University of Lille

Doctoral School of Engineering and System Sciences

Laboratory of Civil and Geo-Environmental Engineering

THESIS

submitted to obtain the

Doctoral Degree (Ph.D.)

Specialty: **Civil Engineering**

By

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Multiscale and Multisector Analysis of Greenhouse Gas Emissions in Conflict Areas

Defended on July 8th, 2024, in front of the jury composed of:

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Université de Lille
Ecole doctorale Science de l'ingénierie et des systèmes
Laboratoire Génie Civil et géo-Environnement

THÈSE

soumise pour l'obtention du

Grade de Docteur

Discipline : **Génie Civil**

Par

Hanan JAFAR

Analyse Multiéchelle Et Multisectorielle Des Émissions De Gaz À Effet De Serre Dans Les Zones De Conflit

Soutenue le Juillet 8ème 2024 devant le jury composé de

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Acknowledgement

First and foremost, I would like to thank God Almighty whose grace and guidance have illuminated my path throughout this journey. Without His blessings, this endeavor would not have been possible.

Apart from my efforts, the success of this thesis depends largely on the encouragement and guidelines of many others. I extend my deepest appreciation to my supervisor, Professor Isam SHAHROUR, whose wisdom, mentorship, and unwavering support have been instrumental in shaping this thesis. Your encouragement and belief in me have been a constant source of inspiration. Thanks belongs also for my co-director Professor Hussein MROUEH for his guidance and support.

I would like to thank the esteemed committee members for their review and invaluable contributions, which have greatly enhanced the quality and depth of my research. I would also like to extend my deepest gratitude to the members of LGCgE; whose collaboration, camaraderie, and dedication have fostered an environment conducive to exploration and discovery.

To my dear friends, who have been my pillars of strength and sources of encouragement, I am deeply thankful for your unwavering support, understanding, and companionship. Your belief in me, even during the most challenging times, has been a source of motivation.

Last but certainly not least, I express my profound gratitude to my family for their unconditional love, unwavering support, and sacrifices throughout this journey. Your belief in me has been my guiding light, and your encouragement has fuelled my determination to succeed. With heartfelt gratitude and deep affection, I extend warm thanks to each of you for enriching my life in ways beyond measure,

With warmest regards and deepest appreciation,

Hanan Jafar

Abstract

Greenhouse gas emissions (GHGEs) in developing countries present unique challenges and complexities, exacerbated by conflict and instability in certain regions. To bridge the critical gap in understanding emissions in developing countries, especially conflict zones, this research developed a novel methodology to estimate GHGEs based on a hybrid approach that goes beyond national reports.

The thesis is presented in six chapters:

The 1st chapter presents the state of the art of existing research on major issues related to GHGEs in conflict areas. It discusses the challenges of GHGEs in developing countries and conflict areas. Accordingly, highlights the limitations/gaps of previous research and introduces the contributions of this research to fill this gap.

The 2nd chapter outlines the general methodological approach employed in this research for the evaluation of GHGEs in multiscale conflict areas. And presents the case study targeted for application in this research.

The 3rd chapter is; the national GHGE inventory; the chapter provides a comprehensive picture of GHGEs from the energy sector in Palestine. The analysis here is based on the IPCC Guidelines for National Inventories and the IEA's Method for Estimating Electricity-related Emission Factors. By quantifying the emissions embodied in a nation's electricity Imports, this chapter reveals the impact of this component of GHGEs in the study area.

The 4th chapter; sectoral focus analysis; presents a more in-depth analysis of key sectors identified as major contributors to GHGEs in Palestine. The application here is in the transportation sector. This chapter presents the development of a hybrid approach based on the IPCC Guidelines to provide a detailed breakdown of vehicular emissions by vehicle category and fuel type.

The 5th chapter; maps GHGEs, providing a comprehensive picture of emissions distribution in the country. The chapter presents the development of a hybrid vector map approach applied to map emissions from electricity consumption in Palestine. The analysis provides insights into mapping emissions at different administrative geographical scales and discusses the factors influencing this spatial distribution.

The 6th chapter explores emission reduction pathways for GHGEs. Trend and regression analysis were employed to explore the factors influencing the activity data. Utilizing these insights, emission projections were estimated to evaluate the effectiveness of reduction scenarios. The chapter offers valuable insights into potential strategies for reducing emissions, accompanied by actionable policy recommendations

Keywords: Emissions, Inventory, CO_2, GHGEs, Mapping, Spatial Analysis, Reduction, Developing Countries, Conflict Zones, Palestine

Résumé

Les émissions de gaz à effet de serre (GHGEs) dans les pays en voie de développement présentent des défis majeurs, exacerbés par les conflits et l'instabilité dans certaines régions. Cet recherche a pour but de contribuer à développer des connaissances sur l'estimation émissions dans ces régions, à travers le développement d'une méthodologie novatrice pour estimer les GHGEs à l'aide d'une approche hybride allant au-delà des rapports nationaux.

Le travail de thèse est présenté en six chapitres.

Le premier chapitre présente l'état de l'art de la recherche existante sur les principaux problèmes liés aux GHGEs dans les zones de conflit. Il aborde les défis des GHGEs dans les pays en voie de développement et les zones de conflit. Il souligne les limitations des recherches précédentes et introduit les contributions de cette thèse pour combler cette lacune.

Le second chapitre décrit l'approche méthodologique multi-échelle utilisée dans cette recherche pour l'évaluation des GHGEs dans les zones de conflit. Il présente également le territoire palestinien qui fait l'objet de l'application dans cette recherche.

Le troisième chapitre concerne l'inventaire national des GHGEs. Il chapitre propose une analyse approfondie des GHGEs issues du secteur énergétique en Palestine. L'analyse est basée sur les lignes directrices du GIEC pour les inventaires nationaux et la méthode de l'AIE pour estimer les facteurs d'émission liés à l'électricité. Ce chapitre révèle l'impact de cette composante des GHGEs dans la zone d'étude.

