Evaluating the Achievement of Singapore's Environmental Policy Goals for Enhanced Sustainability and Livability through Big Data Analysis

Yuchen Zhao *

University of New South Wales, Sydney, Australia

* Corresponding author: 1912100220@mail.sit.edu.cn

Abstract. In the face of rapid urbanization and increasing environmental concerns, the imperative of achieving sustainable development has become a global priority. Singapore, a pioneering advocate of innovative urban planning and governance, has emerged as a beacon of sustainability and livability through its strategic environmental policies. This research employs big data analysis to evaluate the extent to which Singapore's environmental policy goals have contributed to enhanced sustainability and livability. By curating and analyzing datasets spanning urban development, environmental quality, resource management, and societal well-being, this study quantitatively assesses policy outcomes. The analysis highlights both achievements and challenges within Singapore's policy framework. The research reveals an increase in population density, impacting resource allocation and urban development. Moreover, a rise in methane emissions and decreasing freshwater resources per capita present significant sustainability challenges. Conversely, efforts such as waste-to-energy initiatives and the active, beautiful, clean waters programme have contributed positively to emissions reduction and water resource enhancement.

Keywords: Sustainability, Singapore, Environmental Policy, Livability, Big Data.

1. Introduction

In an age defined by the confluence of urbanization, pressing environmental concerns, and rapid technological advancements, the pursuit of sustainable development has ascended as a paramount global imperative. As cities across the world grapple with the multifaceted challenges posed by the rapid expansion of urban landscapes, the necessity of effective policies that harmonize the goals of enhanced sustainability and improved quality of life has grown increasingly apparent. In this dynamic context, Singapore, renowned for its innovative approaches to urban planning and governance, has emerged as a beacon of sustainability and livability through its strategic environmental policies [1].

A prevalent theme across the studies is the significance of big data in influencing policy formation. Previous researches underline the promise of integrating big data and AI technologies in informing decisions relating to urban design, management, and sustainability strategies. These technological tools equip policymakers with data-driven insights, enabling them to comprehend urban dynamics and devise precise policies tailored to address sustainability challenges effectively [2]. The literature prominently showcases Singapore as a leading example of a smart city that effectively employs big data analysis in shaping its policies. Noteworthy contributions, exemplified by the work of Cavada et al. [3], delve into the ramifications of Singapore's smart city initiatives across multiple aspects of urban living, underscoring the pivotal role that data-driven insights play in enhancing the quality of life for its residents.

Furthermore, the review demonstrates that policy frameworks are a crucial area of investigation. Previous research presents a framework that marries AI technology with dimensions like culture, metabolism, and governance, thereby aligning with Sustainable Development Goal 11 [4]. This underscores the critical nature of holistic policy frameworks that encompass not just technological aspects but also social, economic, and environmental considerations.

However, a noteworthy limitation emerges across the reviewed literature – the absence of in-depth and robust big data analysis to evaluate the extent to which Singapore's sustainable smart city policies have accomplished their objectives. Although some studies touch upon the potential of AI and big

data technologies, few delve into comprehensive data-driven assessments of policy outcomes. This limitation is mainly attributed to the predominance of qualitative analyses and case studies, which fail to provide the quantitative rigor required for a comprehensive understanding of policy effectiveness.

This research embarks on an ambitious exploration into the heart of Singapore's environmental policies and their tangible outcomes, harnessing the formidable capabilities of big data analysis. By delving into vast datasets encompassing facets such as urban development dynamics, environmental quality indices, resource management strategies, and societal well-being indicators, this study sets out to quantitatively assess the degree to which Singapore has materialized its environmental policy aspirations. Employing systematic analysis of data trends, intricate correlations, and discernible patterns, this research endeavors to illuminate the complex interplay between policy initiatives and their resulting influence on the overarching goals of sustainability and livability.

The findings underscore the importance of data-driven policy formulation, implementation, and adaptation. The research underscores the need for continuous monitoring, strategic adjustments, and a holistic understanding of urban dynamics to realize sustainability and livability goals. As cities worldwide seek to harmonize economic growth with environmental preservation, Singapore's experiences serve as a valuable case study, illuminating the potential of data-driven insights in achieving a more sustainable and livable urban future.

2. Background

In an era characterized by unprecedented urbanization, escalating environmental concerns, and rapid technological advancements, the concept of sustainable development has arisen as a paramount global imperative. As cities around the world grapple with the multifaceted challenges posed by the exponential growth of urban areas, the pressing need for effective policies that harmonize the objectives of enhanced sustainability and improved livability has become unmistakably clear. Amid this context, Singapore, a dynamic city-state lauded for its ingenious and forward-thinking approaches to urban planning and governance, has emerged as a pioneering advocate of sustainability and livability [5].

