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An Innovative Strategy to Reduce Carbon Dioxide Emissions Resulting from Stopping at Traffic Lights: A Case Study in Bisha, Saudi Arabia

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Abstract

The rising levels of carbon dioxide (CO2) emissions, notably from idling vehicles while waiting at traffic lights, have evolved into a pressing global issue that requires urgent attention. This comprehensive research delves into the relationship between the distribution of traffic signals and the emission of carbon in Bisha, Saudi Arabia. . This study investigates the correlation between traffic signal distribution and carbon emissions in Bisha, Saudi Arabia. Data was collected through fieldwork, GPS tracking, and emissions measurements. The research reveals that the city's traffic signals are concentrated on main road axes, contributing to increased traffic congestion and emissions. Private cars dominate the vehicle types, followed by taxis and heavy goods transport. The findings show a significant connection between the city's traffic signal placement and the surge in carbon emissions, particularly in the context of Bisha. The research brings to light that a significant concentration of traffic signals is found along the city's primary roads, worsening traffic congestion and contributing to a substantial increase in carbon emissions. Furthermore, the investigation argues that the leading vehicle category in Bisha consists of private cars, followed closely by taxis and heavy goods transport vehicles. These findings provide a valuable perspective on the environmental and societal consequences of this critical issue.

Keywords
Smart strategy, Carbon dioxide, Traffic lights, Safety, City of Bisha

1. Introduction

The global concern over rising carbon dioxide (CO2) emissions and their adverse effects on the environment and human health has led to extensive research in the field of sustainable urban planning and transportation. This literature review explores key themes related to CO2 emissions, the imperative to reduce them, vehicle-related solutions, and identifies gaps in existing research with a specific focus on idling vehicles at traffic lights in the context of Bisha, Kingdom of Saudi Arabia.

In the existing studies, literature emphasizes that there is an increase in carbon dioxide emissions and the various adverse effects of the trend. Even though some regions have worked to reduce their carbon dioxide emissions in the recent years, the dominant trend remains that carbon emissions are on the increase (EPA, 2023). The EPA approximates that global carbon emissions have increased by about 90 percent since the 1970s. The upward trend in carbon dioxide (CO2) emissions is propelled by a complex web of factors, such as rapid urbanization, heavy reliance on fossil fuels in transportation, surging energy consumption, and globalized production patterns (Zhang & Chiu, 2020). As cities expand, energy demands soar, leading to extensive construction and industrial activities, all contributing to heightened emissions. The global increase of vehicle use and dependence on fossil fuels increase the issue, while the energy-intensive technologies and long, carbon-intensive supply chains associated with global trade further drive up CO2 emissions (Liu et al, 2021). Increasingly, urban areas are emerging as significant contributors to carbon dioxide emissions (Awan, Alnour, Jahanger & Onwe, 2022), (Abbasi, Parveen, Khan & Kamal, 2020), (Pu, Wang & Wang, 2022).

The effects of this surge in CO2 emissions are far-reaching for the environment. One of the most prominent consequences is the intensification of the greenhouse effect. As CO2 levels continue to rise, they accelerate the greenhouse effect. The result is an accelerated warming of the Earth's atmosphere, leading to the destabilization of climate patterns, the proliferation of extreme weather events, and the erosion of our planet's delicate ecological balance (Faruque et al, 2022). Such consequences are hardly isolated; they ripple across the global landscape. This interconnectedness means that the impact of heightened CO2 emissions in one region can affect other regions worldwide, impacting ecosystems, weather systems, and communities far removed from the primary sources of emissions (Carleton et al, 2022). In light of these trends, several scholars have advocated for a collective, rather than individual effort towards mitigating the effects of the greenhouse effect (Sabherwal, Pearson & Sparkman, 2021). In this context, the impact of escalating CO2 emissions on Sustainable Development Goals (SDGs) is a cause for concern. SDG 13, which is dedicated to climate action, stands particularly vulnerable. The intensifying CO2 emissions pose an immense challenge to the realization of this goal and, by extension, the broader tapestry of sustainable development (Jansson, 2023). Climate change, spurred by the greenhouse effect fueled by rising CO2 levels, touches upon numerous other SDGs, from eradicating poverty (SDG 1) to ensuring clean water and sanitation (SDG 6) and sustaining life below water and on land (SDGs 14 and 15) (Laumann et al, 2022). Thus, the surge in CO2 emissions is not merely an environmental issue but a holistic threat to human well-being and the planet's future.