Le quatrième chapitre porte sur l'analyse sectorielle approfondie des secteurs clés des émissions des GHGEs en Palestine, avec une analyse approfondie du secteur des transports. Une approche hybride est utilisée pour analyser les émissions de véhicules selon leurss catégories et le type de carburant.

Le cinquième chapitre cartographie les GHGEs pour illustrer leur la répartition à travers le territore. Une approche vectorielle hybride est utilisée pour cartographier les émissions liées à la consommation d'électricité. Il fournit des informations sur la cartographie des émissions à différentes échelles géographiques administratives et discute des facteurs influençant cette distribution spatiale.

Le sixième chapitre explore les approches pour réduire les émissions de GHGEs. Une analyse de tendance et de régression est utilisée pour étudier les facteurs influençant les données d'activité. Ces informations sont utilisées pour prévoir les émissions et évaluer l'efficacité des scénarios de réduction des émissions. Il offre des perspectives sur les stratégies potentielles de réduction des émissions, accompagnées de recommandations pour les décideurs.

Mots-clés : Émissions, Inventaire, CO2, GHGEs, Cartographie, analyse spatiale, Réduction, Pays en voie développement, Zones de conflit, Palestine

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Abbreviations

Abbreviation	Definition
CO_2	Carbon Dioxide
N_2O	Nitrous Oxide
C_2H_6	Ethane
CH_4	Methane
GHG	Greenhouse Gas
GHGEs	Greenhouse Gas emissions
CO_2eq	Carbon Dioxide Equivalent
GWP	Global Warming Potential
LCA	Life Cycle Assessment
UNFCCC	United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel on Climate Change
GHG Protocol	Greenhouse Gas Protocol
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute
BUR	Biennial Update Report
MRIO	Multi-Regional Input-Output Models
GIS	Geographic Information Systems
EDGAR	Emission Database for Global Atmospheric Research
ODIAC	Open-Source Data Inventory for Anthropogenic CO_2
CDIAC	Carbon Dioxide Information and Analysis Center
FFDAS	Fossil Fuel Data Assimilation System
UHI	Urban Heat Islands
UFZs	Urban Functional Zones
GVCs	Global Value Chains
ECAM	Carbon Emissions Assessment and Monitoring Tool
NDC	National Determination Contribution
PCBS	Palestinian Central Bureau of Statistics
OCHA	UN Office for the Coordination of Humanitarian Affairs
VKT	Vehicle Kilometres Travelled
IEA	International Energy Agency
INCR	Initial National Communication Report
NIR	National Inventory Reports
PENRA	Palestinian Energy and Natural Resources Authority
MoF	Palestinian Ministry of Transport
IEC	Israel Electric Corporation
IRENA	International Renewable Energy Agency
LPG	Liquefied Petroleum Gas

OSM	OpenStreetMap
PERC	Palestinian Electricity Regulatory Council
MOLG	Palestine Ministry of Local Government
GIZ	German International Cooperation
LGP	Local Governance and Civil Society Development Programme
JDECO	Jerusalem District Electricity Company
NEDCO	The North Electricity Distribution Company
TEDCO	Tubas Electricity Distribution Company
SELCO	Southern Electric Company
GEDCO	Gaza Electricity Distribution Company
BAU	Business-as-Usual
CCS	Carbon Capture and Storage
EVs	Electric Vehicles
PIPA	Palestinian Investment and Promotion Agency
RMSE	Root Mean Squared Error
GCF	Green Climate Fund
GAM	Generalized Additive Model
PV	Photovoltaic
EMEP	European Monitoring and Evaluation Programme
EEA	European Environmental Agency
M-K test	Mann Kendall non-parametric test

General Introduction

I. Problem Statement

This research deals with a major scientific and environmental-related question, "How to develop a multiscale and multisector analysis of greenhouse gas (GHG) emissions in developing and conflict areas under limited information?".

This question is particularly important because developing countries have been described as climate change hot spots in the Scientific literature and official United Nations reports (Murun et al., 2021; Umemiya et al., 2021; UNDP, 2018, 2019; Waha et al., 2017). These countries are responsible for about 63% of total global emissions of GHGs (Jonah Busch, 2015). Despite the major contribution of developing countries to global emissions, limited studies targeted these countries in the field of GHGEs (Abbass et al., 2018).

The systematic literature review reveals significant gaps and challenges in estimating GHGEs in developing countries. One major hurdle is the limited availability of data and resources in these regions, hindering efforts to obtain a comprehensive understanding of emissions dynamics (DeFries et al., 2007; Kawanishi & Fujikura, 2018; Murun et al., 2021; Umemiya et al., 2017). Additionally, many existing methodologies are frequently data-intensive, requiring comprehensive datasets and tailored to developed countries, where data availability differs, making them less applicable to developing nations.

Moreover, the impact of conflict on emissions in these regions has yet to be largely overlooked. In particular, conflict areas face unique challenges due to the disruptive effects of conflict on GHGEs (Michaelowa et al., 2022; Michaelowa & Koch, 2001; Sasmoko et al., 2023). The interplay between conflict dynamics and emissions remains poorly understood, limiting the progress toward achieving emission reduction targets in these areas. Furthermore, spatial analysis, crucial for understanding emission patterns, is also lacking in developing countries, with virtually no studies focusing on conflict areas. Understanding how conflict affects emissions, such as through population displacement and trade restrictions, is essential for effective emission reduction strategies.

To ensure a comprehensive examination of this complex issue, this research is guided by the following subsidiary questions designed to support the main research question:

1. What are the primary challenges encountered by developing countries and conflict-affected regions in developing comprehensive emission inventories, and what methods are available to overcome these challenges
2. How do conflicts impact the GHGEs?
3. How can conflict-affected regions develop effective pathways for reducing emissions despite ongoing conflicts?

