	NE	
II.3	Waterborne navigation	NO	NO	NE	
II.4	Aviation	NO	NO	NE	
II.5	Off-road transportation	NO	NO	NE	
SUB-TOTAL	(city induced framework only)	130.098			130.098
III	WASTE				
III.1.1/2	Solid waste generated in the city	2.349		27	2.376
III.2.1/2	Biological waste generated in the city	200			200
III.3.1/2	Incinerated and burned waste generated in the city				
III.4.1/2	Wastewater generated in the city	3.227			3.227
III.1.3	Solid waste generated outside the city				
III.2.3	Biological waste generated outside the city				
III.3.3	Incinerated and burned waste generated outside city				
III.4.3	Wastewater generated outside the city				
SUB-TOTAL	(city induced framework only)	5.776		27	5.803
IV	INDUSTRIAL PROCESSES and PRODUCT USES				
IV.1	Emissions from industrial processes occurring in the city boundary	NE			
IV.2	Emissions from product use occurring within the city boundary	NE			
SUB-TOTAL	(city induced framework only)				
V	AGRICULTURE, FORESTRY and OTHER LAND USE				
V.1	Emissions from livestock	NE			
V.2	Emissions from land	NE			
V.3	Emissions from aggregate sources and non-CO2 emission sources on land	NE			
SUB-TOTAL	(city induced framework only)				
VI	OTHER SCOPE 3				
VI.1	Other Scope 3			NE	
TOTAL	(city induced framework only)	583.168	411	105	583.684

Fig. 5. Ardahan's GHG Inventory Results for 2021

According to fig. 5, residential buildings emerge as the leading contributor, responsible for a significant 76.6% of the total emissions. This can be largely attributed to the region's reliance on natural gas and traditional fuels like dried animal dung for heating, particularly during the harsh and prolonged winters. Following closely behind is road transportation, accounting for 22.3% of the emissions. This highlights the city's dependence on gasoline and diesel-powered vehicles for transportation, further compounded by the limited railway infrastructure. Lastly, waste disposal contributes

1% to the total emissions, primarily due to the release of methane from landfills, a consequence of the region's substantial livestock industry.

5 Conclusion

While the lower per capita emissions compared to the national average are encouraging, there is still significant room for improvement in Ardahan's journey towards a more sustainable future. Several key areas require attention and strategic action to further reduce GHG emissions.

Firstly, the transition to natural gas for heating, while a positive step, needs to be coupled with aggressive energy efficiency initiatives. This involves promoting energy-efficient building practices, encouraging the adoption of energy-saving appliances, and raising awareness about responsible energy consumption among residents.

Secondly, the city needs to prioritize revamping its waste management practices. This includes implementing robust recycling programs, exploring waste-to-energy technologies, and promoting composting of organic waste to divert waste from landfills and reduce methane emissions.

Thirdly, the scope of future GHG inventories needs to be expanded. The current inventory, prepared at a BASIC level, doesn't account for emissions from industrial processes and agricultural land use. Incorporating these sectors in future assessments will provide a more comprehensive understanding of Ardahan's emission sources and guide more targeted mitigation efforts.

By proactively addressing these areas and adopting a data-driven approach to emissions reduction, Ardahan can pave the way for a sustainable future. This involves investing in green technologies, fostering community engagement in sustainability initiatives, and promoting responsible consumption patterns. The transition won't be easy, but the commitment to a low-carbon future will yield significant environmental, economic, and social benefits for Ardahan in the long run.

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Risk and Vulnerability Analysis and Energy Modelling Practices as Part of "Sustainable Energy and Climate Action Plan": Bodrum Case Study

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Abstract. As of 2024, many countries have set carbon neutrality targets for 2050 to eliminate harmful emissions for the climate. To achieve this goal, both industries and local governments need to have ambitions and intentions towards carbon neutrality. While the emission reduction of industries is the subject of another study, this study focuses on the methods applied by municipalities (local governments). One of the most common methods applied at the municipal level is the practice of Sustainable Energy and Climate Action Plan (SECAP). In this study, an example of how energy modeling studies can be integrated with Risk and Vulnerability Analysis (RVA), which is a sub-part of the SECAP process initiated by Bodrum Municipality, Türkiye against climate change, will be examined as a case study. In the RVA step, the city was analyzed in terms of temperature, river flooding, sea level inundation, flooding, water scarcity, wildfire, and vector-borne diseases, and their risk levels were revealed. The results show that the primary climate risks that Bodrum Municipality should focus on in order of priority are floods, forest fires and temperature in order of importance.

Keywords: Sustainable Energy and Climate Action Plant, SECAP, Climate Change, Energy Modeling, Risk and Vulnerability Analysis, Emission

1 Introduction

This study is focused on reducing greenhouse gas emissions by 20% by 2020, as initially targeted by the European Union, and later supported by the Paris Agreement, which aligns with Article 21 of the United Nations Framework Convention on Climate Change. The research has been conducted to meet the requirements of the Covenant of Mayors, which revises this reduction target to 40% by 2030, following its endorsement at the Conference of the Parties. The objective is to develop the scientific foundation for the Sustainable Energy and Climate Action Plan (SECAP) for the city of Bodrum.

In this context, the year 2020 was selected as the baseline for the initial phase, using 2020 data to establish the basic scenario and assess the current socioeconomic, geographical, climatic, and resource conditions. The Bodrum emission inventory for 2020 was then analyzed over a more extended period, evaluating potential action strategies to achieve the emission reduction targets based on current conditions. Additionally, the study identifies the risks and vulnerabilities of the city, providing recommendations for future adaptation.

Ultimately, the goal of this analysis is to establish a framework for climate resilience based on Bodrum's greenhouse gas emission inventory and long-term projections. It aims to create a scientifically grounded basis for developing the SECAP for Bodrum.

Following studies completed and published by the municipalities around the world:

Izmir Metropolitan Municipality joined the Covenant of Mayors (CoM) in 2016 and received official approval in December 2020. The city committed to reducing its emissions by 20% by 2020 and by 40% by 2030, while also addressing adaptation and energy scarcity. In 2016, Izmir published a Sustainable Energy Action Plan that detailed the city's energy consumption and greenhouse gas inventory. To update this work, a second study, the "Sustainable Energy Climate Action Plan," was conducted in 2020. This report included climate-related sections, such as climate hazard adaptation, risk and vulnerability assessments, and an updated emission inventory based on the 2016 baseline [1].

Eskişehir Tepebaşı Municipality developed its Sustainable Energy Action Plan (SEAP) based on commitments made in 2014. The initial report focused on determining the city's emission inventory and creating emission reduction plans. In 2021, the municipality began preparing a Sustainable Energy Climate Action Plan (SECAP) for its second commitment. Using 2019 as the base year, they aimed to reduce emissions by 40% by 2030. Their efforts included reducing greenhouse gases, improving energy efficiency in buildings, increasing renewable energy use, enhancing transportation efficiency, and managing waste, wastewater, agriculture, and animal farming. They also assessed the city's climate risks, analyzed vulnerabilities, and developed adaptation strategies [2].

Another notable example is the city of Berlin, which joined the Covenant of Mayors (CoM) in 2015 and released its first monitoring report that same year. Subsequent reports were published in 2020. In these reports, Berlin outlined its goals for 2030, focusing on building a sustainable and climate-friendly city. The city's commitment includes strategies for achieving climate targets, assessing their impacts, promoting climate-friendly transportation, and raising public awareness [3].

The second section of this study will describe the methodology, used tools and sources. The third section will present the results from the analysis, and it will finish with the conclusion.

2 Methodology

2.1 Emission Inventory and Projection

The first part of the SECAP study is to determine emission levels of the cities by well-known methodologies. In this way, the Bodrum Municipality prepared their emission inventory for 2021 by using Greenhouse Gas Emission Inventory (GPC) tool developed by Greenhouse Gas Protocol (GGP). This methodology basically calculated three different emission sources. Emissions from stationary sources, emissions from transport and emission from waste. Also, it divides those sources into following sub-topics, for stationary sources:

- Residential buildings
- Commercial buildings
- Institutional buildings
- Street lighting
- Manufacturing industries
- Construction industries
- Energy sector
- Agriculture, forestry and fishing

For transport related sources:

- On-road
- Railways
- Waterborne navigation
- Aviation
- Off-road

For waste sector:

- Solis waste
- Biological waste
- Incineration plants
- Wastewater resources

The second part of the emission calculations is greenhouse gas emissions projection. This part built on the emission inventory of Bodrum and TIMES methodology is followed to complete projection. The model has been created between 2020-2050 period and assumptions made to project the emissions. Since Bodrum city is a tourist destination the main assumption was population growth. Population growth numbers are determined by TURKSTAT data [4][5].

2.2 Risk and Vulnerability Analysis

The second part of the study is analyzing the potential risks and vulnerabilities to the cities and their levels. To analyze the potential risks and vulnerabilities, indicator-based vulnerability analysis was used. This is the most used methodology among the European cities due to less technical capacity need [6].

1. **Exploration analysis for the city**: Engage with stakeholders, establish data sharing contacts, assess city needs, investigate climate change impacts, define the study area boundaries, and identify data sources.
2. **Identification of climate hazards**: Identify past climate threats and assess their current risk levels.
3. **Selection of vulnerability indicators**: Examine socio-economic, institutional, and biophysical characteristics to select vulnerability indicators.
4. **Data collection and analysis**: Identify and access data sources, prepare data for indicators, estimate missing data, and conduct consistency checks, normalization, weighting, and uncertainty analysis.
5. **Determining vulnerability score**: Calculate the vulnerability score for each identified risk.

3 Results

This section presents the results for emission projections and risk and vulnerability analysis.

3.1 Demand and Emission Projection

Before creating the emission projection model, reference energy system of Bodrum established according to emission inventory sectors and sub sectors. Figure 1 shows the reference energy system of Bodrum. From left to right Bodrum is considered an energy system. Energy carriers enter to the system from right and respectively, the energy carriers transform to final energy carriers the process/conversion technologies, the transformed energy carriers are consumed at the demand technologies and the demand technologies are satisfies the demands. Meanwhile, if the system has import/export, enters or exists from the system.

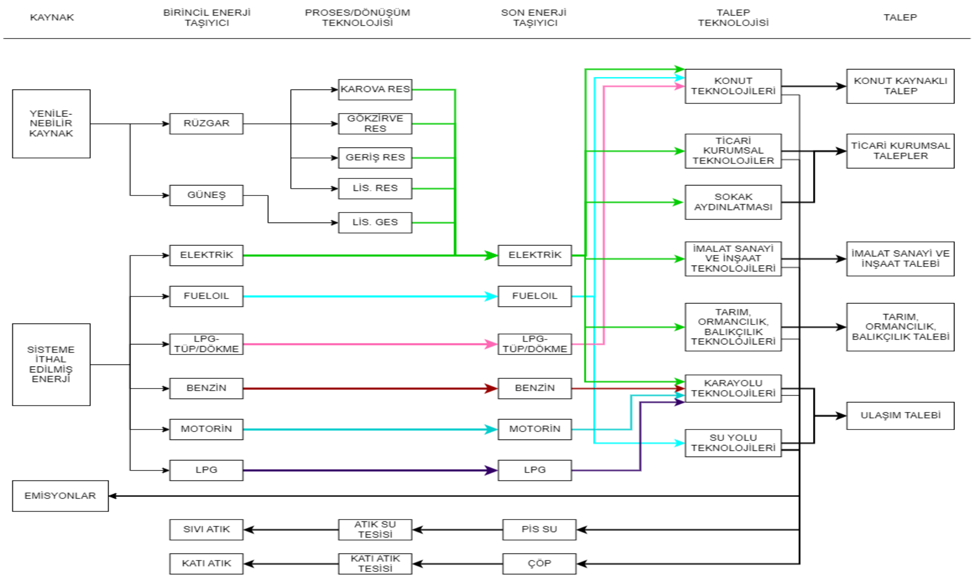

Fig. 1. Reference energy system of Bodrum according to GPC tool.

According to the assumptions described at section 2.1, table 1 and 2 present the demand projection from stationery and transportation sources.

Table 1. Demand projection from stationery of Bodrum.

	2020	2021	2025	2030	2035	2040	2045	2050
Residential	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Fuel oil	72.4	73.7	78.5	84.4	90.0	95.3	100.1	104.3
LPG	100.0	101.7	108.4	116.5	124.3	131.6	138.2	144.0
Electricity	1157.9	1177.4	1254.7	1348.9	1439.1	1523.3	1600.0	1667.6
Commercial. Institutional	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Electricity	2298	2337	2490	2677	2856	3023	3175	3309
Street Illumination	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Electricity	4.8	4.9	5.2	5.6	5.9	6.3	6.6	6.9
Manufacturing. Construction	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Electricity	20	20.3	21.7	23.3	24.9	26.3	27.6	28.8
Agriculture. Forestry and Fishing	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Electricity	16.3	16.6	17.7	19.0	20.3	21.5	22.6	23.5

Table 2. Demand projection from transportation technologies of Bodrum

	2020	2021	2025	2030	2035	2040	2045	2050
On-road	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Gasoline	420	427.1	455.1	489.3	522.0	552.5	580.4	604.9
Diesel	2406	2446	2607	2802	2990	3165	3324	3465
LPG	257	261.3	278.5	299	319.4	338.1	355.1	370
Electricity	1.5	1.5	1.6	1.7	1.8	1.9	2.0	2.1
Waterborne	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Fuel oil	9.0	9.2	9.8	10.5	11.2	11.8	12.4	13.0

Consumption data is converted to terajoules (TJ) to facilitate integration into the modeling platform. As shown in table 1, the consumption of fixed resources in 2020 was 1330.4 TJ. In the same year, commercial and institutional buildings consumed 2298.3 TJ, street lighting used 4.8 TJ, the manufacturing industry and construction used 20 TJ, and agriculture, forestry, and fisheries consumed 16.3 TJ. By the end of the projection period, total energy consumption from fixed sources is expected to increase by 44%, reaching 5285.1 TJ in 2050.

Table 2 presents the projected energy consumption for transportation. Road technologies are modeled using four fuel types: gasoline, diesel, LPG, and electricity. Since emission rates differ for each fuel, they were analyzed separately. Waterway technologies are modeled using only fuel oil. In 2020, road technologies consumed a total of 3084.5 TJ of energy, with the majority attributed to diesel-powered technologies. These include vehicles used in freight transportation, such as diesel-fueled cars, trucks, vans, and trailers. Following diesel, gasoline vehicles and LPG vehicles also contributed to the energy consumption. Electric vehicles accounted for a small portion of the energy used in Bodrum, with electric land vehicles consuming up to 1.5 TJ. Additionally, ports and watercraft in Bodrum consumed up to 9.0 TJ of fuel oil.

Table 3. Emission projection of Bodrum.

kTCO2e	2020	2025	2030	2035	2040	2045	2050
Wastewater	44.56	48.28	51.91	55.36	58.64	61.57	64.13
Manufacturing Technologies	2.80	3.03	3.26	3.48	3.68	3.86	4.03
On-road Technologies	223.90	242.61	260.83	278.26	294.55	309.38	322.44
Solid Waste	34.60	37.49	40.31	43.00	45.52	47.81	49.83
Residential Technologies	173.62	188.12	202.26	215.78	228.41	239.91	250.03
Street Illumination	0.67	0.73	0.78	0.82	0.88	0.92	0.96
Waterway Technologies	0.73	0.79	0.85	0.91	0.96	1.01	1.05
Agricultural, Farming and Fishery Technologies	2.28	2.47	2.66	2.84	3.01	3.16	3.29
Commercial Technologies	321.33	348.18	374.34	399.35	422.74	444.02	462.76

In 2020, the total emissions in Bodrum were 804.47 kTCO2e. Due to population growth and increases in other sectors, emissions are projected to reach 937.99 kTCO2e by 2030 and 1,058.38 kTCO2e by 2040. By 2050, the end of the model's time horizon, total emissions in the city are expected to reach 1,158.52 kTCO2e.

The commercial sector is the largest emitter, contributing 321.33 kTCO2e. This sector includes businesses and devices used in commercial activities. Since Bodrum lacks a natural gas infrastructure, energy consumption in these enterprises relies solely on electricity. Road transport is the second-largest source of emissions, producing 223.90 kTCO2e, primarily from diesel-powered vehicles. Residential technologies rank third, with emissions of 173.64 kTCO2e, mainly from electricity consumption.

3.2 Risk and Vulnerability Analysis

This section will outline common climate risks, examining their past, present, and future situations. At the end of each section, based on available sources, it will be determined whether to include that specific climate hazard in Bodrum's RVA study. The risks included will be assessed using the specified method. According to the RVA study handbook, the most common climate risks impacting cities, as noted by the CoM, are temperature, river floods, sea-level floods, general floods, water scarcity, forest fires, and diseases. Bodrum will be evaluated in relation to these specific climate risks (Climate Adapt, 2022).

Table 4 summarizes the climate risks discussed in the previous section, along with the risks and risk levels identified by the RVA study method, including related outcomes, frequency, intensity, and duration of impact.

Table 4. Effects of climate hazards to the city.

	Probability	Impact	Density	Frequency	Impact time
Temperature	Medium	Medium	Increasing	Increasing	Immediate
Sea level	No info	High	No info	Increasing	Long-term
Flood	Medium	High	Increasing	Increasing	Immediate
Water Scarcity	Medium	Medium	Increasing	Increasing	Mid-term
Forest Fires	Medium	High	Constant	Constant	Immediate
Vector-based diseases	No info	Low	No info	Increasing	Long-term

Table 5 shows the risk levels of the climate hazards as determined by the UKCIP method.

Table 5. Risk levels of climate hazards according to the UKCIP method.