The integration of big data analysis into the realm of urban governance has opened unprecedented vistas for evaluating the efficacy of policies directed at achieving pivotal environmental objectives. At the forefront of this movement, Singapore has fervently embraced its aspiration to evolve into a resplendent "City in Nature," a commitment demonstrated concretely through its comprehensive Green Plan 2030 [6]. This forward-looking plan, coupled with the influential Singapore Sustainable Blueprint 2015 and the pioneering ABC Programme initiated in 2006, propels Singapore into the spotlight as a compelling subject for discerning the potential of big data in gauging policy triumphs and their impact on sustainability and livability [7-9]. Singapore's innovative urban strategies serve as a beacon of inspiration, illuminating a path towards a future where urban environments not only thrive but coexist harmoniously with their natural surroundings. With urbanization surging at unprecedented rates, the demand for adaptable policies that cater to both the burgeoning urban landscape and the preservation of the environment has never been more pressing. Singapore's endeavors reflect a global acknowledgment that progress must be measured not only by economic growth but also by its sustainability, resilience, and the quality of life it bestows upon its citizens [10-14].

3. Methodology

3.1. Data

The foundational basis of this research rests upon data meticulously sourced from the esteemed repository https://data.humdata.org/. From this repository, four distinct datasets were carefully

curated, each accompanied by its dedicated CSV file. These datasets were acquired through direct downloads, facilitated by the comprehensive offerings of the website.

Central to this research are the CSV files housing a wealth of time-series data. Each file serves as a repository for multiple variables or indexes of paramount importance. With a temporal breadth spanning from 1960 to 2022, these data values adroitly accommodate any potential gaps inherent within certain years. The conduits of data exploration, the CSV files, underwent meticulous processing utilizing the versatile R programming language. This endeavor embraced two distinct formatting approaches, each distinct in its presentation yet synergistic in its role.

3.2. Selection of Variable of the Data

From the corpus of 149 variables, an incisive process of selection culminated in the choice of 30 variables for intensive scrutiny and analysis. These selections were rigorously governed by a duet of selection principles:

Completeness: A conspicuous emphasis was placed upon the completeness of data, with a predilection towards variables that exhibited minimal lacunae or gaps within the temporal spectrum of 1960 to 2022.

Relevance: The selection process was equally informed by the relevance of variables to the purview of environmental considerations and other cognate facets.

The complete roster of all 149 variables, together with the chosen 30 variables for in-depth investigation. This meticulous orchestration of data curation, intricate processing, and judicious variable selection collectively underscores the rigorous scientific integrity embedded within this study. These chosen data variables effectively encapsulate pivotal facets spanning urban development, environmental quality, resource management, and societal well-being. By virtue of their meticulous selection, these data variables constitute the bedrock upon which the assessment of policy efficacy, vis-à-vis the enhancement of sustainability and livability, is deftly forged.

3.3. Analysis methods

To ensure that the data were analysed correctly, the research carried out 4 different data analysis approaches, those includes:

Univariate Data Analysis: To study the distribution of individual variables and their trends over time, for each variable, graphs including histograms, boxplots, or density plot can be conducted to study its distribution, as well as scatter plots and line charts to study the trend of the variables over certain period.

Time Series Chart of Selected Variables: The research analysis provides a time series chart for all 30 selected variables, organizing them into panels using facets to visualize their trends over time.

Correlation Analysis: The research calculated pairwise correlations among the selected variables and used the corrplot package to visualize the correlations using color-coded squares.

Linear Regression Analysis: The research performed linear regression analysis on pairs of variables to understand their relationships and visualize them with scatter plots and fitted regression lines.

Following the creation of graphs and charts, an in-depth analysis will be carried out in the context of Singapore's government environmental policy. The objective is to assess the extent to which the policy has accomplished its envisioned goals and objectives successfully.

4. Results

4.1. Evolution of Forest Area

The data presented from 2010 to 2022 underscores several critical challenges that indicate Singapore has not fully achieved the objectives outlined in its environmental policy, the Green Plan 2030 (Figure 1). This is evident from specific trends and figures that reveal a gap between the vision

and the actual environmental changes that have transpired. Here's a more specific breakdown of what this data signifies to readers:

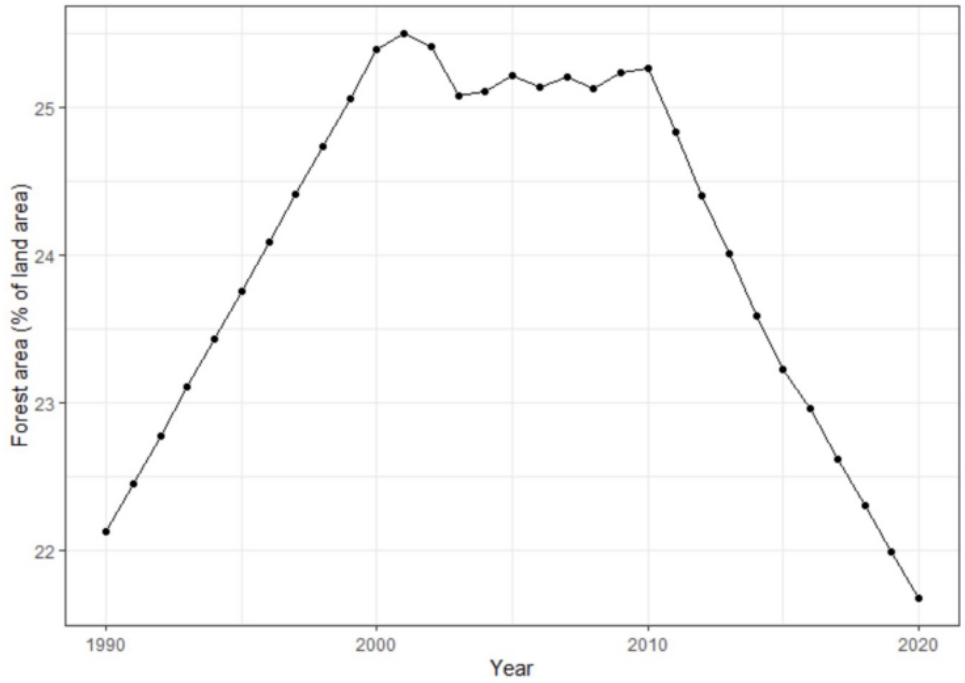

Figure 1. Evolution of Forest Area

(1) Reduction in Tree Cover: The initial data point in 2010 indicated that Singapore had 20.6 thousand hectares (kha) of tree cover, making up about 30% of its land area. However, by 2022, there was a net loss of 103 hectares of tree cover. This reduction in tree cover contradicts the Green Plan's objective of expanding green spaces and increasing tree cover. The loss of tree cover is significant, not just for aesthetic reasons, but because trees play a crucial role in absorbing carbon dioxide, which contributes to cleaner air and a more sustainable urban environment.

(2) Emissions Impact: The loss of 103 hectares of tree cover resulted in the emission of 57.7 thousand metric tonnes of CO2. This signifies that not only did Singapore fail to enhance its green spaces, but the environmental consequences of this loss extend to carbon emissions, thereby exacerbating the city's carbon footprint. This is directly at odds with the Green Plan's aim to mitigate climate change through tree planting.

(3) Primary Forest Loss: The loss of 46 hectares of humid primary forest between 2001 and 2022 further compounds the challenges. Despite the emphasis on biodiversity enhancement, the reduction in primary forest area by 5.4% sends a concerning signal about the conservation efforts. The loss of primary forest has implications for the habitat of various wildlife species and undermines the goal of fostering coexistence between humans and wildlife.

(4) Biodiversity Impact: The Green Plan aspires to create conducive environments for diverse wildlife species. However, the data shows that the loss of tree cover and primary forest has a direct impact on biodiversity. This is particularly alarming given that the plan seeks to enhance habitats for migratory birds, hornbills, otters, and other species. The loss of primary forest, which is often critical for wildlife habitats, contradicts this objective.

(5) Policy-Reality Gap: The data's implications underscore a discrepancy between Singapore's ambitious vision and the challenges it has encountered in translating that vision into action. The documented loss of tree cover, primary forest, and their subsequent impacts on emissions and biodiversity reveals a gap between policy objectives and on-ground reality.

In essence, the data shows that despite Singapore's aspirations to become a "City in Nature" and the comprehensive goals outlined in the Green Plan 2030, there is a clear discrepancy between the intended outcomes and the actual environmental changes observed. The environmental challenges, such as tree cover reduction, emissions increase, and loss of critical habitats, indicate that factors like

urbanization, deforestation, and other drivers are impeding the progress toward the green vision. This discrepancy signifies that while the aspirations are commendable, there's an urgent need to address the challenges and recalibrate strategies to achieve the desired environmental outcomes by 2030.

4.2. Evolution of other variables

By using the same graphing methods used to study forest cover, it is possible to study all 30 variables over time, and to save space, we use facets to the 30 variables over time in the same graph. It shows that some of them have a monotonically increasing or decreasing trend, and some of them have a fluctuating pattern (Figures 2 and 3).