II. Research Objective

The primary objective of this research is to develop a multiscale approach to estimate GHGEs within conflict areas of developing countries. This approach goes beyond national reports by providing a spatial distribution for emission patterns in these targeted regions. This method aims to address the unique challenges associated with data scarcity and dynamic conflict environments by employing alternative data sources, spatial analysis, and innovative methodologies less reliant on comprehensive datasets. We aim to bridge the data gap and provide a more in-depth understanding of GHGEs across multiple scales within developing countries and conflict areas.

By developing a robust and adaptable methodology, the research seeks to provide a more in-depth understanding of GHGEs across multiple scales within developing countries and conflict areas and improve the precision and reliability of emissions inventories in conflict-affected regions, thereby providing a valuable tool for policymakers and researchers towards mitigating emissions and promoting environmental sustainability in these vulnerable areas.

III. Significance and Contributions

The primary significance of this research lies in its focus on conflict areas within developing countries, where the impact of conflict on emissions remains poorly understood. By targeting these regions, this study seeks to shed light on the complex relationship between conflict dynamics and GHGEs patterns, offering valuable insights into the environmental consequences of conflicts and providing a basis for targeted interventions for emission reduction. Understanding the emissions profile of conflict-affected areas is essential for developing effective strategies to mitigate emissions and promote environmental sustainability in these vulnerable regions. Therefore, this research is a critical step toward addressing the interaction between GHGEs and conflicts in some of the world's most fragile contexts.

The significance of this research stems also from the originality of the study area. This research focuses on an interesting study case: Palestine, a developing country that combines several challenges for the estimation of GHGs because of enduring conflict in the area, strong economic dependency, territorial fragmentation, and a complex geopolitical context.

The contribution of this research extends beyond the mere identification of emissions in conflict areas of developing countries; it offers:

1. Development of a novel methodology: The research proposes a new approach to estimating GHGEs in conflict areas and developing countries, addressing the limitations of existing methods.
2. Improved understanding of emissions patterns: By applying the developed methodology, the research enhances the understanding of emission patterns in these conflict areas and shows the complex relationship between conflict and emissions patterns, shedding light on the drivers, sources, and trends of GHG emissions in conflict-affected regions.
3. Informing targeted mitigation strategies: The research findings provide valuable insights for policymakers, enabling them to develop targeted mitigation strategies that address the specific emissions challenges faced by conflict areas and promote environmental sustainability and resilience in these areas.

IV. Research Methodology

The research methodology comprises four main phases designed to systematically achieve the goal of this research in developing a novel approach to estimate GHGEs in conflict areas:

- Phase 1: National Inventory of GHGEs. This is a crucial step in our multiscale analysis as it provides a baseline for understanding the region’s emissions and how conflict influences the composition and magnitude of GHGEs within a region. Second, it identifies the key emitting sectors of GHGEs and how they differ from emissions drivers in non-conflict regions. This phase serves as a roadmap for subsequent stages
- Phase 2: Sectoral Focus Analysis. This analysis targets sectoral emissions to understand the main contributors to emissions in these sectors and the factors influencing emissions within each sector. By identifying the factors responsible for emissions within each key sector, valuable insights will be gained for developing targeted mitigation strategies.
- Phase 3: Spatial Analysis. In this phase, a vector-mapping-based approach is developed to provide a comprehensive picture of emissions distribution. This approach will allow identifying hotspot areas and pinpointing the specific drivers of emissions within each location. This analysis allows

the understanding of how conflict dynamics, such as displacement of populations, damage to infrastructure, and other discriminatory restrictions, impact the spatial pattern of GHGEs in conflict areas.

- Phase 4: Scenario-Based Emissions Reduction Pathways. This stage involves building emission reduction scenarios. Various hypothetical scenarios are developed and analyzed to assess their effectiveness in curbing emissions. The analysis at this phase is aimed at exploring how conflict-affected regions can develop effective pathways for reducing emissions despite ongoing conflicts that impede their ability to mitigate emissions.

V. Organization of the Thesis

This thesis is organized in six chapters as follows:

- Chapter 1: Presents the state of the art of existing research on major issues related to GHGEs in conflict areas. It starts by presenting the emission inventories. Then it reviews research concerning carbon accounting methods and the spatial analysis of GHGEs. Finally, it discusses the challenges of GHGEs in developing countries and conflict areas. Accordingly, the chapter highlights the limitations/gaps of previous research and introduces the contributions of this research to fill this gap.
- Chapter 2 outlines the general methodological approach employed in this research to evaluate GHGEs in multiscale conflict areas with limited data and presents the case study targeted for application in this research.
- Chapter 3: National GHGE Inventory: this chapter provides a comprehensive national picture of GHGEs from the energy sector in Palestine. The analysis in this chapter is based on the IPCC Guidelines for National Inventories and the IEA’s Method for Estimating Electricity-related Emission Factors. By quantifying the emissions embodied in a nation's electricity Imports, this chapter reveals the impact of this component of GHGEs in the study area.
- Chapter 4: Sectoral Focus Analysis – Transport sector: this chapter presents a more in-depth analysis of key sectors identified as major contributors to GHGEs in Palestine. The application here is in the transportation sector. This chapter presents the development of a hybrid approach based on the IPCC Guidelines to provide a detailed breakdown of vehicular emissions by vehicle category and type of fuel.
- Chapter 5: Spatial Analysis – Electricity consumption: this chapter maps GHGEs, providing a comprehensive picture of emissions distribution in the country. It presents the development of a hybrid vector map approach applied to map emissions from electricity consumption in Palestine. This chapter provides insights on mapping emissions at different administrative geographical scales and discusses the factors influencing this spatial distribution.
- Chapter 6: Scenario-Based Emissions Reduction Pathways: utilizing the insights and information gained from previous analysis, this chapter explores pathways for reducing GHGEs within the study area to develop targeted emission reduction strategies. The chapter provides insights on possible emission reduction strategies with policy recommendations.