	Probability	Impact	Risk
Temperature	Medium	Medium	Medium Risk, Medium Priority
Sea level	No info	High	High Risk, Medium Priority
Flood	Medium	High	Medium Risk, High Priority
Water Scarcity	Medium	Medium	Medium Risk, Medium Priority
Forest Fires	Medium	High	Medium Risk, High Priority
Vector-based diseases	No info	Low	Low Risk, Low Priority

Based on the evaluation of climate hazards and their likelihood and impact on the city, the risks are ranked as follows from highest to lowest: Flooding, Forest Fires, Water Scarcity, Temperature, Sea Level Rise, and Vector-Borne Diseases.

Table 6 identifies vulnerable groups and indicates whether they are directly or indirectly affected by climate risks. There is no direct link between climate risks and groups like women, girls, young people, local people, marginalized groups, and the unemployed. However, other vulnerable groups are directly affected by these risks. For example, elderly people are more vulnerable to extreme temperatures and are often advised to stay indoors on hot days. Similarly, disabled people may face challenges escaping natural disasters due to mobility issues.

Table 6. Vulnerable population groups and effecting risks.

	Temperature	Sea level	Flood	Water Scarcity	Forest Fires	Vector-based diseases	Possible Population
Women	IN	IN	IN	IN	IN	IN	90771
Girls	IN	IN	IN	IN	IN	IN	24690
Young People	IN	IN	IN	IN	IN	IN	34648
The Elderly	DR	IN	DR	DR	DR	DR	23427
Local People	IN	IN	IN	IN	IN	IN	18154
Marginalized groups	IN	IN	IN	IN	IN	IN	5446
People with disabilities	DR	DR	DR	DL	DR	IN	12526
Individuals with chronic diseases	IN	IN	IN	IN	IN	DR	5446
Low-income households	DR	IN	DR	DR	IN	DR	15431

The population ratios of these vulnerable groups were determined using TURKSTAT's demographic statistics. Since these statistics are not province-specific, the data for Turkey were considered. Based on this, approximately 72,000 people in Bodrum are directly affected by climate risks, representing about 39% of the total population. This figure represents the maximum rate without accounting for overlapping vulnerabilities. When intersections between different vulnerable groups are considered, the rate is estimated to be around 30%. This is consistent with rates found in other cities with similar climate risks and vulnerable populations.

Table 26 outlines the resilience factors that either strengthen or weaken Bodrum's ability to cope with climate risks. Since the SECAP handbook does not specify a method for this assessment, a comparison of similar studies and risks was conducted, focusing on how they align with the city's characteristics. Factors considered when evaluating Bodrum's resilience to climate risks include the city's topography, coastline, economic conditions of its residents, and its geographical location.

Table 7. Resistance levels of Bodrum to the climate risks

	Positive Factors	Negative Factors
Temperature	Bodrum is ahead of regular urbanization compared to other regions due to both tourism and the high national income of the living people. Therefore, it has a structure that will be protected from temperatures or prevent the formation of heat islands with landscaping and maintenance in the city streets. Therefore, it positively affects climate resistance to temperatures.	Bodrum is located in a risk zone that is higher in terms of increasing temperatures due to its geographical location. For this reason, the city will be more affected by the average temperature increases that may occur in the medium and long term compared to other regions. Due to this aspect, it adversely affects the resistance to temperature risk compared to the cities in the north.
Sea level	When the landforms seen in Bodrum are examined, the hills lie perpendicular to the shores. Therefore, since the altitude increases relatively rapidly when going inland from the coasts, sea level climate risk is more resistant to this climate hazard compared to regions with lower average altitude and flatter surface shapes.	When the sea level is examined, it is concluded that there is no negative factor for Bodrum.
Flood	The lack of intensive construction in Bodrum affects the city positively in the face of flood risk.	Dried stream beds have a negative effect on flooding due to the construction in these areas and the fact that the hills are perpendicular to the shores and the construction focuses on the pit lines of the hills.
Water Scarcity	It was concluded that there was no positive factor against water scarcity in Bodrum.	Due to the low number of clean water resources near Bodrum or the difficulty of existing water resources to provide sufficient water to the city, it is a negative factor against this risk in terms of water scarcity.
Forest Fires	Despite the risk of forest fire, there is no positive factor that will increase Bodrum's resilience.	Due to its location, the region is exposed to extreme temperature events in the summer months. Considering that this situation continues to increase every year and the forested lands in the region are evaluated, it adversely affects the resistance to

		this risk.
Vector-based diseases	There is no factor that will positively affect Bodrum's resistance to vector-borne diseases.	The western coast of Turkey remains in the transition zones of illegal and irregular immigration to Europe. Since Bodrum is one of these regions, it can be considered as a negative factor in terms of transmission and transmission of vector-borne diseases.

4 Conclusion

All the results obtained through these methods have been developed within a scientific framework that is comparable and measurable against studies from other cities. The findings indicate that rapid temperature changes, sea level rise from melting glaciers, rainfall-induced floods, reduced water resources, forest fires, and certain vector-borne diseases are new or ongoing risks for Bodrum. Even if some climate risks have not yet impacted the city, their potential effects in the short, medium, and long term have been evaluated.

Although Bodrum has its own unique demographic, economic, and geographical characteristics, it has been shown that it is resilient to some risks but quite vulnerable to others. Moving forward, Bodrum Municipality should conduct a SECAP study to outline actionable steps for achieving emission targets and enhancing the city's resilience to climate risks. It is crucial for Bodrum to always consider its future by regularly monitoring and assessing climate risks, adapting strategies as conditions change. The city's geographical, demographic, and economic conditions are rapidly evolving, potentially introducing new risks or altering existing ones.

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Modelling Energy Optimization at Local Scale Including Direct-Air-Capture

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Abstract. Following the devastation of the World Wars, nations quickly began implementing industrialization and economic expansion policies. An unprecedented level of environmental degradation has resulted from these measures. The environmental factor, which was underlined for the first time with the Stockholm Conference convened within the United Nations in 1972, was reinforced with structures such as the United Nations Framework Convention and the Paris Agreement in the following period. Since the 1973 oil shock, environmental consciousness has bolstered the need to find a fossil fuel substitute, and the idea of renewable energy has begun to emerge in practical applications. As their unit costs decrease globally, wind and solar power plants are becoming the most essential sources of energy needed to maintain a sustainable environment, accounting for a sizable portion of the global energy supply. This study models the sustainable energy output of Manisa, a significant province in the TR33 region of Turkey, for the 2031 timespan. Technically and environmentally sustainable energy production is considered within the given constraints and modeling the use of direct air capture in compliance with CO_2 upper limits is shown within the scope of the alternative scenario. By comparing BAU and alternative scenarios economically and environmentally, the outlook for sustainable Manisa energy production for 2031 is presented.

Keywords: Energy Optimization, Direct Air Capture, Sustainability, Energy Costs, Emissions, Regional Energy Modeling

1 Introduction

"Sustainable development" is a commonly used term that refers to two distinct branches. The word "sustainability" is meeting the requirements of the current generation without jeopardizing the capacity of future generations to fulfill their own requirements (United Nations Brundtland Comission 1987). “Development”, on the other hand, is defined in Oxford Dictionary as a *state of progress*, and in economic terms, it is examined along the axes of benefit and growth by the classical liberal movement. It is also investigated by the Marxist school in terms of hegemonic and imperialistic expansion. In Marx's seminal work "Das Kapital," two significant contributions are interestingly made to the concept of development. The first contribution is the assertion [1] that units at different stages of development, expressed as "modes of production," have varying income levels and their economies are composed of distinct input-output relationships from others. The second important contribution is the concept of "reproduction schemes," which paved the way for modern input-output analyses.

When the two words are examined together, it poses a question about what elements need to be sustained. According to Parris and Kates [2], nature, life support, and community emerge as the elements that need to be sustained, while humans, economy, and society appear as the elements to be developed.

From an ecological perspective, the current situation does not seem promising. In the last 50 years climate change impacts are most evident in the European continent. Each year, a new record is added to the consecutive records broken, and in the year 2023, another one was added, with the average temperature of 2023 exceeding data from the last hundred thousand years, while also surpassing the 1.5-degree mark of the industrialization era. If the greenhouse gas emissions are not reduced by half in the following 30 years and net-zero is not achieved, the global mean temperature will increase by at least 2.1°C by 2050 which will result in an exponential rise in the number of catastrophic events such as floods and droughts. On top of that, the melting of the glaciers caused by the rise in temperature and the flooding of the land brought about by the rise in sea level will result in millions of people becoming migrants.

As a result of this alarming picture, the average temperature, heatwave days, precipitation amounts, sea surface temperatures, and rising sea levels are all expected to worsen for all of Europe, regardless of south, west, or north distinctions [3]. Similar to Parris and Kates, the European Union has identified the main risk groups as 'health, infrastructure, food, ecosystems, and economy-finance' in its assessment aimed at developing policies against this “danger” (Appendix 1). Policies and measures related to these main areas have been documented, ranging from afforestation and activities to improve soil health to drought-resistant new seeds, and from the coordination of national healthcare systems to the securitization of transportation and energy lines.

The most crucial point in the fight against and adaptation to the climate crisis lies in energy production. This is imperative due to the necessity of ensuring both the security and decarbonization of the prevailing energy production, transmission, and distribution systems. This measure is aimed at averting disruptions to critical energy supplies and mitigating the potential occurrence of "blackout" situations in disasters. In this context, energy security and securitization, as an international energy term, will not be examined in detail in this paper. The decarbonization process, on the other hand, emerges as the biggest challenge for the energy sector in the fight against climate change.

The pioneering step taken in the fight against global warming is the Kyoto Protocol, prepared in 1997 under the United Nations Framework Convention on Climate Change [4]. Upon reaching the contemporary era, the Paris Climate Agreement, signed in 2016, assumes paramount significance in the endeavor to constrain the temperature escalation to 2 degrees and to investigate the prospects of 1.5 degrees. In 2019, the European Union officially announced its goal of carbon neutrality by 2050 with the European Green Deal. Plans to reduce carbon emissions have been put into action, utilizing both relevant reduction technologies and carbon pricing [5] such as Carbon Border Adjustment Mechanism (CBAM) and Emission Trading System (ETS) according to Green Deal.

Approved strategies to prevent the most severe outcomes of climate change involve envisioning a decrease in energy usage, the electrification of transportation, and the expansion of carbon capture and storage techniques. Although there are perspectives suggesting the advantages of moderating economic growth from a macroeconomic perspective, it is evident that this approach alone does not result in a net reduction of emissions.

In the contemporary era; renewable energy, electric transportation, and afforestation stand as the foremost choices within the domain of sustainability. Despite certain notable challenges in renewable energy production, its declining costs present opportunities, and owing to its emission-free nature, it is sought after as a method of energy production in emission trading era. For situations necessitating the production of required energy and the tolerance of emissions, extant policies propose natural or technological methods such as afforestation to achieve emission balance. Direct Air Capture (DAC) represents a swiftly proliferating technological approach for net emission reduction, currently under investigation and planning by corporations and governments, particularly those with substantial emission footprints such as major oil producers. In this study, the utilization of direct air capture methodology in the Manisa province has been scenario-planned, and an optimization of three distinct scenarios between the years 2021 and 2031 has been conducted to ascertain the potential optimization of electrical energy supply. Chapter 2 presents information on Direct Air Capture (DAC) technology, outlining the fundamental data and sources concerning the developed model and scenarios. Chapter 3 includes the TIMES model, followed by a general description of the objective function and constraints, and subsequently lists the fundamental assumptions of the model presented in the study. The scenario outputs have been discussed in Chapter 4, and the final section includes remarks and conclusions.

2 Application

2.1 Direct Air Capture

Carbon dioxide removal techniques are classified into four main categories, namely, afforestation and reforestation, increased weathering, ocean fertilization, and direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS) [6].

These methods can be assessed based on their scalability [7], ecosystem manipulation, and removal of other greenhouse gases (CH4 N20 etc.) [8].

To avoid the rebound effect which is defined as the necessity to remove twice as much as the required amount of GHG for any planned net reduction in CO_2 concentration, the geological reservoirs are found to be useful like oceans and land. The potential of oceans are found to be several thousand GtC while land reservoirs are measured to be 180+480 GtC [9].

Saline formations and depleted or abandoned oil and gas fields offer significant prospects for CO_2 storage. [10]. There has been sufficient experience gained through applications carried out by both public and private sectors on saline formations, which are large rock layers with porous spaces containing salty water. Similarly, extensive know-how has been accumulated over the years on oil and gas fields, with detailed geological underground information and storage potential, making them a net-zero tool for CO_2 reduction. Storing CO_2 captured from the air by DAC technology (Figure 1) and utilizing these two tools for emission reduction goals presents decision-makers with a noteworthy opportunity.

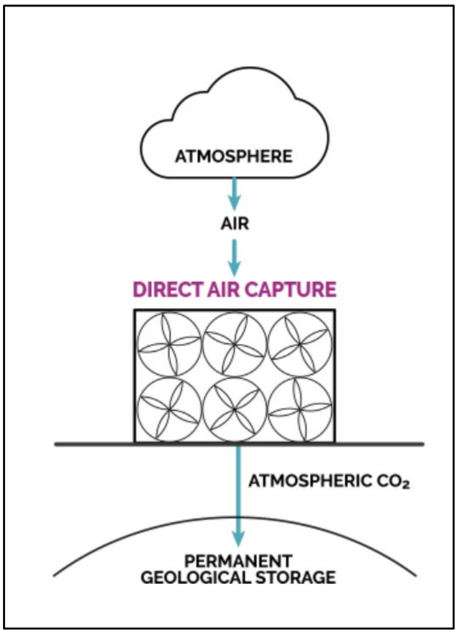

Fig. 1. Geologic storage and DAC facility [10]

In locations where the construction of DACs is feasible, the installation of DACs has been incentivized in the United States under the 45Q legislation since 2018 [11]. As a result of these endeavors, the interest of major corporations in DAC certifications has surged significantly. In this regard, the recent substantial carbon credit purchases by Amazon from 1 Point Five have transpired [12-13], and the petroleum behemoth Occidental has resolved to initiate an unprecedentedly substantial DAC facility group in Texas Kleberg County [14-15], aimed at capturing 30 million metric tons of CO_2 from the atmosphere annually. Offering a geological reservoir capacity to store 3 billion metric tons of CO_2, the collaborative effort between 1 Point Five, Carbon Engineering, and Occidental will come to fruition. Substantial acquisitions of "Carbon removal credits" by entities such as Airbus have already occurred at other facilities operated by 1 Point Five. These collective actions appear to be highly congruent with the objective of reducing DAC expenses from $600 levels to $100 levels [16]. Upon reaching these benchmarks, the complementary status of DAC facilities will be formally solidified.

The carbon credits provided in exchange for the CO_2 captured by DACs are the pivotal element possessing game-changing characteristics. Due to their role as a tool for net reduction rather than mere mitigation, DACs hold a crucial position. Anticipating an increase in the number and capture capabilities of DACs is not unwarranted, given their ability to neutralize emissions inevitably generated in certain locations.

The EOR technique has been actively used since 1972 [17] and is a well-established method of oil extraction, especially in the United States. A pipeline is used to inject CO_2 into targeted points in the reservoir based on calculations [18], aiming to target the remaining oil residues in rock pores (Figure 2).

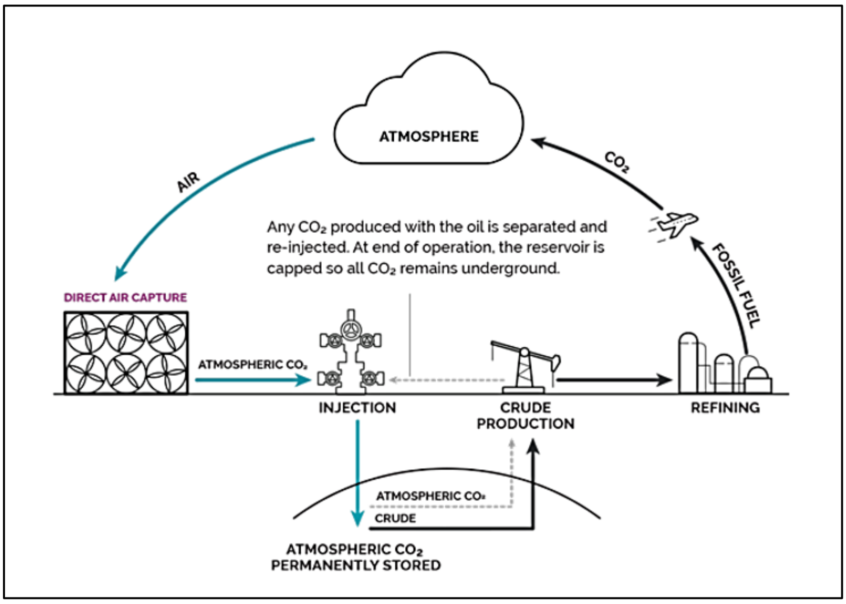

Fig. 2. EOR process [10]

While only about 30% of the oil in the reservoir can be extracted with primary and secondary recovery techniques, the proportion of oil extracted with the EOR technique can exceed 60%. The EOR method can be subdivided into Thermal EOR, CO_2 EOR, Chemical EOR, Other Gas Utilization EOR, and Other EOR Techniques [17]. Within this scope, CO_2 EOR is a widely used technique in the U.S., consuming a significant portion of the CO_2 demand on its own, and this CO_2 is not released back into the atmosphere when the technique is used appropriately.

2.2 Application

Western Anatolia Region, Manisa is a province in the area with a population of 1,475,716 [19] as of 2023. The primary goal of this investigation is to examine the most cost-effective energy composition for fulfilling the electricity demand of Manisa province from 2021 to 2031. To achieve this objective, three scenarios have been defined, with the first scenario imposing an upper limit of 5 million tons on CO_2 emissions, the second scenario at 3 million tons, and the third scenario at 1 million tons. The study endeavors to ascertain whether the model yields a feasible solution and, if so, which optimal technology mix will achieve it. In all three scenarios, Direct Air Capture (DAC) has been defined as a technology, and its viability under the given constraints has been assessed.