1.2. Research Objectives

The main aim of this study is to develop a smart strategy to reduce carbon dioxide emissions based on GIS Analysis to assess spatial distribution of traffic signals in Bisha.

The research objectives include the following:

1. To investigate the correlation between the distribution of traffic signals and carbon dioxide emissions in Bisha city.
2. To examine the relationship between the distribution of old cars and increased carbon emissions in Bisha city.

1.3. Problem Statemen

Globally, CO2 emissions from the transportation sector have surged significantly over the past few decades. According to the International Energy Agency transportation-related emissions accounted for approximately 24% of global CO2 emissions in 2022, a figure that has been steadily rising, to reach 8 Gt CO2 in 2022 (International Energy Agency, 2022). This alarming trend underscores the growing carbon footprint of the transportation sector, of which idling vehicles constitute an often-ignored facet. Within Saudi Arabia, a nation deeply entrenched in the fossil fuel industry, the challenge of mitigating CO2 emissions from idling vehicles acquires

a unique dimension. According to data from the World Bank, Saudi Arabia's CO2 emissions reached 14.3 million metric tons per capita in 2020, marking a considerable increase over the previous decade (World Bank, 2021). While a substantial portion of these emissions is attributed to energy production, the transportation sector, particularly urban traffic, plays an increasingly pivotal role (Zhang & Chiu, 2020).

In Bisha, Saudi Arabia, frequent stops at traffic lights contribute significantly to carbon dioxide (CO2) emissions, negatively impacting air quality and exacerbating environmental concerns. The current traffic management system lacks an efficient strategy to mitigate these emissions during idle times at intersections. This necessitates the exploration and implementation of an innovative approach that addresses the specific traffic patterns and environmental challenges in Bisha, aiming to reduce CO2 emissions, enhance traffic flow, and contribute to a more sustainable urban environment.

In the city of Bisha, the issue of carbon dioxide (CO2) emissions resulting from idling vehicles at traffic lights has evolved into a critical environmental concern. With a mean of 3.06, 80% of respondents in a study by Abuhasel affirmed that carbon emissions in the city of Bisha were increasing (Abuhasel, 2023). Urbanization and population growth have led to a surge in the number of vehicles on the road, consequently exacerbating traffic congestion (Mallick, Almesfer, Alsubih, Ahmed & Ben Kahla, 2022). The expansion of road networks has been unable to keep pace with the escalating demand for mobility, resulting in frequent traffic jams and prolonged idling at traffic lights. The consequences of this traffic congestion are not confined solely to inconvenience; they extend to a significant rise in CO2 emissions (Abuhasel, 2023).

As the global community rallies to combat climate change and meet the targets set forth in the Paris Agreement, addressing CO2 emissions from idling vehicles is no longer optional but a moral and environmental imperative. Failing to act on this issue poses immediate and long-term risks to public health, air quality, and exacerbates climate change. Furthermore, with Bisha's urbanization trajectory showing no signs of slowing down, this issue is poised to intensify, amplifying its impact on the environment and the well-being of Bisha's residents. In light of these statistics and trends, this study aims to shed light on the extent of the problem, assess its consequences, and propose sustainable strategies to mitigate the environmental and societal impacts of this critical issue.

Traffic Congestion Impact: Bisha experiences notable traffic congestion, especially at intersections controlled by traffic lights. Prolonged idling times at these junctions contribute significantly to vehicular emissions, specifically carbon dioxide, exacerbating the city's air quality issues.

Environmental Consequences: High levels of CO2 emissions not only pose environmental challenges but also have adverse effects on public health. Addressing this issue is crucial for creating a healthier living environment and aligning with global efforts to combat climate change.

Urban Development: Bisha's growth necessitates a comprehensive strategy that integrates innovative traffic management solutions, considering both current and future urban development plans. The proposed strategy should align with the city's sustainable development goals and promote eco-friendly practices.