Chapter 1. State of the Arts

This chapter includes a review of existing research on major issues related to Greenhouse Gas emissions (GHGEs) in conflict areas. It starts by presenting the emission inventories. Then it conducts a review of research concerning carbon accounting methods and the spatial analysis of GHGEs. Finally, it discusses the challenges of GHGEs in developing countries and conflict areas.

1.1. GHGEs Inventories

1.1.1. Overview

Emission inventories of GHGs are the cornerstone for analyzing and mitigating GHGEs to combat climate change. An emissions inventory is a database that provides a systematic identification and quantification of human-induced GHGEs to the atmosphere broken down by fossil fuel type and by GHG over a specific period, typically a year, within a defined geographical area (Bun et al., 2019; European Environment Agency, 2019; IPCC, 2006). Inventories help in the implementation of new agreements and policies to monitor the reduction of GHGEs, provide input data for air quality and climate models, and facilitate the estimation of the global carbon budget and the prediction of carbon emissions under different scenarios (Bun et al., 2019; C40 Cities, 2019; Hutchins et al., 2017; Nicholls et al., 2015).

Various methodologies and guidelines were developed by international bodies and researchers to estimate the emissions of GHGs at different geographical or spatial scales (Bun et al., 2019; Eggleston et al., 2006; European Environment Agency, 2019; Fry et al., 2018; Kennedy et al., 2010; Pla et al., 2021; Shan et al., 2017). These scales include global, national, regional, state/provincial, local, and even facility-specific levels (Baayoun et al., 2019; Eskander & Nitschke, 2021; Kennedy et al., 2010; Olivier & Peters, 2020; Zheng et al., 2022; Zhou et al., 2021)

1.1.2. Global Inventories

Global inventories offer the broadest perspective, encompassing the Earth's atmosphere. They provide a crucial big-picture view of total global emissions, allowing for international comparisons and the assessment of overall progress towards climate goals (Friedlingstein et al., 2022; Maenhout et al., 2017; Olivier & Peters, 2020; Yuan et al., 2022). Regional inventories focus on a specific geographic region, such as a continent, a group of countries and in some cases a group of districts or provinces within a country (Chen et al., 2020; Denier Van Der Gon et al., 2017; European Environmental Agency, 2023; Hao et al., 2014; Ivanovski & Awaworyi Churchill, 2020; C. Wang et al., 2020a). These inventories provide a more focused analysis of emissions within a particular region, highlighting shared challenges and potential collaborative solutions. National inventories targeting a specific country. They are the foundation of most climate change mitigation strategies, informing national policies and targets for reducing emissions (Belgian Interregional Environment Agency, 2022; de Azevedo et al., 2018; Epa & Change Division, 1990; Haider et al., 2020; Institute for Environmental Protection and Research, 2022; IPCC, 2006; Maenhout et al., 2017; Ministry of Ecological Transition and Territorial Cohesion, 2017; Mir et al., 2017; Sim et al., 2015; Tonooka et al., 2003).

1.1.3. Local or Community-Scale Inventories

Local or community-scale inventories focus on emissions within a specific city or smaller geographical area. They provide crucial data for understanding the GHGEs in these areas to inform local climate action plans (Pulselli et al., 2019; Shan et al., 2017; Sówka & Bezyk, 2018; Su et al., 2020; Zhou et al., 2021). Facility-specific inventories offer the finest level of detail, pinpointing emissions from a single industrial facility, power plant, or company. They are essential for identifying major emission sources within a sector and guiding targeted reduction strategies for individual entities (Delre et al., 2017; Hansen et al., 2022; Jensen et al., 2017; Provaty et al., 2024).

These inventories can encompass all economic sectors within the targeted geographical scale, creating a comprehensive picture of GHGEs (Belgian Interregional Environment Agency, 2022; Epa & Change Division, 1990; Institute for Environmental Protection and Research, 2022). However, depending on the specific aim or objective, inventories may also be targeted towards a specific sector, such as energy or transportation, for a more focused analysis (Boychuk & Bun, 2014; Cellura et al., 2018; Eskander & Nitschke, 2021; Hao et al., 2015; Sim et al., 2015; C. Wang et al., 2020a).

1.1.4. National Inventories

While emission inventories exist at various geographical scales, national inventories hold particular importance in fighting climate change (Falkner, 2016; Nicholls et al., 2015; UNFCCC, 2015). These inventories serve as the cornerstone of effective climate action under international agreements like the Paris Agreement (IPCC, 2006; UNFCCC, 2015). National inventories submitted to the United Nations Framework Convention on Climate Change (UNFCCC) under the Paris Agreement represent comprehensive reports, encompassing all sectors of a country's economy, and provide a detailed breakdown of its GHGEs serving as the foundation for tracking progress, informing policy decisions, and ultimately, achieving the ambitious goals of the Agreement (Falkner, 2016; IPCC, 2006; UNFCCC, 2009).

The importance of consistency and international comparability cannot be overstated when it comes to national inventories submitted to the UNFCCC by Parties to the Paris Agreement. To ensure robust and reliable data, countries adhere to international frameworks (UNFCCC, 2009). The most common carbon accounting methodology is the IPCC 2006 guidelines for national inventories (IPCC, 2006). It is mainly used to report national GHG emissions in the national communication reports by parties under the Paris Agreement. The IPCC guidelines extend beyond official reporting, providing a valuable framework for researchers (Baayoun et al., 2019; de Azevedo et al., 2018; Epa & Change Division, 1990; Mir et al., 2017; Qureitem et al., 2020; Xin et al., 2020).

