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VOLUME 5, ISSUE 1

JANUARY 2025

CONTENTS

Research Article

Energy, Environment and Storage (2025) 05-01:1-9

Energy, Environment and Storage

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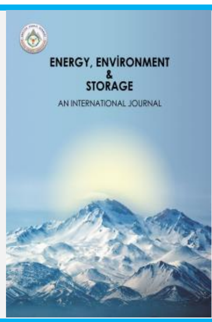

The Potential of Teacher Involvement in Improving the City's Environment

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ABSTRACT. This study aims to determine the role of teachers in environmental education and disaster mitigation in Mataram City, West Nusa Tenggara. Conducted in August 2023, the study involved 422 primary school teacher respondents through the distribution of questionnaires covering four aspects: teachers' perception of students' interest in the environment, teachers' attention to rivers, teachers' role in disaster mitigation, and teachers' contribution to environmental education. Results showed the majority of teachers play an active role in environmental education and disaster mitigation, with 65% of students interested in learning about the environment and 60% of teachers teaching environmental education. Mataram City, as a tourism-based city, faces environmental challenges such as river pollution, suboptimal waste management, limited infrastructure, and drainage problems. This research explores the strategic role of teachers as agents of change in shaping the mindset and behavior of the younger generation towards environmental issues. Through the integration of environmental education in the curriculum and daily practices, teachers can be effective catalysts in instilling environmental awareness and encouraging action among students. This study aims to assess teachers' perceptions of students' interest in the environment, teachers' attention to rivers, teachers' role in disaster mitigation, and teachers' contribution to environmental education. This research is expected to shed light on the relationship between education and environmental action, and advocate for a proactive role of educators in urban sustainability efforts.

Keywords: Teacher, Environmental Education, Disaster Mitigation, Mataram City

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1. INTRODUCTION

In the face of increasing environmental challenges, urban areas need innovative solutions to promote sustainability and improve the quality of life of their residents. This covers a wide range of aspects, from efficient waste management, green infrastructure development, to the utilization of smart technologies to optimize resource use [1]. Cities need to adopt a holistic approach that combines smart urban planning, the use of renewable energy, eco-friendly transportation systems, and public education programs on sustainable lifestyles. By implementing these strategies, urban areas can not only reduce negative environmental impacts, but also create a healthier, more comfortable and resilient environment for current and future generations [2]. Collaborative efforts between the government, private sector and communities are key in realizing the vision of sustainable and livable cities amidst the challenges of climate change and rapid urbanization [3]..

One resource that is often overlooked in these efforts is the potential involvement of teachers as primary agents of change, especially in the environmental field [4]. One resource that is often overlooked in these efforts is the potential involvement of teachers as primary agents of change. Teachers have a strategic role in shaping the mindset and behavior of the younger generation towards environmental issues. With their knowledge, skills and influence, these educators can be effective catalysts in instilling environmental awareness and encouraging action among students [5]. Through the integration of

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environmental education in the curriculum, school-based projects, and exemplary daily green practices, teachers can play a key role in shaping a generation that cares and is responsible for the preservation of nature [6]. Therefore, empowering and actively involving teachers in environmental initiatives is not only important, but also a strategic step in creating sustainable positive change for our planet.

Educators have unique insights and skills that can significantly influence students and the wider community regarding environmental management. This article explores the diverse roles of teachers in urban environmental initiatives, examining how their involvement can foster a culture of sustainability, inspire young people, and encourage collective action. By integrating environmental education into their curriculum and participating in local projects, teachers can not only increase their students' environmental awareness and responsibility but also mobilize community efforts to create greener and more resilient cities.

This research was conducted in the city of Mataram, a tourism-based city that has a lot of sea, land and mountain beauty But behind it all, it has a lot of environmental waste problems. Mataram City faces some serious environmental problems. Severe river pollution. The Jangkok River in Mataram City has been categorized as heavily polluted since 2015. Waste management is not optimal. Waste disposal is still not well managed, causing environmental problems. Infrastructure limitations. Mataram City faces resource and infrastructure issues that need to be addressed to build a resilient city environment. Drainage problems. Poorly absorbed rainwater around housing estates causes puddles on the road surface. To address these issues, efforts are needed to improve infrastructure, better waste management, and improvement of the city's drainage system, and issues related to the presence of waste in the river.

This research has several objectives (1) Assessing teachers' perceptions of students' interest in the environment (2) Assessing teachers' attention to rivers (3) Assessing teachers' role in disaster mitigation (4) Assessing teachers' contribution to environmental education. Finally, this paper expects to explain the intersection between education and environmental action, ultimately advocating a more proactive role for educators in urban sustainability efforts.

2. MATERIALS AND METHODS

2.1 Location of Study

The research location is Mataram City. Mataram City is a city and the capital of the Indonesian province of West Nusa Tenggara, in Fig.1 Location of Study. The city is surrounded on all the landward sides by (but is not administratively part of) West Lombok Regency and lies on the western side of the island of Lombok, Indonesia. It is also the largest city of the province, and had a population of 441,147 at the 2024 Census [6] (comprising 219.625 males and 221.522 females).

The city is an economic, cultural, and education center of the province. Administratively, Mataram City has a land area of 61.30 km² and 56.80 km² of sea water, divided into 6 districts, namely Ampenan, Cakranegara, Mataram, Sandubaya, Selaparang and Sekarbela sub-districts with 50 ward and 297 neighborhoods.

2.2 Method

The questionnaire survey comes from two parts. The role and characteristics of teachers in the world of education section was obtained from TALIS - the Teaching and Learning International Survey - is the world's largest international survey about teachers and school leaders [7]. The other part is a direct questionnaire survey in Mataram City regarding (1) Teachers' perceptions of students' interest in the environment (2) The Teacher's Attention to the River (3) Teachers and disaster mitigation and (4) Teachers and Contributions to Environmental Education.

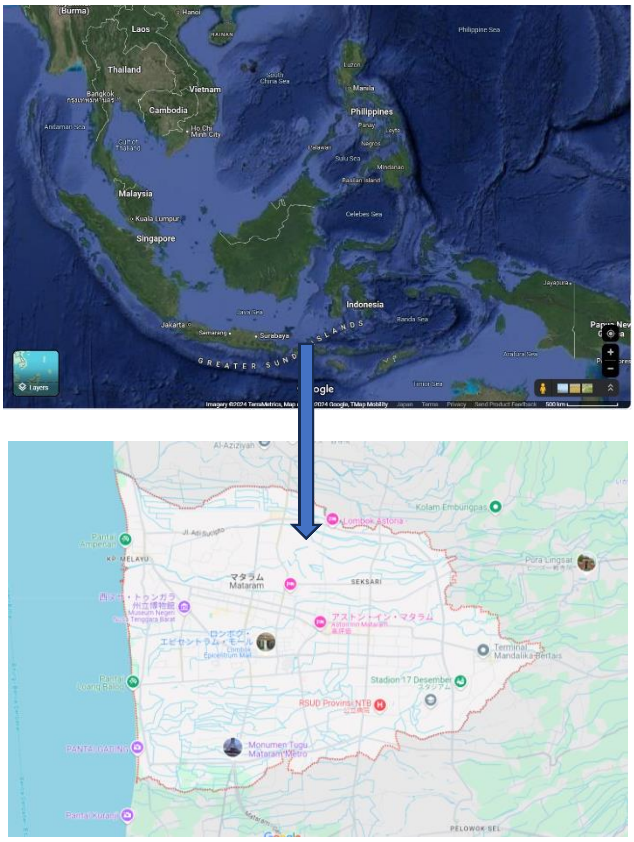

Fig. 1. Location of Study

The survey was conducted by distributing questionnaires through Google Form to 500 primary school teachers located near the river in Mataram city. The target schools were selected based on recommendations from the Mataram City Education Department. of the 500 teachers invited to participate, 422 teachers responded, indicating a high participation rate of 86.4%. This research was conducted using a questionnaire survey by giving 15 close questions to elementary school teachers. The questionnaire results were then processed quantitatively and described to obtain an interpretation of the questionnaire data.

3. RESULT AND DISCUSSION

Teachers should think about their potential involvement in improving the urban environment for several important reasons. Teachers have a key role in shaping future generations. Through teaching and example, teachers can instill environmental awareness in students at an early age [8]. Teacher involvement in urban environmental issues can enrich students' learning experiences. Teachers can integrate environmental topics into the curriculum and learning activities, making education more relevant and contextualized [9].

Teachers involved in urban environmental improvement efforts can be an inspiration and motivator for students and communities. The role of teachers as role models and inspirers can encourage active participation in protecting the environment. Teachers' knowledge and research skills can be utilized to identify urban environmental problems and propose evidence-based solutions. Collaboration between teachers, schools and communities on environmental projects can strengthen school-community relationships and create broader positive impacts [10].

By thinking about their potential involvement, teachers can optimize their role as change agents in improving the urban environment and forming environmentally responsible citizens [11].

Designing Lessons

The Role and Characteristics of Teachers in the World of Education

In managing the classroom, the teacher's role is very important in the development of students' education [12]. Various questionnaire survey questions regarding the role of teachers provide an overview of how classroom management is carried out by elementary school teachers. Survey data in this segment comes from TALIS - the Teaching and Learning International Survey - is the world's largest international survey about teachers and school leaders [13] .

Teachers say they spend a lot of time preparing teaching materials. A total of 61% respondents were of the opinion that the internet was used to prepare learning materials in class. In addition, 59% stated that they often consult with colleagues at other schools. This illustrates that teachers in are not fixated on limited sources of information but open opportunities for them to expand sources of information in compiling learning materials for teaching. Another source used as a reference material for learning in class is books, 58% consider books as the main reference source.

From the aspect of learning media, Powerpoint and other learning media have been implemented, where 62% of respondents think they have used learning media so that learning does not take place conventionally. The dominant number of respondents, namely 63%, thought that they had collected various information to create teaching materials every day.

In preparing classes, respondents generally agreed that they took into account the characteristics of the school and region as well as taking into account the students' actual situation, this provides an understanding that learning develops dynamically and is not static. Classes are prepared by teachers with awareness of their relationship to everyday life, the majority of respondents agreed to this.

At the beginning of the lesson, the teacher used the lesson clearly until students (51%) agreed. The majority (65%) of teachers instruct students to prepare for learning. Most teachers prepare classes to make students interested in learning (52% agree). As many as 65% of teachers agreed to provide guidance according to each person's abilities.

As many as 65% of teachers agree that they are designing ways to encourage students to learn independently, where most of them have used teaching materials and teaching tools that are considered effective for encouraging student learning.

The main obstacle that is usually faced in the teaching and learning process is that teachers cannot understand explanations to students [13], but most respondents answered that they agreed that they had provided explanations that were easy to understand in class. The average teacher elementary schools have taken advantage of student reactions and transformations and used them in the classroom.

Furthermore, as many as 58% of respondents agreed that they should motivate students to learn and 68% of respondents also agreed that they knew each student's learning abilities.

The results of the questionnaire survey further showed that 67% of teachers tried to understand each student's changes in receiving lessons. Furthermore, most respondents agreed that they accurately understand the developmental stage, friendships, family situation, of each student.

In the teaching and learning process, 66% agree that they pay attention to each student when speaking, most teachers agree that they empathize with students' words and actions. When students are asked to express various opinions in class, the teacher gives appreciation to the students even though their answers are not quite correct.

As much as 39% teacher agree that students will not try to learn unless Stimulated from Outside. As many as 55% agreed and 42% strongly agreed that it is important to engage with different ways of thinking for effective learning, free discussion between students should be allowed.

In the process of independent learning, most teachers do not agree that students do nothing when left alone. As much as 47% teacher agree that if students are free, they will do something original.

3.1 Profile of Respondents from Mataram City Teacher

Respondents consisted of state school teachers from grades one to six, totaling 422 people. Most respondents were aged 31- 40 years, as much as 38% and aged 20-30 years as much as 24%. As many as 73% of respondents were female teachers and the remaining 27% were male. The level of teacher education is 97% with a bachelor's degree while the rest have a master's degree and diploma, and have teaching experience, for an average of about 14.09 years.

In elementary schools in Indonesia, Mataram City there are various subjects, among all respondents the subjects most interested in by teachers are mathematics subjects, second place are Indonesian language subjects, then science subjects and other subjects.

3.2 Teachers' perceptions of students' interest in the environment

Environmental education has been widely discussed by experts who aim to develop environmentally responsible citizens. This concept is known as environmental citizenship, which is considered an important factor in addressing environmental challenges such as climate change [14].

Environmental citizenship involves the active participation of citizens in protecting the environment through various means, including community training, environmental education, and involvement in voluntary organizations5. Environmental citizenship activities include an understanding of environmental issues, citizens' rights and responsibilities related to the environment, and proactive actions to reduce environmental problems [15].

Regarding environmental issues in Mataram City, teachers assessed that students have an interest in improving the school and home environment into a friendly environment. Students are also considered to have the habit of keeping the environment clean. This indicates a positive potential among students to develop environmental citizenship.

To further develop environmental citizenship among students, several strategies can be implemented: Integration of environmental education into the comprehensive school curriculum. Involvement of students in community service projects that focus on environmental issues. Organization of simulations and debates on environmental issues to enhance critical thinking. Encouraging students to start and lead their own environmental initiatives. Developing special programs in green technology in accordance with regional potential [16]. By implementing these strategies, it is expected that the interest and positive habits of students in Mataram City can be further developed into active and responsible environmental citizenship.

Environmental education has been widely discussed by experts who aim to develop citizens who are responsible for the environment [17]. Regarding environmental issues in Mataram City, teachers consider that students have an interest in improving the school and home environment into a friendly environment. Students are also considered to have the habit of keeping the environment clean.

Almost all respondents were aware of the causes of flooding, mainly caused by overflowing rivers and garbage. The results of the questions distributed, found that, Students are Interested in Garbage Problems in Lombok 43% of teachers agreed, 60% of students are Interested in Improving the School Environment, and 83% said yes, to the question Flooding is taught at school. While 10% answered maybe and 7% answered never. This is written in figure 2 to figure 4. .