Technology Integration: The strategy should explore the integration of cutting-edge technologies, such as smart traffic lights, adaptive signal control systems, or alternative transportation solutions, to optimize traffic flow and reduce emissions during idle times.

Stakeholder Involvement: In developing and implementing this strategy, collaboration among various stakeholders, including city authorities, traffic management departments, environmental agencies, and the public, is essential to ensure its effectiveness and successful adoption.

Addressing these facets in the problem statement will provide a comprehensive understanding of the challenges and lay the groundwork for proposing an innovative solution to reduce carbon dioxide emissions resulting from stopping at traffic lights in Bisha, Saudi Arabia.

By addressing these additional elements in the problem statement, the development and implementation of an innovative strategy to reduce carbon dioxide emissions in Bisha can be approached holistically, considering environmental, economic, social, and regulatory dimensions.

1.4. Study Area

The study takes the city of Bisha as an applied field. The city is located in the Asir region in the southwest of the Kingdom of Saudi Arabia, and it is one of the thirteen regions in the Kingdom. Fig. 1.below shows that the city of Bisha extends from north to south with a length of 185 km, and its width varies from east to west, as its lowest width was recorded in the south by about 48 km, and the maximum width in the north by about 120 km. 659 km2, while its population is 248,452 people in 2022 AD, and its importance is gained from its location on Wadi Bisha, the largest and most important valley in the Kingdom, and the valley has the largest dam in the Kingdom, with a storage capacity of 325 million m 3, and Bisha is famous for agriculture, especially date palms, and the city of Bisha in the neighboring cities with a good network of roads, the most important of which is the Khamis Mushait-Bisha-Raniyeh-Khurmah road, which is one of the pivotal roads linking the Asir region with the Makkah region.

The city of Bisha has become a microcosm of the challenges associated with CO2 emissions from idling vehicles at traffic lights. Respondents in a study significantly agreed- a mean of about 3.06 that air pollution in Bisha was increasing in comparison to other cities such as Abha (Abuhasel, 2023). Scholars explain that as urbanization rapidly transforms Bisha and the traffic volume increases, so do emissions from stationary vehicles (Abuhasel, 2023), (Mallick et al, 2022). This localized issue reflects broader trends observed in urban centers across the Middle East and, indeed, the world.

Addressing this challenge in Bisha not only contributes to Saudi Arabia's commitment to SDG 13 but also offers insights into tackling urban environmental issues in the broader Middle East context (Figure 1).

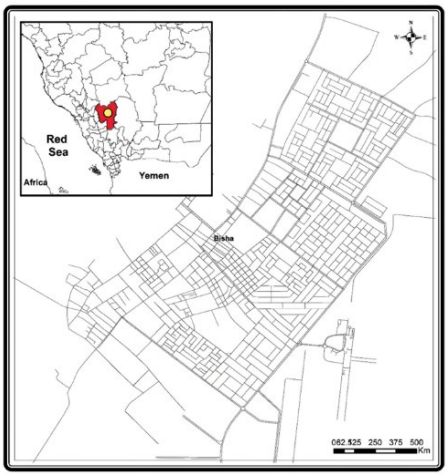

Figure 1. The location of the city of Bisha in the Kingdom of Saudi Arabia in 2023

1.5. The Hypothesis of the Study

To achieve the main objective of the study, there are two hypotheses were formulated:
Hypothesis 1. There is a strong correlation between the distribution of traffic signals and carbon dioxide.
Hypothesis 2. There is a strong correlation between the distribution of old cars and increased carbon emissions.

2. Data Collection

Data used in this research have been collected from various sources such as research studies, surveys, government databases, public records, private companies, academic institutions. The accessibility of the data depends on its source and any restrictions or permissions associated with it. The availability of the data on which an operation is performed depends on various factors. It can be determined by the source of the data, whether it is publicly available or proprietary. Additionally, the data's accessibility may depend on any legal or privacy restrictions that apply to it. In

some cases, the data may be readily available and easily accessible, such as public datasets or open-source databases. These types of data are typically freely available for anyone to use. However, there may be situations where the data is not readily available or requires specific permissions or licenses to access. This can be the case with proprietary datasets owned by companies or organizations that restrict access to their data. Furthermore, certain types of sensitive data, such as personal information or classified government data, may have strict regulations and restrictions on their availability and usage.