The IPCC guidelines focus on direct emissions and are based on emission factors and activity data which vary considerably between countries. It estimates the emissions as the national totals of four main categories: (i) energy, (ii) industrial process and product use, (iii) agriculture, forestry, and other land uses, and (iv) waste.

The guidelines have three levels of methodological sophistication, Tier 1, Tier 2, and Tier 3. Complexity and required data increase with the tier degree (IPCC, 2006). Tier 1 is the simplest, relying on basic activity data and default emission factors established by the IPCC. These factors are based on global data. Tier 1 offers a quick and efficient way to estimate emissions, making it suitable for countries with limited resources. Moving to a more refined level, Tier 2 methods incorporate country-specific data when available. This involves using national emission factors derived from local measurements or sophisticated modelling techniques. Tier 2 offers a more accurate estimation of emissions compared to Tier 1, but it requires more investment in data collection and expertise. The most complex and data-intensive tier, Tier 3 methods involve highly detailed, country-specific models and emission factors. These models consider factors like specific technologies, fuels, and local conditions. While Tier 3 offers the most accurate results, it requires significant resources and expertise, often only feasible for developed countries with robust data collection infrastructure.

The Greenhouse Gas Protocol (GHG Protocol), developed by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI), offers a standardized framework for categorizing national emissions (GHG Protocol, 2024). This framework defines three distinct scopes, each encompassing a specific set of emission sources as presented in **Figure 1.1**:

- Scope 1: Direct emissions: This scope includes all GHGEs directly generated by the entity's (country/city/company) activities within its defined operational boundaries. Examples include fuel combustion in on-site facilities, company vehicles utilized for transportation, or industrial processes undertaken by the entity.
- Scope 2: Indirect emissions from purchased energy: While not directly produced by the entity, Scope 2 emissions originate from the generation of electricity and heat consumed by the entity. These emissions are attributed to the entity based on the specific source of energy (e.g., power grid mix) and consumption patterns.
- Scope 3: Unveiling the eider impact: This all-encompassing category captures all other indirect emissions associated with the entity's activities, even if they occur outside its direct control. Examples include:

   1. Embodied emissions in purchased goods and services: Emissions associated with the production and transportation of goods and services the entity procures (Fang et al., 2019).
   2. Emissions from business travel: Emissions generated by employees travelling for business purposes.

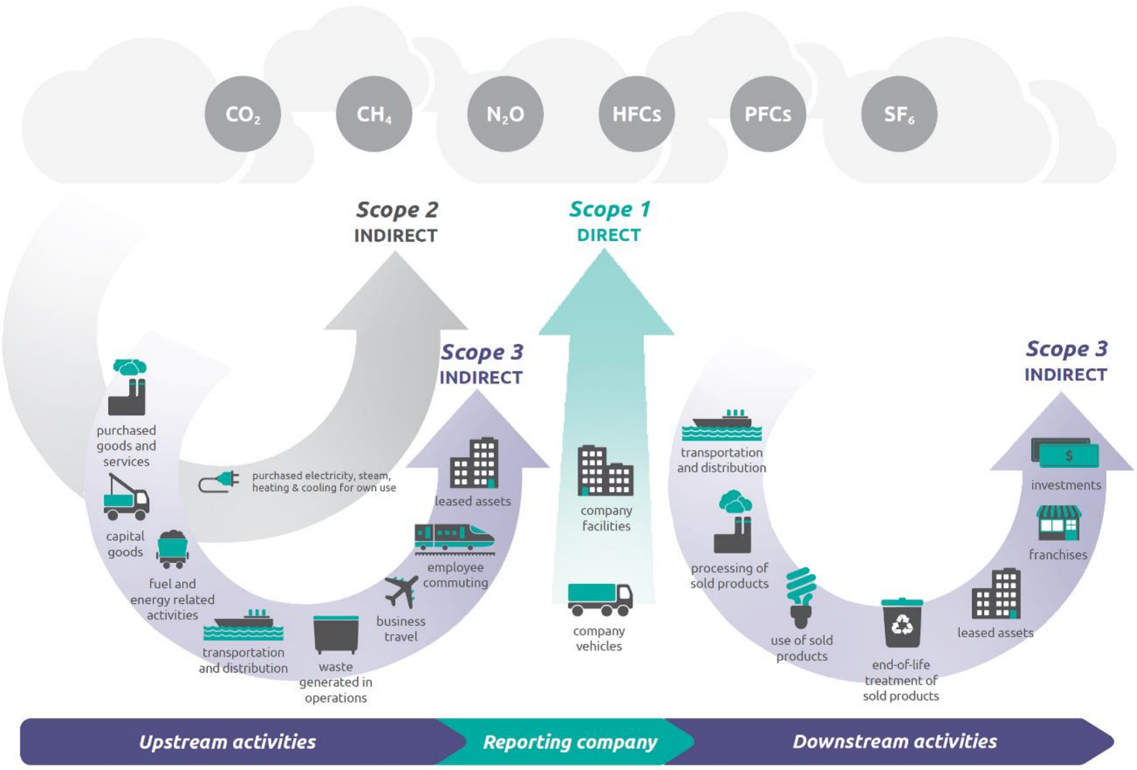


Figure 1.1: Scope 1, 2, and 3 of GHGEs according to the GHG Global Protocol.
Note: Upstream emissions: this is emissions in the supply chain originating at suppliers' organizations. Downstream emissions: this is emissions happen after the service or product has left the organization for the next step in the supply chain. Reference: (GHG Protocol, 2024)

1.2. Carbon Accounting

This section presents the complexities of carbon accounting. Specifically, it will explore the various methodologies and approaches employed for emission estimation and attribution.

Two primary approaches exist for estimating GHGEs top-down and bottom-up approaches (IPCC, 2006). Top-down and bottom-up approaches offer contrasting insights into GHGEs, providing a broad picture and detailed source information, respectively (Bergamaschi et al., 2015; Fung et al., 2023). However, they are complementary approaches, as top-down data can verify bottom-up inventories and vice versa (Bergamaschi et al., 2015; Fung et al., 2023; Hwang et al., 2021; IPCC, 2006).