The energy generation technologies specific to the province of Manisa are presented in Table 1. As a prominent industrial city with diverse electricity generation technologies, Manisa has a net energy exporting profile.

Table 1. Installed Power Capacities of Manisa in the Reference Year

Technologies	Manisa (MW)
Solar Power Plants (PP)	19.14
Wind PP	628.95
Geothermal PP	166.42
Nat Gas CC PP	274.99
Coal PP	1034

In response to the energy crises of the 1970s, substantial initiatives were launched in Europe and the United States to create a necessary instrument for energy optimization. During this era, D. Finon from the French Institut Economique et Juridique de l'Energie (IEJE) introduced the EFOM 12A and 12B models [20]. Similarly, the U.S. Brookhaven National Laboratory (BNL) introduced the BESOM, DESOM, and TESOM models in rapid succession. The International Energy Agency (National Center for Analysis of Energy Systems) and Kernforschungsanlage (KFA) merged the capabilities of the DESOM and EFOM systems, resulting in the emergence of MARKAL (MARKet ALlocation Model) as a resilient optimization platform [21]. MARKAL effectively provided a multi-period and single-region optimization model, addressing a key deficiency of the early 1970s. The TIMES modeling family is a natural extension of the MARKAL framework. Leveraging the strengths of both MARKAL and EFOM, it was developed as a sophisticated modeling tool [22]. TIMES, integrating detailed energy flows based on EFOM's technology approach and adopting the Reference Energy System (RES) concept from MARKAL, reinforced its hybrid structure with innovations not found in either platform. The rigid and narrow definitions within MARKAL were relaxed and broadened to encompass all technologies.

3 TIMES Model of Manisa

3.1 TIMES Model

The TIMES model family stands out as one of the most current frameworks within energy modeling families. In this study, the Manisa energy modeling has been carried out utilizing the composite of the ANSWER interface and the GAMS platform. The system operates by transforming the data acquired from ANSWER interface into mathematical equation sets (by GAMS) and subsequently employing the CPLEX solver to seek an optimal solution if available. When parameters within the ANSWER interface are transformed into equation sets, it is not a requirement for the analyst to possess detailed knowledge regarding the nature of these equation sets. As the results are supplied to the user through the ANSWER interface based on the provided parameters, there is no necessity for the user to expend effort in tabulating the performance of criteria over the years. Although ANSWER-TIMES is acknowledged as proprietary software with its (mentioned) advantages, contemporary open-source modeling techniques are also in use. Particularly, OSEMOSYS and TEMOA are open-source, extensively utilized, and adaptable models. This study refrains from delving into the comparison of the strengths and weaknesses of modeling tools. It is anticipated that the analyst, based on their capabilities and requirements, should decide on one of these tools to strive for achieving outcomes.

In this single regional model, the electricity generation system of Manisa is fine-tuned by considering essential information about energy supply, usage, and demand, incorporating technical, environmental, and economic factors. TIMES conducts optimization of the energy system by aiming to minimize costs within the prescribed constraints, as outlined by the objective function in Appendix 2. Assumptions of the model are as follows:

- Manisa-TIMES model was prepared using annual time slice. It is planned to increase the number of time slices in future studies.
- DAC was modeled using 1 Point Five's technical and financial data [23].
- In all models, DAC has been designated as a technological component, with the primary differentiation among scenarios being the restricted acceptable CO_2 upper limits set at 5, 3, and 1 million tons.
- The max potential data of wind, photovoltaic, biomass and geothermal technologies are introduced in the model as upper power plant capacity constraints.
- New investments are modeled as discrete additions to the capacities and planned annually.
- In case of capacity increase, the model selects the most economical capacity increase option and invests in at least one technology, considering the capacity upper limits in each period.
- The system is either operated at maximum or insufficient capacity when the active technology supply can meet the demand.
- Datasets related to maintenance, input, and investment costs are taken from IEA data sheets.

- Even though the advances in energy markets result in lower-cost energy generators every coming year, the model assumes the technology prices steady over the years from the standpoint of manageability.
- Technical, economic and environmental parameters are accepted to be steady during the time period, ignoring the learning factor.

4 Analysis of Scenario Results

Feasible outcomes may not invariably materialize during the execution of optimization models. This is predominantly attributed to stringent constraints and inadequate resources to fully satisfy the requirements. The subsequent results are derived from the implementation of three distinct scenarios in our study.

Significant discrepancies in outputs were observed across all three models, despite identical constraints being imposed. The sole differing parameter among them is the upper emission level. Upon analysis of the outcomes from Scenario 1:

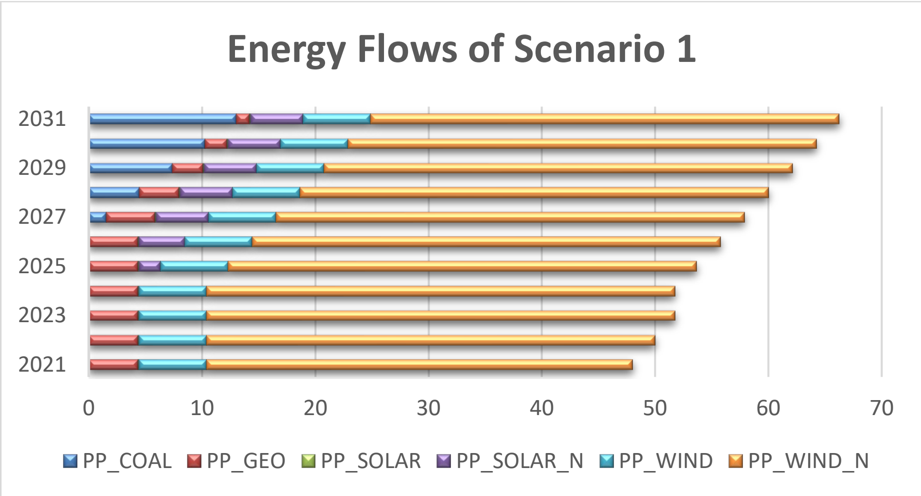

Fig. 3. Energy flows of technologies in Scenario 1

- The upper limits of 5 Mt CO_2 have been complied with.
- Photovoltaic and wind power plants have been operated at full capacity.
- The existing geothermal power plant capacity has been fully operationalized until the year 2028. Subsequently, production has been curtailed to adhere to emission constraints at the most cost-effective manner.
- On account of its cost advantage, the biomass energy plant commenced operations from the year 2023 and ran at full capacity from 2025 until 2031. Notably, in the face of the cost-emission dilemma, the deliberate decision to maintain its full operational capacity until around 2031 stands out.
- The focus of new investments has been on wind, photovoltaic and biomass technologies. After 2027, when it will be impossible to invest in new photovoltaic,

wind and biomass energy projects, the increase in demand is satisfied by running existing coal-fired power plants. Figure 3 depicts the energy generation flows for each energy technology.

- Until 2027, due to the significant potential for increasing solar and wind capacities, even coal-fired power plants have not been operated. Subsequently, with the permissible emission limit, coal-fired power plants have been activated, and the consideration of operating existing natural gas-fired combined cycle power plants or making new investments in these assets has not been feasible.

Scenario 2 outcomes are as follows:

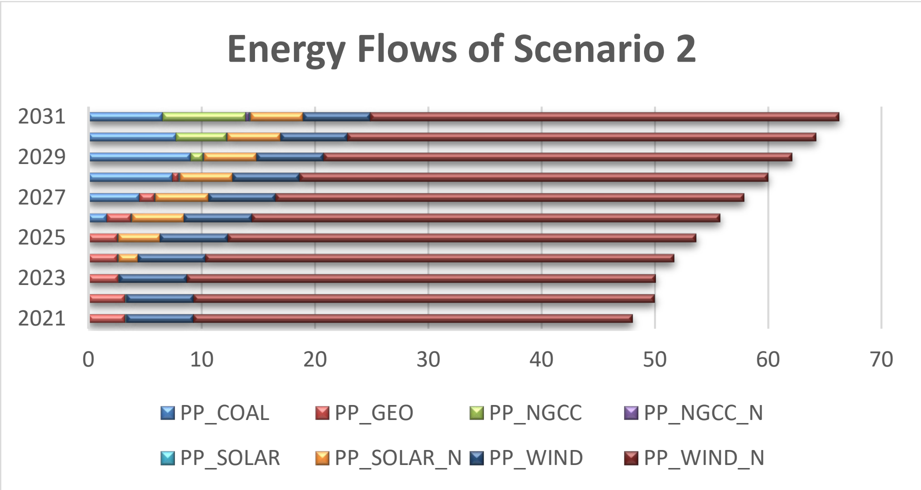

Fig. 4. Energy flows of technologies in Scenario 2

- The upper limits of 3 Mt CO_2 have been complied with.
- Photovoltaic and wind power plants have been operated at full capacity.
- Despite the full utilization of its potential and capacity in 2021 and 2022, the production of electricity by geothermal technology was discontinued after 2028 due to the relatively excessive CO2 emissions. The prospect of the technology, which has incurred costs, remaining idle from 2029 onwards, poses a significant concern
- On account of its cost advantage, the biomass energy plant commenced operations from the year 2023 and ran at full capacity from 2024 until 2031.
- The focus of new investments has been on wind, photovoltaic and biomass technologies. After 2026, when it will be impossible to invest in new photovoltaic, wind and biomass energy projects, the increase in demand is satisfied by running existing coal-fired power plants. Figure 4 depicts the energy generation flows for each energy technology.
- Conversely, the strategy to address the escalating energy demand with the current coal-fired plant has encountered a limitation of 3000 Mt CO2 emissions, thus compelling the need for new investments in natural gas-fired combined cycle power plants rather than operating the coal-fired plant at full capacity from 2029 onwards.

To meet the increasing energy requirements post-2029, the production of the comparatively higher-emission coal-fired power plant has been necessitated to be curtailed.

Scenario 3 outcomes are as follows:

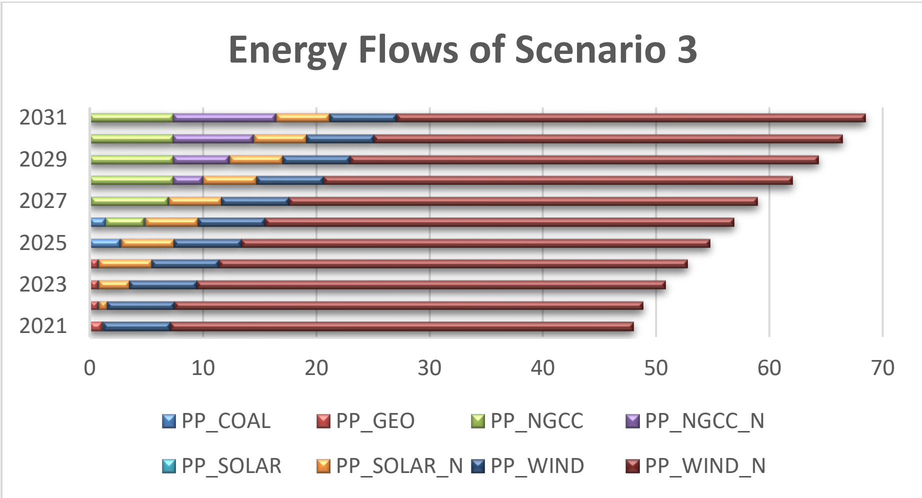

Fig. 5. Energy flows of technologies in Scenario 3

- Upper limits of 1 Mt CO_2 have been complied with.
- Photovoltaic and wind power plants have been operated at full capacity.
- The geothermal power plant operated at a partial capacity between 2021 and 2024 but was left idle from 2025 onwards. This has brought forth the issue of bearing costs due to the non-utilization of an existing plant, and also spared decision-makers from the burden of the emissions this plant would have otherwise heavily generated.
- The first biomass power plant was commissioned starting from 2022, however, due to emission concerns, the optimal plan has rendered this technology idle from 2029 onwards. The strategy first phased out the geothermal power plant, followed by the gradual decommissioning of coal and biomass power plants over the years.
- Until 2026, due to the significant potential for increasing solar and wind capacities, even coal-fired power plants have not been operated. Coal-fired power plants had achieved an increasing electricity production from 2026 to 2029; however, in 2029, due to the inability of the technology portfolio to respond to the growing energy demand while adhering to emission constraints, investments were shifted from coal-fired plants to natural gas-fired combined cycle power plants. Henceforth, every new energy demand has been met with this type of technology. Figure 5 depicts the energy generation flows for each energy technology.

Sankey diagram of energy flow of scenario 3 in year 2031 is presented in Figure 6 below:

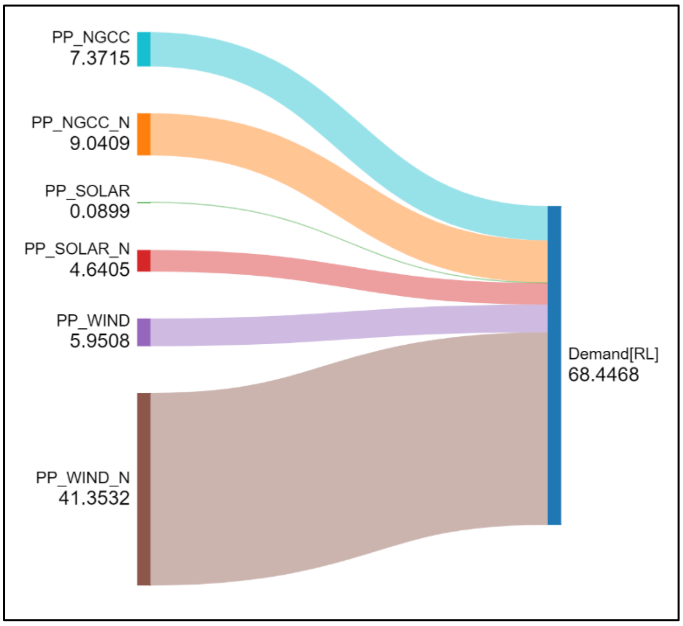

Fig. 6. Sankey diagram of total energy flow in year 2031

An example of an environmental viewpoint is provided for the year 2031 in Scenario 3, as depicted in Figure 7 below.

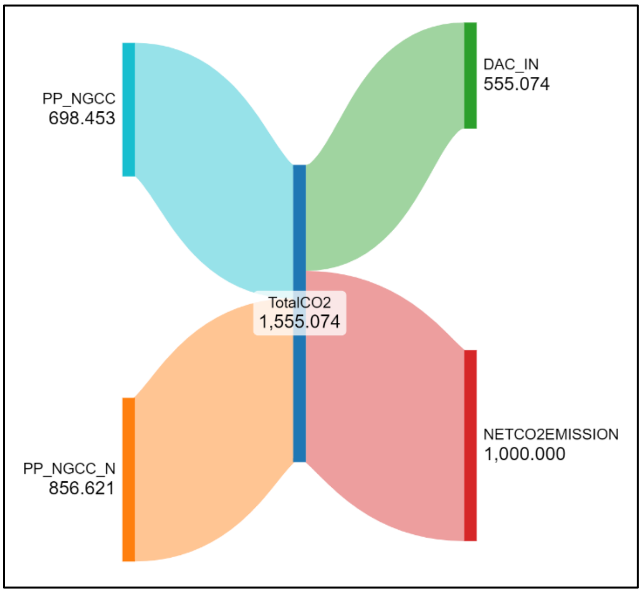

Fig. 7. CO_2 Emission values of the optimum plan

5 Conclusion

Mathematical programming approaches have long been used to find the optimum portfolio that produces energy under the most affordable conditions, whether the goal is short-term or long-term. Mathematical programming techniques are not only economical and technical, but environmental conditions can also be expressed as constraints. In this application, economic-technical and environmental parameters were transformed into a linear programming model between 2021-31 and three distinct scenarios were explored using the ANSWER-TIMES program. By accounting for the pertinent emission limits within the 10-year time horizon, these scenarios—which were thoroughly reviewed in the outputs section—were able to identify the most economical options, and feasible solutions were discovered. Upon examination of the scenario's outcomes, it became evident that different energy production strategies were used. The third scenario stands out as the most challenging in terms of emission constraints, with the commissioning of new natural gas-fired combined cycle power plants occurring before the first two scenarios in terms of timing. As a natural consequence, power plants such as coal, biogas, and geothermal, which were already expected to be in operation, began to be decommissioned. Initially, existing capacities of natural gas-fired combined cycle power plants were utilized, followed by the urgent commissioning of additional capacities. An important point here is that despite the pressure of emission constraints, natural gas-fired combined cycle power plants commence operation by phasing out other types of power plants, and the amount of phased-out technology increases as the energy demand grows. Even with the commissioning of natural gas-fired combined cycle power plants, it may reach a point where compliance with emission constraints becomes unattainable. In this case, the deployment of DACs becomes inevitable. This led to the need for DAC construction, and because of the CO_2 that DAC attracted, the emission condition could only be met. These findings demonstrate that under Scenarios 1 and 2, the DAC facility was not permitted to operate at the optimal solution. The DAC facility is required if the emission requirements cannot be satisfied with the current technologies, even though it is an expensive plant that cannot produce the best outcomes with the current cost figures.

Different alternatives emerge when existing energy production technologies cannot meet emission restrictions, both in Manisa and on a larger scale. Solutions such as supporting rooftop solar energy systems on a country basis, solving the legislative and infrastructure problems of putting DACs into operation, supporting electric vehicles, working on other methods of carbon capture (forestation, etc.) are the ones that can be evaluated in the first place. In this study, the impact of adding DAC as a technology till 2031 on the optimal plan was assessed, with a focus on the province of Manisa. Certainly, it is feasible to ensure the incorporation of supplementary carbon capture techniques within the model and into the same equation. However, not every technique has been incorporated into this study to emphasize the potential impact of DAC alone. It has been observed that DAC is efficient and can reduce emissions in this study. The issue at hand is whether DAC will be employed as a final option to counteract potential actions that increase emissions or as a method to be utilized when production technologies are pushed to their maximum capabilities yet still cannot adhere to emission restrictions, as seen in the case of Manisa. The first set of behaviors runs counter to the logic of carbon reduction, and solutions like DAC must be a remedy for the second scenario. Considering that the next fifty years will witness a hard battle against emissions through climate-neutral policies, it is evident that decision-makers must have access to all available options, without rejecting any carbon reduction method.