3. Methodology

The researcher utilized Geographic Information System (GIS) as a tool for generating maps and conducting spatial analysis. This was accomplished using a software program known as "Arc GIS 10.8," with the aim of elucidating the spatial arrangement of the phenomenon under investigation. The accomplishment of this step involved the establishment of a geo-database through the utilization of a software application known as "Arc Catalogue" which consists of a collection of feature classes containing data on various aspects of urban areas. This allows researchers to perform spatial statistical analyses, density analyses, pattern analyses, proximity analyses, and spatial interpolation analyses.

The study relies mainly on field work, to monitor the study variables as follows:

- Determining traffic signal distribution locations through a GPS device (ground positioning device).
- Measuring the percentage of carbon emissions from cars parked at traffic lights through an emissions measuring device, and collecting them in a special database in the city of Bisha.

In addition to designing a form to inventory the number of cars at each signal according to the variables of type, fuel type, and year of manufacture. The field study will be conducted during the month of October 2023 AD, and it is expected that the number of inventory forms will reach more than 300 forms that will be distributed during three different times a day, in the morning, the peak time, as well as during noon, and evening.

4. Results and Discussion

4.1. Spatial distribution of traffic signals on the road network in the city of Bisha:

There are many traffic lights in the city of Bisha, as the traffic lights direct and organize traffic on the city's roads, to reduce accidents or collisions at dangerous intersections. The roads of the city of Bisha include twenty-eight pretimed signals (Figure 2), in which the Signal timing periods are specified for different traffic movements, through a fixed time cycle that does not take into account the volume of instantaneous traffic demand on the road.
The distribution of traffic signals is concentrated on the main road axes in the city of Bisha, led by King Saud Road, where traffic is regulated by fourteen traffic lights, due to its extension. The large longitudinal road runs from the northeast to the southwest of the city, with a length exceeding 25 km, followed by Prince Sultan Road with five traffic lights.

As for the distribution of signals at the neighborhood level, they are clearly concentrated in the Al-Fahd and Al-Khuzama neighborhoods, as they together occupy about 16 traffic signals, making up more than half of them in the city. This is due to the concentration of the road network in them and the large number of intersections.

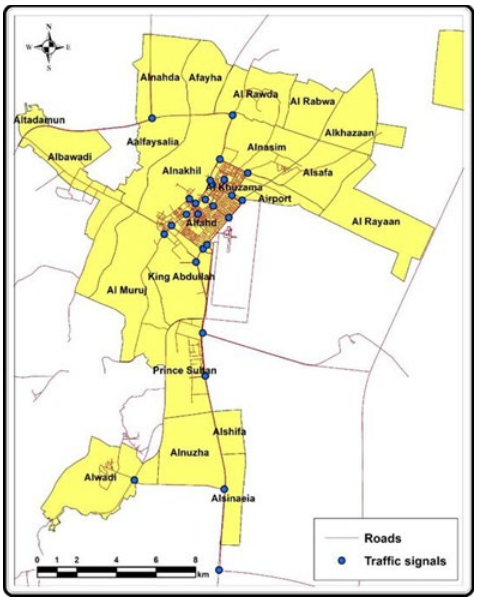

Figure 2. Distribution of traffic signals in the city of Bisha in 2023

4.2. Spatial analysis of vehicle distribution at traffic signals

There are many means of transportation at traffic signals in the city, and their characteristics and distribution vary. Private cars, private fares, and large buses are used to transport passengers. The field study yielded several results, which we summarize as follows:

Average vehicle traffic volume/hour:

Traffic movement varies from one hour to another during the day, and is generally characterized by severe congestion during rush hours, as it is determined by the daily work trip, educational and recreational trips, or trips for treatment and shopping. Three periods can be distinguished in which traffic reaches its peak at traffic lights. In the city, the morning period is from (7-9 am), which constitutes the period for going to work and studying, and the second period begins from (1-3 pm) during the return of employees and students, while the third period begins from (5-7 pm) and sometimes extends until ten. In the evening, for the purpose of shopping, visits, household needs, etc.