1.2.1. Top-Down Approaches

Top-down approaches provide a broad picture of GHGE for a large region (city, country, or even the entire globe) (Bergamaschi et al., 2015). This approach relies on two key elements: atmospheric data and sophisticated modelling techniques. Top-down approaches utilize atmospheric observations to estimate total emissions for a specific region. This method relies on atmospheric data from aircraft observations, satellite remote-sensing and/or networks of ground-based instruments to measure the atmospheric concentration of GHGs (Hwang et al., 2021). These measurements are then integrated into atmospheric transport models that account for factors like wind patterns (Fung et al., 2023). By employing complex atmospheric inverse modelling techniques, scientists can infer the total emissions that must have occurred to produce the observed atmospheric concentrations (Bergamaschi et al., 2015; Fung et al., 2023).

This approach offers significant advantages. Firstly, the top-down approach could be used to verify the bottom-up IPCC inventories traditionally used for regulations (Bergamaschi et al., 2015; Etiope & Schwietzke, 2019; Fung et al., 2023; IPCC, 2019). This is particularly valuable when dealing with situations where reported emissions data may be uncertain. The IPCC's recent refinement report (2019) emphasized that atmospheric measurements (top-down approaches) hold significant scientific value for independent verification of bottom-up inventories (IPCC, 2019). Watanabe et al. (2023) explored verifying emissions reports from developing countries using top-down approaches. This research proposed using satellite data on atmospheric CO_2 to verify emission inventories submitted by non-Annex I countries to the UNFCCC. The study focused on Mongolia's Second Biennial Update Report (BUR) for the energy sector in 2018 (Watanabe et al., 2023). The top-down estimates closely matched the official report, suggesting promise for this method in verifying bottom-up approaches.

Secondly, top-down methods excel at capturing emissions in broader regions, encompassing entire continents or even the globe. This wider coverage provides a more comprehensive picture compared to bottom-up approaches, which can be limited by focusing on specific countries or sectors (Marcotullio et al., 2014). Friedlingstein et al. (2022) relied on a top-down approach to estimate the various components of the Earth's carbon cycle (Friedlingstein et al., 2022). The study highlighted the critical need for stricter emission reduction polices at the global scale to tackle the continued rise in atmospheric CO_2 levels. Thompson et al. (2016) employed a top-down atmospheric inversion technique to assess the role of Asian ecosystems in CO_2 absorption. This study revealed a broader perspective – the Asian land biosphere acted as a net carbon sink, underlining its significance for climate change mitigation. (Thompson et al., 2016).

Furthermore, top-down approaches hold promise for track emissions data close to real-time. By leveraging satellite data or atmospheric observation networks, top-down methods can deliver near real-time or high temporal resolution data. This allows for tracking emission trends and identifying potential changes over time. Mota & Wooster (2018) and Mukherjee et al. (2021) highlight this advantage in their respective studies (Mota & Wooster, 2018; Mukherjee et al., 2021). Mukherjee et al. (2021) explored a novel top-down approach for estimating road transport emissions using satellite imagery and machine learning models. This method, while requiring further refinement, has the potential to provide near real-time data on emissions from this significant contributor to climate change (Mukherjee et al., 2021). Similarly, Mota & Wooster (2018) proposed a new top-down approach for estimating emissions from biomass burning events. This approach utilizes satellite data, offering the potential for more frequent monitoring of emissions compared to traditional bottom-up methods (Mota & Wooster, 2018). This ability to track changes over time facilitates evaluating the effectiveness of emission reduction policies and identifying areas where further mitigation strategies are needed.

Despite the previously mentioned advantages, top-down approaches have some limitations. The complex atmospheric models employed to infer emission sources from atmospheric data require significant computational resources (Fung et al., 2023; Kondo et al., 2020). The accuracy of top-down emission estimates has limitations. These approaches rely on models, and these models require continuous validation and refinement to maintain their accuracy (Maksyutov et al., 2022). Additionally, the accuracy of these estimates can be limited by the quality of the input data, such as atmospheric measurements or satellite imagery (Cusworth et al., 2021; Thompson et al., 2016). A study by Fairley & Fischer (2015) exemplifies this. The study employed a top-down approach using atmospheric measurements to estimate the San Francisco Bay Area's methane (CH_4) emissions. The results revealed significantly higher emissions compared to existing bottom-up inventories, suggesting potential underestimation from traditional inventories. However, the accuracy of top-down estimates is influenced by the assumptions about atmospheric models and background methane levels which can introduce uncertainties. (Fairley & Fischer, 2015).

Another limitation lies in the level of detail provided regarding specific emission sources. While top-down methods offer a broad picture, they may struggle to identify specific sources. This does not allow the development of targeted mitigation strategies that focus on specific sectors or activities responsible for emissions. Fairley & Fischer (2015) provided a holistic view but lacked source attribution within the study region (Fairley & Fischer, 2015). Even the novel Bayesian framework (Cusworth et al., 2021) designed to estimate emissions by sector acknowledges limitations in estimating the accurate contribution from agriculture and fossil fuels sectors requires further research.

In conclusion, the top-down approach offers a valuable tool for understanding the overall picture of GHG emissions across a large region. Its independence from emission reporting and broad coverage make it a powerful technique. However, the limitations associated with complex modelling and lack of source detail highlight the need for complementary methods for a more comprehensive understanding of GHGEs..

1.2.2. Bottom-Up Approaches

In contrast to top-down approaches, bottom-up approaches offer detailed source-specific information. This detailed analysis allows for identifying specific sources that contribute the most to overall emissions (Erickson et al., 2012).