Areas of Challenge or Potential Concern:

Increasing CO2 Emissions from Fuel Consumption and Methane Emissions: The increasing emissions of CO2 and methane are not aligned with the Green Plan's objectives to reduce emissions and achieve carbon neutrality. These trends could potentially hinder Singapore's progress towards its emission reduction targets.

Population Density and Urbanization: While urbanization and economic growth driven by population density are important, the sustainability of this growth is critical. Ensuring that urbanization aligns with sustainable development principles, as outlined in the Green Plan, is crucial to managing the environmental impact.

Decreasing Agriculture Land and Forestry and Fishing Value Added: The decline in agriculture land and natural resource-related economic activities may raise concerns about the potential impact on biodiversity, ecosystems, and sustainable resource management. These trends could challenge the Green Plan's goals related to conserving and enhancing Singapore's natural environment.

4.3. Multi-variate data analysis

For any two variables, since both are values measured for each year, we can calculate their correlation. For 30 variables, the pairwise correlation would be caclulated choose (30,2)=435 time. Here I use the Hmisc package to compute the correlation coefficient, which has two conveniences, 1) it is fast to compute and 2) it can handle correlations between missing data (Figure 4). After obtaining 435 correlation coefficients, the correlation between variables was demonstrated using the corrplot package.

As colorbar points out in Figure 4, blue means a positive correlation and red is signal of a negative correlation. Positively correlated variables are clustered together and negatively correlated variables are clustered together. For example, the variables in the upper left corner of the figure are positively correlated, so they are clustered together.