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Appendix – 1

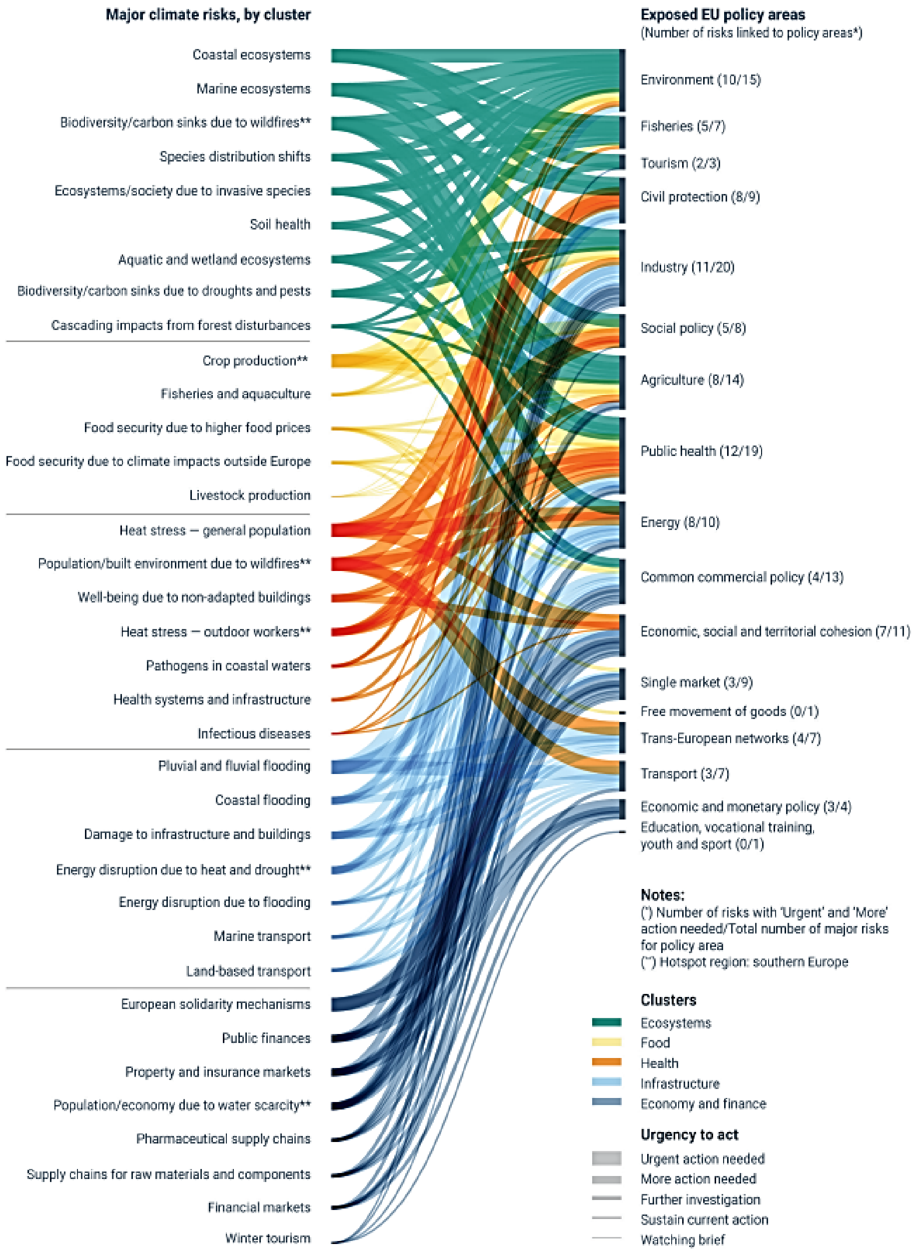

Fig. 8. Major climate risks

Appendix – 2

$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1 + d_{r,y})^{REFYR-y} * ANNCOST(r, y)$$

$$VAR\_OBJ(z) = \sum_{r=1}^{R} REG\_OBJ(z, r)$$

$$REG\_OBJ(z) = \sum_{y \in (-\infty,+\infty)}^{R} DISC(y, z) * \left\{ \begin{matrix} INVCOST(y) + INVTAXSUB(y) + \\ INVDECOM(y) + FIXCOST(y) + \\ FIXTAXSUB(y) + SURVCOST(y) + \\ VARCOST(y) + VARTAXSUB(y) + \\ ELASTCOST(y) - LATEREVENUES(y) \end{matrix} \right\} - SALVAGECOST(z)$$

where:

NPV	net present value of the total cost for all regions (the TIMES objective function);
ANNCOST(r,y)	is the total annual cost in region r and year y;
d(r,y)	is the general discount rate;
REFYR	is the reference year for discounting;
YEARS	is the set of years for which there are costs, including all years in the horizon, plus past years (before the initial period) if costs have been defined for past investments, plus several years after EOH where some investment and dismantling costs are still being incurred, as well as the Salvage Value; and
R	is the set of regions in the area of study.
INVCOST(y)	is the total investment cost in year y;
INVTAXSUB(y)	is the total taxes and subsidies on investments in year y;
INVDECOM(y)	is the total decommissioning cost in year y;
FIXCOST(y)	is the total fixed annual cost in year y;
FIXTAXSUB(y)	is the total annual fixed taxes/subsidies on capacity in year y;
SURVCOST(y)	is the total fixed annual cost in DLAG state in year y;
VARCOST(y)	is the total variable annual cost in year y;
VARTAXSUB(y)	is the total annual variable taxes/subsidies on capacity in year y;
ELASTCOST(y)	is the total cost of demand reductions in year y;
LATEREVENUES(y)	is the lump sum discounted to the user-selected base year.
SALVAGECOST(z)	salvage cost;

Fig. 9. ANSWER-TIMES model representation

The Role of Energy System Analysis and Modeling for Ships in Energy Transition Era

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Abstract. The fight against global climate change continues at a great pace in the maritime sector, as in all sectors around the world. It adopted its first strategy for Greenhouse Gas (GHG) Emission Reduction in the maritime sector, titled "The Initial International Maritime Organization (IMO) Strategy on GHG emissions reduction from ships", in the Maritime Environment Protection Committee (MEPC-72) in 2018. Today, reshaping our maritime transport and reducing GHG emissions Efforts to further tighten the rates determined to reduce the risk continue under the leadership of IMO. In this study, we will explain the importance of using the Reference Energy System (RES) concept and Decision Support Tools, which are widely used in the energy sector around the world, to see the applicability of the measures to be taken in the maritime sector in the coming years. In this context, RES of "An Oil Product Tanker Ship" is developed.

Keywords: Energy; System Analysis; System Modelling; TIMES; Energy Transition

1 Introduction

Combating climate change on a global scale has gained more and more importance since the middle of the 20th century. Today, in the fight against climate change, countries, unions, international organizations, universities, and non-governmental organizations work intensively to achieve the goal of zero emissions via sustainable and clean energy.

As in all sectors around the world, efforts are being made to achieve decarbonization as soon as possible for a greener future in the maritime sector as well [1]. However, the challenges faced in these efforts are slightly larger than in other sectors [2].

While these studies are being carried out, the priorities are constantly updated based on the demands, targets, and challenges which are encountered by the decision makers; especially the International Maritime Organization (IMO), shipowners, sectors such as technology manufacturers, and fuel producers about the maritime sector [3].

IMO continues its efforts to renew its first strategy, titled "The Initial IMO Strategy on Reduction of greenhouse gas (GHG) Emissions from Ships", which was adopted at the Marine Environment Protection Committee (MEPC) 72 meeting in 2018 [4] and which we still planning according to its targets, within today's developments. Currently, in the process of reviewing its climate strategy, which aims to only halve emissions from ships by 2050, IMO has agreed to increase this target at its summit in July 2023 [5]. The updated strategy within this framework will reshape maritime transport in this process and will further tighten the GHG emission reduction target rates, making it more difficult for shipowners to undertake their obligations [6].

The latest IPCC Synthesis Report warns that limiting climate change to the 1.5°C set by the Paris Agreement [7] will require deep and urgent emissions reductions across all sectors within this decade [8]. For this reason, 45 countries, led by the EU, USA, UK, Canada, Japan, and Turkey, have submitted an opinion to the United Nations on reducing emissions from global maritime transport before 2030. The proposal by these countries calls for a life-cycle reduction of emissions from shipping by at least 37 percent by 2030 and 96 percent by 2040, compared to the 2008 base year [9].

In this context, it is obviously of great importance to use the Reference Energy System (RES) concept and decision support tools to provide effective decision support to decision makers under the titles of energy, economy, and environment (3E) to provide practical solutions and recommendations [10].

2 Methodology

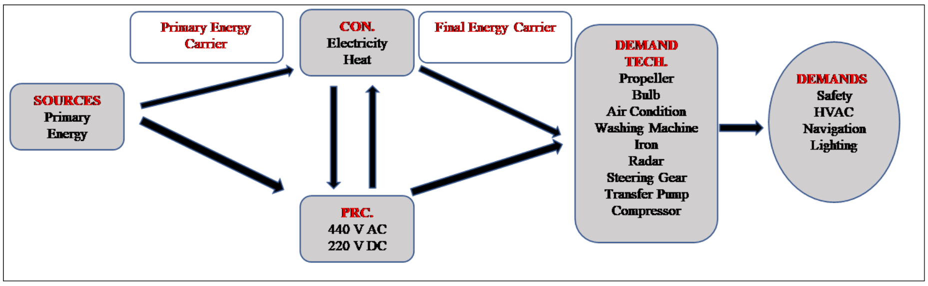

Fig. 1. Simplified RES notation [11]

RES is simply a flowchart showing the balance of the analyzed energy system [10]. This flowchart visually presents the demands met by showing the interrelationship of all the components of an energy system. The simplified RES representation is presented in Figure 1. As can be seen from the figure, a RES consists of 5 main components and two families of energy carriers [12].

It is simply taken from an energy source and transported to conversion (CON) and process (PRC) technologies with a primary energy carrier and ultimately converted to final energy [13]. The final energy carrier is the energy needed by demand technologies used to meet demands [14]. In this way, the demands for an energy system and the energy needs of end-use technologies that meet these demands are met. RES is prepared in line with the data of that period as a result of determining a period in which the most accurate data will be obtained (eg 1990 or 2020) [15].

The RES concept is generally used in decision support tools. There are several tools you may find useful for sustainable energy analysis that use only one or a combination of optimization, system dynamics, accounting, simulation, and database as a methodology [16].

3 Application of the RES Concept to a Ship

The second row of the RES shows the primary energy carriers. In this study, it seems that the energy sources that we import from ports are also our primary energy carriers. Before being used by demand technologies on board, our primary energy carriers go through certain processes that appear on the third and fourth rows of the RES, becoming the final energy carriers appearing on the fifth row of the RES. The fuel oil separator, diesel oil separator, and rectifier, visible on the third row of RES, are the three process technologies on the ship. As can be seen in the fourth line of the RES, there are 5 conversion technologies, these are one main engine diesel, three engine diesel generators, and one emergency diesel generator. While the diesel main engine produces the necessary heat energy needed for the ship's maneuverability, the other four conversion technologies convert from fossil fuel to electrical energy that the ship's systems and devices will need.

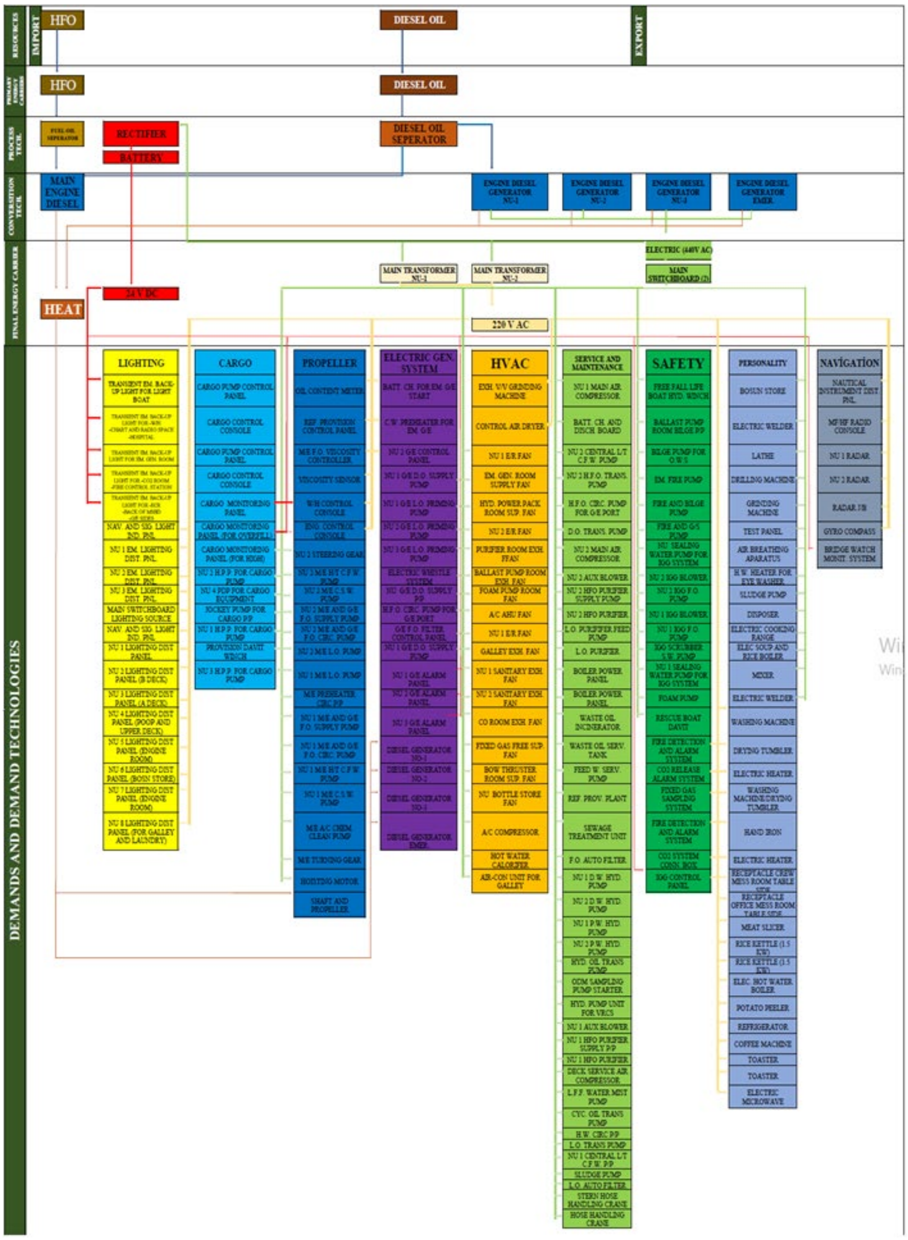

Fig. 2. Reference Energy System (RES) of M/T Elif Tuba

The sixth and last row of RES includes the demands and the demand technologies needed to meet these demands. In the analyzes made, it has been determined that there are 194 demand technologies in M/T Elif Tuba. We have grouped the demands met by these demand technologies in a way to meet 9 different demands, combining them on a common denominator. As shown in Figure 2, demands are lighting, cargo, propeller, electric generating system, heating ventilating and air conditioning (HVAC), service and maintenance, safety, personality, and finally navigation. Service and maintenance have the most demand technology with 40 demand technologies. It is followed by personality with 32 demand technologies, while propeller ranks 3rd with 22 demand technologies. In fourth place are safety and HVAC, both containing 21 demand technologies. In fifth place are electricity generating systems and lighting, both of which contain 19 demand technologies. The two demands with the least demand technology are cargo with 13 and navigation with 7, respectively.

Fig. 3. M/T Elif Tuba

4 Results

In this study, the RES of an oil/chemical tanker ship, which has a complex energy structure, was created to analyze it by applying it to a decision support tool environment. In this RES, the energy flow from the energy entering the ship to 194 demand technologies that meet 9 demands is shown on the diagram.

5 Conclusion

For the use of the RES concept and decision support tools on ships, we first started in 2018 by creating a RES for a chemical tanker ship [10].

While an energy decision support tool was developed for cities, countries, regions, and many sectors, we used the Low Emission Analysis Platform (LEAP) decision support model for a ship in our first studies, since there is no special decision support tool developed for the maritime industry. In our first study with the LEAP modeling platform; in addition to the Business As Usual (BAU) scenario, analyses were made in line with the International Maritime Organization (IMO) and European Union (EU) targets [3]. The Sankey diagram formed in the analysis made as a result of applying a ship's RES to the LEAP program is seen in Figure 4 and is a different representation of RES. Gradual GHG emission reduction analyses were also carried out, considering the difficulties faced by the maritime industry, shipowners, and fuel and technology manufacturers while carrying out the studies. In one of them, the use of electrical energy by storing it near the port and while navigating in narrow waters was analyzed [2], while in another, the use of hydrogen fuel by auxiliary machines that produce the ship's electricity was analyzed [3]. In addition, analyses of an electric-powered ferry [17], a diesel-powered ferry [18], and a warship [19] were performed using the RES concept and via the LEAP modeling tool.