Quantifying GHGEs using the bottom-up approach is based on two pillars: activity data and emission factors. Activity data quantifies the level of activity that generates emissions (IPCC, 2019). For instance, this could be the amount of fuel combusted at a power plant or the number of vehicles travelling on a specific road. Emission factors, on the other hand, represent the amount of emissions per unit of activity (IPCC, 2006; UNFCCC, 2009). By multiplying activity data by the corresponding emission factor, it's possible to estimate the emissions from each individual source.

A significant advantage of the bottom-up approach is its ability to provide detailed, source-specific information. Unlike top-down methods that struggle to pinpoint specific sources, bottom-up approaches highlight which sectors or activities are the most significant contributors to emissions (Desjardins et al., 2018). This granular detail is crucial for developing targeted mitigation strategies. Cai et al. (2020) illustrated this strength by constructing a "city-level greenhouse gas emissions inventory for 305 Chinese cities" using a bottom-up approach. This detailed inventory empowers the development of targeted mitigation strategies specific to each city (Cai et al., 2020).

Furthermore, Bottom-up approaches can be used to evaluate emission reduction policies and strategies. It provides flexibility for scenario modelling by simulating changes in activity data or emission factors associated with a specific policy or technology. Kuramochi et al. (2017) demonstrated how bottom-up approaches can be utilized in evaluating the effectiveness of emission reduction policies and technologies. Their analysis of Japan's 2030 target showcases how these approaches can inform policy decisions towards achieving ambitious climate goals (Kuramochi et al., 2017). Zeng et al. (2016) investigated how motor vehicles will affect major Chinese cities (Beijing, Shanghai, Guangzhou, Chongqing) by 2035. The study employed a bottom-up approach to estimate vehicular emissions utilizing data on fuel consumption, and vehicle types, along with vehicle ownership data, distance travelled, and fuel efficiency (Zeng et al., 2016). This research offers valuable insights for policymakers aiming to curb emissions from transportation in China, providing a baseline scenario for future planning.

While bottom-up approaches offer valuable insights, they have some limitations. The accuracy of these estimates heavily depends on the quality of the data used. Inaccurate activity data or outdated emission factors can skew results (Unnewehr et al., 2022). Cai et al. (2020) acknowledged the uncertainty associated with their findings due to the use of single, representative emission factors for various source categories (Cai et al., 2020). Similarly, Zhang et al. (2020) reported a significant difference between estimates from bottom-up inventory and those derived from satellite observations using a top-down approach. This difference is attributed, in part, to the use of a single emission factor in the bottom-up approach.

Additionally, this approach is resource-intensive and requires significant time and investment to compile data for complex sectors with numerous emission sources (Erickson et al., 2012). Furthermore, bottom-up approaches may not capture all emission sources, particularly smaller or less well-defined sources, such as fugitive emissions from natural gas pipelines (SCARPELLI, 2021). Schwietzke et al. (2014) highlighted the difficulty of acquiring precise data for fugitive emissions, such as CH_4 and ethane (C_2H_6), released from fossil fuels (Schwietzke et al., 2014). Incomplete or inaccurate data can lead to significant underestimates or overestimates of emissions. Similar to Schwietzke et al. (2014), Chan et al (2020) observed a substantial difference between bottom-up inventory estimates and those derived from atmospheric measurements in Canada (Chan et al., 2020). The authors attribute this discrepancy to under-reported emissions from various fugitive in the bottom-up approach.

Overall, bottom-up approaches offer a powerful tool for understanding the specific sources contributing to GHGEs emissions. The effectiveness of this approach depends on the quality and comprehensiveness of activity data and emission factors. Resource limitations and potential inaccuracies in these elements can introduce uncertainties. Therefore, for a robust understanding of regional or global emissions, the bottom-up approach is best employed in conjunction with complementary methods,

1.2.3. Hybrid Approaches

The hybrid approach emerges as a powerful tool that leverages the combined strengths of top-down and bottom-up approaches (Bergamaschi et al., 2015; Maenhout et al., 2017). This approach provides a comprehensive understanding of GHGEs with a detailed breakdown of emission sources (Bergamaschi et al., 2015). It takes the efficiency of top-down approaches, which provides an estimation of emissions from large sectors like energy, and utilizes the detail of bottom-up methods to identify specific sources within those sectors. This detailed breakdown paves the way for the development of more effective mitigation strategies (Fry et al., 2018).

The specific applications of hybrid approaches vary depending on the research question. At the national scale, Scarpelli (2021) developed a hybrid approach for evaluating national CH_4 emission inventories. This method offers a more comprehensive picture of national emissions, ultimately contributing to more robust inventories(SCARPELLI, 2021). Furthermore, researchers used this approach to capture a city's total emissions (Cai et al., 2020; Fry et al., 2018). Fry et al. (2018) assess city carbon footprint using a hybrid approach combining sub-national multi-regional input-output (MRIO) tables with global MRIO tables (top-down and bottom-up elements). Captures a more comprehensive picture of a city's emissions, including those associated with imported goods and services (Fry et al., 2018). This approach allows for comparisons between cities. However, it relies on the availability of accurate and complete MRIO data, which can be limited for some cities. Cai et al combined bottom-up data on building attributes, and traffic flow with top-down modelling techniques (Cai et al., 2020). This study provided a comprehensive picture of urban carbon emissions from different sectors and identified major contributors to urban emissions. Similar to Fry et al. (2018), this approach requires access to comprehensive open urban form data. This can be a challenge for cities lacking such publicly available datasets, hindering its wider application.

Another application of hybrid approaches is found in the transportation sector (Das et al., 2023; Nicholls et al., 2015; C. Wang et al., 2020a; Zeng et al., 2016). Nicholls et al. (2015) developed a hybrid model combining GDP elastic coefficient, mode split, and vehicle population methods. Integrates the strengths of different forecasting methodologies to provide a more robust prediction (Nicholls et al., 2015). This model allows for analyzing the impact of various factors (e.g., GDP growth rate) on transportation demand. Despite these insights, the model has limitations in capturing all the complexities of transportation demand behaviour.