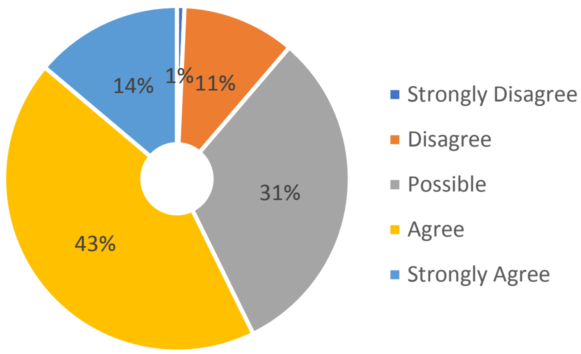

Fig. 2 Students are Interested in Lombok's Waste Problem

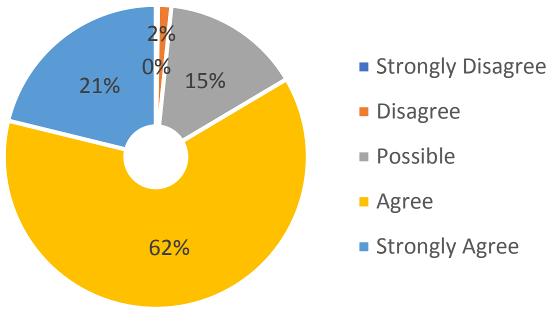

Fig. 3 Students are Interested in Improving the School Environment

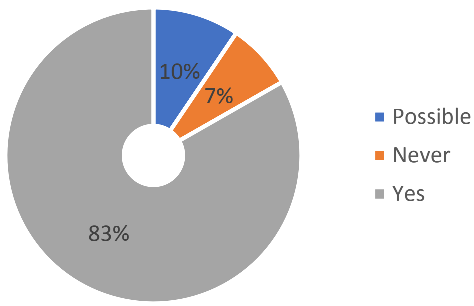

Fig. 4 Flooding is taught in schools

3.3 The Teacher's Attention to the River

Rivers are one of the natural resources that are very important to support the life of human civilization [18]. Since ancient times, rivers have been a source of life, where people have used rivers for drinking water, agriculture, transportation and fishing [19]. Protecting rivers means preserving nature [20]. Most students know the distance from school to the nearest river which shows that they are very concerned about the surrounding natural environment. On average, the river is considered close and accessible on foot, apart from that, some respondents access the river by motor vehicle. Most of teachers and students think they have visited the river closest to school. Most respondents answered that they went to the river to enjoy the view, so for them the river was considered a recreational function to enjoy nature. Rivers are considered to have various kinds of animals that live in river ecosystems. The respondents also agreed that this river is rich in various plants.

As many as 52% of respondents said they knew about stories or legends about rivers in Lombok, while 26% said they didn't know. Furthermore, many teachers want to

Quesioner	Strongly Disagree	Disagree	Possible	Agree	Strongly Agree
School students are aware of natural threats.	0%	8%	11%	59%	22%
Students are interested in learning about the environment	0%	0%	12%	65%	23%
Students are interested in learning about natural disasters.	0%	0%	11%	64%	25%
Introduction to earthquakes comes from school.	3%	21%	76%	0%	0%

Fig. 7 Questionnaire Results Teachers and Disaster Mitigation

Quesioner	Strongly Disagree	Disagree	Possible	Agree	Strongly Agree
The school environment is quite clean and there is no rubbish scattered around.	0%	3%	0%	64%	33%
Teacher teaches environmental education to students.	0%	2%	2%	60%	36%
Students who maintain the school environment from rubbish.	0%	0%	0%	64%	30%
Guidance is needed for students to want to maintain the school environment.	0%	1%	0%	51%	48%
Teachers and students must work together to maintain the school environment.	0%	0%	0%	38%	62%
Environmental education is needed, both for students and teachers.	0%	1%	0%	44%	55%

Fig. 8 Teachers and Contributions to Environmental Education

introduce educational programs, about the river environment, waste problems, biodiversity, etc. in the future. In figure 5 and 6.

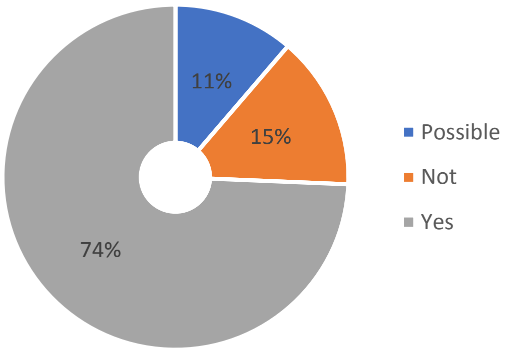

Fig. 5 Possibility Teacher Teaches the River Theme in Class

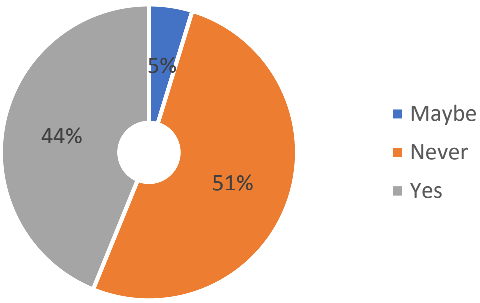

Fig. 6 Teachers and Students have been to The River Together

3.4 Teachers and disaster mitigation

This section will discuss students' knowledge of disaster mitigation and the role of teachers in the field of disaster mitigation in elementary school education. As many as 96% of respondents stated that they had experienced an earthquake. The actions they took when an earthquake occurred were to save themselves, run and avoid buildings. Most respondents learned about the earthquake from their parents, 78%, as well as from school. Most elementary school teachers know about the causes of earthquakes, namely plate friction and volcanic activity. Questionnaire results of Teachers and disaster mitigation. In figure 7. the results of the questionnaire distribution found below, School Students are Aware of Natural Threats, respondents answered Agree: 59% and Strongly Agree: 22%. This means that the majority of respondents (81%) agreed or strongly agreed that school students are aware of natural threats. Only a small percentage (8%) disagreed, while 11% chose the “maybe” option. This indicates a fairly high level of awareness among students about natural threats. As for the question Students are interested in learning about the environment. Respondents responded Agree: 65% and Strongly Agree: 23%. These results are very positive, with 88% of respondents agreeing or strongly agreeing that students are interested in learning about the environment. No respondents disagreed, and only 12% chose “maybe”. This shows a high interest among students in environmental issues.

On the question Students are Interested in Learning about Natural Disasters, Respondents answered Agree: 64% and Strongly Agree: 25%, showing these results were also very positive, with 89% of respondents agreeing or strongly agreeing that students are interested in learning about natural disasters. No respondents disagreed, and only 11% chose “maybe”. This indicates a high interest among students in the topic of natural disasters. As for the question regarding Introduction to earthquakes comes from school, answers ranged from Disagree: 21% and Possible: 76%. These results show significant uncertainty. The majority of respondents (76%) chose “possible”, while 24% disagreed or strongly disagreed. No respondents agreed or strongly agreed. This suggests that schools may not be the main source of information about earthquakes for students, or that there is uncertainty about the role of schools in providing an introduction to earthquakes.

Overall, the results of this questionnaire show that students have a high awareness and interest in natural threats, the environment and natural disasters. However, there is uncertainty about the role of schools in providing an introduction to earthquakes.

3.5 Teachers and Contributions to Environmental Education

Teachers are at the forefront in contributing to environmental education [21]. This section explains the role of teachers in environmental education. Fig. 8 is result of questioner about Teachers and Contributions to Environmental Education

Based on the results of the questionnaire given, the following is a detailed narrative along with the information. The school environment is quite clean and free of litter. The majority of respondents agreed that the school environment is quite clean and free from litter. 64% of respondents agreed, and 33% strongly agreed with this statement. Only 3% expressed possibility, while no one strongly disagreed. This shows that in general, the cleanliness of the school environment is perceived positively by most respondents.

On the question regarding teachers teaching environmental education to students, the majority of respondents acknowledged that teachers teach environmental education to students. 60% of respondents agreed and 36% strongly agreed with this statement. Only 2% stated that it is possible and another 2% stated that it is not possible. No respondents strongly disagreed. This shows that environmental education is already part of the learning process at school.

As for the question about students protecting the school environment from litter, most respondents agreed that students protect the school environment from litter. 64% agreed and 30% strongly agreed. However, there were 6% of respondents who strongly disagreed with this statement. This shows that although the majority of students are considered to play a role in maintaining cleanliness, there is still room for improvement in student participation in this regard.

On the question of whether guidance is needed for students to take care of the school environment, almost all respondents agreed that guidance is needed to encourage students to take care of the school environment. 51% agreed and 48% strongly agreed with this statement. Only 1% stated that it was a possibility. This shows a high awareness of the importance of guidance in shaping students' positive behavior towards the environment.

The next question was about teachers and students having to work together to protect the school environment. This statement received full support from respondents. 62% strongly agreed and 38% agreed that teachers and students should work together to protect the school environment. There were no respondents who disagreed or were undecided. This shows a strong awareness of the importance of collaboration between teachers and students in maintaining the school environment.

Environmental education is necessary for both students and teachers, a large majority of respondents recognized the importance of environmental education for both students and teachers. 55% strongly agreed and 44% agreed with this statement. Only 1% expressed possibility. This shows a high awareness of the importance of environmental education as an integral part of the education system, not only for students but also for educators.

Overall, the results of this questionnaire indicate a high awareness and positive attitude towards the importance of protecting the school environment and environmental education among respondents. However, there is still room for improvement, especially in terms of students' active participation in keeping the school environment clean.

From the questionnaire distributed to respondents in the form of elementary school teachers in Mataram City, on average they gave positive answers which illustrate the positive contribution of teachers in environmental education.

Based on the survey results presented, the following is a narrative discussion on the role of teachers in environmental education and urban environmental improvement:

Teachers have an important role in shaping future generations who are environmentally conscious. Through teaching and example, teachers can instill environmental awareness in students at an early age. Teachers' involvement in urban environmental issues can enrich students' learning experiences by integrating environmental topics into the curriculum and learning activities. The survey results show that the majority of teachers in Mataram City have made efforts to integrate environmental education in the learning process: 96% of teachers agreed that they teach environmental education to students, 97% of teachers agreed that guidance is needed to encourage students to protect the school environment.

100% of teachers agreed that teachers and students should work together to protect the school environment and 99% of teachers recognized the importance of environmental education for both students and teachers. Teachers also assessed that students have positive interests and habits related to the environment, 60% of teachers agreed students are interested in improving the school and home environment to be environmentally friendly, while 83% of teachers said students have a habit of keeping the environment clean. 88% of teachers agreed that students are interested in learning about the environment and 89% of teachers agreed that students are interested in learning about natural disasters.

However, there is still room for improvement in students' active participation, 6% of teachers strongly disagree that students protect the school environment from litter. To optimize the role of teachers as agents of change, several strategies can be implemented. Integrate environmental education comprehensively in the school curriculum. Involving students in community service projects that focus on environmental issues. Organizing simulations and debates on environmental issues to enhance critical thinking. Encouraging students to start and lead their own environmental initiatives. Developing special green technology programs according to regional potential. By implementing these strategies, it is hoped that the positive interests and habits of students in Mataram City can be further developed into active and responsible environmental citizenship.

4. CONCLUSION

As educators, teachers are considered to have a big role in environmental education. Research in Mataram City, West Nusa Tenggara Province, proves that students' interest in environmental sustainability is driven by teachers' efforts in the teaching process regarding environmental materials. This research proves teachers' attention to rivers where 75% agree to teach river themes in class. Apart from that, the role of teachers in disaster mitigation is very large where 64% of students are interested in learning about natural disasters. Finally, 55% strongly agree that environmental education is needed, both for students and teachers. The role of teachers in environmental education and disaster mitigation is very significant, especially in shaping students' awareness and interest in environmental and disaster issues. Based on research in Mataram City, West Nusa Tenggara, several important points were found:

Students' interest in environmental sustainability is influenced by teachers' efforts in the process of teaching environmental materials. Almost 75% of teachers agreed to teach the river theme in class, showing their attention to specific environmental issues and 55% of respondents strongly agreed that environmental education is needed, both for students and teachers.

As for the Disaster Mitigation theme, the role of teachers in disaster mitigation proved to be huge, with 64% of students showing interest in learning about natural disasters. Teachers act as planners, implementers, and evaluators in the learning process of disaster mitigation in basic education. Geography teachers can take a direct role in filling the limited professional human resources in the field of disaster mitigation, equipped with appropriate training. For implication, teachers have a big responsibility in shaping environmental awareness and disaster preparedness in students. Environmental education and disaster mitigation need to be integrated into the school curriculum. Increasing teacher competence in the field of environment and disaster mitigation is very important to improve the quality of teaching. Thus, the role of teachers as educators is not only limited to transferring knowledge, but also shaping students' awareness and preparedness for critical environmental and disaster issues.

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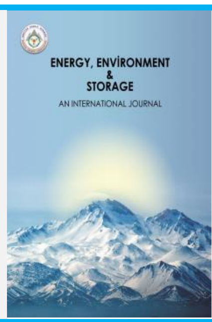

Carbon Footprint and Energy Relationship: Fossil Fuel Vehicles and Electric Vehicles in Turkey

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ABSTRACT. As technology advances today, energy demand is also increasing, with approximately 85% of this demand being met by fossil fuels. The use of fossil fuels leads to the release of greenhouse gases, which are known to be one of the main causes of global warming. Although electrical energy is the most common and easily accessible form of energy, it is not found in nature and must be produced from other energy sources. Renewable energy sources, on the other hand, are not yet sufficient in terms of both cost and meeting energy demand. Therefore, additional taxation is being planned on countries and businesses that use fossil fuels with high greenhouse gas emissions. In this context, the carbon footprint becomes an important parameter for measuring polluting effects. However, calculating the carbon footprint is quite complex, which makes it challenging to ensure fair taxation in energy production and consumption. Thus, it would be fairer to base additional taxation on the amount of greenhouse gases produced per capita in a country. According to calculations, the global average per capita emission of fossil fuel-based greenhouse gases is around 5300 kg. Saudi Arabia and the UAE, as major oil producers, are responsible for producing 15 times this average, while Kuwait is responsible for 23 times the average. The largest energy consumers, such as the United States and Russia, emit three times the average, while Germany, Japan, and China contribute approximately twice the amount. For Turkey, this value is around 1.5 times the global average. Recently, electric vehicles (EVs), which have been promoted as a more environmentally friendly option, have been compared to conventional vehicles under the conditions in Turkey. Since each country has different sources of electricity generation, the goal of EVs producing fewer greenhouse gases is influenced by these factors. The results of calculations specific to Turkey show that while EVs are more environmentally friendly compared to gasoline and diesel vehicles, the situation is more complex and debatable for LPG-powered vehicles.

Keywords: Carbon Footprint, Emission, Electricity, CO_2 , Greenhouse Gas

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1. INTRODUCTION

The growing global population and increasing use of technological products are leading to higher energy consumption. The most consumed forms of energy in social and industrial life are electrical and thermal energy. Especially in the case of electrical energy, there is no area left untouched by it. From personal use to massive factories, a future without electricity is almost unimaginable. The energy sector no longer just influences social and technological life but also plays a role in shaping the political landscape of countries. On the other hand, the biggest drawback of both electrical and thermal energy is that they do not exist naturally on Earth. These types of energy must be produced from existing energy sources on Earth, such as fossil fuels, biofuels, nuclear fuels, wind energy, solar energy, hydropower, and geothermal energy. Today, there is a technological race to convert all available fuels and energy sources into electrical energy. Currently, approximately 85% of the world's primary energy consumption is met by fossil resources. [1]. Fossil fuels, such as oil, coal, lignite, and natural gas, are primarily composed of chemical compounds made up of hydrogen (H) and carbon (C) atoms. To produce electrical or thermal energy from these fuels, they must be burned in the presence of atmospheric air. In the high-temperature combustion chamber, the elements in the fuel and air form various gas compounds, which are then released back into the atmosphere through chimneys or exhaust systems. These harmful gases, known to be detrimental to plant and animal life, are collectively referred to as greenhouse gases. Over time, these gases, such as water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), and hydrofluorocarbons (HFCs), accumulate in the atmosphere, trapping radiation from the Earth's surface and gradually increasing atmospheric temperatures.