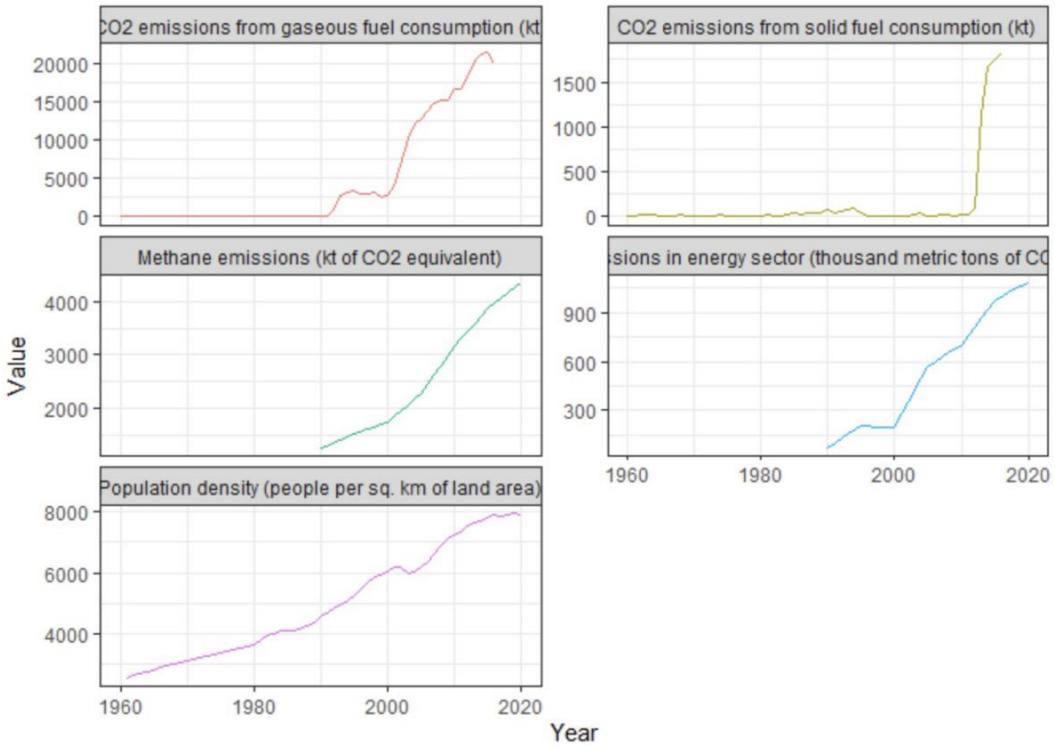

Figure 2. Monotonically Increasing Variables

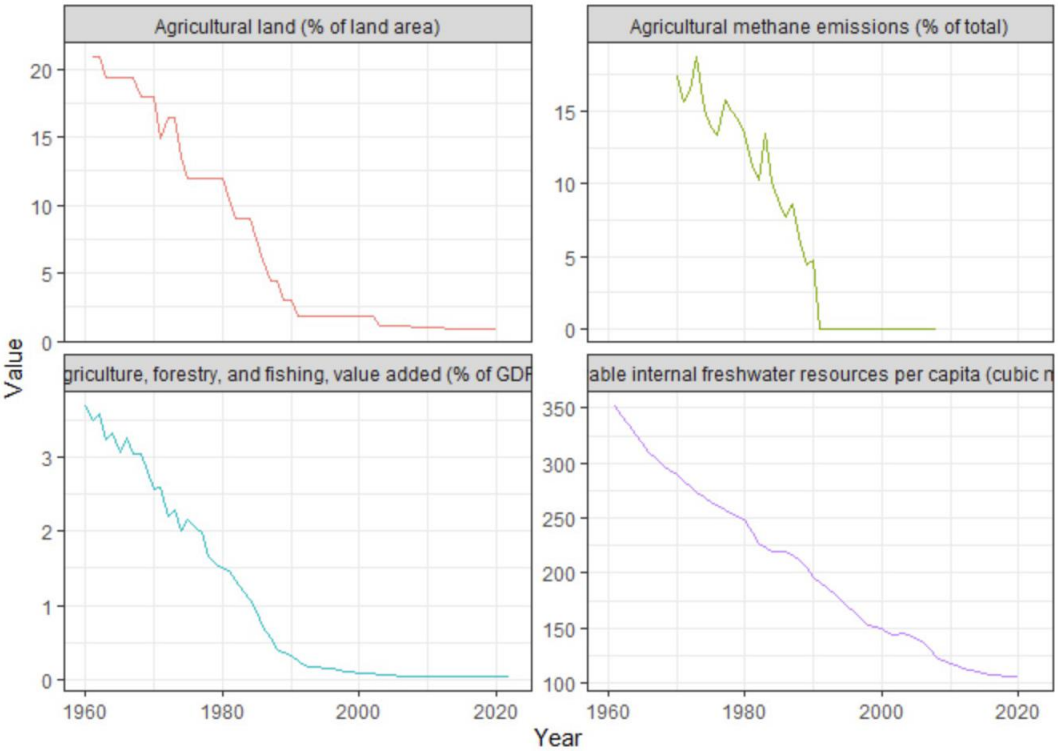

Figure 3. Monotonically Increasing Variables

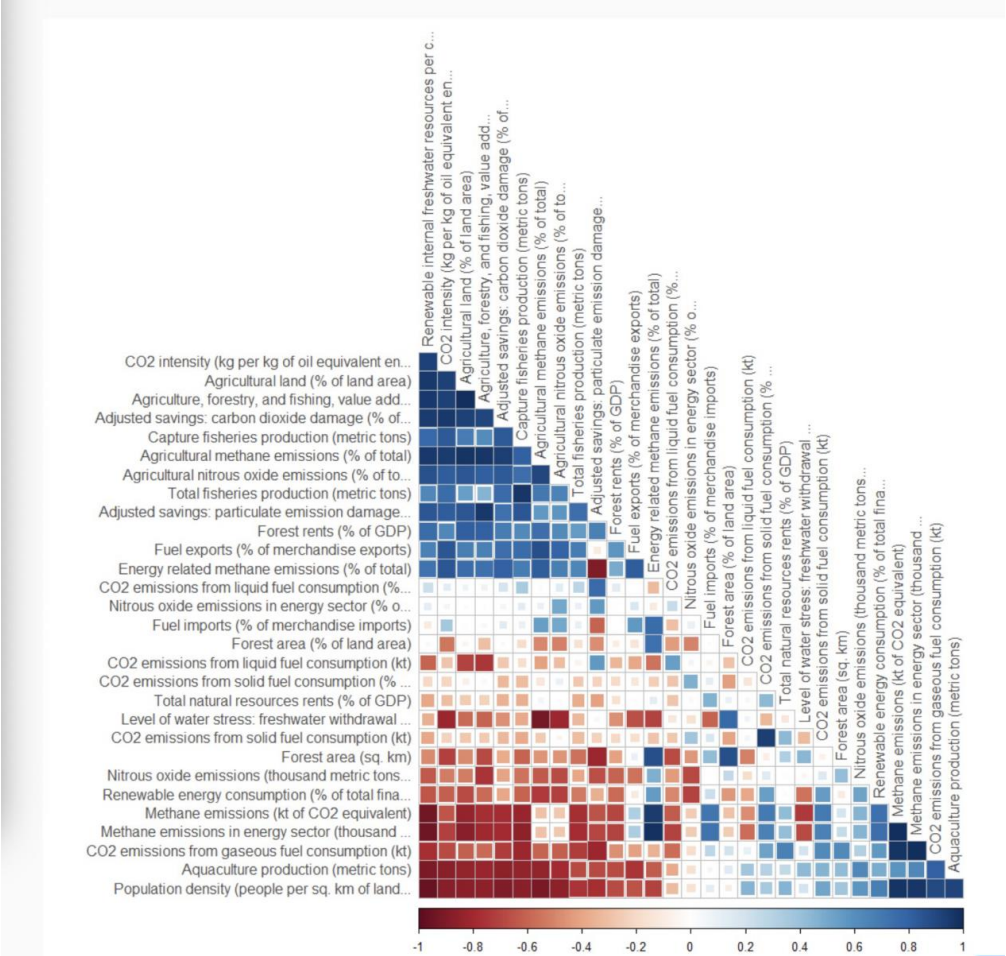

Figure 4. Correlation among Variables

5. Discussion

5.1. Evaluation of Sustainable Singapore Blueprint 2015 and Green Plan 2030

5.1.1. Data analyses

The increasing population density (people per square kilometer of land area) suggests that Singapore's population has been growing and becoming more concentrated over time (Figure 2). High population density can lead to increased vehicular traffic and industrial activities, resulting in higher emissions of air pollutants, including particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs). This can lead to deteriorating air quality, which poses health risks, particularly to vulnerable populations. Secondly, a higher population density often means increased energy consumption, transportation emissions, and industrial activity, all of which contribute to higher carbon dioxide (CO2) emissions, a major driver of climate change (Figure 5). Thirdly, the concentration of buildings, roads, and other urban infrastructure in densely populated areas can create urban heat islands. These areas experience higher temperatures than surrounding rural areas due to increased heat absorption and reduced vegetation. Elevated population density can exacerbate this effect, impacting local microclimates and energy consumption. Finally, urbanization associated with high population density often leads to habitat destruction, fragmentation, and reduced green spaces, which can negatively impact local biodiversity.