This indicates the importance of the city and the multiplicity of its functions and services to its residents and surrounding centers. The researcher conducted a field study on the five largest traffic signals in terms of vehicle density, with two each in the Al-Khuzama and Al-Fahd neighborhoods, and one in the King Abdullah neighborhood. The vehicles were standardized in application. For the equivalent unit factor according to the English rates on urban roads, a private car, taxi, and light transport are equivalent to one unit of measurement, while a medium and heavy transport vehicle is equivalent to two units, a “bus” is equivalent to three, and a motorcycle and bicycle are equivalent to 0.75, 0.33 of a unit. Measured in order, the results of the field study presented in Table 1 revealed the following facts:

- The average volume of vehicle traffic at traffic signals in the city in both directions is 1,192 equivalent units/hour, and the movement reaches its peak in the evening period to record 1,332 equivalent units/hour, followed by the morning period with an average of 1,236 equivalent units, noting the approximate equality of vehicle entry traffic in the morning and evening. While traffic out of the city is greater in the evening, this is explained by the high temperatures in summer, and therefore residents prefer to make their trips in the evening, especially with the long distance between the city of Bisha and neighboring cities.

Table 1. Average volume and percentage of vehicle traffic at traffic signals in the city of Bisha in 2023 (equivalent unit/hour)

District	Period	Entry		Exit		Total
		unit/hour	%	unit/hour	%	
Signal NO. (1)	**The morning**	1124	54.1	954	45.9	2078
	Noon	923	58.4	714	41.6	1637
	Evening	1089	49.7	1101	50.3	2190
	Average	1045	53.1	923	46.9	1968
Signal NO. (2)	**The morning**	984	50.7	955	49.3	1939
	Noon	944	58.9	658	41.1	1602
	Evening	735	47.5	811	52.5	1546
	Average	887	52.3	808	47.7	1695
Signal NO. (3)	**The morning**	458	47.7	501	52.3	959
	Noon	422	54.4	353	45.6	775
	Evening	562	47.5	622	52.5	1184
	Average	481	49.4	492	50.6	973
Signal NO. (4)	**The morning**	401	49	417	51	818
	Noon	388	56.5	298	43.5	686
	Evening	484	40.3	718	59.7	1202
	Average	424	47.1	477	52.9	901
Signal NO. (5)	**The morning**	175	45.3	211	54.7	386
	Noon	231	67.1	113	32.9	344
	Evening	287	52.5	260	47.5	547
	Average	231	54.3	194	45.7	425
Total average	**The morning**	628	50.8	608	49.2	1236
	Noon	582	57.7	427	42.3	1009
	Evening	630	47.3	702	52.7	1332

Source: Field inventory results.

- The average vehicular traffic decreased in the afternoon, reaching 1009 equivalent units/hour, and this is clearly visible at all signals, with more than two-thirds of the volume of traffic passing through it, which is traffic mainly related to education.

- Signal No. (1) issues the city's signals regarding the average daily volume of vehicle traffic (1968 equivalent units/hour), followed by Signal No. 2. This is due to them linking the city of Bisha with cities with economic, administrative and demographic weight, namely Khamis Mushait and Abha, while the traffic reached the lowest level is at signal number (5), as it does not exceed 425 equivalent units/hour.

- Traffic movement increased in the evening in both directions at all city signals, while vehicular movement topped in the morning at signal number (2) with an average of 1939 equivalent units/hour in both directions. This is attributed to its coincidence with official working hours, especially at the University of Bisha.

The average volume of vehicle traffic varies according to their types, as the relative distribution of vehicle types is linked to the nature of the relationship between the city and neighboring areas. The field study revealed the superiority of private cars in the volume of vehicle traffic at all traffic lights in the city, as their percentage ranges between 30.1% and 44.1%, and this is due to There has been an increase in private car ownership in the city, reaching 876 cars per 1,000 families, and their movement increases clearly on all days of the week except Friday, especially in the morning with all city signals.

Private taxis come in second place with a percentage of 28.1% of the total vehicle movement at traffic signals in the city of Bisha. This is due to the concentration of their movement within the city, and heavy goods transport vehicles ranked penultimate in terms of the total vehicle movement at all traffic signals. This indicates the city's reliance on To meet their needs for various goods from neighboring major cities, and even from the penultimate distant cities,

which are about 800 km away. This may explain the preference for using heavy goods transport vehicles over long distances to reduce the material costs of transported goods, or due to the large size and abundance of goods.
Light goods transport vehicles came in last place, and this is explained by the proximity of the main traffic lights to the old neighborhoods of the city, where markets are concentrated near it, especially vegetables and fruits, which are brought daily.