It is known that before the industrial era, about 200 years ago, the concentration of greenhouse gases in the atmosphere was between 200-280 ppm (parts per million), whereas today, this concentration has risen to 400-420 ppm. When this concentration reaches 450 ppm, it is predicted that global temperatures will be 2°C higher than pre-industrial levels, potentially triggering catastrophic climate scenarios. Carbon dioxide (CO_2) is the most produced greenhouse gas, accounting for 82% of all greenhouse gases. Since the Industrial Revolution, the amount of CO_2 in the atmosphere has increased by 31%. Therefore, other greenhouse gases are calculated based on their carbon equivalents. To prevent climate catastrophe, the international system promotes the use of solar, wind, and hydropower—energy sources that produce no greenhouse gases—instead of fossil fuels. It also supports the use of electric vehicles over gasoline, diesel, and LPG-powered cars. Additionally, to reduce the appeal of cheap fossil fuel energy, the international community is imposing additional taxes on countries. One of the parameters for applying these taxes will be the carbon footprint. This term, which expresses the amount of greenhouse gases emitted per unit of energy produced (kg/kJ, kg/kWh, kg/kcal), has become a significant topic of discussion today. Three international conferences have been held at different times to reduce greenhouse gas emissions into the atmosphere, prevent climate change caused by these gases, and establish methods for determining the carbon footprint. The Montreal Protocol was adopted in 1987, following the Vienna Convention in 1985, which aimed to reduce substances that deplete the ozone layer. It came into effect in 1989. The Intergovernmental Panel on Climate Change (IPCC), established through collaboration between the World Meteorological Organization and UNEP, laid the foundation for international discussions on climate change, which later resulted in key conventions and protocols. Greenhouse gas emission calculation methods are divided into various levels, referred to as "Tiers." The difference between these levels is related to the technological details involved. The Tier 1 approach is a basic method with general information limitations, while the Tier 3 approach is more complex and requires specialized knowledge compared to Tier 1. It is possible to differentiate between Tier 1, Tier 2, and Tier 3 approaches, although the more complex Tier 2 and Tier 3 approaches are built on a similar foundation to Tier 1 [2].

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted by 195 countries in June 1992, with the goal of reducing carbon dioxide and other greenhouse gas emissions to 1990 levels by the year 2000. The Kyoto Protocol, signed in 1997, came into force in 2005. For the protocol to become effective, the countries that ratified it needed to account for 55% of global emissions in 1990. This threshold was only reached after eight years, when Russia joined. The Paris Agreement, signed during the 21st Conference of the Parties in 2015, marked a significant turning point in the fight against climate change.

The main goal of the Paris Agreement is to keep the global temperature rise well below 2°C above pre-industrial levels, and if possible, limit the increase to 1.5°C. The European Green Deal is a comprehensive strategy set by the European Union, aiming to reduce carbon emissions by 55% by 2030 and make Europe a carbon-neutral continent by 2050. Its key objectives include eliminating pollution, promoting sustainable industry and production, preserving biodiversity, supporting sustainable transportation, clean energy, and eco-friendly construction.

Despite the outcomes of various international meetings, no clear methodology for calculating greenhouse gas emissions has been established. The Tier-1 approach is relatively simple and can be easily applied based solely on the physical properties of the fuel. However, it does not account for the carbon footprint associated with the production process of the fuel before use, nor the impact after consumption. This is because the processes involved from raw material extraction to the disposal of the product after a certain usage period are highly complex. For example, the carbon footprint of the electricity used in these processes varies significantly across countries.

In one study, the average CO_2 equivalent emissions per kilowatt-hour ($kgCO_2/kWh$) of electricity in the 27 EU countries was calculated as 0.2883 $kgCO_2/kWh$. However, this value was 0,0456 $kgCO_2/kWh$ for Sweden and 1,0595 $kgCO_2/kWh$ for Poland, highlighting the variation in carbon footprints depending on the energy mix of each country [3]. According to data shared by Turkey's Ministry of Energy and Natural Resources, 0.439 kg of CO_2 equivalent greenhouse gas emissions are released for every 1 kWh of electricity produced in Turkey [4]. These values indicate that the same products produced in different countries will result in varying greenhouse gas emissions. A study conducted in different U.S. states shows that in two states, the use of electric vehicles (EVs) causes more pollution than conventional vehicles. In about 15 states, EVs and conventional vehicles have almost the same potential for greenhouse gas emissions. This suggests that it is not easy to claim that EVs are environmentally friendly across all states within a single country, as their impact varies based on the local energy mix [5]. A detailed analysis has been conducted on the greenhouse gas emissions of electric light trucks that will be launched in China in 2025. This analysis includes factors such as electric carbon intensity, vehicle technical performance, temperature-capacity balancing coefficient, battery degradation coefficient, energy consumption per unit load, and battery system energy density. The results, covering 31 provinces of China, reveal that the situation is particularly critical for northern provinces with colder temperatures. The findings indicate that with long-term use of the battery and mechanical components, this problem is likely to worsen, highlighting the impact of colder climates on the efficiency and environmental performance of electric vehicles [6]. When adding the complexity of differences in energy production sources and the long lifecycle of a product—from raw material extraction to disposal—reaching a consensus on carbon footprint analyses becomes extremely difficult. The variability in energy mixes, production processes, and disposal methods across different regions makes it challenging to establish a uniform standard for accurately calculating and comparing carbon footprints. This complexity underscores the need for more localized and detailed methodologies to assess the environmental impact of products throughout their entire lifecycle.

Product-based studies have also been conducted to determine carbon footprints. The use of electric vehicles (EVs) is encouraged for a cleaner environment, with the battery being a crucial component of EVs. During the production phase of batteries manufactured for EVs, approximately 60 to 100 kg of CO_2 equivalent greenhouse gas emissions are generated per kWh. This highlights the significant environmental impact associated with battery production, which is an important factor to consider when assessing the overall sustainability of electric vehicles [7]. According to a study conducted in China, which is the largest producer of batteries, the range of greenhouse gas emissions associated with battery production is between 114.3 kg CO_2/kWh and 137.0 kg CO_2/kWh. This indicates that the environmental impact of battery manufacturing is even higher than previously mentioned values, underscoring the importance of addressing emissions in the battery production process to enhance the overall sustainability of electric vehicles [8]. In this context, when considering the hundreds of other components used in the production of an electric vehicle (EV), each sourced from different countries, it becomes very challenging to draw definitive conclusions about the greenhouse gas emissions and carbon footprint of an EV. As can be seen, discussions and confusion regarding how to accurately calculate the carbon footprint are ongoing, and it is unlikely that these debates will be resolved in the near future. Thus, implementing taxation based on unreliable carbon footprint values would not be appropriate. Establishing a control mechanism for accurate carbon footprint assessment through government or international systems appears to be a daunting task. Relying on the declarations of governments and companies may not be trustworthy. Therefore, it has been proposed that a more logical and equitable approach would be to impose additional taxes based on the amount of greenhouse gases produced per capita, starting from the very beginning of the energy production process, acknowledging that the polluted atmosphere should be considered a shared resource for all people. By making high greenhouse gas-emitting energy production more expensive from the outset, the preference for costlier energy sources among firms and individuals can be discouraged. This approach aims to prevent the exploitation of inexpensive energy production that generates high greenhouse gas emissions while providing significant economic benefits. Through additional taxes within the country and increased customs duties on imported goods, governments can protect their citizens. In this regard, the per capita greenhouse gas emissions are seen as a fair reference or criterion for determining these additional taxes.

This study will evaluate the efforts made to determine the carbon footprint and focus on the relationship between energy and carbon footprint. In addition to carbon footprint analyses for both the world and Turkey, the study will also examine per capita greenhouse gas production values. A comparison will be made regarding the performance of electric vehicles (EVs) in Turkey in terms of their lower greenhouse gas emissions, highlighting the potential benefits of promoting EV usage for pollution reduction.

2. FOSSIL FUELS, ENERGY, AND CARBON FOOTPRINT ANALYSIS

2.1 Analysis of Greenhouse Gases from Fossil Fuels

As previously stated, 85% of the world's primary energy consumption is derived from fossil fuels, which leads to significant greenhouse gas emissions. Understanding the distribution of these emissions at both global and national levels is crucial for fair taxation. It would be unrealistic to claim that all countries play an equal role in greenhouse gas emissions. If we consider the polluted atmosphere as a common asset of humanity, it would be more logical to impose responsibilities based on per capita pollution levels. To begin the analysis on a global scale, it is essential to understand the fossil fuel consumption values worldwide. Below are the analyses for oil, coal, and natural gas.

Crude oil extracted from the ground is used in energy consumption as gasoline, diesel, and LPG after undergoing refinery processing. Therefore, the carbon footprint calculations for petroleum can be conducted using the Tier-1 approach based on the products derived from oil, specifically gasoline, diesel, and LPG. To carry out these calculations, it is essential to know the proportions of the products generated from crude oil. This information allows for the calculation of annual or daily gasoline, diesel, and gas quantities based on the amounts of oil produced or consumed by countries. In 2022, global oil production reached 93.8 million barrels per day (v/d), while consumption was recorded at approximately 94.4 million barrels per day. Natural gas production was 4.04 trillion cubic meters, with consumption at 3.94 trillion cubic meters, global coal production was reported at 7.9 billion tons. Additionally, global lignite production reached 638.5 million tons in 2020 [9]. Consumption also occurred at similar levels.

The distribution of products derived from petroleum varies regionally and according to the quality of the oil. For a simple analysis, it suffices to reference the United States, one of the largest fossil energy-consuming countries. According to refinery data in the U.S., the refining and processing of crude oil results in a volumetric average yield of approximately 43% gasoline, 18% fuel oil and diesel, 11% LPG (liquefied petroleum gas, propane, or a propane-butane mixture), 9% jet fuel, 5% asphalt, and 14% other products. One barrel of oil is equivalent to 159.5 liters and 42 gallons in everyday measurements. One gallon corresponds to 3.78541 liters. Using this data and the Tier-1 approach, greenhouse gas emissions from petroleum can be calculated simply. The necessary physical properties and coefficients for the calculations are provided in Table-1. For simplicity, jet fuel has been classified under gasoline in these calculations.

Table.1 Physical Properties of Fuels Tier-1 Coefficients

Fuel	Density [kg/m^3]	Conversion Factor [TJ/t] (IPCC, 2006)	Emission Factor [kg/TJ] (IPCC, 2006)
Gasoline	747	0.0443	69300
Diesel	830	0.0430	74100
LPG	550	0.0473	63100
Natural Gas	0.687	0.0442	64200

Based on this data, the quantities of gasoline, diesel, and LPG produced from crude oil extracted globally in a year can be approximately calculated as follows:

$$m_{\text{gasoline}} = 93.8x10^6x365x0.52x42x3.78541x10^{-15}x747 = 2.114 \ \ billion \ \ tons$$

$$m_{diesel} = 93.8x10^6x365x0.18x42x3.78541x10^{-15}x830 = 0.813 \ \ billion \ \ tons$$

$$m_{LPG} = 93.8x10^6x365x0.11x42x3.78541x10^{-15}x550 = 0.329 \ \ billion \ \ tons$$

Based on these values, the greenhouse gas emissions released into the atmosphere will be calculated as follows using Tier-1 coefficients:

$$Gasoline, \quad m_{CO_2} = 0.0443x2.114x69300 = 6489.96 \ \ billion \ \ kg$$

$$Diesel, \quad m_{CO_2} = 0.0430x0.813x74100 = 2590.46 \ \ billion \ \ kg$$

$$LPG, \quad m_{CO_2} = 0.04730x0.329x63100 = 981.94 \ \ billion \ \ kg$$

$$Petroleum, \quad m_{CO_2} = 6489.96 + 2590.46 + 981.94 = 10062.36 \ \ billion \ \ kg$$

Assuming a world population of 8 billion, it will be observed that the amount of greenhouse gases released into the atmosphere per capita from oil production is approximately 1257.8 kg or 1.257 tons over the course of a year. Similar calculations can be made for the greenhouse gas emissions released from the natural gas produced in the world as follows:

$$Natural \ \ gas, \quad m_{CO_2} = 0.0442x4.04x10^9x0.687x64200 = 7875.81 \ \ milyar \ \ kg$$

According to this result, 984.26 kg of greenhouse gases are emitted per person per year from natural gas.

Calculations for coal and lignite (brown coal) extracted from underground will be somewhat more challenging. There are not significant differences in the chemical and physical properties of oil extracted from different geographies. For example, a typical bituminous coal may have a final analysis of 84.4% carbon, 5.4% hydrogen, 6.7% oxygen, 1.7% nitrogen, and 1.8% sulfur on a dry, ash-free weight basis. [10]. In lignite, the carbon content can drop to around 25%. On average, the carbon content in lignite can be estimated at about 35%. As the carbon content in lignite decreases, the amount of ash produced increases. The hydrogen (H) present in coal converts to water during combustion and is released into the atmosphere as vapor. As the temperature of the water vapor drops, it condenses and falls to the ground. Therefore, in greenhouse gas analyses, the presence of hydrogen in coal can be disregarded, focusing solely on the carbon content. Assuming that all carbon is combusted, the resulting greenhouse gas emissions can be calculated as follows.

$$m_{CO_2} = \frac{44}{12}xCoal \ \ QuantityxCarbon \ \ Percentage$$

$$Coal, \quad m_{CO_2} = \frac{44}{12}x7.9x0,84 = 24332 \ \ billion \ \ kg$$

$$Lignite, \quad m_{CO_2} = \frac{44}{12}x638.5x0.35 = 819.41 \ \ million \ \ ton$$

These calculations indicate that approximately 3041.35 kg of greenhouse gases are produced per person annually from coal and lignite. Therefore, the total annual greenhouse gas emissions per person from fossil fuels worldwide can be summarized as follows;

$$Per \ \ person, \quad m_{CO_2} = 1257.8 + 984.26 + 3041.35 = 5283.41 \ \ \text{kg/yr}$$

This average value can be validated with real-world data. We can assume that a family uses approximately 100 liters or 75 kg of gasoline in a month, consumes 500 kWh of electricity per month, and utilizes 3,000 m³ of natural gas equivalent to 0.1 TJ in a year. In this case, the family's contribution to greenhouse gas emissions can be simply calculated on an annual basis as follows.

$$Family, \quad m_{CO_2} = 12x0.075 \ \ tx0.0443\frac{\text{TJ}}{\text{t}}x69300\frac{\text{Kg}}{\text{TJ}} + 0.1 \ \ TJx64200\frac{\text{Kg}}{\text{TJ}} + 12.500 \ \ kWhx0.439 \ \ \frac{kgCO_2}{kWh} = 2763 + 6420 + 2634 = 11818 \ \ kg$$

Assuming the family consists of 3 or 4 people, it can be stated that approximately 3000 kg of greenhouse gases are produced per person from social activities. Given that the world average is around 5300 kg, the difference of 2300 kg would reflect the contributions from society, industry, and other activities of the state. As a result, considering the annual amount of greenhouse gases produced from fossil resources globally at 5300 kg per person is largely accurate. Both consumer and producer countries should be held responsible for the pollution of the atmosphere with greenhouse gases from fossil fuels. The prosperity level provided by the export of fossil resources must come at the cost of greenhouse gas emissions. Therefore, an analysis of the contributions to greenhouse gas production from the production potentials of certain OPEC countries and Turkey, which are the largest fossil fuel producers, has been conducted. The tables below show the quantities produced, populations, and calculated greenhouse gas amounts.