The increase in methane emissions (kt of CO2 equivalent) is a concern as methane is a potent greenhouse gas (Figure 2). As methane is a potent greenhouse gas that, when released into the atmosphere, contributes to the formation of ground-level ozone, a major air pollutant. Elevated methane emissions can worsen air quality and exacerbate respiratory problems. Secondly, methane

emissions from sources such as agriculture (e.g., rice paddies and livestock), landfills, and fossil fuel extraction can significantly contribute to Singapore's overall greenhouse gas emissions. These emissions amplify the country's carbon footprint and contribute to global warming. While methane itself does not directly contribute to the urban heat island effect, its role in enhancing ozone formation can indirectly exacerbate heat-related problems. Finally, while methane emissions are not directly linked to ecosystem degradation, the broader issue of climate change, which methane contributes to, can disrupt ecosystems and threaten biodiversity.

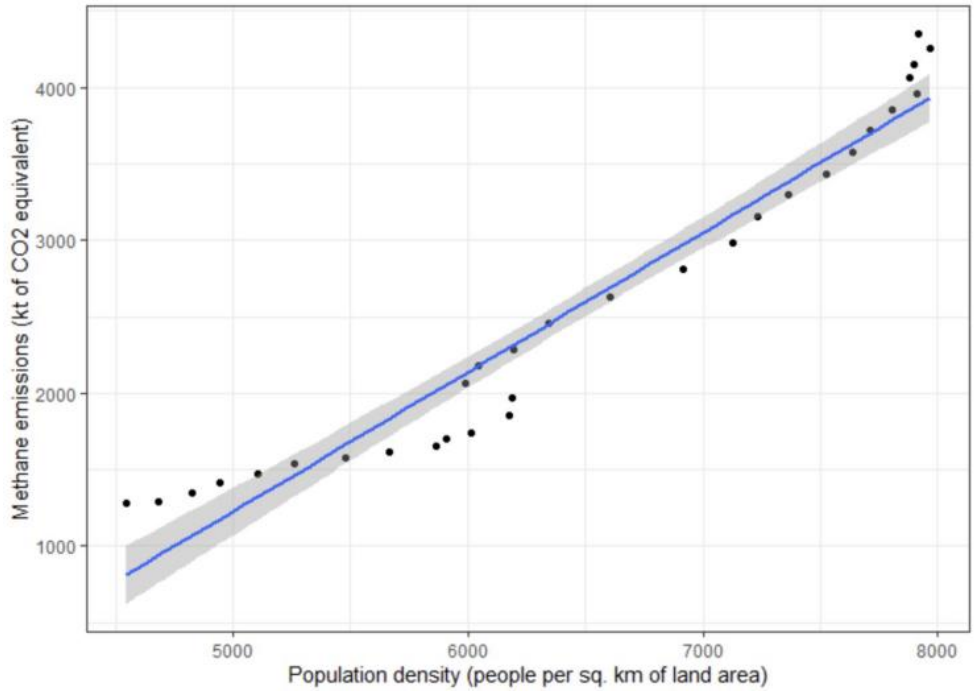

Figure 5. Linear Regression for Positive Variables

5.1.2. Evaluation of Sustainable Singapore Blueprint 2015 and Green Plan 2030

(1) Green Plan 2030

The Singapore Green Plan 2030 is a comprehensive sustainability initiative aimed at addressing a range of environmental challenges, with a particular focus on reducing emissions. One of its key initiatives is waste management and the promotion of a circular economy, which involves strategies to manage waste effectively and decrease emissions from landfills, potentially impacting methane emissions positively (Green Plan, 2023).