5. Conclusion

The study conducted in Bisha, Saudi Arabia, shows the significant challenges stemming from the increasing carbon dioxide (CO2) emissions associated with idling vehicles at traffic lights. Bisha, serving as a sample of broader urban trends, struggles with rising traffic congestion and emissions driven by rapid urbanization and population growth. These research findings emphasize the urgent need for implementing sustainable strategies to mitigate the environmental and societal impacts of this issue. The implications of this research extend beyond Bisha, becoming a global concern. Addressing CO2 emissions resulting from idling vehicles has become a moral and environmental obligation with immense consequences for public health, air quality, and the fight against climate change. The study illustrates the need for collaborative efforts to combat climate change and align with the Sustainable Development Goals. As Bisha's urbanization continues rapidly, the challenge of reducing CO2 emissions remains pressing. The findings of this study inform policy and urban planning, not only in Bisha but also in other urban areas facing similar challenges. Embracing sustainable urban planning, improving traffic management, and promoting eco-friendly transportation options are critical steps in mitigating the environmental impact of idling vehicles at traffic lights. Taking action now is essential to protect the environment and ensure the well-being of current and future generations.

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Biographies

Maha Nimshan Alshehri is a student at University of Bisha, College of Engineering, in her final year of Industrial Engineering 2019-2024. Member in the Research and Publication section at UB IEOM, and is a member of the Renewable Energy Club. Leader of several academic projects, including projects under the supervision of Professor Dr. Khaled Abuhasel, including a project to analyze cost and time to improve an air quality in a Bisha Cement Factory. She interested in the field of renewable energy, and she aspires to get training in a place befitting her skills and interests. Her research interests include optimization, sustainability, intelligent systems, environmental health, and risk analysis.

Hadeel Abdulrahman Alshahrani student studying to get bachelor's in industrial engineering in Bisha university 2019-2024. she participated in few projects under Professor Dr. Khaled Abuhasel supervising in engineering project management [Green Bisha], Operations Research and Engineering Economics. she aims to be researcher in the sustainability field to optimize the environmental health, and to follow the kingdom of Saudi Arabia's vision 2030 into a green country.

Maali Shealan Alshahrani student studying to get bachelor's in industrial engineering in Bisha University 2019-2024. She worked under Professor Dr. Khaled Abuhasel supervising in some courses in the last 3 years got some experience in research, development and optimization aiming to be a professional researcher in the Industrial Engineering.

Sheikha Masoud Alshehri is a student at University of Bisha, College of Engineering, majoring in industrial engineering. She is expected to graduate this year in 2024 and obtain a bachelor's degree. She worked on many projects under the supervision of Professor Khaled Abuhasel. She did field training at the Bisha Chamber of Commerce and Industry and obtained a certificate from the Training Department. She also obtained certificates for attending many training courses offered by the University of Bisha and the Engineering Club. She aspire to be a successful industrial engineer and work in investment companies concerned with the areas of quality, projects, maintenance and safety, such as oil and gas companies and manufacturing industries.

Abeer Hathal Alaklobi student studying to get bachelor's in industrial engineering in Bisha university 2019-2024. She volunteered in Compassion for the care of orphans Bisha, participated in few projects under Professor Dr. Khaled Abuhasel supervision. Her goal is to get as much experience and knowledge as possible to be a professional researcher in the Industrial Engineering field.

Khaled Ali Abuhasel received the B.Sc. and M.Sc. degrees from the University of Central Florida, Orlando, FL, USA, in 2009 and 2010, respectively, and the Ph.D. degree from New Mexico State University, Las Cruces, NM, USA, in 2012, all in industrial engineering. He is currently a Professor with the Mechanical Engineering Department, University of Bisha, Saudi Arabia. He holds three U.S. patents, and more than 67 publications in journals and proceeding of very reputable conferences. His research interests include optimization, systems engineering, health care systems, intelligent systems, artificial neural network methodologies, and statistical analysis.