Table.2 Fossil Fuel Exporting Countries' CO_2 Greenhouse Gas Production [Billion Kg]

Country	Petroleum	Coal	Lignite	Natural Gas
World	10062.36	24332	819.41	7875.81
Russia	1941.47	1225.46	0.01	1403.61
India	112.08	2340.08	0.05	116.42
Australia	35.60	226.99	0.05	233.93
USA	2366.84	1493.34	0.06	2144.40
Canada	1025.61	254.02	0	487.35
Saudi Arabia	2371.75	0	0	311.91
Chinese	829.54	18204.89	509.53	0.27
Iraq	908.73	0	47,33	0
United Arab Emirates	595.76	0	144.79	0
Iranian	750.36	4.23	576.36	0
Kuwait	531.66	0	47.33	0
Brazil	595.76	29.64	144.79	0
Türkiye	14.91	10.1	1.57	0.09

Country	Population [Billion]	Total Emission [Billion Kg]	Emission per capita [kg]
World	8000	43089.58	5386
Russia	0.144	4570.5576	31739
India	1.42	2568.637	1808
Australia	0.026	496.57733	19099
USA	0.334	6004.6493	17977
Canada	0.039	1766.9945	45307
Saudi Arabia	0.037	2683.6695	72531
Chinese	1,409	19544.233	13870
Iraq	0.043	956.06272	22234
United Arab Emirates	0.01	740.55915	74055
Iranian	0,089	1330,9536	14954
Kuwait	0.005	578.99853	115799
Brazil	0.205	770.19915	3757
Türkiye	0.089	26.670595	299

As seen in the table above, the amount of greenhouse gases produced from fossil fuels globally is around 5.400 kg per person per year. For Australia, which has a low population and lacks significant political weight on the world stage, this value rises to 19.099 kg. For OPEC countries, which rely solely on underground oil and have a total population of approximately 442 million, the value is around 9.750 kg. Saudi Arabia and the UAE produce greenhouse gases at levels 15 times higher than the average, while Kuwait's production is 23 times the average. Even indirectly, these countries contribute significantly to greenhouse gas production, well above the average. In contrast, countries that govern the world today, such as the USA and Russia, show values that are far above the average. India, which is rich in coal but lacks oil, has shown below-average trends. Despite its high population, China has had an impact that is more than double the average. For Turkey, which is particularly poor in oil and natural gas, the per capita value is quite low.

The main responsible countries for greenhouse gas emissions are the developed countries that consume the most fossil energy. The results calculated for the G7 countries, Turkey, and the total world regarding the highest thermal and electrical energy production are presented in the table below.

Table-3. Greenhouse Gas CO2 Production of Fossil Fuel Importing Countries [Billion Kg]

Country	Petroleum	Coal	Lignite	Natural Gas
World	10437.4	23339.2	820.0	7695.7
Russia	558.1	692.7	91.0	751.9
Germany	373.2	526.5	133.0	136.7
India	927.6	2918.9	45.0	126.9
Chinese	2982.0	11780.4	173.0	781.3
USA	3548.0	1681.2	54.0	175.8
England	232.6	21.1	0.0	223.2
France	188.2	12,7	0,0	111.5
Japan	621.2	296.0	17.0	245.5
Türkiye	135.7	372.0	88.0	117.2

Country	Population [Billion]	Total Emission [Billion Kg]	Emission per capita [kg]
World	8000	42292.3	5286
Russia	0.144	2093.7	14539
Germany	0.84	1169.4	1392
India	1.4	4018.4	2870
Chinese	1.43	15716.7	10990
USA	0.334	5459.0	16344
England	0.069	476.9	6911
France	0.068	312.5	4595
Japan	0.124	1179.7	9513
Türkiye	0.089	712.9	8009

It should be considered normal for the world average calculated based on consumption to fall below production values. In addition to the use of all produced fossil fuels, their storage is also a factor. According to the results in the table above, the per capita greenhouse gas emissions of the countries that consume the most energy are well above the world average. The countries in the table are the leading nations that influence world politics, with only two countries falling below the average. India, being a developing country with a very large population, has fallen significantly below the world average. France, on the other hand, has a lower average because it obtains about 70% of its electricity from nuclear power plants, resulting in less fossil fuel consumption.

China has demonstrated its status as a superpower by producing more than twice the average greenhouse gas emissions. Considering China's very high coal consumption, this result should be seen as normal. The superpowers of the world, namely the USA and Russia, have produced three times the average amount of greenhouse gases. Germany and Japan, as major world economies, have also contributed approximately twice the average amount of greenhouse gases. Despite making significant investments in renewable energy, Germany still ranks among the top three due to its high coal usage and a relatively small population for its economy. Japan, using less coal but having a larger population, has ranked below Germany.

Turkey, as a developing country, has performed slightly above the average. This poor performance is influenced by the high usage of lignite and coal, as well as its ongoing efforts in achieving efficient energy use. Consequently, it would be fair for countries that contribute to greenhouse gas production, from both production and consumption perspectives, to pay a higher cost in terms of carbon taxation. It would not be equitable for end users with a higher carbon footprint to bear the brunt of increased taxes.

2.2 Greenhouse Gas Analysis of Electric Vehicles for Turkey

One of the proposed solutions for environmental sensitivity today is Electric Vehicles (EVs). Traditional vehicles that use internal combustion gasoline and diesel engines have a significant negative impact on urban air quality due to the greenhouse gases emitted from their exhaust systems. Therefore, efforts are being made to mitigate this effect with EVs. However, these EVs are still powered by the city grid, and the use of fossil fuels for electricity generation indirectly contributes to greenhouse gas emissions for these vehicles.

It is also important to mention a detail regarding the production phase of electric vehicles. The production of electric vehicles results in a higher amount of greenhouse gas emissions due to their batteries. According to research conducted by a consulting firm named Ricardo, the average CO_2 emissions during the production phase of gasoline vehicles is about 5.6 tons, while this value is 8.8 tons for EVs. Half of the 8.8 tons of CO_2 emitted occurs during battery production. In other words, there is a difference of 3.2 tons of CO_2 equivalent greenhouse gas emissions between the production of the two types of vehicles [11].

In Turkey, the greenhouse gas burden of electricity produced is reported as 0.439 $kgCO_2/kWh$. This value is higher than the EU average. Therefore, while the use of EVs is a suitable choice for a cleaner environment in Sweden, the situation is debatable for Poland and Turkey. How much greenhouse gas emissions do vehicles used in Turkey produce? The answer to this question cannot be provided very accurately based on the catalog values given by companies under ideal conditions. The fuel consumption is traditionally defined as the liters of fuel consumed per 100 km of travel. A vehicle's fuel consumption can vary significantly depending on the age of the vehicle, the technology of the vehicle and engine, the driver's usage, and the weather and road conditions.

In the calculations below, the amounts of greenhouse gas emissions generated by different fuels for every 100 km have been calculated for reference. It is assumed that the consumption of gasoline, diesel, and LPG is 5 liters (= 0.005 m^3) per 100 km. According to online research, an EV (Togg V2 RWD Long Range) consumes 16.9 kWh of electricity per 100 km. However, this value is not definitive and can vary depending on the manufacturer and the condition of the vehicle. The calculations of the amounts of greenhouse gases produced by fuels used in internal combustion engines over 100 km are presented in Tables 4, 5, and 6.

$$\mathrm{Fuel\ \ Consumption} = \mathrm{Density}\ * \ \mathrm{Fuel\ \ Volume}$$

$$\mathrm{Energy\ \ Consumption} = \mathrm{Fuel\ \ Consumption} * \mathrm{Conversion\ \ Factor}$$

$$CO_2\ \ Emission = \mathrm{Energy\ \ Consumption} * Emission\ \ Factor$$

$$Carbon\ \ Footprint = \frac{CO_2\ \ Emission}{Energy\ \ Consumption}$$

Table.4 The Amount of Greenhouse Gas Produced by Gasoline per 100 km and Carbon Footprint

Density	747 kg/m^3 0.747 $t/\ m^3$
Conversion Factor (IPCC, 2006)	44.30 TJ/Gg 0.0443 TJ/t
Fuel Consumption per 100 km	0,003735 t
Energy Consumption	0.00016546 TJ 45.96 kWh
CO_2 Emission Factor (IPCC, 2006)	69300 Kg/TJ
CO_2 Emission	11.47 kg
Carbon Footprint	0.249 $kgCO_2/kWh$

Table.5 The Amount of Greenhouse Gas Produced by Diesel per 100 km and Carbon Footprint

Density	830 kg/m^3 0,830 $t/\ m^3$
Conversion Factor (IPCC, 2006)	43.00 TJ/Gg 0.0430 TJ/t
Fuel Consumption per 100 km	0.00415 t

Energy Consumption	0.00017845 TJ 49.57 kWh
CO_2 Emission Factor (IPCC, 2006)	74100 Kg/TJ
CO_2 Emission	13.223 kg
Carbon Footprint	0.266 $kgCO_2/kWh$

Table.6 The Amount of Greenhouse Gas Produced by LPG per 100 km and Carbon Footprint

Density	550 kg/m^3 0.550 t/m^3
Conversion Factor (IPCC, 2006)	47.30 TJ/Gg 0.04730 TJ/t
Fuel Consumption per 100 km	0.00275 t
Energy Consumption per 100 km	0.00013075 TJ 36.32 kWh
LPG CO_2 Emission Factor(IPCC, 2006)	63100.00 Kg/TJ
CO_2 Emission	8.21 kg
Carbon Footprint	0.226 $kgCO_2/kWh$

Table.7 Amount of Greenhouse Gas Produced and Carbon Footprint per 100 km for EV

Carbon Footprint of Electricity	0.439 $kgCO_2$/ kWh
Electricity Consumption per 100 km	16.9 kWh
CO_2 Emission	7.42 kg
Carbon Footprint	0.439 $kgCO_2$/ kWh

According to the calculations above in Table 7, electric vehicles (EVs) provide the least emissions for every 100 km distance in Turkey. Diesel vehicles have the highest emissions. If conventional vehicles consume 5 liters of fossil fuel per 100 km, they will produce an average of 8 to 13.5 kg of CO_2 emissions. For a conventional vehicle to cause emissions equivalent to an EV over its lifespan, it would need to consume less than 5 liters per 100 km. Unfortunately, under current technological conditions, especially for gasoline and diesel vehicles, this is not feasible. For gasoline, diesel, and LPG to have emissions equivalent to EVs, their consumption values would need to be 3.25 liters, 2.81 liters, and 4.5 liters, respectively.

This simple analysis indicates that EVs and LPG vehicles, which produce more greenhouse gases during manufacturing, may have an intriguing dynamic. In other words, if LPG vehicles can meet the 5 liters/100 km target, they could cause lower greenhouse gas emissions than electric vehicles. In such a case, the only advantage of EVs would be overcoming the difficulty of controlling greenhouse gases from mobile systems. Since electricity is produced in fixed centers far from cities, this would mean that EVs contribute positively to urban pollution.

The simple and ideal analyses provided above may not be sufficient for decision-making. It is essential to determine the actual values. Achieving completely accurate values is often not possible; however, it may be feasible to get close to the truth. To obtain results that are close to reality, it is necessary to know the number of vehicles and the amount of fuel consumed in Turkey. In 2023, Turkey had sales of 5454312.3 m^3 (4074371.35 tons) of gasoline, 31344927.31 m^3 (26016289.67 tons) of diesel fuel, and 3519265 tons of autogas LPG **[**12**]**. The emission values resulting from the combustion of these sold fuels over a year have been calculated using the Tier-1 approach and are presented in Tables 8, 9, and 10.

Table.8 The Amount of Greenhouse Gas Produced from Gasoline in a Year in Turkey and Carbon Footprint

Density	747 kg/m^3 = 0.747 t/m^3
Conversion Factor (IPCC, 2006)	44.30 TJ/Gg = 0.0443 TJ/t
Fuel Consumption in 1 Year	4074371.35 t
Energy Consumption in 1 Year	180494.65 TJ = 50137402777.77 kWh
Gasoline CO2 Emission Factor	69300.00 Kg/TJ = 69.3 t/TJ
CO_2 Emission	12508279.3 t
Carbon Footprint	0.249 $kgCO_2/kWh$

Table.9 The Amount of Greenhouse Gas Produced from Diesel in Turkey in a Year and Carbon Footprint

Density	830 kg/m^3 = 0.830 t/m^3
Conversion Factor (IPCC, 2006)	43.00 TJ/Gg = 0.043 TJ/t
Fuel Consumption in 1 Year	26016289.67 t
Energy Consumption in 1 Year	1118700.5 TJ = 310750138888.88 kWh
Diesel CO2 Emission Factor	74100.00 Kg/TJ = 74.1 t/TJ
CO_2 Emission	82895707 t
Carbon Footprint	0.266 $kgCO_2/kWh$

Tablo.10 The Amount of Greenhouse Gas Produced from LPG in Turkey in a Year and Carbon Footprint

Density	550 kg/m^3 = 0.550 t/m^3
Conversion Factor (IPCC, 2006)	47.30 TJ/Gg = 0.0473 TJ/t
Fuel Consumption in 1 Year	3.519.265 t
Energy Consumption in 1 Year	166.461 TJ = 46239166666.6 kWh
LPG CO2 Emission Factor	63100.00 Kg/TJ = 63.1 t/TJ
CO_2 Emission	10503689.1 t
Carbon Footprint	0.227 $kgCO_2/kWh$

The values presented in the tables above reflect Turkey's annual fuel consumption by various vehicles. According to the initial results, a significant portion of greenhouse gases originates from diesel vehicles. Diesel fuel is primarily used by heavy-duty vehicles and generators. Therefore, to achieve lower greenhouse gas emissions, it is essential to produce not only passenger cars but also heavy vehicles in electric versions.

To obtain more accurate results from the data above, it is necessary to know the number of vehicles for estimating their greenhouse gas production potential. According to 2023 data, there are 28,951,792 registered vehicles in traffic. Of these vehicles, 15,723,762 are cars and minibuses, while 5,657,777 consist of trucks, buses, and construction machinery [13]. All heavy-duty vehicles consume diesel fuel. Cars and minibuses, on the other hand, can consume all three types of fuel. One of the effective parameters in fuel consumption is vehicle mass. There is not a significant difference in mass values between cars and minibuses. Therefore, it is necessary to classify the vehicles according to their fuel types within the categories of cars and minibuses.

As of the end of 2023, the number of gasoline vehicles registered in Turkey is 4,362,975, the number of diesel vehicles is 5,425,652, and the number of vehicles using LPG is 5,094,751. The number of electric vehicles has been determined to be 80,043 [12]. According to traffic records, it can be assumed that 502,628 minibuses use diesel fuel, and they can be included among diesel cars. If a diesel vehicle at the car level is used for commercial purposes, it is normal to cover an annual distance of 30,000 km. Assuming it consumes 8 liters of diesel per 100 km, the annual consumption per vehicle would be 2400 liters of diesel. This means approximately 2 tons of diesel fuel used annually. About 5.5 million diesel cars consuming 11 million tons of diesel fuel annually implies that only a small portion of the total 26 million tons of diesel consumption is used by cars. Therefore, it would be highly inaccurate to assume that almost all of the diesel released into the market in Turkey is used by cars and minibuses. It is essential to remember that diesel fuel is also used by generators alongside cars and heavy-duty vehicles. Considering the number of vehicles and the fuel consumed, matching gasoline and LPG with cars would be logical. Table 11 shows the amount of greenhouse gases released into the atmosphere in Turkey for gasoline and LPG vehicles over one year.