However, despite the Green Plan's ambitious goals of creating a sustainable and nature-friendly urban environment, the available data highlights persistent challenges. Singapore is grappling with issues such as population growth, resource scarcity, and increasing emissions. The trends observed in the data, including a rising population density, declining freshwater resources per capita, and increasing methane emissions, suggest that certain aspects of the Green Plan's vision may not have been fully realized as of 2022. These trends underscore the ongoing environmental pressures and the need for further efforts to achieve the plan's objectives.

(2) Sustainable Singapore Blueprint 2015

The Sustainable Singapore Blueprint 2015 is a policy framework designed to tackle environmental challenges, with a strong focus on addressing climate change and reducing emissions. Its core objective is to promote sustainability and foster a greener environment within Singapore (Sustainable Singapore Blueprint, 2021).

One of the key initiatives outlined in this blueprint is the promotion of waste-to-energy facilities. These facilities are highlighted as a crucial strategy to convert solid waste into energy, with the dual benefit of managing waste effectively and reducing methane emissions generated from landfills.

However, it's important to note that the available data indicates an increase in methane emissions, which suggests potential challenges in fully achieving emissions reduction goals. While waste-to-energy facilities play a role in emissions reduction, their overall effectiveness depends on various factors, including waste management practices and the efficiency of energy recovery processes. Therefore, while the blueprint emphasizes waste-to-energy as a strategy, it's essential to consider additional measures and improvements in waste management practices to comprehensively address methane emissions and achieve emission reduction objectives.

5.2. Evaluation of ABC Waters Programme

The results suggest there is a decrease in renewable internal freshwater resources per capita, this data shows an impact on Singapore's environmental aspects (Figure 6). The decreasing renewable internal freshwater resources can impact local ecosystems and biodiversity. Singapore's environment faces increasing challenges due to climate change, including more intense rainfall and prolonged droughts.

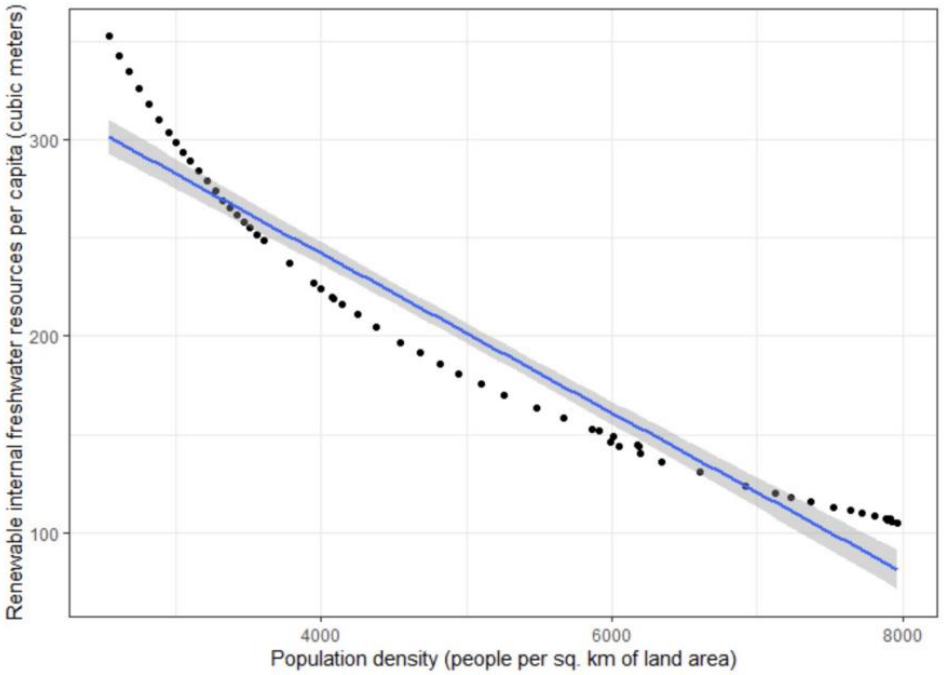

Figure 6. Linear Regression Analysis for Negative Variables

The decreasing renewable internal freshwater resources per capita is a concerning global trend driven by factors such as population growth, urbanization, and climate change. For the Active, Beautiful, Clean Waters (ABC Waters) Programme in Singapore, this trend underscores the urgency and relevance of its mission to improve water quality, create sustainable water bodies, and enhance water resources. This study shows the process of this concerning trend aligning with and motivating the ABC Waters Programme's goals and objectives.