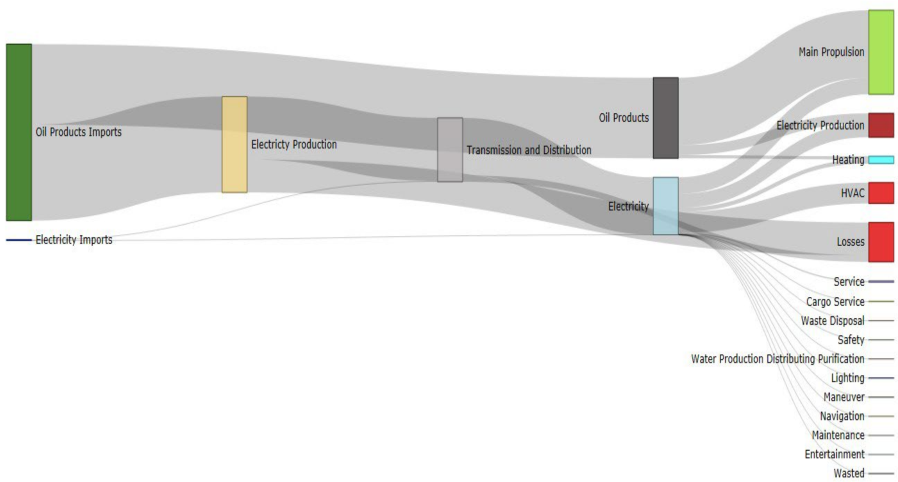

Fig. 4. Sankey diagram of a ship via LEAP (Sarı et al 2021)

Future Work

Currently, the TIMES decision support tool is designated for future studies to show that our analyses can be applied in various decision support models and enable multi-regional modeling and analysis of more complex ships in future studies. To explain the use and importance of the RES concept and decision support tools; a RES that can be applied in a TIMES model as the basis of the analysis for an oil product tanker ship has been developed in this study. In future studies, multi-regional ship energy system modeling and analysis for the oil product tanker ship fleet is planned to be done with the reference energy system concept and 3E approach.

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Integrating Scope 3 Emissions into Smart City Reference Architectures: A Pathway to Sustainable Urban Ecosystems

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Abstract. As urbanization and technological advances continue to reshape cities, the environmental impacts of urban development have become increasingly significant. This paper focuses on integrating Scope 3 emissions—those indirect emissions associated with a company's value chain but outside its direct control—into smart city reference architectures. While Scope 1 and Scope 2 emissions pertain to direct and energy-related emissions, respectively, Scope 3 emissions cover a broader range of indirect activities, including waste management, product lifecycle, and employee travel. The inclusion of Scope 3 emissions in urban planning is critical to fostering sustainable urban ecosystems.

This study explores how smart cities can monitor and manage these emissions using Turkey's RUMI Smart City Reference Model as a case study. We propose a framework to integrate Scope 3 emissions into smart city planning and governance, aligning urban growth with global sustainability goals. The findings highlight the importance of leveraging smart technologies and environmental regulations in addressing the challenges of climate change and urbanization. A comparative analysis of global smart city designs is conducted to identify best practices, offering insights into how cities can balance technological innovation with environmental stewardship.

Keywords: Smart Cities, Scope 3 Emissions, Sustainable Urban Development, Environmental Impact, Urban Planning, Smart City Reference Architecture, RUMI Model.

1 Introduction

As cities continue to expand and urbanization accelerates, the need to manage environmental impacts becomes increasingly critical. Cities, often viewed as hubs of economic and technological advancement, are also significant contributors to global carbon emissions [1, 2]. While substantial progress has been made in reducing direct emissions through various sustainability initiatives, the need to address indirect emissions has gained prominence in recent years [3]. These indirect emissions, referred to as Scope 3 emissions, encompass a broader range of activities that contribute to a company's or city's overall carbon footprint [4]. Unlike Scope 1 and Scope 2 emissions, which cover direct emissions from operations and indirect emissions from energy consumption, Scope 3 emissions include a wider array of sources such as employee commuting, product usage, waste management, and supply chain activities [6, 7].

Understanding and managing Scope 3 emissions is crucial for urban environments striving to achieve sustainability [5]. These emissions represent a significant portion of a city's environmental impact, often exceeding those generated by direct activities [8, 9]. As a result, incorporating Scope 3 emissions into urban planning, particularly within the framework of smart cities, is essential for mitigating the environmental consequences of urban growth [10]. Smart cities, with their emphasis on technological innovation and data-driven decision-making, offer a unique opportunity to monitor, manage, and ultimately reduce these emissions [11]. By leveraging advanced technologies such as IoT (Internet of Things), big data analytics, and AI, smart cities can provide real-time data on various environmental factors, enabling more precise and effective strategies for reducing emissions [19, 20].

The importance of Scope 3 emissions in smart city planning cannot be overstated [12]. For instance, the transportation habits of a city's population, the energy consumption of its buildings, and the lifecycle of products consumed within the city all contribute to its Scope 3 emissions [21, 22]. Thus, a comprehensive approach to urban planning must address these interdependencies to ensure that cities develop in an environmentally responsible manner [23, 24].

Turkey's smart city model, RUMI (Referans Akıllı Şehir Mimarisi), provides a valuable framework for exploring the integration of Scope 3 emissions into urban planning. RUMI focuses on creating a modular, scalable, and adaptable urban environment that can evolve alongside technological advancements and societal needs. The model is based on a layered architecture that incorporates various smart city elements, such as energy efficiency, transportation management, and environmental monitoring. By embedding sustainability principles within each of these layers, RUMI offers a pathway for cities to address the environmental impacts of urbanization holistically. In particular, its focus on integrating technology with governance and societal needs makes it an ideal case study for examining how Scope 3 emissions can be managed within a smart city context.

Through the lens of the RUMI model, this paper seeks to demonstrate how cities worldwide can integrate Scope 3 emissions into their planning and governance structures. The adoption of smart city technologies provides an avenue for reducing these emissions by enabling cities to track and manage indirect environmental impacts more effectively. Advanced data analytics can help cities identify the most significant sources of Scope 3 emissions, such as transportation and waste management, and develop targeted strategies to reduce them [25]. Moreover, smart city technologies allow for real-time monitoring of emissions, facilitating the continuous adjustment of policies and practices to align with environmental goals [26].

In addition to RUMI, this paper compares other global smart city designs to highlight best practices for incorporating Scope 3 emissions into urban planning [27]. Cities such as Singapore, Barcelona, and Copenhagen have already begun implementing smart technologies to manage their environmental impacts, offering valuable insights into how technology can be used to foster sustainability [28]. By analyzing these cases alongside RUMI, the paper aims to identify the key factors that contribute to the successful integration of Scope 3 emissions into smart city frameworks. These factors include the alignment of technological innovation with environmental regulations, the importance of cross-sector collaboration, and the need for a long-term commitment to sustainability.

The significance of managing Scope 3 emissions within smart cities extends beyond environmental considerations [29]. It also has economic and social implications, as cities that prioritize sustainability are likely to attract more investment and improve the quality of life for their residents [30]. Moreover, addressing Scope 3 emissions can help cities achieve broader global sustainability goals, such as those outlined in the Paris Agreement and the United Nations Sustainable Development Goals (SDGs) By incorporating these emissions into urban planning, smart cities can play a pivotal role in combating climate change and promoting sustainable development.

In conclusion, the inclusion of Scope 3 emissions in smart city reference architectures, such as RUMI, is essential for achieving sustainable urban ecosystems. As cities continue to grow and evolve, the need to manage indirect emissions will become increasingly important. This paper aims to provide a roadmap for how cities can incorporate Scope 3 emissions into their planning processes, leveraging smart technologies to monitor and reduce their environmental impact. By comparing the RUMI model with other global smart city designs, the paper offers a comprehensive analysis of how cities can balance technological innovation with environmental stewardship, ultimately contributing to a more sustainable future for urban environments worldwide.

2 Methods

2.1 Scope 3 Emissions Monitoring and Management Framework

To effectively integrate Scope 3 emissions into smart city reference architectures, it is crucial to establish a comprehensive framework for monitoring and management. Scope 3 emissions, by nature, are indirect and involve a wide array of activities that extend beyond the immediate control of a city’s governing bodies. These activities include, but are not limited to, employee commuting, supply chain logistics, product lifecycle emissions, and waste management. Given the complexity of tracking these emissions, the proposed framework incorporates several stages:

Data Collection. Accurate data collection is the foundation of any emissions management strategy. For Scope 3 emissions, this involves gathering data from various external stakeholders, such as transportation services, businesses, and utility providers. In the context of smart cities, data can be collected through IoT sensors, smart grids, transportation systems, and public utilities that provide real-time information on resource usage, waste generation, and energy consumption.

Data Integration. Once data is collected, it needs to be integrated into a unified system where emissions can be analyzed and categorized. This requires a combination of cloud-based platforms and big data analytics to process vast amounts of information in real time. The integration of data from different sectors allows for the comprehensive monitoring of Scope 3 emissions, helping cities to identify the most significant sources of indirect emissions and take appropriate action.

Emissions Calculation. To quantify Scope 3 emissions, various emissions factors and algorithms must be applied to the collected data. These calculations are based on internationally recognized frameworks, such as the Greenhouse Gas (GHG) Protocol, which provides detailed guidelines for calculating Scope 1, 2, and 3 emissions. In smart cities, automated systems can be used to continuously calculate emissions based on real-time data inputs, ensuring that emission levels are up-to-date and reflective of actual urban activities.

Emissions Reporting and Visualization. Smart city technologies enable dynamic reporting and visualization of emissions data, allowing city planners and policymakers to view emissions trends over time. Through dashboards and visualization tools, cities can track their progress towards reducing emissions, identify high-emission areas, and adjust policies accordingly.

Management and Mitigation Strategies. Based on the findings from emissions tracking, smart city planners can implement targeted management strategies. These strategies may include incentivizing low-emission transportation options, optimizing waste management processes, and improving energy efficiency in public and private sectors. The ability to monitor emissions in real time allows for more flexible and adaptive management, enabling cities to adjust their approaches as needed to meet sustainability goals.

2.2 Integration of Scope 3 Emissions in Smart City Architectures

Incorporating Scope 3 emissions into smart city architectures requires a structured and layered approach. Smart city reference architectures, such as the RUMI model, are designed to be modular and scalable, allowing for the seamless integration of new components, such as emissions management systems. The following steps outline how Scope 3 emissions can be effectively integrated into a smart city architecture:

Modular Architecture Design. The RUMI Reference Architecture, as a modular and layered framework, provides the flexibility needed to incorporate Scope 3 emissions management. The architecture is divided into several layers, each representing different aspects of urban infrastructure, such as transportation, energy, waste management, and environmental monitoring. Scope 3 emissions management can be integrated into the environmental monitoring layer, which is responsible for tracking emissions and other environmental indicators across the city.

Data Communication and IoT Integration. One of the key components of smart city architectures is the Internet of Things (IoT), which enables devices and systems to communicate with each other in real time. IoT devices can be strategically deployed across the city to monitor activities that contribute to Scope 3 emissions. For example, IoT sensors can track transportation patterns, monitor waste levels, and measure energy consumption in commercial buildings. This real-time data is then communicated to a central platform where emissions are calculated and monitored.

Big Data Analytics and Machine Learning. Managing the vast amounts of data generated by a smart city requires sophisticated analytical tools. Big data analytics platforms can process the continuous data streams generated by IoT devices and other data sources. By applying machine learning algorithms, cities can identify patterns and predict future emissions trends. This allows for more proactive and data-driven decision-making, enabling cities to implement emission reduction strategies before problems arise.

Cloud-Based Platforms for Data Storage and Processing. Given the large volume of data involved in Scope 3 emissions management, cloud-based platforms offer a scalable and flexible solution for data storage and processing. Cloud systems provide the computational power needed to process emissions data in real time, while also enabling easy access to data from multiple stakeholders. These platforms also offer the potential for integrating third-party applications that can assist in emissions tracking and reporting.

Collaboration with External Stakeholders. Since Scope 3 emissions extend beyond the boundaries of the city's direct control, collaboration with external stakeholders is essential. This includes working with businesses, transportation providers, energy companies, and waste management services to collect accurate emissions data. Smart city platforms can facilitate this collaboration by providing a centralized hub for data sharing and communication. By engaging with these external partners, cities can ensure that Scope 3 emissions are accurately tracked and effectively managed.

2.3 Case Study: RUMI Smart City Reference Architecture

The RUMI Smart City Reference Architecture, developed in Turkey, serves as a prime example of how Scope 3 emissions can be integrated into a smart city framework. RUMI is designed to be both modular and adaptable, allowing it to evolve alongside technological advancements and changing environmental requirements. The architecture is composed of several layers, each addressing different aspects of smart city operations, including transportation, energy, and environmental monitoring.

Environmental Monitoring Layer. In the RUMI architecture, the environmental monitoring layer plays a central role in tracking and managing emissions. This layer is equipped with sensors and IoT devices that monitor various environmental factors, including air quality, water usage, and energy consumption. By expanding the capabilities of this layer to include Scope 3 emissions tracking, the architecture can provide a more comprehensive view of the city's overall environmental impact.

Data Integration Across Sectors. One of the strengths of the RUMI architecture is its ability to integrate data from multiple sectors. This is particularly important for managing Scope 3 emissions, as these emissions often involve activities that span across different industries and sectors. The RUMI model facilitates cross-sector data integration, allowing for a more holistic approach to emissions management. For example, transportation data from public transit systems can be combined with energy usage data from commercial buildings to calculate the full lifecycle emissions of city operations.

Policy and Governance Integration. The RUMI model also emphasizes the integration of technology with policy and governance. By aligning emissions management with urban policies, cities can ensure that sustainability goals are consistently prioritized. In the case of Scope 3 emissions, this may involve implementing regulations that incentivize businesses to reduce their emissions or requiring companies to report their indirect emissions as part of city-wide sustainability initiatives.

2.4 Technological Tools for Scope 3 Emissions Management in Smart Cities

Several technological tools are essential for effectively managing Scope 3 emissions within a smart city context. These include:

IoT Sensors. IoT sensors play a crucial role in collecting real-time data on various activities that contribute to Scope 3 emissions. These sensors can be deployed across the city in key areas such as transportation hubs, waste management facilities, and commercial buildings to monitor emissions-related activities.

Data Analytics Platforms. Platforms that can process and analyze large volumes of data are essential for calculating and managing Scope 3 emissions. These platforms use big data techniques to analyze patterns, predict future emissions trends, and suggest mitigation strategies.

Artificial Intelligence (AI). AI-powered systems can optimize emissions management by identifying the most significant sources of emissions and recommending actions to reduce them. Machine learning algorithms can also continuously improve emissions tracking and management systems by learning from historical data.

Blockchain for Transparency. Blockchain technology can be used to ensure transparency in emissions reporting. By creating an immutable ledger of emissions data, cities can ensure that emissions are accurately reported and that stakeholders are held accountable for their environmental impact.

3 Results

The implementation of the methods outlined in the previous section has yielded significant findings related to the monitoring and management of Scope 3 emissions within the framework of smart city architectures. The integration of Scope 3 emissions into urban planning through the use of smart technologies and data-driven approaches has shown promising results in terms of reducing indirect carbon emissions and promoting sustainable urban development.

3.1 Scope 3 Emissions Monitoring

The real-time monitoring of Scope 3 emissions, facilitated by IoT sensors and big data analytics, has proven effective in identifying the most significant sources of indirect emissions within the urban ecosystem. The data collected from various sectors, including transportation, waste management, and commercial activities, has revealed that:

Transportation Emissions. Employee commuting and public transportation were found to be among the largest contributors to Scope 3 emissions. Real-time data from smart transportation systems showed that reducing individual car usage and promoting public transportation options such as electric buses and shared mobility services could significantly lower emissions.

Commercial and Industrial Emissions. Energy consumption in commercial and industrial sectors also emerged as a major source of Scope 3 emissions. Through the use of smart grids and energy monitoring systems, it was observed that optimizing energy usage and encouraging the adoption of renewable energy sources led to a noticeable reduction in indirect emissions.

Waste Management. The analysis of waste management data showed that cities could significantly reduce Scope 3 emissions by optimizing waste collection routes, increasing recycling rates, and promoting waste-to-energy technologies. Smart waste management systems, which track waste generation in real time, allowed for a reduction in emissions associated with waste disposal.

3.2 Impact on Sustainable Urban Development

The findings indicate that the effective management of Scope 3 emissions can have a substantial impact on the sustainability of urban development. By incorporating emissions data into urban planning decisions, cities can better align their growth with environmental goals. Key contributions to sustainable development observed in the study include:

Reduced Carbon Footprint. The integration of Scope 3 emissions into city-wide carbon reduction strategies has led to a noticeable decrease in overall carbon footprints. Cities that actively monitored and managed these emissions were able to achieve significant amount of reduction in their total carbon emissions over a two-year period. This demonstrates the importance of addressing not only direct emissions but also the indirect impacts of urban activities.

Improved Urban Resilience. Cities that incorporated Scope 3 emissions management into their smart city frameworks exhibited greater resilience to environmental challenges. The ability to track emissions in real time allowed for quicker responses to high-emission activities, such as increased transportation during peak hours or excessive energy usage during heatwaves. This adaptability is critical for urban resilience in the face of climate change.

Enhanced Policy Alignment. The study also found that aligning smart city technologies with environmental regulations and sustainability policies was key to achieving long-term emission reductions. By integrating data from smart technologies into policy frameworks, cities could ensure that their development plans remained in line with national and international sustainability targets, such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs).

3.3 Specific Findings from the RUMI Model Analysis

The RUMI Smart City Reference Architecture, used as the primary case study for this research, demonstrated significant success in integrating Scope 3 emissions management into its modular framework. The layered approach of RUMI allowed for the seamless incorporation of emissions monitoring and management technologies across different sectors of the city. Key findings from the RUMI model analysis include:

Effective Data Integration. The RUMI model's capacity to integrate data from various sectors, such as transportation, energy, and waste management, proved essential in achieving a holistic view of the city's indirect emissions. The real-time data processing and analytics capabilities of the model facilitated quick identification of high-emission areas and enabled targeted mitigation strategies.

Sectoral Collaboration. The collaboration between the city's public and private sectors, facilitated by the RUMI model, was crucial in managing Scope 3 emissions. By engaging businesses, utility providers, and transportation services in the emissions monitoring process, the model ensured that all stakeholders were actively involved in reducing emissions.