Tablo.11 Emission Amount Per Gasoline and LPG Vehicle

Gasoline CO_2 Emission Amount [t]	12,508,279.3
Number of Gasoline Vehicles	4,362,975
Emission Amount per Gasoline Vehicle [kg]	2866,91
LPG CO_2 Emission Amount [t]	10,503,689.10
Number of LPG Vehicles	5.094.751
Emission Amount Per LPG Vehicle [kg]	2061.66

According to the given vehicle numbers, the previously calculated CO_2 emission of 12,508,279.3 tons of gasoline would result in an average of 2,866.9 kg per vehicle. Taking as a reference the CO_2 emission of 11.47 kg generated by consuming 5 liters of gasoline per 100 km, this indicates an annual usage of 24,994.76 km (= 2866,9 / 11.47 * 100). This number, suggesting approximately 25,000 km of annual usage, is considered high for a vehicle that is not used for commercial purposes. Vehicles used for commercial activities can cover much greater distances in a year and generally use diesel fuel. The typical annual distance covered is around 15,000 km. Considering that gasoline commercial vehicles are not frequently used and diesel vehicles are generally preferred, the following scenario arises: the vehicle may have consumed more than 5 liters of gasoline per 100 km, indicating higher fuel consumption per kilometer. Thus, for a normal annual distance of 15,000 km, the consumption per 100 km would be around 8.3 liters (= 24,994.76 / 15,000 * 5). Based on this result, it is very reasonable to claim that using electric vehicles (EVs) instead of gasoline vehicles will contribute to a lower carbon footprint in Turkey.

This value indicates that the CO_2 greenhouse gas emission previously calculated for gasoline at a consumption of 5 liters per 100 km (11.47 kg) would now be 19 kg (= 8.3 / 5 * 11.47). However, it should not be forgotten that more greenhouse gases are produced during the manufacturing of EVs. In this case, there would be approximately 11.5 kg of additional greenhouse gas emissions for every 100 km between EVs and conventional vehicles. According to reference 14, there is an excess greenhouse gas emission of 3.2 tons in the production of electric vehicles. Therefore, EVs could result in less greenhouse gas production compared to gasoline vehicles after approximately 28,000 km (= 3200 / 11.5 * 100) of usage. This distance corresponds to about 2 years of usage. In other words, after two years of use, an electric vehicle would cause lower greenhouse gas emissions.

When we conduct the same analysis for LPG, the previously calculated greenhouse gas emission of 10,503,689.10 tons would equate to approximately 2,061.66 kg per vehicle. Taking as a reference the CO_2 emission of 8.25 kg generated by consuming 5 liters of LPG per 100 km, this indicates an annual usage of 24,990 km (= 2061.66 / 8.25 * 100). LPG is widely used in Turkey because it is cheaper in vehicles. It is especially a preferred option in older and heavily used vehicles. Therefore, an annual usage of 20,000 km for LPG vehicles should be considered normal.

In this scenario, the fuel consumption would be around 6.25 liters per 100 km (= 24,990 / 20,000 * 5). This value corresponds to a CO_2 emission value of 10.3 kg per 100 km for LPG vehicles. As a result, LPG vehicles would produce approximately 3 kg more greenhouse gas emissions per 100 km than electric vehicles (EVs). According to reference 28, considering the 3.2 tons of excess greenhouse gas emissions in vehicle production, after approximately 106,600 km (= 3200 / 3 * 100) of usage, LPG and EVs would contribute equally to pollution. This distance corresponds to about 5-6 years of usage.

In today’s electric vehicles, Li-ion batteries with capacities generally ranging from 10 to 90 kWh are preferred, and it is expected that future generations of electric vehicles will predominantly utilize these types of batteries [14]. Although the lifespan of these batteries can vary depending on usage conditions, we can generally assume a lifespan of 5 to 10 years. These values indicate a value that would be higher than the previously mentioned 3,200 kg in Reference 14. Considering that China is the largest battery producer, it would be difficult to make optimistic statements about electric vehicles (EVs). If we take a good-faith approach and assume that a lithium-ion battery produces 40-90 kg of CO_2 per kWh, a 90 kWh battery would mean producing between 3,600 and 8,100 kg of CO_2. If we consider 8,100 kg as a reference, the point at which a gasoline vehicle would match an EV in terms of emissions would extend to 5 years. For LPG, this point would exceed 10 years. Assuming a battery lifespan of 10 years, this would imply that over a 30-year usage period, three battery replacements would occur. Each battery would result in only 5 years less greenhouse gas emissions when compared to gasoline vehicles. For LPG vehicles, claiming that EVs are cleaner would be challenging. To achieve lower greenhouse gas emissions, the battery's lifespan would need to be well above 10 years. In conclusion, the analyses indicate that recommending the use of electric vehicles for a cleaner environment is appropriate for gasoline and diesel vehicles in Turkey, while the situation is more contentious for LPG vehicles.

3. DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

With the developing technology of today, there has been a high demand for energy. This energy is largely supplied by fossil fuels. Approximately 85% of the primary energy consumption used today comes from fossil sources. The combustion of fossil fuels releases significant amounts of greenhouse gas compounds, namely water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), and hydrofluorocarbons (HFC), into the atmosphere. These compounds create a greenhouse effect in our atmosphere and contribute to global warming. Generally, electricity is the easiest type of energy to use. However, its main drawback is that it does not exist naturally in the environment. Therefore, it is produced from other energy sources found on Earth. However, under current conditions, renewable energy sources are not in a good position in terms of cost and their ability to synchronize with energy demand. For this reason, to implement a system based on the use of more expensive renewable energy, an additional tax plan is being prepared, aiming to impose higher taxes on countries and businesses that utilize dirtier sources in terms of greenhouse gas emissions as a deterrent measure. In the developed tax system, a parameter called carbon footprint has been defined as a unit of measure. This parameter aims to measure the carbon equivalent burden of the produced services and technological products, and consequently, the pollution effect it causes. However, literature research has revealed that calculating the carbon footprint of products and services is quite complex. For example, accurately determining the carbon footprint of a car composed of thousands of parts produced in very different countries is nearly impossible. Each country has different electricity production technologies and energy sources it uses. In today’s world, it is not very feasible for a country to produce all parts of a car within its own borders. There is a necessity to import certain parts from other countries. At least, the raw materials required for car parts cannot be fully sourced domestically. As a result, it has been predicted that it will be very difficult for countries and companies that produce and consume energy in today's world to pay a fee based on their carbon footprint. Therefore, it is considered more rational and fair to impose an additional tax based on the amount of greenhouse gas produced per person, acknowledging that polluted air has equal rights for all individuals. This would prevent the burden from being shifted entirely onto consumers by making energy production that produces excessive greenhouse gases more expensive from the outset through state intervention. This will prevent firms and individuals from opting for more expensive energy. In this way, it will be possible to prevent achieving high economic benefits through very cheap energy production that generates high greenhouse gases. States will protect their consumers through additional taxes within the country and additional customs duties on imported products at their borders. The amount of greenhouse gas produced per person will serve as a fair reference for determining these additional taxes.

In the first phase of this study, the contribution of countries that extract and produce fossil fuels to greenhouse gas emissions was investigated. It was calculated that the per capita average of greenhouse gas production from fossil sources, such as oil, natural gas, and coal, is approximately 5,295 kg in a world population of 8 billion. When looking at individual countries, Saudi Arabia and the UAE, which are among the largest oil exporters, contribute to greenhouse gas emissions at 15 times the average, while Kuwait causes emissions at 23 times the average. Additionally, for Australia, which has a low population and lacks significant political weight globally, this value rises to 19,110 kg. In contrast, the situation for Turkey remains significantly below average at 301 kg. These rates should be used as parameters in taxation related to greenhouse gases. If taxation is imposed on produced goods, countries with very low populations will pay less tax.

In the second phase of the analysis, calculations were made for countries that use fossil energy. India, being a developing country with a large population, has a value of 2,804 kg, which is significantly below the world average. France, on the other hand, derives approximately 70% of its electricity from nuclear power plants, leading to lower fossil fuel usage and resulting in a value of 4,596 kg, which is slightly below average. China demonstrates its status as a superpower by producing greenhouse gases at twice the average. Considering China's very high coal consumption, this result can be seen as normal. The superpowers of the world, the USA and Russia, have produced three times the average amount of greenhouse gases. In contrast, our country, with its status as a developing nation, has performed above average with a value of 7,040 kg per capita. It would be more equitable for countries that contribute significantly to greenhouse gas production through both production and consumption to pay a higher carbon tax. It would not be fair for end users to bear a higher tax based on carbon footprints.

One of the proposed solutions brought forward in terms of individual environmental sensitivity today is Electric Vehicles (EVs). These vehicles do not emit greenhouse gases directly during daily use, unlike internal combustion engine vehicles. However, attention must be paid to the sources from which the electricity they use is produced. The greenhouse gas burden associated with electricity is calculated as an average of 0.2883 kg CO_2/kWh in the EU, while it is 0.0456 kg CO_2/kWh for Sweden and 1.0595 kg CO_2/kWh for Poland. In Turkey, the emissions are 0.439 kg CO_2 equivalent per kWh of electricity produced. This value of 0.439 kg CO_2/kWh is higher than the EU average. Therefore, while the use of EVs would be a sound choice for a cleaner environment in Sweden, the situation is debatable for Poland and Turkey.

Assuming that vehicles with internal combustion engines consume 5 liters of fuel every 100 km, gasoline vehicles can emit 11.47 kg, diesel vehicles 13.22 kg, and LPG vehicles 8.21 kg of greenhouse gases. The fuel consumption values for every 100 km will vary significantly due to many parameters. Based on the number of vehicles used in Turkey in 2023 and actual fuel consumption values, analyses indicate that these consumption values are approximately 19 kg for gasoline vehicles and 10.3 kg for LPG vehicles per 100 km. For a domestically produced electric vehicle in Turkey, this calculation is given as 7.42 kg/100 km. It can be said that the assertion that EVs are environmentally friendly is reflected in reality when looking solely at usage data. For an internal combustion engine vehicle to reach the same emission values as EVs, the fuel consumption must be 3.25 liters for gasoline, 2.81 liters for diesel, and 4.5 liters for LPG. Achieving these values will be very challenging for gasoline and diesel vehicles under current technological conditions. However, if LPG vehicles meet the target of 5 liters/100 km, it is highly likely that they will emit less greenhouse gas than electric vehicles and be more environmentally friendly.

There is a particularly interesting situation regarding the comparison between EVs, which cause higher greenhouse gas emissions during the production phase, and LPG vehicles. Analyses conducted based on data from Turkey indicate that gasoline vehicles will become more environmentally friendly after approximately two years of use, while LPG vehicles will do so after five years of use. Today, the lifespan of li-ion batteries used in EVs is at most 10 years, and considering the performance drop over time and uncertainties regarding the amount of greenhouse gas produced during battery manufacturing, it can be said that LPG vehicles could cause nearly the same environmental pollution as EVs. In conclusion, the analyses suggest that advocating for the use of EVs for a cleaner environment is appropriate for gasoline and diesel vehicles in Turkey, while the situation for LPG vehicles remains contentious.

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Research Article

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Investigation of the Effect of Stearic Acid Addition to Diesel on Combustion in a Compression Ignition Engine

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ABSTRACT. Stearic acid is a saturated fatty acid with the chemical formula CH3(CH2)16COOH. Stearic acid is used in the literature as a surfactant, plasticizer, reducer of flow resistance, water repellent (hydrophobic), reducing agent of hygroscopicity and dielectric film layer former. In addition, according to scientific studies, coating nanoparticles such as aluminium and boron with stearic acid increases their combustion stability. This study is a preliminary study for experimental studies on combustible solid particles. Due to the above-mentioned properties of stearic acid, it is desired to use it as a surfactant. However, the effect of stearic acid on combustion in a compression ignition engine needs to be investigated experimentally. For this purpose, stearic acid was used as an additive to diesel fuel in a compression ignition heavy-duty diesel engine. Stearic acid was added to the diesel fuel in the amounts of 125, 250, 500 and 1000 ppm by mass. Then it was mixed with a stirrer for 45 minutes. The test engine was operated at 700 rpm and 300 Nm load. Engine performance and emission data were examined.

Keywords: Stearic acid, diesel, surfactant, performance, emission

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1. INTRODUCTION

While increasing energy consumption pushes researchers to seek alternative fuels, efficiency studies on existing internal combustion engines are also of great importance. For this reason, many researchers are working on diesel fuel additives. Stearic acid is used in the literature as a surface active agent, lubricant, lubricator, coating material that reduces flow resistance, water repellent, moisture absorbent, and insulating film layer forming agent. In addition, according to scientific studies, coating nanoparticles such as aluminium and boron with stearic acid increases their combustion stability [1-4]. Especially aluminium powder has a strong explosion sensitivity. Therefore, the concern of explosion in the use of aluminium and similar materials has been stated in the literature [7-10]. In addition, elements such as aluminium, boron and magnesium oxidize very quickly during combustion, which can reduce the combustion efficiency of these materials [11, 12]. There are studies in the literature on surface coating methods to avoid these problems [13-15]. In the literature, studies have been conducted on materials coated with surface coating materials containing fluorine, such as fluorographene, fluoroalkyl silane, and polyvinylidene fluoride, although they have improved combustion, these materials have serious environmental damage [16, 17]. Therefore, stearic acid, a saturated fatty acid found in nature and in various oils, comes to the fore as a coating material for coating materials such as aluminium and boron. Stearic acid is a non-toxic fatty acid with hydrophobic properties. [18] and [1] have coated elements with high explosion sensitivity with stearic acid. As a result of their studies, they stated that the resistance of the materials coated with stearic acid to oxidation increased and a more controlled combustion reaction occurred.