(1) Water Resource Maximization: The ABC Waters Programme recognizes that Singapore's limited land area and decreasing internal freshwater resources per capita necessitate innovative approaches to water management. By integrating water bodies with urban development, the program effectively capitalizes on available space to store and manage water. This approach maximizes the use of every drop of water that falls within the city's boundaries, ensuring that it contributes to both water quality and quantity.

(2) Water Quality Enhancement: As freshwater resources become scarcer, it becomes imperative to protect and enhance the quality of available water. The ABC Waters Programme's emphasis on improving water quality within these water bodies aligns with the need for clean and safe water. Clean water bodies are not only aesthetically pleasing but also support various uses, including recreation,

biodiversity preservation, and potential drinking water supply in the future if treated to the required standards.

(3) Climate Resilience: The decreasing renewable internal freshwater resources per capita are exacerbated by climate change, which can lead to more erratic rainfall patterns and prolonged droughts. The ABC Waters Programme's approach to designing water bodies for climate resilience directly addresses these challenges. By creating water bodies that can accommodate heavy rainfall and mitigate flooding while also ensuring water availability during dry spells, the program contributes to climate adaptation and resilience.

(4) Rainwater Harvesting and Water Reuse: The program's promotion of rainwater harvesting aligns perfectly with the need to augment water resources in the face of decreasing per capita availability. Rainwater, a local and sustainable source, can be captured, stored, and used for various non-potable purposes. By encouraging rainwater harvesting, the ABC Waters Programme helps to reduce the demand on traditional freshwater sources, effectively increasing water availability.

(5) Community Engagement: Given the importance of adoption rates and water demand management, the program actively engages with the community to promote responsible water usage and water-saving practices. In a context of decreasing renewable internal freshwater resources per capita, behavioral changes among residents and businesses are crucial to ensuring long-term water resource sustainability. The ABC Waters Programme fosters a sense of shared responsibility for water conservation and resource management.

Overall, the decreasing renewable internal freshwater resources per capita highlights the critical need for policies like the ABC Waters Programme in Singapore. This program's multifaceted approach addresses the challenges posed by decreasing water resources by maximizing water use efficiency, enhancing water quality, promoting climate resilience, and engaging the community. By doing so, the ABC Waters Programme not only aligns with the imperative to address water scarcity but also serves as a model for sustainable water management in a world where freshwater resources are becoming scarcer and more valuable.

6. Conclusion

The data analysis highlights critical environmental challenges faced by Singapore, particularly in the context of decreasing renewable internal freshwater resources per capita and increasing methane emissions. These trends emphasize the urgency of addressing environmental sustainability and achieving the objectives outlined in Singapore's relevant policies, including the Green Plan 2030, the Sustainable Singapore Blueprint 2015, and the Active, Beautiful, Clean Waters (ABC Waters) Programme.

The Green Plan 2030 and the Sustainable Singapore Blueprint 2015 have set ambitious goals to create a more sustainable and nature-centric urban environment. However, the data reveals several challenges and areas of concern that indicate a gap between policy aspirations and on-ground realities. These challenges include the reduction in tree cover, increasing CO2 emissions from fuel consumption and methane emissions, and the loss of primary forest and biodiversity.

The ABC Waters Programme, on the other hand, demonstrates a proactive approach to addressing environmental challenges, particularly in the context of decreasing freshwater resources. It aligns with the need to maximize water use efficiency, enhance water quality, promote climate resilience, and engage the community in sustainable water management practices.

Considering these findings, it is evident that while Singapore's policies represent commendable efforts towards sustainability, there is a pressing need to recalibrate strategies and address the challenges effectively. The policies must be adaptable, considering both positive developments and challenges in the journey towards a more sustainable future. Continuous monitoring, assessment, and adjustment of these policies will be essential to bridge the gap between policy objectives and environmental outcomes.

Ultimately, the data analysis underscores the critical importance of holistic and integrated approaches to environmental sustainability. Achieving a balance between urbanization, resource management, emissions reduction, and biodiversity conservation is paramount for Singapore's path towards becoming a sustainable and resilient "City in Nature." It serves as a reminder that sustainable policies and proactive programs like the ABC Waters Programme are vital tools in mitigating environmental challenges and securing a sustainable future for Singapore.

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