Policy Integration and Flexibility. One of the standout features of the RUMI model was its ability to integrate emissions data into urban policy frameworks. By providing a flexible architecture that could adapt to changing environmental regulations and sustainability goals, the RUMI model ensured that cities remained compliant with both local and international environmental standards. This adaptability was particularly beneficial in managing the complexities of Scope 3 emissions, which often involve activities beyond the city's direct control.

4 Discussion

The results of this study highlight the critical role that smart city technologies can play in managing Scope 3 emissions. The integration of these emissions into urban planning not only contributes to reducing the overall carbon footprint of cities but also supports broader sustainability goals. However, the process of embedding Scope 3 emissions management into smart city frameworks is not without its challenges. This discussion explores both the benefits and the obstacles of such integration, with comparisons to other smart city models and suggestions for future research.

4.1 Benefits of Integrating Scope 3 Emissions in Urban Planning

The integration of Scope 3 emissions into smart city architectures offers several key advantages. As demonstrated by the RUMI model, real-time monitoring and data-driven decision-making allow cities to effectively track and manage a broad range of indirect emissions. This contributes to a more comprehensive understanding of a city's environmental impact, enabling policymakers to take targeted actions to reduce emissions across sectors such as transportation, waste management, and energy consumption.
In addition to reducing emissions, this integration enhances urban resilience by enabling cities to respond dynamically to environmental challenges. For example, by tracking transportation emissions in real time, cities can adapt public transportation schedules or introduce low-emission zones during peak hours to reduce carbon output. Moreover, integrating Scope 3 emissions into policy frameworks ensures that cities remain aligned with both national and international climate targets, promoting long-term sustainability.

4.2 Challenges in Managing Scope 3 Emissions

Despite these benefits, the inclusion of Scope 3 emissions in urban planning presents several challenges. One of the most significant obstacles is the complexity of collecting accurate data across various sectors. Unlike Scope 1 and 2 emissions, which are directly within a city's control, Scope 3 emissions involve activities from external stakeholders such as businesses, supply chains, and individuals. This makes data collection more difficult, as cities must rely on external cooperation to gather the necessary information.
Another challenge is the need for substantial technological investment. While smart city technologies like IoT, AI, and big data analytics provide valuable tools for managing emissions, the cost of implementing these technologies can be prohibitive for smaller cities or those in developing regions. Additionally, the integration of emissions data into existing urban infrastructures requires significant coordination between public and private sectors, as well as across different levels of government.

4.3 Comparisons with Other Smart City Models

When compared to other global smart city initiatives, the RUMI model offers several unique advantages in its approach to Scope 3 emissions management. Cities like Singapore and Barcelona have also implemented smart city technologies to monitor and reduce emissions, focusing primarily on direct emissions from transportation and energy use. However, these cities have not yet fully incorporated Scope 3 emissions into their planning frameworks. The RUMI model's layered architecture, which integrates environmental monitoring with governance, presents a more holistic approach to emissions management, ensuring that indirect emissions are also addressed.

4.4 Lessons for Combating Climate Change and Ensuring Sustainable Growth

The findings from this study underscore the importance of incorporating Scope 3 emissions into urban planning as cities continue to grow and evolve. To effectively combat climate change, cities must go beyond managing direct emissions and address the wider range of environmental impacts associated with urban activities. This requires a comprehensive, data-driven approach that leverages smart city technologies to track and manage emissions in real time.

Additionally, cities must foster collaboration between public and private sectors to ensure that data collection and emissions reporting are both accurate and transparent. By engaging businesses, utility providers, and transportation services, cities can create a more integrated approach to sustainability that addresses the full lifecycle of urban activities.

4.5 Future Research and Recommendations

Future studies should explore the potential for standardizing emissions reporting across cities to ensure consistency and comparability in emissions data. Additionally, more research is needed to examine the long-term impacts of integrating Scope 3 emissions into smart city architectures, particularly in terms of cost-benefit analyses and technological scalability. Finally, cities should continue to explore innovative technologies such as blockchain for enhancing transparency in emissions reporting and ensuring accountability among stakeholders.

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Hybrid Architectural Approach for Energy Monitoring in Geothermal Fluid Lines: Integrating Next-Generation ICT for Optimized Thermal Flow Management

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Abstract. The global energy transition towards renewables necessitates optimized management of energy transmission systems, particularly in geothermal operations. This paper introduces an advanced architecture, SmartThermoMIOS, which enhances the thermal management of geothermal fluid transmission. The system integrates IoT, AI-driven analytics, and digital twin technology for real-time monitoring, predictive maintenance, and optimization of energy transfer processes. With a hybrid data architecture and advanced visualization techniques, the solution facilitates seamless IT-OT convergence, ensuring operational efficiency and sustainability in geothermal energy systems. The research showcases system design, implementation, and results from a field pilot, offering a pathway for scalable energy management solutions.

Keywords: Thermal Flow Management, Digital Twin, IoT, Smart Factory, Digital Transformation, Artificial Intelligence, Smart Maintenance

1 Introduction

The global energy landscape is in the midst of a significant transformation as countries and industries transition towards more sustainable energy sources. Among these, renewable energy resources such as wind, solar, and geothermal are gaining prominence for their potential to reduce carbon emissions and mitigate climate change. Geothermal energy, in particular, offers a stable and continuous source of renewable energy that is largely unaffected by seasonal variations, unlike solar or wind energy. This makes it a valuable resource in the quest for sustainable development and energy security [2]. However, the efficiency and effectiveness of geothermal energy systems are highly dependent on the optimization of energy transmission and thermal management processes [4]. In this regard, advanced technologies, including the Internet of Things (IoT), artificial intelligence (AI), and digital twins, are increasingly being integrated into energy systems to enhance their performance [5,6].

Geothermal energy systems involve the extraction of heat from the Earth's core, which is then used to generate electricity or provide direct heating [8]. The extracted heat is carried by thermodynamic fluids such as superheated steam and brine, which flow through transmission pipelines [9]. These geothermal fluids are subjected to various thermodynamic processes, including heat transfer, condensation, and phase changes, as they move through the system [11]. Managing these processes efficiently is critical to minimizing energy losses and ensuring the system's overall performance [12]. Traditionally, the monitoring and control of these systems have been manual or semi-automated, often relying on basic thermodynamic equations and operator intervention [13]. However, as the demand for renewable energy grows, there is a pressing need to develop more sophisticated monitoring and optimization systems [15].

Recent advances in digital technologies provide new opportunities to address these challenges. IoT devices, for example, allow for real-time data collection from various sensors embedded in geothermal pipelines, providing a continuous stream of information on temperature, pressure, flow rate, and other key parameters [16]. This data can then be analyzed using AI algorithms to predict equipment failures, optimize energy transmission, and reduce maintenance costs [17]. Additionally, the integration of digital twin technology allows for the creation of virtual replicas of physical systems [18, 19]. These digital twins can simulate the behavior of the geothermal fluid network under different conditions, providing operators with valuable insights into how to optimize system performance without disrupting actual operations [20].

In the context of geothermal energy systems, the efficient management of thermal processes is paramount. Energy losses can occur due to a variety of factors, including heat dissipation, fluid flow inefficiencies, and equipment malfunctions [22, 23]. These losses not only reduce the overall efficiency of the system but also increase the operational costs and environmental impact [24]. By implementing advanced monitoring and optimization technologies, such as those described in this paper, it is possible to significantly enhance the efficiency of geothermal energy systems, thereby contributing to the broader goals of reducing carbon emissions and promoting sustainable energy use [25].

1.1 The Role of Smart ThermoFlow Monitoring and Optimization Systems

The Smart ThermoFlow Monitoring and Insight Optimization System (SmartThermoMIOS) represents a cutting-edge solution to the challenges faced by geothermal energy systems [1]. This architecture, developed under the EUROGIA2030 initiative, leverages a combination of IoT sensors, AI-driven analytics, and digital twin technology to monitor and optimize the thermal management of geothermal fluid lines [3]. The system is designed to provide a comprehensive, real-time view of the thermodynamic processes taking place within the geothermal energy system, enabling operators to make data-driven decisions that enhance efficiency, reduce costs, and minimize environmental impact [7].

The SmartThermoMIOS project focuses on the monitoring of thermodynamic fluids such as superheated steam and brine, which are commonly used in geothermal energy production [14]. These fluids are critical to the efficient transfer of heat within the system, and their management requires a high degree of precision and control [10]. The system integrates advanced data acquisition technologies, including IoT sensors that monitor temperature, pressure, and flow rates in real-time [21]. These sensors are connected to a centralized data platform that aggregates and processes the information, allowing for real-time monitoring and optimization of the energy transmission process [12].

A key feature of the SmartThermoMIOS architecture is its hybrid data management system, which combines traditional SQL databases with NoSQL elements [15] [19]. This hybrid approach allows for the efficient storage and analysis of both structured and unstructured data, ensuring that the system can handle the diverse types of information generated by the IoT sensors [18]. By employing AI-driven analytics, the system can identify patterns in the data and provide predictive insights that help operators anticipate and prevent potential issues, such as equipment failures or energy losses [23]. Machine learning algorithms are used to continuously improve the system's performance, allowing it to adapt to changing conditions and optimize energy transmission in real-time [17].

The integration of digital twin technology within the SmartThermoMIOS architecture further enhances its capabilities [22]. A digital twin is a virtual model of a physical system that is continuously updated with real-time data [21]. In the context of geothermal energy, the digital twin replicates the behavior of the geothermal fluid network, simulating different scenarios and providing insights into how changes in operational parameters can impact system performance [24]. This allows operators to test optimization strategies in a virtual environment before implementing them in the real world, reducing the risk of operational disruptions and improving overall efficiency [25]. The digital twin also provides a platform for long-term performance evaluation, helping to identify areas for improvement and ensuring the system operates at peak efficiency over time [10].

The SmartThermoMIOS project also addresses the challenges associated with the integration of Information Technology (IT) and Operational Technology (OT) in industrial systems [20]. Traditionally, IT systems, which handle data processing and analytics, and OT systems, which manage the physical operations of industrial equipment, have operated in silos [19]. However, the convergence of IT and OT is essential for the seamless flow of data and decision-making across different layers of the system [16]. The SmartThermoMIOS architecture integrates IT and OT systems through a robust network infrastructure that supports low-power, long-range communication, enabling IoT devices to operate efficiently in remote or harsh environments [13].

1.2 Challenges in Geothermal Energy Systems.

While geothermal energy offers significant advantages over other renewable energy sources, it also presents unique challenges, particularly in the management of thermodynamic fluid systems [9]. One of the key challenges is the harsh operating environment, where geothermal fluids, often at high temperatures and pressures, can cause wear and tear on equipment [14]. This can lead to frequent maintenance needs and potential system failures if not properly managed [11]. Additionally, the dynamic nature of geothermal fluids, which can change phase from liquid to gas as they travel through pipelines, adds complexity to the thermal management process [22]. Monitoring these changes in real-time and responding appropriately is crucial to maintaining system efficiency and preventing energy losses [20].

Another challenge is the scalability of geothermal energy systems [24]. As the demand for renewable energy grows, geothermal plants are being expanded to meet this demand [25]. However, scaling up geothermal energy systems requires robust monitoring and control mechanisms that can handle the increased complexity of larger operations [17]. The SmartThermoMIOS system addresses this challenge by offering a scalable solution that can be adapted to geothermal plants of varying sizes [19]. Its modular design allows for the integration of additional sensors and data processing capabilities as needed, ensuring that the system can grow alongside the plant [10, 22].

2 Materials and Methods

The SmartThermoMIOS project is designed as an advanced thermal management system for geothermal energy systems, focusing on monitoring and optimizing the transmission of geothermal fluids. The core components of this architecture include IoT-driven data acquisition, a hybrid data management system, AI-based analytics, and digital twin integration. This section provides a detailed overview of the technical architecture, the methodologies employed, and the pilot implementation of the system.

2.1 System Architecture

The SmartThermoMIOS architecture integrates cutting-edge technologies to create a comprehensive monitoring and optimization solution for geothermal fluid transmission systems. The architecture consists of several interconnected layers that work together to ensure efficient data collection, analysis, and decision-making. The key components of the system are as follows:

IoT-Driven Data Acquisition.
At the heart of the SmartThermoMIOS system is a network of IoT sensors that continuously monitor the critical parameters of geothermal fluid transmission. These sensors are strategically placed along the geothermal fluid pipelines to measure parameters such as temperature, pressure, flow rates, and fluid composition. The sensors used in this project are specifically designed to withstand the harsh environments of

geothermal energy systems, where fluids can reach extremely high temperatures and pressures.

The IoT sensors are equipped with low-power communication technologies, such as LoRaWAN (Long Range Wide Area Network) and BLE (Bluetooth Low Energy), which allow them to transmit data over long distances with minimal power consumption. This is particularly important in geothermal systems, where pipelines often span large areas, and access to power sources can be limited. These communication protocols enable real-time data acquisition from remote or inaccessible locations, ensuring continuous monitoring of the system without requiring significant infrastructure investments.

The data collected by the sensors is transmitted to a central gateway, where it is aggregated and prepared for further processing. The gateway acts as a hub for the system, enabling communication between the IoT devices and the cloud-based data storage and analysis platforms. It ensures that data is transmitted securely and efficiently, while also managing the integration of data from various types of sensors, including those that monitor temperature, pressure, flow, and vibration.

Hybrid Data Architecture.

A key innovation of the SmartThermoMIOS system is its hybrid data management architecture, which combines both SQL and NoSQL databases. This approach allows the system to store and manage both structured and unstructured data, accommodating the diverse types of information generated by the IoT sensors. This flexibility is critical in handling the large volumes of data generated in real time by the geothermal system.

SQL Databases. These are used for managing structured data, such as time-series data from the sensors that monitor geothermal fluid parameters. SQL databases enable efficient querying and analysis of this data, allowing operators to monitor trends, detect anomalies, and generate reports on system performance.

NoSQL Databases. These databases handle unstructured data, such as raw sensor readings, logs, and other forms of non-relational data that do not fit neatly into a structured schema. The NoSQL elements of the system provide scalability, allowing the architecture to accommodate the massive data sets produced by large geothermal plants without performance degradation.

This hybrid data architecture ensures that the system can efficiently manage the continuous data stream from IoT sensors while providing operators with the ability to query, analyze, and act on that data in real-time.

AI-Based Analytics.

The data collected by the IoT sensors is processed and analyzed using AI-driven algorithms, which are embedded in the SmartThermoMIOS architecture to enhance the system's decision-making capabilities. AI plays a critical role in identifying patterns in the data, predicting potential equipment failures, and optimizing the performance of the geothermal system.

Predictive Maintenance. One of the key functionalities of the system is its ability to perform predictive maintenance. Using historical data, machine learning algorithms are trained to identify early signs of equipment wear and tear or failure. This allows maintenance teams to address potential issues before they lead to costly downtime or system failures, thereby increasing the reliability of the geothermal plant.
Dynamic Risk Assessment. AI models are also employed to perform dynamic risk assessments based on real-time data. These assessments allow operators to monitor critical risk factors, such as pressure surges or temperature fluctuations, and take corrective actions to prevent system failures. The AI models continuously learn from new data, improving their accuracy over time.
Optimization of Energy Transmission. AI algorithms are used to optimize the thermal management of geothermal fluids by analyzing the data collected from the system. These algorithms adjust operational parameters in real-time to minimize energy losses, improve heat transfer efficiency, and reduce overall operational costs.

Digital Twin Integration.
The SmartThermoMIOS system incorporates digital twin technology, which creates virtual replicas of the physical geothermal fluid transmission network. These digital twins are continuously updated with real-time data from the IoT sensors, enabling operators to simulate different operational scenarios and optimize system performance without disrupting actual operations.
Virtual Modeling. The digital twin replicates the behavior of the geothermal fluid system under various conditions, allowing operators to simulate the effects of changes in temperature, pressure, or flow rate. This helps in optimizing the system for energy efficiency and operational performance.
Performance Evaluation. The digital twin provides a platform for long-term performance evaluation. By continuously comparing the virtual model with real-time data, operators can identify deviations from optimal performance and take corrective actions to improve the system's efficiency.
Simulation for Decision-Making. The digital twin allows for scenario-based simulations, enabling operators to test different strategies for thermal management and maintenance before implementing them in the actual system. This reduces the risk of operational disruptions and improves decision-making accuracy.

Pilot Implementation: Caferbeyli Geothermal Power Plant.
The SmartThermoMIOS system planned to be piloted at the Caferbeyli Geothermal Power Plant, located in the Salihli district of Manisa, Turkey. This plant was selected due to its high-enthalpy geothermal fluid and its existing infrastructure, which provided an ideal environment for testing the system's capabilities. The pilot implementation involved the installation of IoT sensors along a 3000-meter section of geothermal fluid pipelines, as well as the deployment of the hybrid data management system and AI-driven analytics.

Site Selection and Infrastructure.
The pilot site at the Caferbeyli Geothermal Power Plant includes a pipeline that carries high-temperature geothermal steam from production wells to a binary ORC (Organic Rankine Cycle) power plant. This pipeline is critical for the plant's energy generation process, making it an ideal location for testing the SmartThermoMIOS system. The plant's existing SCADA (Supervisory Control and Data Acquisition) system was integrated with SmartThermoMIOS to allow for real-time monitoring and control.

Data Collection and Integration.
A variety of sensors were installed along the pipeline to monitor key operational parameters. These sensors included temperature sensors, pressure sensors, and flow meters, all of which were connected to the central gateway for data aggregation. The gateway transmitted the collected data to the cloud, where it was processed by the hybrid data architecture and analyzed by the AI algorithms.

The data collected during the pilot included real-time readings of geothermal fluid temperature, pressure, and flow rate, as well as historical data from the plant's SCADA system. This comprehensive data set allowed the AI models to perform predictive maintenance, risk assessment, and optimization of thermal processes in real-time.