The current study investigated the effects of stearic acid on combustion when used with diesel fuel in a compression ignition engine due to these properties. It was evaluated whether stearic acid has a negative effect on combustion.This study aims to be preliminary for the studies to be carried out later on to use combustible metals coated with stearic acid in a diesel engine

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Nomenclature

BSFC	Brake Specific Fuel Consumption	**CO**	carbon monoxide
BTE	Brake Thermal Efficiency	**NO**	nitrogen oxides
Nm	Newton meter	**D100**	Pure Diesel
rpm	revolution per minute	**St125**	125ppm Stearic acid + Diesel
g	gram	**St250**	250ppm Stearic acid + Diesel
mm	millimeter	**St500**	500ppm Stearic acid + Diesel
P_b	Brake power	**St1000**	1000ppm Stearic acid + Diesel
min.	minute	**LHV**	Lower Heat Value
ppm	Parts per million	**$\dot{m}$**	Mass flow
kWh	kilowatt-hour		

2. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Format

In this study, a compression ignition heavy-duty diesel engine was used as shown in **Figure 1**. The test engine has 11,670 cc engine volume and 6 cylinders (Table 1). The

Figure 1 Test Engine

Table 1: Diesel engine which use at the experiment [19]

Engine Parameters	Specification
Bore and Stroke	133 mm, 140 mm
Number of cylinders	6
Displaced volume	11,670 cc
Max. Power and Speed	234 Hp, 2300 rpm
Compression ratio	16.5
Injection timing	16 'BTDC

A magnetic stirrer was used to ensure homogeneous distribution of the solution. Each fuel mixture was mixed for 45 minutes using 750 rpm and 40 degrees heat (**Figure 2**). A scale with 0.5 g sensitivity was used to measure liquid fuel consumption. Consumption was determined by 5-minute measurements. Emissions measuring was fulfilled with the Bosch-BEA60 emission analyzer. The technical specifications of the emission device are presented in **Table 2.**

Table 2 : Bosch BAE 60 gas analyzer

Components	Measurement Range	Precision
CO	% 0,000 – 10,00	% 0,001
CO_2	% 0,00 – 18,00	% 0,01
HC	0 - 9999 ppm	1 ppm
O_2	% 0,00 – 22,00	% 0,01
NO	0 - 5000 ppm	1 ppm

experiments launched with pure diesel (D100) and then continued with St1000, St500, St250, and St125, respectively in the current scrutiny. Pure diesel fuel (D100) was taken as a reference and efficiency and emission performances were compared by adding different amounts of stearic acid (St1000-1000ppm, St500-500ppm, St250-250ppm, St125-125ppm).

Figure 2 The Magnetic Stirrer

Experimental data were obtained thanks to the PCS performance measurement system. The data obtained with experiments were considered comparatively with each other, it was discussed in the section of results.
After the experimental setup, the experiments were first started with pure diesel fuel. The data obtained from the experiments conducted with pure diesel fuel were determined as the base values for comparison with other fuel types. Then, the experiments were continued with st125, st250, st500 and st1000 fuel types, respectively. Before the experimental data were obtained, the test engine was started and the engine speed was set to 700 rpm and the engine load was set to 300 Nm. After the test engine had run for at least 10 minutes under these operating conditions, a 5-minute period was started and the fuel consumption was measured. The same method was applied in the experiments conducted with each fuel type. In addition, at each fuel type change, the remaining fuel in the test engine fuel system was drained and the other fuel type to be tested was given to the system. The data obtained after the experimental procedure followed in this way were analysed and compared with pure diesel fuel.

3. RESULTS

BTE and BSFC are the most important performance indicators showing engine thermal efficiency and specific fuel consumption. BTE and BSFC are inversely proportional to each other as shown in **equation 1** (Equation 1 is derived from equations 2 and 3). It is logical that the engine with high thermal efficiency has low specific fuel consumption and vice versa [21, 22]. The BTE and BSFC graphs calculated in line with the data obtained in this study are presented in **Figure 4** and **Figure 5**, respectively. **Figure 4** shows the thermal efficiencies of D100 (pure diesel), st125, st250, st500 and st1000 fuels under 300 Nm torque. According to **Figure 4**, the thermal efficiencies of D100, st125, st250, st500 and st1000 fuels are 32.4, 31.0, 34.2, 34.9 and 33.5%, respectively. **Figure 5** shows the specific fuel consumptions of D100 (pure diesel), st125, st250, st500 and st1000 fuels under 300 Nm torque. According to **Figure 5**, the specific fuel consumptions of D100, st125, st250, st500 and st1000 fuels are 258.8, 269.8, 244.6 239.7 and 249.8 g/kWh, respectively. As can be seen from the graphs, the experiment in which the highest thermal efficiency was obtained was the experiment in which st500 fuel was used. Accordingly, the lowest BSFC value was obtained with ST500 fuel. When the BTE of St500, i.e. diesel with 500ppm stearic acid additive, was compared with the BTE of pure diesel, ST500 was observed to be 7.78% more efficient than pure diesel.

$$\boldsymbol{BTE} = \frac{1}{\boldsymbol{BSFC*LHV}} \quad (\%) \qquad (1)$$

$$\boldsymbol{BTE} = \frac{P_b}{\dot{m}*LHV} \quad (\%) \qquad (2)$$

$$\boldsymbol{BSFC} = \frac{\dot{m}}{P_b} \quad (g/kWh) \qquad (3)$$

Although 125 ppm stearic acid added to diesel fuel has a negative effect on thermal efficiency, it has been concluded that diesel fuels with 250, 500 and 1000 ppm stearic acid added have higher thermal efficiency than pure diesel. In this context, it can be said that stearic acid generally has a positive effect on thermal efficiency. In this study, in order to find the optimum amount of stearic acid needed to be added, it was started with 125 ppm stearic acid added and continued by increasing it 2-fold in each experiment. At the end of the study, st500 fuel with the highest thermal efficiency showed that the optimum stearic acid added was 500 ppm.

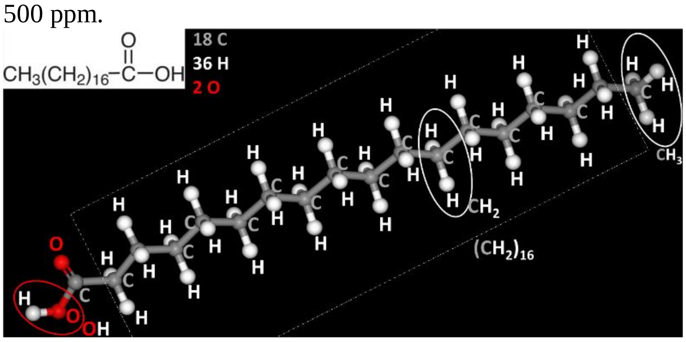

Figure 3 – Stearic Acid Crystal Structure [25]

Stearic acid has 18 carbons, 36 hydrogens and 2 oxygen in its structure. The crystal structure of stearic acid is a saturated fatty acid with an 18 carbon chain as shown in figure 3 [25, 26]. The reason why stearic acid has a positive effect on thermal efficiency can be attributed to the high hydrogen content as well as the fluidity enhancing feature, which ensures that the fuel is well atomized in the combustion chamber and provides more stable combustion [20, 1]. The presence of stearic acid, which is rich in hydrogen and oxygen in diesel fuel, has affected the ignition delay. Therefore, different efficiency values were obtained at different stearic ratios. 500 ppm stearic acid additive provided optimum ignition delay in the test engine. Therefore, it contributed to the highest thermal efficiency of St 500 fuel. The most important factor in obtaining different thermal efficiency values with different stearic acids is that stearic acid changes the ignition delay. As seen in **Figure 6**, st500 fuel significantly increased the ignition delay.

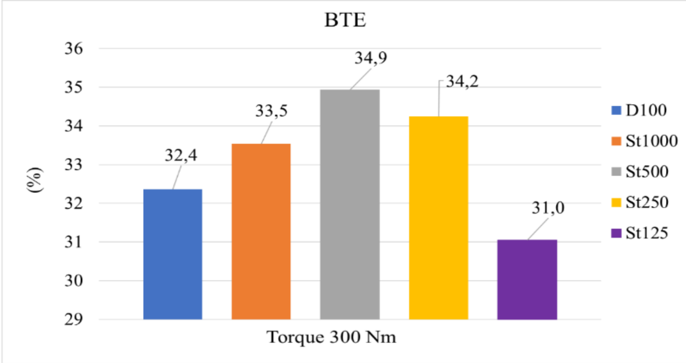

Figure 4 - BTE

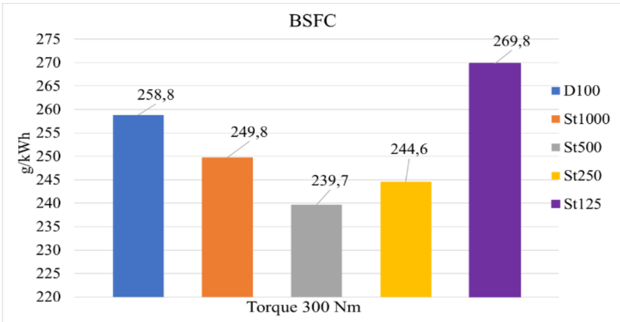

Figure 5 - BSFC

Table 3 shows Lambda values and **Figure 6** shows the in-cylinder pressure graphs. The graph shows the in-cylinder pressure values of D100, st125, st250, st500 and st1000 fuels in the 300-420 crank angle range in bar under 300 Nm Torque. Although the thermal efficiency of St500 fuel is the highest, the in-cylinder pressure is relatively lower than other fuels. High in-cylinder pressure is not a factor that affects thermal efficiency linearly. High pressure can often cause engine vibration and knocking combustion. In diesel engines, a flatter pressure graph at the top dead centre is desired rather than a very sudden pressure increase. 500 ppm stearic acid additive diesel fuel provided this situation and therefore thermal efficiency was higher than other fuels. In addition, the ignition delay of ST500 was observed to be longer than other fuels. This situation shows that the sudden pressure increase occurs at a more optimum crank angle degree compared to other fuels.

Table 3 Lambda

Fuel Types	Lambda
D100	3,063
St1000	2,979
St500	3,071
St250	2,976
St125	3,089

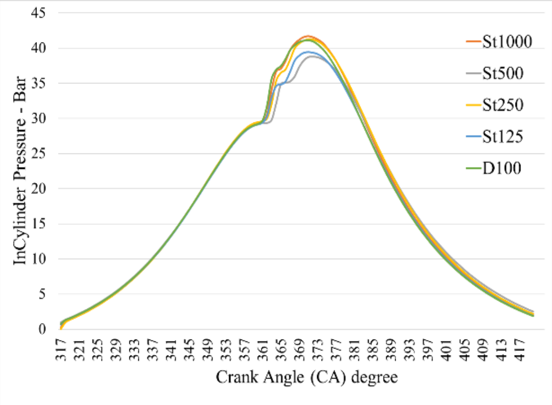

Figure 6 – In-Cylinder Pressure

The fact that stearic acid additive to diesel fuel does not generally affect thermal efficiency negatively is a positive data for future studies. Especially, the fact that more stable combustion is achieved with 500 ppm stearic acid additive sheds light on the ongoing studies of the authors of this study. Positive information has been produced that paves the way for the use of stearic acid as a surfactant in the use of elements sensitive to combustion such as Al, B and Mg as additives in diesel engines.

Nitrogen and oxygen atoms, which are broken down by high temperature and pressure, react and form nitrogen oxides [5]. Nitrogen oxide formation also depends on the length of the combustion period. A long combustion period, high oxygen density, and high combustion temperature result in the formation of high amounts of nitrogen oxides [6]. Nitrogen oxides are harmful gases that are not wanted in the atmosphere. **Figure 7** shows the NO emission graph. In the graph, the NO emission values of D100, st125, st250, st500 and st1000 fuels are 520, 483, 466, 487 and 546 ppmvol under 300 Nm engine load, respectively, and the pressure values are shown in bar. The NO graph provides information about the combustion temperature and air-fuel mixture quality [6, 23]. St500 has reached the highest thermal efficiency while showing a medium value in NO emissions. This situation shows that the additive amount is at the optimum level and that the combustion contributes to the maximum energy conversion without reaching high temperatures.

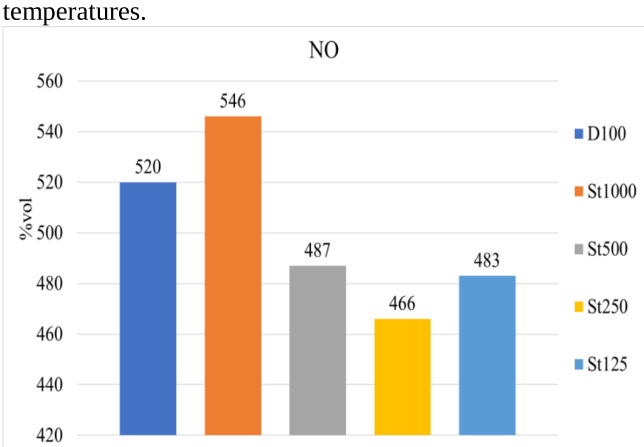

Figure 7 - Nitrogen Oxide

Figure 8 shows the graph of CO emissions. In the graph, the CO emission values of D100, st125, st250, st500 and st1000 fuels are 0.021, 0.018, 0.019, 0.012 and 0.015 ppmvol, respectively, under 300 Nm engine load. The amount of CO emissions is an important factor that helps us understand how efficient the combustion is [24]. Low CO emissions indicate that the fuel is approaching complete combustion and high combustion efficiency. According to the graph, D100 has the highest CO emissions, which indicates that the combustion is not good and the combustion efficiency is low. St500 has both low CO emissions and the highest thermal efficiency in the BTE graph. This shows that the St500 additive level optimizes combustion, producing maximum work from the fuel's energy, and the engine is operating more efficiently.

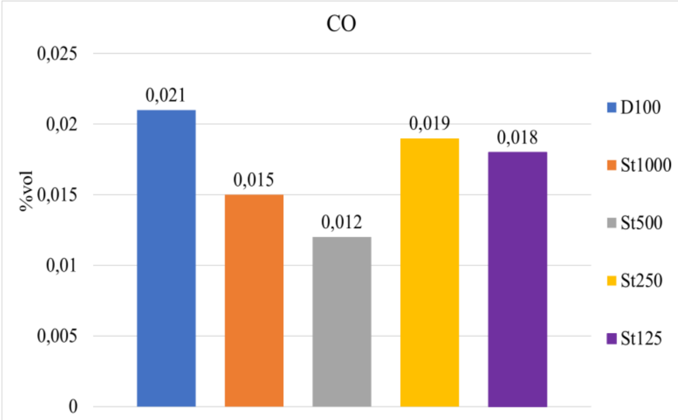

Figure 8 - Carbon monoxide

4. CONCLUSION

In this study, the effects of stearic acid on combustion due to these properties when used with diesel fuel were investigated in a compression ignition engine. Experiments were conducted at 300 Nm torque and 700 rpm constant engine speed by adding 125, 250, 500 and 1000 ppm stearic acid to pure diesel fuel. It was evaluated whether stearic acid had a negative effect on combustion. This study is preliminary for the studies to be carried out later on the use of flammable metals coated with stearic acid in diesel engines.

1- Stearic acid additive to diesel fuel generally has a positive effect on thermal efficiency. Thermal efficiency decreased relatively at 125 ppm stearic acid additive. However, thermal efficiency increased at 250, 500 and 1000 ppm stearic acid additives. The optimum stearic acid additive reached as a result of the experiments is 500 ppm. Because st500 fuel was observed to have 7.78% higher thermal efficiency than D100 fuel.
2- Stearic acid additive generally reduced NO emissions except st1000 fuel. CO emission value of all stearic acid additive fuels is lower than pure diesel. Stearic acid improved CO emissions.
3- Stearic acid additive generally did not have a negative effect on thermal efficiency and emissions. Positive information was produced that it can be used as a coating material in the authors' ongoing studies with elements sensitive to combustion.

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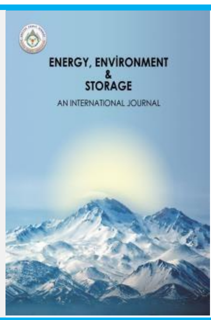

Evaluation of Cikapundung River Water Quality Based on Upstream, Middle, and Downstream Characteristics: A Comparative Approach

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ABSTRACT. This study evaluates the water quality of the Cikapundung River based on upstream, midstream, and downstream characteristics using a comparative approach. The water quality data include parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and total dissolved solids (TDS). The analysis revealed that DO, BOD, COD, and TSS parameters in certain river segments did not meet the surface water quality standards set forth in Government Regulation No. 22 of 2021, Class II. The high pollution levels were mainly attributed to domestic, industrial and other human activities. This study provides important insights into the water quality conditions of the Cikapundung River and their implications for environmental management in the region.

Keywords: Cikapundung, water quality, evaluation, and comparative

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1. INTRODUCTION

The Cikapundung River, a tributary of the Citarum River, is approximately 28 km in length and traverses West Bandung Regency upstream, Bandung City in the middle, and Bandung Regency downstream before discharging into the Citarum River. The confluence area of these two rivers is prone to flooding, particularly during the rainy season. The most significant impacts are observed in Baleendah, Dayeuhkolot, and Bojongsoang.

The Cikapundung River catchment area encompasses 111.3 km² in its upstream region, 90.4 km² in the central portion, and 76.5 km² in its downstream reach. The Cikapundung watershed area is home to approximately 750,559 individuals, with an average population density of 122 people per hectare. At 2004, the riparian area is home to 1,058 buildings, with a total population of 71,875. This has resulted in significant pollution due to the presence of domestic, household, and industrial waste.

As reported by the West Java Regional Environmental Management Agency (BPLHD) in 2016, the high concentration of settlements adjacent to the Cikapundung River results in the direct discharge of approximately 90% of domestic waste into the river. Consequently, the Cikapundung River receives in excess of 2.5 million liters of waste on a daily basis, in addition to waste from the industrial sector. This finding aligns with the conclusions by Rahayu et al. [1], who determined that the river, which traverses West Bandung Regency, Bandung City, and Bandung Regency, is particularly susceptible to contamination from domestic sewage.

Some cases of pollution include domestic waste in Babakan Siliwangi and Babakan Ciamis, textile waste in Bojongsoang, and pollution in the Cikapundung watershed [2]. In fact, the upstream part of the Cikapundung watershed shows an increase in pollution if there are no early preventive measures [3]. Based on field studies and chemical analysis, water quality in the upper Cikapundung watershed (Bukti Tunggul) continues to decline compared to previous studies (Surtikanti, 2004; Surtikanti & Priyandoko, [2] [4].

2. MATERIALS AND METHODS

2.1 Study Area

This research was conducted in the Cikapundung River area, with the research site divided into three main segments: upstream, middle, and downstream. The upstream segment was situated at Dago Pakar, the middle segment at Viaduct Road, and the downstream segment at Soekarno-Hatta Road. The objective of this segmentation was to observe variations in water quality at each location based on geographical conditions and human activities along the river.

2.2 Water Quality Analysis

This research was conducted through a comparative analysis of the surface water quality of the Cikapundung river, encompassing the upstream, middle, and downstream segments. The analysis employed secondary data of water Quality Cikapundung River at 2022 sourced from Saeful and Artiningrum's research [5]. The parameters utilized as constraints in this investigation encompass dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total suspended solids, and total dissolved solids. The suitability of the water quality was then evaluated in accordance with the surface water quality standards outlined in Government Regulation Number 22 of 2021, Class II, and a comparative approach to water quality was undertaken for each river segment.

3. MATERIALS AND METHODS

3.1 Dissolved Oxygen (DO)

DO plays a vital role as an indicator of water quality due to its involvement in the oxidation and reduction of both organic and inorganic substances [6]. It is crucial for various biochemical processes in aquatic ecosystems, supporting the breakdown of organic materials and the respiration of aquatic organisms. Consequently, the level of dissolved oxygen is often used to assess the health of water bodies and the extent of potential pollution.

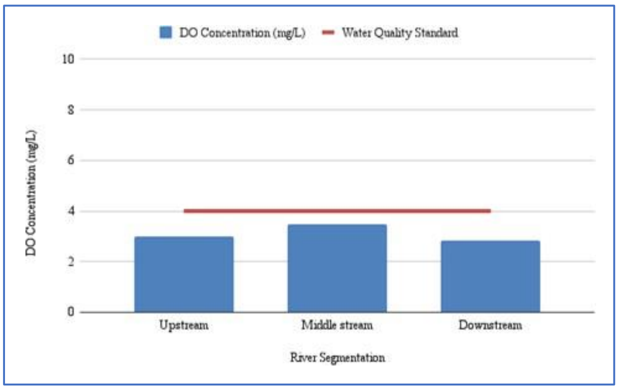

Fig. 1. DO concentration profile in the Cikapundung River

As illustrated in the Figure 1, the graph depicts the DO concentration profile across three segments of the Cikapundung River, namely the upstream, middle, and downstream regions. The data indicates that the DO concentration in these segments falls below the quality standards, with a range of 3.07 to 3.47 mg/L. This suggests that the DO concentration levels in the Cikapundung River do not align with the established quality standards across all segments. The highest concentration of dissolved oxygen is observed in the middle segment of the Cikapundung River, while the lowest concentration is found in the downstream segment.

The observed decline in DO levels suggests the potential influence of industrial or human- related activities in the surrounding residential areas, as reported by Effendi [7]. This finding aligns with the hypothesis that a reduction in DO concentration can be attributed to the decomposition of organic and inorganic materials.

3.2 Biochemical Oxygen Demand (BOD)

BOD, is a parameter used to assess water quality. It represents the amount of dissolved oxygen required by aerobic biological microorganisms to decompose organic matter present in water samples at a specific temperature over a defined period of time.

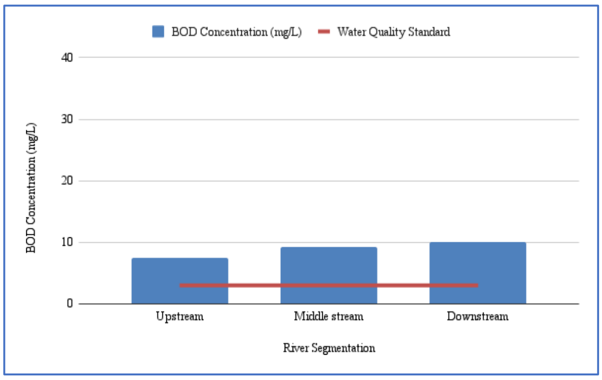

Fig. 2. BOD concentration profile in the Cikapundung River

As illustrated in Figure 2, the graph depicts the concentration profile of biochemical oxygen demand (BOD) across three segments of the Cipundung River, namely the upstream, middle, and downstream regions. The data demonstrate that the BOD concentration in these segments exceeds the quality standards, with a range of 7.52 to 10 mg/L. This indicates that the BOD concentration levels in the Cikapundung River do not correspond with the established quality standards across all segments. The highest concentration of BOD is observed in the downstream segment of the Cikapundung River, while the lowest concentration is found in the upstream segment. This is potentially because the condition of settlements in the downstream area of the Cikapundung River is very dense, and the sanitation conditions of the surrounding communities are not very good, especially in the management of garbage and domestic wastewater.

3.3 Chemical Oxygen Demand (COD)

COD is a parameter utilized to assess the quality of water. It quantifies the quantity of oxygen necessary to decompose the total organic matter present in the water through chemical processes. A high concentration of COD indicates a high content of organic matter in the water.

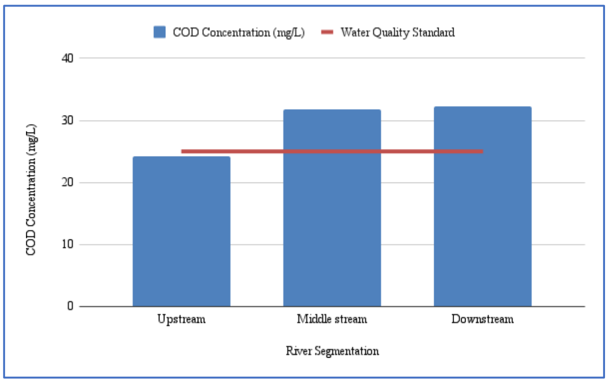

Fig. 3. COD concentration profile in the Cikapundung River

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As illustrated in Figure 3, the graph depicts the concentration profile of chemical oxygen demand (COD) across three segments of the Cipundung River, namely the upstream, middle, and downstream regions. The data demonstrate that the concentration of chemical oxygen demand (COD) in the middle and downstream segments exceeds the quality standards, with a range of 24.27 to 32.26 milligrams per liter (mg/L). This indicates that the concentration levels of COD, particularly in the middle and downstream segments of the Cikapundung River, are not in accordance with the established quality standards. The highest concentration of COD is observed in the downstream segment of the Cikapundung River, while the lowest concentration is found in the upstream segment. The industrial activities conducted in the downstream area of the Cikapundung River are a significant contributing factor to the elevated concentration of chemical oxygen demand (COD) observed in the region.

3.4 Total Suspended Solid (TSS)

As defined by Effendi [7], TSS, or Total Suspended Solids, represents a water quality parameter comprising materials or substances that are suspended in water and contribute to turbidity. The TSS component of water comprises mud, fine sand, and microscopic organisms, which are primarily derived from soil erosion and sedimentation transported by water flow.

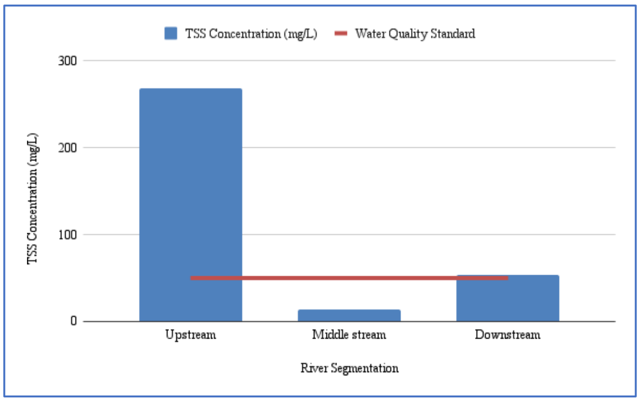

Fig. 4. TSS concentration profile in the Cikapundung River

As illustrated in Figure 4, the graph depicts the total suspended solid (TSS) concentration profile across three segments of the Cikapundung River, namely the upstream, middle, and downstream regions. The data demonstrate that the TSS concentration in the upstream and downstream segments exceeds the quality standards, with a range of 14 to 269 mg/L. This indicates that the TSS concentration levels in the upstream and downstream regions of the Cikapundung River are not in accordance with the established quality standards. The highest concentration of TSS is observed in the downstream segment of the Cikapundung River, while the lowest concentration is found in the middle segment. The condition of the river channels in the Cikapundung River Basin area has relatively little pavement construction, so the potential for sediment erosion is very high, which can contribute to increasing TSS concentrations in water bodies. In addition, livestock activities in the upstream area also contribute to the high TSS content in the upstream river. Cikapundung, because the management of livestock waste by the community is not optimal.

3.5 Total Dissolved Solid (TSS)

Total Dissolved Solids (TDS) represents the content of dissolved materials with a diameter of 10^{-6} mm, as well as colloids between 10^{-6} and 10^{-3} mm in diameter, and is one of the water quality parameters. The materials in question consist of chemical compounds and other materials that cannot be filtered using filter paper with a pore diameter of 0.45 µm [7]. The high TDS value also indicates the presence of dissolved sediment and turbidity [8].

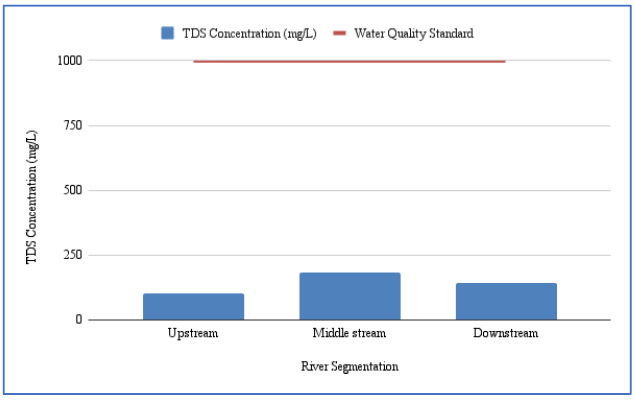

Fig. 5. TDS concentration profile in the Cikapundung River

As illustrated in Figure 5, the graph depicts the total dissolved solid (TSS) concentration profile across three segments of the Cikapundung River, namely the upstream, middle, and downstream regions. The data indicate that the dissolved oxygen (DO) concentration in these segments falls below the quality standards, with a range of 104 to 182 milligrams per liter (mg/L). This indicates that the TDS concentration levels in the Cikapundung River are consistent with the established quality standards across all segments. The highest concentration of TSS is observed in the middle segment of the Cikapundung River, while the lowest concentration is found in the uppermost segment.

4. CONCLUSION

The study shows that the water quality of the Cikapundung River varies among its segments, DO levels are consistently low in all river segments, with the highest concentration observed in the middle segment and the lowest in the downstream segment, reflecting the impact of human activities. BOD and COD parameters exceed quality standards in the downstream segment, indicating high levels of organic material from domestic and industrial waste. TSS levels are high in the upstream and downstream segments due to soil erosion and livestock activities, while TDS is within acceptable limits in all segments. These results highlight the need for improved waste management, especially in the downstream segment, to improve the water quality of the Cikapundung River and support environmental sustainability in the region

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Grey Parallel Assembly Line Balancing

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ABSTRACT.

Purpose: The purpose of this paper is to solve a grey parallel assembly line balancing problem with type-I (G-PALBP-I) to minimize the number of stations under the major constraints and restrictions of the PALs.

Design/methodology/approach: A manufacturing system with parallel assembly lines (PALs) consists of at least two assembly lines placed next to each other in the facility layout. To design real-life PAL applications, the processing durations of the tasks may not always be fixed due to workers getting tired or making mistakes. In addition, the variability in customer demands may also affect the cycle duration called the total processing duration of a station. To better reflect the real-life applications of PALs, task and cycle times are expressed with grey system theory and grey numbers. A binary integer linear programming model is proposed to solve the G-PALBP-I.

Findings: The proposed model is implemented to the PAL systems designed by using a simple assembly line data in the literature. The results show that considering precedence relationships and variability in task and cycle durations provides a more flexible and consistent perspective.

Originality/value: The grey system theory and grey numbers, to the best of the authors' knowledge, have not been considered to describe the uncertainty of task and cycle times in PALBPs. Therefore, this study provides important insight to both researchers and decision-makers in practice.

Keywords: Parallel assembly line balancing, grey numbers, uncertain processing times, uncertain cycle time, mathematical model, binary integer linear programming

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Abbreviations:

ALBP: Assembly line balancing problem
BILP: Binary integer linear programming
PAL: Parallel assembly line
PALBP: Parallel assembly line balancing problem
G-PALBP-I: Grey parallel assembly line balancing problem with type-I
SALBP: Simple assembly line balancing problem
SA: Simulated annealing

1. INTRODUCTION

Assembly lines have been an indispensable element of production facilities for over a century. To meet the variable demands of the customers and compete in the global economy, an assembly line system can be designed in different ways depending on the nature of the product, the capacity demand of the firm, and various restrictions. One of these design types is the parallel assembly lines (PALs) placed next to each other to produce the same or similar products within a single facility. In real-life applications of PALs, there may be common stations, i.e., common workers, on two adjacent parallel lines. Thus, both the length of the assembly line is shortened and the installation of more stations is prevented. Due to the common stations between the adjacent lines, the idle/waiting times in the separate stations are converted to value-added periods. The most important advantage of PALs is the increase in the facility's production capacity. In addition, since a problem occurring on one line will not prevent other parallel lines, this provides a great advantage in terms of production continuity.