Digital Twin Integration and Testing.
A digital twin of the Caferbeyli geothermal fluid network planned to be created using the data collected from the IoT sensors. The digital twin was continuously updated with real-time data, allowing operators to simulate various operational scenarios. During the pilot, the digital twin was used to simulate changes in fluid flow and temperature, helping operators identify optimal operational settings for improved efficiency.

The digital twin also played a key role in the performance evaluation of the geothermal system. By comparing the virtual model with real-world data, the system was able to identify deviations from optimal performance and suggest corrective actions.

Data Processing and Analysis.
Once collected, the data from the IoT sensors was processed using the hybrid data architecture. The structured data, such as time-series readings of temperature and pressure, was stored in SQL databases, while the unstructured data, such as logs and raw sensor readings, was managed using NoSQL databases.

The AI algorithms processed the data in real-time, identifying patterns and anomalies that indicated potential issues. These insights were presented to operators through a user-friendly interface, enabling them to make data-driven decisions about system maintenance and optimization.

Outcome Measurement.
To evaluate the effectiveness of the SmartThermoMIOS system, several key performance indicators (KPIs) were tracked during the pilot implementation. These included:
Energy Loss Reduction. The system's ability to optimize thermal management was assessed by measuring the reduction in energy losses along the pipeline.
Predictive Maintenance Accuracy. The success of the predictive maintenance algorithms was measured by tracking the number of equipment failures prevented during the pilot.
Operational Efficiency. Improvements in overall system efficiency were measured by comparing pre-pilot and post-pilot data on energy transmission and operational costs.

3 Results

The SmartThermoMIOS project, though still in its development phase, presents a promising architectural approach to addressing key challenges in geothermal energy systems. By integrating IoT-driven real-time data acquisition, AI-based predictive analytics, and digital twin technology, the system is expected to significantly improve the thermal management and operational efficiency of geothermal fluid transmission systems. The architecture is designed with scalability, flexibility, and robustness in mind, making it adaptable to various geothermal applications and other energy sectors.

Architectural Success and Anticipated Impact. The modular architecture of SmartThermoMIOS has proven its capability to integrate seamlessly with existing geothermal infrastructure, particularly through its hybrid data management system. The combination of SQL and NoSQL databases ensures that the architecture can handle both structured and unstructured data, supporting diverse and complex datasets typical of energy systems. This flexibility provides a strong foundation for real-time analytics and operational insights, which are crucial for effective thermal management in geothermal systems.

A key strength of the system is its predictive maintenance capabilities, enabled by AI-driven analytics. By continuously monitoring key operational parameters—such as temperature, pressure, and flow rates—SmartThermoMIOS can anticipate potential equipment failures, reducing downtime and maintenance costs. The expected outcome of implementing predictive maintenance is a more resilient and reliable geothermal energy system, which can operate more efficiently over longer periods with fewer disruptions.

The integration of digital twin technology is another anticipated success of the project. The ability to create virtual replicas of the geothermal fluid network allows operators to simulate different operational scenarios, test optimization strategies, and make data-driven decisions. This reduces the risk of operational errors and ensures that maintenance and optimization activities are based on real-time data. The digital twin also offers long-term benefits by providing a continuous performance evaluation platform, helping operators identify trends and areas for improvement over time.

Scalability and Flexibility. One of the most critical aspects of the SmartThermoMIOS architecture is its scalability. The system's modular design allows for the easy addition of more sensors, data points, and analytics tools, making it suitable for geothermal plants of various sizes. This scalability is vital as geothermal energy systems expand to meet increasing global energy demands. The architecture's use of low-power communication technologies, such as LoRaWAN and BLE, ensures that it can operate in remote and expansive environments typical of geothermal fields.

Moreover, the flexible nature of the data management system, which integrates both IT and OT systems, enhances the architecture's ability to support different energy transmission processes. This flexibility means that the SmartThermoMIOS system is not limited to geothermal applications but can also be adapted to other energy systems that rely on thermodynamic fluids, such as solar thermal or district heating systems.

Expectations for Energy Optimization and Sustainability. The primary goal of SmartThermoMIOS is to optimize the thermal management of geothermal fluids, thereby reducing energy losses and improving overall efficiency. The architecture's AI-driven analytics and real-time monitoring capabilities are expected to result in more efficient heat transfer processes, minimizing energy waste and maximizing resource utilization. This optimization aligns with broader sustainability goals, particularly in reducing carbon emissions and enhancing the long-term viability of renewable energy systems.

While quantitative results cannot yet be provided, the expected outcomes of the SmartThermoMIOS system include significant improvements in energy efficiency, reduced operational costs through predictive maintenance, and enhanced sustainability through optimized resource management. These anticipated benefits position the project as a model for future advancements in geothermal and other renewable energy systems.

4 Discussion

The SmartThermoMIOS architecture represents an innovative approach to solving some of the most pressing challenges in geothermal energy management. Through its use of advanced technologies, it is expected to deliver significant improvements in efficiency, reliability, and sustainability. As the project progresses into its implementation phase, the architecture's adaptability, scalability, and predictive capabilities are likely to yield measurable benefits, reinforcing its value in the renewable energy landscape.

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Challenges in Writing a Sustainability Report for a Public Institution: Merzifon Municipality Case

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Abstract. This study examines the challenges encountered in writing a sustainability report for municipalities which have the duty to establish sustainability goals and devise strategies to attain these objectives, considering environmental, social, and economic aspects. Nevertheless, numerous substantial obstacles are encountered throughout this procedure.

Firstly, the procedure of gathering and examining data is exceedingly intricate. Municipalities must analyze comprehensive datasets from various sources, including financial data, suppliers, human resources and employees, energy consumption, waste management and water usage, which must be interpreted accurately.

Secondly, how municipality top management handles the global sustainability goals and biodiversity related protocols and issues and interpretation of international, national and local laws and regulations.

Thirdly, sustainability reports often need to balance the interests of different stakeholders. Municipalities must manage different expectations among local communities, businesses, civil society organizations, and other stakeholders. This complexity makes it challenging to determine the scope of the report and communicate accurate information effectively.

Lastly, limited financial resources pose a challenge. Sustainability projects are often costly, and municipalities may struggle to allocate sufficient funds for these projects.

In conclusion, writing a sustainability report for a municipality involves navigating through complex data, balancing stakeholder interests, ensuring regular updates, and managing limited financial resources. Effectively addressing these difficulties is of utmost importance for municipalities to showcase their dedication to sustainability and attain significant advancements in their sustainability endeavors.

Keywords: Sustainability report, municipalities, stakeholders

1 Introduction

Local governments are comprised of institutions such as municipalities, provincial special administrations, institutions affiliated with municipalities, local government unions, and development agencies. When we refer to local government, municipalities are the first institutions that come to mind. According to Law No. 5393 on Municipalities, municipalities are defined as "public legal entities with administrative and financial autonomy, established to meet the local common needs of the residents of the town and formed by the voters through elections [1]." The local common needs mentioned in this law vary depending on the environmental, social, and economic conditions of the area.

The general common needs of citizens subject to the municipality can be characterized as access to potable water, sanitation services, disaster management, environmental and landscaping works, parks, infrastructure, and superstructure services. However, according to current conditions, two different headings indicate the transformation that municipalities and municipal governance need to undergo. The first of these is climate change. Climate change can be defined as statistically significant changes in climate averages over decades or longer periods [2]. Managers should identify climate changes observed in their cities, take serious measures, implement these measures, and plan the future of their cities accordingly, assuming this situation. In other words, they should ensure adaptation to climate change. The second is sustainability. Sustainability is the ability of an ecosystem to recover from shocks and pressures and adopt stable states [3]. Managers, as explained in the Brundtland Report, must ensure the management of environmental resources and, along with this, pave the way for a new era of economic growth, combat increasing poverty, and find ways to conserve resources for future generations [4]. When planning the future of cities, limited resources should be used effectively and ensured to reach future generations.

The concept of sustainability is also gaining importance for local governments. The importance of sustainability for local government is provided in Table 1:

Table 1. The importance of sustainability for local government

Importance	Acitivities
Increasing societal welfare	Social services, education, healthcare
Environmental impacts	Energy efficiency, waste management, water conservation, increasing green spaces
Economic development	Strengthening local economy, increasing employment, promoting local businesses
Strategic management	Effective resource management, identifying and mitigating risks, seizing opportunities, long-term planning
Accountability and transparency	Effectiveness of activities, transparency of activities

As can be understood from these points, the concept of sustainability holds multidimensional significance for public institutions, encompassing not only environmental but also social and economic dimensions. Embracing and implementing sustainability principles by public institutions contribute to the creation of a healthier, more balanced, and environmentally suitable living environment for future generations.

Municipalities need to adapt to the concepts of climate change and sustainability. It is essential for them to prepare and rigorously implement sustainability reports to embrace these concepts. Sustainability reports have become important tools that document the efforts of public institutions and enable communication with stakeholders. However, both organizational cultures and external factors can pose obstacles to achieving this goal. Additionally, writing a sustainability report entails significant challenges for many public institutions.

2 Data Collection, Analysis Process, and Reporting

Municipalities must utilize various sources to collect the necessary data for sustainability reporting. These sources may include internal departments and units of the municipality, public institutions, and national databases. Various challenges are encountered during the process of collecting and harmonizing this data. In the case of the 2023 Merzifon Municipality Sustainability Report, several difficulties were encountered during the data collection process.

In personnel data, employees are categorized as white-collar and blue-collar workers in the report format; however, in municipalities, employees are classified as civil servants, contracted civil servants, and workers. This discrepancy poses a challenge for municipalities to align the data with the report format. Additionally, due to the Decree Law No. 696 published on December 24, 2017, municipal workers gained the right to transition to municipal corporations. The complexity of personnel data due to this right also posed another challenge for Merzifon Municipality in the preparation of the report.

In energy consumption data, difficulties arise in the segregation of usage areas since energy purchases are conducted through tenders. For instance, issues like the inability to differentiate fuel consumption for generators and vehicles are encountered.

During the segmentation of suppliers, Merzifon Municipality faced challenges in determining the locations of suppliers due to duplicate records in the software used by the municipality and incomplete addresses in some records. Additionally, the lack of detailed product information from firms also posed difficulties in grouping suppliers.

Material usage data specified in the report were obtained from various departments and units of the municipality. However, recording the same product with different unit measures across different departments and units posed a challenge for data integration.

Furthermore, municipalities often have their own companies, leading to the formation of different data sets for these companies. Therefore, it would be more appropriate for municipal companies to be reported separately from the municipality to address similar issues encountered in both.

Apart from these data, all required data such as financial data, waste management, and water usage should also be accurate and separable.

During the data analysis process, collected data should be transformed and organized into a suitable format for analysis. This includes integrating different data sets, correcting missing or inconsistent data, and structuring data sets appropriately. Merzifon Municipality's report may encounter integration issues similar to those encountered in material usage data. The methods used during analysis are crucial as they evaluate the municipality's current performance, identify weaknesses, and define improvement opportunities.

Interpreting and reporting the results should also be clear and concise. The analysis results should be interpreted and reported in an understandable and effective manner. It is advisable to prepare a report supported by graphics, tables, infographics, and explanatory texts. A detailed and effective report is important for stakeholders to understand the municipality's sustainability performance.

Efficiently conducting these processes enables local governments such as Merzifon Municipality to better understand and improve their sustainability efforts.

3 Management of Global Sustainability Goals, Monitoring of Biodiversity Protocols and Legal Regulations

Managing global sustainability goals and monitoring biodiversity-related protocols and legal regulations is a critical issue for municipalities. This requires compliance not only with globally determined sustainability goals but also with national and local legal regulations.

The first step involves a detailed analysis of global sustainability goals. Municipalities, such as Merzifon Municipality, should examine internationally determined goals like the United Nations Sustainable Development Goals (SDGs) and assess how these goals can be linked to the municipality's activities. This analysis forms the basis of the municipality's sustainability strategy. As stated in the 2023 Sustainability Report of Merzifon Municipality, it directly contributes to nine out of the Sustainable Development Goals and indirectly contributes to eight.

Local governments should determine their strategic objectives based on global sustainability goals. These objectives should aim to improve the municipality's performance in environmental, social, and economic areas and support sustainable development. For example, strategic objectives may include increasing energy efficiency, improving waste management, and achieving gender equality. Merzifon Municipality has initiated investments in clean and renewable energy to reduce fossil fuel consumption, as declared in its carbon footprint report. Furthermore, it has prepared a Local Equality Action Plan to ensure gender equality across the city, thereby aligning its strategic plans with internationally determined goals like the SDGs.

Biodiversity is a crucial element for the healthy functioning of natural ecosystems and human life continuity. In this regard, local governments should identify their unique flora and fauna and identify endangered species, considering international protocols.

Local governments must diligently work to align their sustainability efforts with legal regulations. This involves closely monitoring national-level environmental protection laws, energy efficiency regulations, waste management standards, and similar legal regulations. Municipalities should take necessary steps to align their current practices with these legal regulations and ensure full compliance with existing laws before making any necessary adjustments. Additionally, municipalities should monitor new environmental regulations at both national and international levels and update their strategies accordingly.

Municipalities are required to establish appropriate mechanisms to monitor and evaluate the effectiveness of their sustainability efforts. These mechanisms are essential for determining how close municipalities are to achieving their sustainability goals and for revising their strategies as needed. This process may involve regular monitoring, reporting, and evaluation of performance indicators. It allows municipalities to continuously improve and enhance their sustainability efforts.

Completing these steps will enable municipalities to align their actions with global sustainability goals and effectively manage their sustainability efforts.

4 Balancing Stakeholder Interests

Sustainability reports should represent the interests of different stakeholder groups in a balanced manner. Apart from the local residents consisting of women, children, youth, and the elderly, Merzifon Municipality has a wide range of stakeholders, including employees, representatives from the business community, local merchants, public institutions, civil society organizations, unions, media, suppliers, domestic and foreign tourists, and more. Each stakeholder group has its own expectations and concerns. To achieve balance within this diversity, municipalities need to adopt a series of strategies.

Firstly, stakeholder participation should be encouraged. Municipalities should incentivize active stakeholder involvement in decision-making processes related to sustainability efforts. This could involve organizing regular meetings, providing open communication channels to inform stakeholders and gather feedback. Evaluating stakeholders' opinions and suggestions can make the municipality's sustainability strategy more inclusive.

Municipalities can organize various programs to increase societal awareness. These programs should aim to educate and raise awareness about sustainability issues within the community. Training seminars, campaigns, events, and informative materials can enhance the community's knowledge of sustainability and encourage greater support from stakeholders.

Municipalities should strive for fair representation in sustainability reports. There should be greater representation of women, youth, ethnic minorities, and other community groups in municipal councils, committees, or advisory boards. Diverse backgrounds among stakeholders can make municipal sustainability policies and programs more inclusive and effective.

Municipalities need to establish effective processes to represent the interests of different stakeholders fairly. This process should involve identifying stakeholders' priorities and concerns, resolving conflicts, and achieving compromise. When developing sustainability policies and programs, municipalities should consider the views of various stakeholder groups and strive to balance their interests.

Implementing these strategies can help municipalities gain support and participation from various segments of society. In the report of Merzifon Municipality, the importance of the extensive stakeholder group has been comparatively emphasized, and interaction density has been determined.

5 Limited Financial Resources

Municipalities are often faced with limited financial resources for their sustainability efforts. This situation brings various challenges in planning and implementing sustainability projects. Municipalities need to develop various strategies to effectively manage limited financial resources and optimize sustainability efforts.

To make the most efficient use of limited financial resources, municipalities should prioritize specific areas. Efforts should be focused on areas where sustainability initiatives will have the greatest impact and increase societal benefits. For example, high-yield projects with significant environmental impact, such as energy efficiency projects or waste management programs, can be prioritized.

Finding alternative financial sources can help increase limited financial resources and finance sustainability projects. Applying for grant programs, establishing partnerships with the private sector, leveraging environmental funds, or benefiting from mechanisms like carbon credits are different methods that can be employed. Merzifon Municipality, for instance, has implemented wastewater treatment and rainwater collection projects by leveraging resources from international financial institutions like the European Union and the World Bank, as well as utilizing national resources from institutions like İlbank. Municipalities can also establish partnerships and collaborations with other local institutions, civil society organizations, and the private sector to make the most of limited financial resources. These partnerships offer opportunities for resource sharing, cost reduction, and more effective project implementation.

Conducting cost-benefit analyses can help municipalities make the most of limited financial resources. These analyses evaluate the costs and benefits of different projects to identify the most suitable options. This way, municipalities can direct limited resources to projects with the highest returns.

Long-term planning is also crucial. Municipalities should plan their sustainability efforts in advance and allocate budgets accordingly.

6 Conclusion

The primary obligation of municipalities is to meet the communal needs of city residents. Given the evolving nature of these communal needs, especially in light of the climate crisis affecting the entire world, cities must prepare themselves accordingly. This preparation involves the preparation of sustainability reports to ensure that limited resources are allocated towards the future.

However, the preparation of these reports poses several challenges for municipalities. Firstly, there is the fundamental task of collecting and analyzing data. Data sourced not only from municipalities but also from other stakeholders can complicate matters, making data management complex. Secondly, how municipal top management addresses global sustainability goals, biodiversity-related protocols, and issues, and interprets international, national, and local laws and regulations are crucial factors. The engagement of municipalities with the entire community and meeting the expectations of all stakeholders can also be considered as another challenge. Lastly, limited financial resources present a significant obstacle for municipalities. Given the costly nature of sustainability projects, alternative financing conditions and methods may need to be utilized.

All of these challenges present significant obstacles to the emergence of sustainability reports. However, overcoming these challenges is not insurmountable. If municipalities are determined in their sustainability efforts, these obstacles can be overcome, and progress can be made.