The parallel assembly line problem (PALBP), which deals with the task assignment processes to stations, was first introduced by Gökçen et al.[1]. They presented a binary integer linear programming (BILP) model. Since then, many papers have been published on different versions and restrictions of the PALBPs such as single-model [2,3,4,5,6,7,8,9,10,11,12,13,14] mixed-model [15, 16, 17, 18], U-shaped [19, 20, 21, 22, 23, 24, 25, 26], two-sided [27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41], uncertainty in task durations [42, 43, 44] and operator capabilities [45, 46, 47, 48, 49, 50, 51, 52].

The academic studies and evaluations implemented on the PALBPs usually have some general assumptions. The most important of these assumptions is that the task processing durations are considered within a deterministic framework. Deterministic and fixed task durations, especially in worker-focused assembly lines, mean that human factors such as workers getting tired, having trouble concentrating, and making mistakes are not considered. That is, treating workers working on PALs as robots and making such assumptions prevents the decision-makers from obtaining consistent results in real-life applications. Therefore, taking an approach that considers the uncertainties of the task processing times in PALBPs would provide a more realistic approach.

According to the aforementioned studies, only three publications are identified on the uncertainty of the task and/or cycle durations. The first one of these papers is presented by Baykasoğlu et al. [42]. They propose a multi-objective ant colony optimization algorithm to minimize the number of stations by addressing the uncertainty of cycle and task durations with a fuzzy logic approach. The second one is published by Özcan [43]. He presents a chance-constrained, piecewise-linear, mixed integer programming formulation and a tabu search algorithm to minimize the number of stations by addressing the stochastic task durations. The last paper is presented by [44]. They, like [43], consider the stochastic task durations. In addition, they also take into account the equipment cost to minimize the number of stations by proposing a hyper-heuristic approach based on a simulated annealing (SA) algorithm. In conclusion, while the fuzzy logic or statistical distribution approaches are used for the uncertainties of task and cycle durations in the PALs, no study addresses grey system theory and grey numbers for the task and cycle durations. Based on the grey system theory [53], the uncertain processing time is expressed as interval grey numbers [54]. Unlike the fuzzy method and the interval method, the interval grey number defines an unknown actual value with a definite range and limits the specified upper and lower bounds of the uncertain processing time [54]. The authors' findings show that only two papers address the task or cycle durations with grey numbers in the assembly line balancing problems (ALBPs). The first paper that considers grey demand and grey task times for the simple ALBP (SALBP) is presented by Arık et al. [55]. They propose a BILP model to minimize the number of stations and evaluate the results of a numerical example solved by the proposed model. In the second paper, Dang and Xie [54] build a mathematical model and design the SA algorithm based on a neighborhood search strategy to solve the ALBP with interval grey processing durations. However, there is no PALBP where the uncertainty in cycle time and task durations is defined by grey numbers. Accordingly, the main contributions of this paper are as follows; (1) this paper introduces the parallel assembly line balancing problem considering grey task processing and cycle durations to minimize the number of stations (G-PALBP-I), (2) this paper proposes a new BILP model to solve the G-PALBP-I.

The remainder of this paper is designed as follows. The problem definition and the proposed BILP model are presented in Section 2. Section 3 includes a numerical example. The last section is the conclusion and future directions.

2. GREY PARALLEL ASSEMBLY LINE BALANCING PROBLEM WITH TYPE-I

2.1 Problem definition

In PAL systems, at least two assembly lines ($\boldsymbol{h} = \boldsymbol{1}, \dots, \boldsymbol{H}; \boldsymbol{H} \geq \boldsymbol{2}$) are placed parallel to each other. One or similar product models can be manufactured in the production facility. Each product model is manufactured on one assembly line. The set of tasks ($\boldsymbol{i} = \boldsymbol{1}, \dots, \boldsymbol{N_h}$) and task precedence relationships ($i \in P_{ih}$) for each product model are known in advance. Each line can have its own separate station or common stations can be established on two adjacent h and $h+1$ lines ($k=1,\dots,K$). At common stations, tasks on both assembly lines are performed. The processing durations of tasks performed entirely by workers are defined as grey numbers. The task durations may include uncertainty due to human factors such as workers getting tired or making mistakes. Therefore, the processing duration of task i on any line h has a closed interval with lower and upper bounds ($\boldsymbol{t_{hi}^{LU}} = [\boldsymbol{t_{hi}^{L}}, \boldsymbol{t_{hi}^{L}}]$). The cycle time C of all stations established in PAL systems is the same. According to the classical approach, the cycle time depends on the product demand. Fluctuations in demand can lead to uncertainty in cycle times. For example, if demand forecast or order quantity information is insufficient to provide insight into the sales status of any product, there may be uncertainty in demand and therefore in cycle times. Therefore, the demand of the product model on line h ($\boldsymbol{D_h^{LU}} = [\boldsymbol{D_h^{L}}, \boldsymbol{D_h^{U}}]$) and the cycle time of the PAL system ($\boldsymbol{C^{LU}} = [\boldsymbol{C^{L}}, \boldsymbol{C^{U}}]$) are defined through grey data with lower and upper bounds. The relation between grey demand and grey cycle time is given in equation (1). In equation (1), $\boldsymbol{AC_h}$ represents the time-dependent annual capacity of the line h. The joint cycle time is obtained by dividing the total of $\boldsymbol{AC_h}$ ($\boldsymbol{AC^{total}}$) by the demand value of the product models to be produced on the lines. The objective is to minimize the number of stations by considering some PAL constraints and task and cycle durations with grey numbers.

$$C^{LU} = [C^L, C^U] = \left[\frac{AC^{total}}{D_h^{LU}}\right] = \left[\frac{\sum_{h=1}^{H} AC_h}{D_h^{LU}}\right] = \left[\frac{\sum_{h=1}^{H} AC_h}{D_h^{U}}, \frac{\sum_{h=1}^{H} AC_h}{D_h^{L}}\right] \quad (1)$$

2.2. Mathematical model

The proposed BILP model for the G-PALBP-I is as follows:

$$\min \sum_{k=1}^{K} Z_k \quad (2)$$

$$\sum_{k=1}^{K} X_{hik} = 1 \quad \forall i = 1,\dots,N_h \text{ and } \forall h = 1,\dots,H \quad (3)$$

$$\sum_{k=1}^{K} X_{hik} \le M \cdot Z_k \quad \forall h = 1,\dots,H \text{ and } \forall i = 1,\dots,N_h \quad (4)$$

$$Z_k \ge Z_{k+1} \quad \forall k = 1,\dots,K-1 \quad (5)$$

$$\sum_{k=1}^{K} (K-k+1)\cdot(X_{hik} - X_{hjk}) \ge 0 \quad \forall h = 1,\dots,H \text{ and } \forall i \in P_{jh} \quad (6)$$

$$\sum_{i=1}^{N_h} X_{hik} \le M \cdot U_{hk} \quad \forall h = 1,\dots,H \text{ and } k = 1,\dots,K \quad (7)$$

$$\sum_{i=1}^{N_h} X_{hik} \ge U_{hk} \quad \forall h = 1,\dots,H \text{ and } k = 1,\dots,K \quad (8)$$

$$U_{hk} + U_{(h+l)k} = 1 \quad \forall h = 1,\dots H-2;\ \forall l = 2,\dots, H-h \text{ and } k = 1,\dots,K \quad (9)$$

$$\sum_{i=1}^{N_h} t_{hi}^{LU} \cdot X_{hik} + \sum_{i=1}^{N_{h+1}} t_{(h+1)i}^{LU} \cdot X_{(h+1)ik} \le C^{LU} \quad \forall h = 1,\dots,H-1 \text{ and } \forall k = 1,\dots,K \quad (10)$$

$$X_{hik}, U_{hk}, Z_k \in \{0,1\} \quad \forall h = 1,\dots,H;\ \forall i = 1,\dots,N_h \text{ and } \forall k = 1,\dots,K \quad (11)$$

The objective function (2) minimizes the number of stations on the PAL systems. Constraint (3) ensures that each task i on line h is assigned to only one station. Constraint (4) states that if any task i on line h is assigned to station k, that station must be established. Constraint (5) prevents the next station from being established before the previous station is established. Constraint (6) ensures that tasks are assigned to stations by checking the precedence relationships between tasks i and j on line h. Constraints (7) and (8) state that if task i on line h is assigned to station k, that station serves line h. Constraint (9) guarantees that station k can only be assigned to two adjacent lines, i.e., assembly lines h and $h+1$. Constraint (10) ensures that the total grey processing times of tasks assigned to a station do not exceed the grey cycle time of the PAL system. Constraint (11) defines the binary decision variables. In constraint (10), the closed lower and upper bounds of total grey task durations must satisfy the closed lower and upper bounds of the grey cycle duration, respectively. Accordingly, satisfying the lower and upper bounds means satisfying all possible alternatives in that range. Therefore, constraint (10) can be updated as constraints (12) and (13).

$$\sum_{i=1}^{N_h} t_{hi}^{L} \cdot X_{hik} + \sum_{i=1}^{N_{h+1}} t_{(h+1)i}^{L} \cdot X_{(h+1)ik} \le C^{L} \quad \forall h = 1,\dots,H \text{ and } \forall k = 1,\dots,K \quad (12)$$

$$\sum_{i=1}^{N_h} t_{hi}^{U} \cdot X_{hik} + \sum_{i=1}^{N_{h+1}} t_{(h+1)i}^{U} \cdot X_{(h+1)ik} \le C^{U} \quad \forall h = 1,\dots,H \text{ and } \forall k = 1,\dots,K \quad (13)$$

3. A NUMERICAL EXAMPLE AND DISCUSSIONS FOR G-PALBP-I

In this section, the numerical example of the SALBP presented by Arık *et al*. [55] is converted to two adjacent parallel assembly lines. Annual capacity information is given in Table 1. Also, grey processing times and precedence relationships are given in Table 2. It is assumed that the same product is produced in both lines. Since there are two assembly lines in the PAL system, the AC^{total} and C^{LU} is calculated as follows:

$$AC^{total} = AC_1 + AC_2 = (300\cdot 60\cdot 8\cdot 1) + (300\cdot 60\cdot 8\cdot 1) = 288000 \text{ minutes/year}.$$

$$C^{LU} = [C^L, C^U] = \left[\frac{288000}{36000}, \frac{288000}{24000}\right] = [8, 12] \text{ minutes/unit}$$

Table 1. Product and annul production information

Parameters	Value
Number of PALs	2
Number of tasks on one assembly line	14
Annual uncertain demand (unit/year)	[24000,36000]
Number of working days per year (day/year)	300
Number of shifts in a working day	1
Working hours in a shift (hour/day)	8

Table 2. Grey task durations and precedence relationships (Arık *et al*. 2019)

Tasks (i)	Grey processing times ($[t_{hi}^L, t_{hi}^U]$)	Predecessor (P_{jh})	Tasks (i)	Grey processing times ($[t_{hi}^L, t_{hi}^U]$)	Predecessor (P_{jh})
1	[1,1.3]	-	8	[8, 12]	5
2	[2,2.6]	1	9	[2, 3]	7, 8
3	[3,4.5]	2	10	[3, 4.5]	9
4	[4,6]	2	11	[4, 7.6]	10
5	[2,3.6]	1	12	[5,8.5]	10
6	[4,4.4]	3, 4, 5	13	[6,9.6]	11
7	[6,6.6]	6	14	[7,10.5]	12, 13

For comparison, each line is solved both as SALBP and PALBP. The task assignments obtained for SALBP and PALBP are given in Tables 3a and 3b, respectively. According to Tables 3a and 3b, 18 stations are established for SALBP and 17 stations for PALBP. For the PALBP, stations 4, 5, 6, and 9 are the common stations. Stations 1, 2, 3, 11, and 14 are established for the line 1, and stations 7, 8, 10, 12, 13, 15, 16, and 17 are established for the line 2. As a result, despite the gray numbered demands and duty periods, G-PALBP-1 contributes to energy conservation with one station lower installation cost.

Table 3a. Task assignments for SALBP with two assemble lines

	Stations	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*

Line 1	**Tasks**	1, 2, 3, 5	4, 6	8	7	9, 10	11	12	13	14
	Grey duration of station	[**8, 12**]	[**8,** 10.4]	[**8, 12**]	[6, 6.6]	[5, 7.5]	[4, 7.6]	[5, 8.5]	[6, 9.6]	[7, 10.5]

	Stations	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***
Line 2	**Tasks**	1, 2, 3, 5	4, 6	8	7	9, 10	11	12	13	14
	Grey duration of station	[**8, 12**]	[**8,** 10.4]	[**8, 12**]	[6, 6.6]	[5, 7.5]	[4, 7.6]	[5, 8.5]	[6, 9.6]	[7, 10.5]

Table 3b. Task assignments for PALBP with two assemble lines

Stations	***1***	***2***	***3***	*4**	***5 ****	*6**	***7***	***8***	*9**	*10*	*11*	***12***	*13*	*14*	*15*	*16*	*17*
Tasks of line 1	1, 2, 3, 5	8	4, 6	7	9, 10	12			11		13			14			
Tasks of line 2				1	5	2	8	3, 4	6	7		9, 10	11		13	12	14
Grey duration of station	**[8, 12]**	**[8, 12]**	**[8,** 10.4]	[7, 7.9]	[7, 11.1]	[7, 11.1]	**[8, 12]**	[7, 10.5]	**[8, 12]**	[6, 6.6]	[6, 9.6]	[5, 7.5]	[4, 7.6]	[7, 10.5]	[6, 9.6]	[5, 8.5]	[7, 10.5]

*****Common station

3. CONCLUSION AND FUTURE DIRECTIONS

This paper introduces the parallel assembly line balancing problem considering the grey task and grey cycle durations to minimize the number of stations (G-PALBP-I). To better reflect the real-life applications of PALs, task and cycle times are expressed with grey system theory and grey numbers. A BILP model is proposed to solve the G-PALBP-I. The proposed model is implemented to the PAL systems designed by using simple assembly line data in the literature. The results show that considering precedence relationships and variability in task and cycle durations provides a more flexible and consistent perspective.

In order to contribute to the literature and application processes of the PAL systems, the following topics may be addressed in future studies: State-of-the-art approaches such as heuristics, meta-heuristics, and hyper meta-heuristics may be proposed for G-PALBP-I including large-sized task sets. On other suggestion is that, in the PALs, worker assignment and line balancing may be solved together by considering different worker capabilities with the grey system theory. In addition, the ergonomic concerns of the workers may be considered as the grey system theory to better handle the real-life applications of the PALs systems.

In future studies, grey robotic PALBP and grey robot/human collaborative PALBP may be considered in terms of energy consumption, energy saving, and energy cost.

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