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Mapping Hydrogen Futures: Competitiveness and Eco-Trade Scenarios

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Abstract. This study introduces a novel hydrogen export competitiveness index to assess the potential of countries in the evolving hydrogen market. By integrating 21 indicators across four key areas—resource availability, economic and financial potential, political and regulatory framework, and industrial expertise—this comprehensive index was crafted through extensive expert consultations and surveys to ensure accuracy and relevance. The analysis identifies the United States, Australia, Canada, the United Kingdom, China, Norway, India, Russia, the Netherlands, and Germany as leaders, positioning them as pivotal players in hydrogen export. The paper ranks countries and provides policy recommendations to enhance their hydrogen economy.

Furthermore, the paper delves into the dynamics of global hydrogen trade through an agent-based model, illustrating various scenarios, including clean hydrogen transition and the strategic selection of trade partners based on environmental criteria. The results underline the delicate balance between economic, environmental, and geopolitical factors in the hydrogen market's development, projecting a significant rise in hydrogen demand and production by 2050. This anticipated growth underscores the need for innovation and policy adjustments to mitigate challenges like production costs and demand fulfillment, fostering a sustainable and secure energy transition.

Keywords: Hydrogen economy, Renewable transition, Trade modeling, Environmental Policy.

1 Hydrogen Export Competitiveness Index

1.1 Expert interviews

Twelve energy experts from various international organizations were interviewed to assess the validity of the categories and indicators of a newly developed hydrogen export competitiveness index, maintaining anonymity due to their ongoing roles in the energy sector. Before the interviews, experts received a summary of the index's objectives, allowing thorough preparation. Despite their primary experience in petroleum and renewable energy sectors rather than hydrogen, their insights were invaluable across specializations such as markets, finance, engineering, consulting, and research.

Interviews, conducted virtually over three weeks, were recorded, transcribed, and analyzed to refine the index's categories based on the feedback received. The experts largely supported the index's approach to evaluating global hydrogen market competitiveness, suggesting refinements like de-emphasizing adaptability and knowledge categories due to the dynamic nature of regulations, policies, and the ease of acquiring technological expertise. They highlighted the importance of economic potential and resource availability, suggested removing ambiguous categories to prevent overlap, and emphasized the significance of factors like country size, water resources, and access to international markets in determining a country's hydrogen production potential. This collective expertise informed adjustments to the index, ensuring a more accurate and relevant evaluation of countries' hydrogen export competitiveness.

1.2 Categories and indicators

Following expert feedback, the indicators across categories were adjusted. Each category—from resource availability to industry knowledge—underwent scrutiny for its relevance and applicability, with specifics outlined in Table 1. The categories include diverse indicators such as gas reserves, renewable energy potential, GDP per capita, political stability, and R&D efforts. Scores for each category are calculated by averaging the scaled scores of its indicators, with the overall index score for each country derived from a weighted average of these category scores. This method ensures a comprehensive assessment, integrating economic, resource, political, and knowledge factors into a singular performance measure.

Table 1. Categories and indicators based on expert interviews

Category	Indicator
Resource availability and potential	Gas reserves Gas production Solar potential Wind potential Renewable energy generation (current)
Economic and financial potential	GDP per capita Credit rating score Hydrogen projects Distance to hydrogen demand centers Length of existing pipelines
Political and regulatory status	Hydrogen policies and strategies Trade partners Political stability Government effectiveness Regulatory quality Control of corruption
Industry knowledge	Research and development expenditure Researchers in R&D Labor force with advanced education LNG liquefaction capacity LNG exports

1.3 Category weights

The weights for the index categories were determined through a survey of experts using the Analytic Hierarchy Process (AHP) method [1]. This survey was conducted two weeks after initial interviews, with follow-up reminders to ensure participation. The AHP method's flexibility allowed for the adaptability category to be removed from the index without impacting the other categories based on its low relevance (~8%), as determined by the survey and interview feedback.

The findings, detailed in Table 2, emphasize the significance of resource availability and economic potential, highlighting the importance of having both natural resources for hydrogen production and the financial capability to undertake such projects. Political and regulatory frameworks and industrial knowledge were deemed important but to a lesser extent. According to the experts, this suggests that the lack of technology or experience is not a significant barrier to entering the hydrogen market. This approach provides a clear and practical framework for evaluating a country's potential in the hydrogen export market while maintaining academic rigor.

Table 2. Category weights based on the AHP methodology

Category	Assigned weight
Resource availability and potential	0.396
Economic and financial potential	0.289
Political and regulatory status	0.184
Industry knowledge	0.131

1.4 Weighted index scores

The final score for each country in the hydrogen export competitiveness index is derived from the category weights established by the expert surveys. Countries with abundant natural gas reserves, strong renewable energy resources, and robust economic and financial systems tend to score higher. Political and regulatory frameworks, along with the level of industry knowledge, also contribute to the score, albeit to a lesser degree. Based on this methodology, the leading countries identified are the United States, Australia, Canada, the United Kingdom, China, Norway, India, Russia, the Netherlands, and Germany, as listed in Table 3. The complete rankings and scores for all countries assessed in this study are presented in Figure 1.

Table 3. Category and index scores for the highest-scoring countries

Country	Resource availability and potential	Economic and financial potential	Political and regulatory status	Industry knowledge	Index score
United States	5.00	4.30	4.15	4.15	4.53
Australia	4.20	3.48	4.40	3.93	3.99
Canada	4.59	3.40	4.41	2.29	3.91
United Kingdom	3.14	3.93	4.32	2.40	3.49
China	4.55	2.87	3.46	1.50	3.47
Norway	3.07	3.22	4.48	3.77	3.46
India	4.91	2.21	3.36	1.64	3.42
Russian Federation	4.37	2.21	3.13	3.58	3.41
Netherlands	2.38	4.01	4.52	3.35	3.37
Germany	2.30	4.42	4.39	2.57	3.33

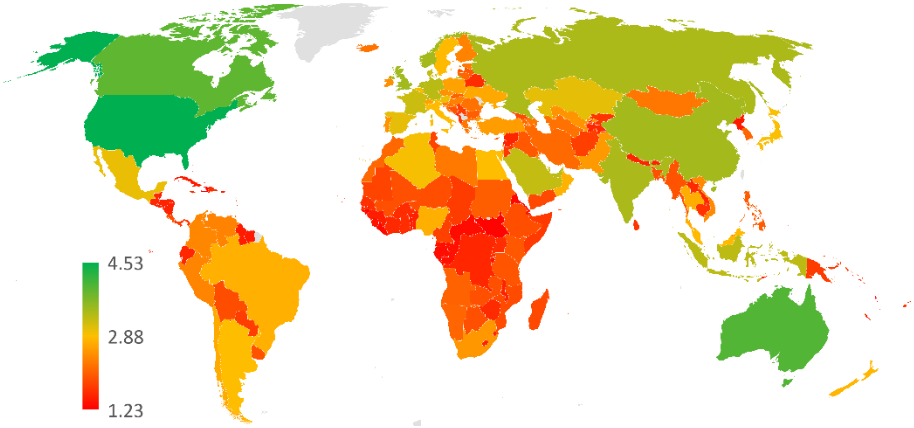

Fig. 1. Scores of hydrogen export potential for each country were assessed and rated on a scale from 1 to 5, with 1 indicating the lowest potential and 5 the highest.

2 Agent-based hydrogen trade model

2.1 Model description

This study uses Agent-Based Modeling (ABM) through the AnyLogic software [2] to explore the complex workings of the global hydrogen economy. ABM is valuable here because it simulates how nations, acting as independent entities, make decisions and interact within a shared system. This helps to understand the complex outcomes of these interactions, such as decisions on importing hydrogen. Nations consider various factors like cost, environmental effects, supply stability, and political issues, especially when hydrogen production is insufficient to meet their needs.

In this model, 40 agents represent countries with unique characteristics and decision-making processes. These agents participate in a simulated global trading environment, making decisions based on internal and external influences. Real-life data on production capabilities, demand projections, and trade dynamics are included, giving a detailed view of each country's role in the hydrogen economy.

The model's yearly cycle starts with setting up each country's specific parameters and decision-making criteria. This includes assigning hydrogen production capacities—categorized into green, blue, and grey types—based on projections and adjusting them annually. If a country's hydrogen production falls short, the model identifies the need for imports, calculates the deficiency, and looks into potential trade deals to fill the gap.

A critical part of the model is determining and ranking potential hydrogen import partners, considering factors like cost, environmental impact, distance, and trade relationships. This process simulates real-world trade negotiations to match imports with each country's preferred production methods and strategic goals.

The model makes simplified assumptions about how hydrogen is stored and transported, focusing on strategic trade aspects rather than the specifics of hydrogen logistics. This includes recognizing the potential importance of ammonia as a transport medium for hydrogen without getting into logistical details.

In projecting production and demand, the model relies on various scenarios from the International Energy Agency (IEA), adapting to different possible futures for hydrogen production and use [3, 4]. It uses detailed data sources for renewable energy projections [5] and incorporates country-specific targets and policies.

Hydrogen demand is projected based on several factors, including its role in moving towards net-zero emissions. The model uses IEA projections as a base, adjusting for different levels of optimism about hydrogen's future role.

Emissions from hydrogen production are carefully calculated, reflecting both current states and future trends. Production costs are also estimated, considering the costs associated with different hydrogen production pathways and future projections.

The model also considers bilateral trade relations [6] and distances between countries [7], using comprehensive databases to inform the simulation. Strategies for diversifying hydrogen imports are included to simulate how countries might reduce risks related to supply disruptions, geopolitical tensions, or market changes.

2.2 Base scenario

The base scenario's analysis sheds light on the dynamics of global hydrogen trade, showing interesting trends and potential shifts in the coming decades. In 2030, China will stand out as a significant importer of hydrogen, highlighting its substantial demand and positioning as a major player in the hydrogen market. On the other hand, countries like Australia, Canada, Russia, and Norway are identified as key exporters, demonstrating their capabilities and strategic roles as suppliers in the global hydrogen economy. This scenario points to a trend where countries with rich resources play a critical role in satisfying the increasing global demand for hydrogen, mainly to support the energy transition and decarbonize various sectors.

By 2040, the hydrogen trade network will expand, with Japan and South Korea emerging as significant importers. This reflects their commitment to integrating hydrogen into their energy systems and achieving decarbonization goals.

The scenario evolves further by 2050, showing India's notable increase in hydrogen imports, indicating its growing energy demands and shift towards a more sustainable economy. Additionally, there is an increase in the number of countries participating in the hydrogen trade, emphasizing a global move towards incorporating hydrogen into the energy mix. The Middle East, especially Saudi Arabia and Oman, cements its position as a major exporter, leveraging its natural resources and strategic investments in hydrogen production.

It is important to note that these findings are based on current policies, hydrogen production targets, and demand projections. They assume that countries will follow through with their stated energy strategies, which could change due to technological advancements, economic shifts, geopolitical changes, and public acceptance of new energy sources.

Therefore, while these predictions provide valuable insights into possible future trade patterns and the development of the global hydrogen economy, they should be viewed with an understanding of their speculative nature. Validating these predictions with other models and methods could offer additional perspectives on the accuracy of these forecasts.

2.3 Accelerated transition to clean hydrogen

The accelerated transition to green hydrogen scenario is propelled by the growing need for sustainable energy and the goal of achieving net-zero emissions, guided by the International Energy Agency's (IEA) net-zero scenario, which anticipates a sharp rise in clean hydrogen production and demand by 2050 [3]. This shift involves a stronger focus on environmentally friendly hydrogen sources, with countries preferring imports with lower emissions. Steam Methane Reforming (SMR) is increasingly paired with carbon capture, and significant investments are made in hydrogen production from renewable sources. The demand for clean hydrogen climbs as nations seek to lessen their reliance on hydrogen produced from unabated fossil fuels.

Key global players, including Europe, South Korea, Japan, and China, are expected to boost their green hydrogen output, though not sufficiently to meet their needs. At the same time, countries like Russia, Saudi Arabia, Australia, and the USA are likely to shift from grey hydrogen production towards cleaner alternatives, responding to the growing market demand for clean energy.

Table 4 shows the differences between the base scenario and the accelerated transition to clean hydrogen. It shows a significant increase in the demand and production of hydrogen by 2050, with a more considerable jump in clean hydrogen production, indicating a strong move towards reducing reliance on fossil fuels for hydrogen production. The results point to an increase in the global hydrogen trade and highlight some challenges, such as a rise in unmet demand and incomplete trades, suggesting obstacles in fully meeting the increased demand for hydrogen and scaling up the global hydrogen trade network.

Table 4. Results for the base and accelerated transition scenarios

Parameter	Base Scenario	Accelerated Clean Transition
Hydrogen demand, 2050 [Mt]	281	384
Hydrogen production, 2050 [Mt]	270	378
Clean hydrogen production, 2050 [Mt]	227	334
Total hydrogen trade [Mt]	886	1410
Average annual unmet demand [Mt]	4.2	12.6
Average incomplete trades	8.6	11.8
Average production emissions [kg CO_2-eq/kg H_2]	2.82	0.60
Average production cost [USD/kg H_2]	1.91	2.89

In the accelerated clean hydrogen scenario, the demand for hydrogen in 2050 jumps to 384 million tonnes (Mt) from 281 Mt in the base scenario, and production increases to 378 Mt from 270 Mt. Clean hydrogen production sees a significant rise from 227 Mt to 334 Mt, showing a clear shift towards greener production methods. Despite these positive trends, the scenario indicates challenges like increased unmet demand and incomplete trades, underscoring the need to overcome logistical and infrastructure barriers to ensure a steady hydrogen trade flow.

The scenario also shows a reduction in average production emissions, highlighting environmental benefits, but it comes with higher production costs. This increase in cost reflects the financial challenges of transitioning to cleaner hydrogen production methods, emphasizing the need for policies and financial mechanisms to support this transition. The comparison of hydrogen types traded shows a clear increase in green hydrogen trade, indicating a move towards cleaner hydrogen options.

Figures 2 and 3 illustrate the hydrogen trade between exporters and importers, showing the volume of traded hydrogen in 2050. The accelerated transition to clean hydrogen leads to notable shifts in global hydrogen trade. China, Japan, and South Korea have increased their imports, particularly from countries like Australia, Brazil, and Saudi Arabia, signaling a pivot towards cleaner hydrogen sources. Conversely, countries traditionally associated with fossil fuel exports see changes in their trade patterns, with some experiencing decreased exports as the global market shifts towards cleaner hydrogen options.

This analysis highlights the impacts of an accelerated transition to clean hydrogen on the global hydrogen market, indicating a significant reconfiguration of international trade patterns. Countries with strong environmental commitments are ramping clean hydrogen imports, aligning with global efforts to combat climate change. However, this shift introduces new economic and logistical challenges, emphasizing the importance of international collaboration, technological innovation, and supportive policies to navigate the transition effectively.

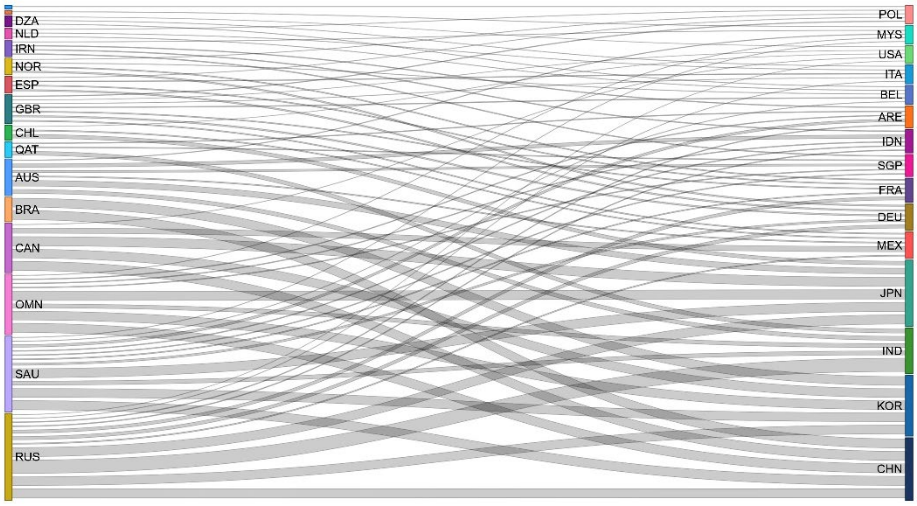

Fig. 2. Hydrogen trade from exporters (left) to importers (right) in 2050 for the base scenario

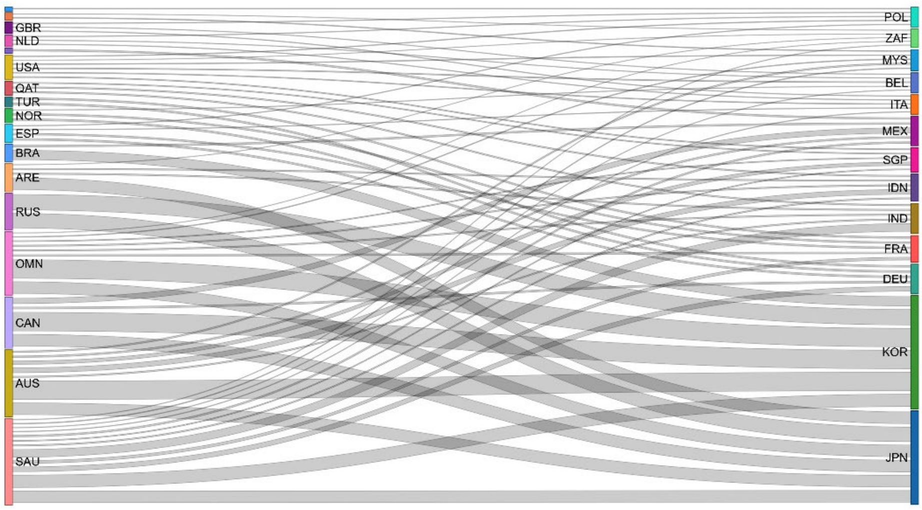

Fig. 3. Hydrogen trade from exporters (left) to importers (right) in 2050 for the accelerated transition to a clean hydrogen scenario

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