Hybrid approaches are utilized to estimate emissions at the chemical plant level. Ng et al. (2017) used a hybrid approach for estimating fugitive emissions from chemical plants during the design phase. It combines existing emission databases with estimations based on process diagrams (Ng et al., 2017). This approach allows for early assessment of emissions and minimizes the cost of adjustments later. However, it depends on existing emission databases, potentially limiting accuracy for new processes. The case study focuses on a specific process, thus, requiring further validation across other processes.

In conclusion, hybrid approaches offer a valuable tool for carbon accounting across various contexts. These approaches can significantly improve the accuracy and comprehensiveness of emission inventories. However, data limitations and model complexity are important considerations that must be taken into account when employing these methods.

1.2.4. Production-Based VS Consumption-Based Accounting

Beyond the estimation approach or method for GHGEs, there's another critical dimension: the scope or coverage of emission inventory. In other words, how responsibility for those emissions is attributed is also a critical consideration.

Traditionally, production-based accounting has been the dominant method (IPCC, 2006). This method assigns emissions to the geographic location where they physically occur, regardless of where the resulting goods and services are consumed (Peters, 2008; Sudmant et al., 2018). Conversely, Consumption-based accounting assigns emissions to the final consumer of a good or service, regardless of where they occur (Afionis et al., 2017). For instance, a country or region that relies heavily on imported goods may have a relatively low production-based carbon footprint. However, this doesn't reflect reality – because the emissions associated with producing those imported goods are not accounted for. Consumption-based accounting addresses this by considering the emissions associated with the goods and services consumed within a specific geographic area, regardless of the production place (Harris et al., 2020; Peters, 2008; Z. Wang et al., 2018). The choice between consumption-based and production-based accounting depends on the specific goals of the analysis.

The traditional method, production-based accounting, focuses on emissions generated within the boundaries of a specific geographical area. This includes activities like burning fossil fuels for energy or industrial processes (Sudmant et al., 2018). The production-based method is used for tracking progress towards national emission reduction targets established under the Paris Agreement (IPCC, 2019, 2024).

While offering simplicity and being a straightforward approach, it has a significant limitation: production-based accounting fails to capture the embodied emissions (emissions generated during production elsewhere) embedded in international trade (Erickson et al., 2012). In the case of import-dependent regions production-based accounting might show low emissions, neglecting the reality of the region's reliance on imports that has also a carbon footprint (Schmid, 2020; Sudmant et al., 2018; Z. Wang et al., 2018).

On the other hand, consumption-based accounting presents a more comprehensive picture of a region's true GHGEs (Afionis et al., 2017; Davis & Caldeira, 2010; Mi et al., 2019). It highlights consumption patterns and provides insights into the environmental impact of global supply chains (Athanassiadis et al., 2018). Consumption-based methods require utilizing bottom-up approaches for carbon accounting (Schmid, 2020).

This approach tracks the carbon footprint of imported goods and services through sophisticated tools like input-output analysis and multi-regional input-output (MRIO) models (Z. Wang et al., 2018). Furthermore, it requires high-quality data on international trade which is challenging and adds complexity to the accounting models (Mi et al., 2019).

Research consistently reveals that production-based accounting often underestimates the true carbon footprint. Studies by Sudmant et al. (2019) and Harris et al. (2020) reveal that consumption-based emissions can significantly exceed production-based emissions, especially in developed cities with a high dependence on imports (Harris et al., 2020; Sudmant et al., 2018). This means the overall carbon footprint is heavily influenced by economic development and consumption patterns (Athanassiadis et al., 2018). Athanassiadis et al. (2018) highlighted that a city's economic development model and resident consumption habits heavily influence its total emissions. Increased spending often leads to higher embodied emissions in imported goods.

While consumption-based accounting offers valuable insights, Balouktsi (2020) emphasizes the importance of standardized methodologies in carbon accounting. Some researchers like Balouktsi (2020) and Athanassiadis et al. (2018) proposed adopting a hybrid approach that joins consumption-based and production-based methods, to provide a more comprehensive picture of GHGEs and inform policy decisions at both local and regional levels. (Athanassiadis et al., 2018; Balouktsi, 2020).

1.2.5. Life Cycle Assessment

Life Cycle Assessment (LCA) goes beyond traditional inventories by considering the environmental impacts of a product or service throughout its entire lifespan, from resource extraction to disposal. It can be used to assess GHG emissions associated with different stages of a product's life cycle.

LCA can be classified into top-down and bottom-up methodologies. Top-down LCA covers the entire supply chain from extraction to final product disposal (Bahramian & Yetilmezsoy, 2020). Conversely, bottom-up LCA focuses on a specific product or process within a narrower system boundary. The choice of the method depends on the objective of the LCA and the required level of detail (Qiao et al., 2019). Furthermore, LCA methodologies can be categorized based on the perspective of environmental impact assessment. Consumption-based LCA assigns the environmental impact of a product/service to the final consumers. In contrast, production-based LCA attributes environmental burdens to the producers throughout the supply chain (Zhan et al., 2018).

LCA has been applied across various sectors. Zhan et al. (2018) quantified energy consumption and CO_2 emissions of an urban residential building in Guangzhou city using a hybrid LCA model (Zhan et al., 2018). Whereas Andersson & Börjesson (2021) targeted the transportation sector. They presented an LCA model to estimate the GHG impact of a current vehicle model using electrification and biofuels

(Andersson & Börjesson, 2021). Bahramian & Yetilmezsoy provided an overview of LCA research in the building industry from 1995 to 2018 (Bahramian & Yetilmezsoy, 2020).

LCA is a valuable tool for decision-making regarding environmental impact, however, it is not without limitations (Qiao et al., 2019; Zhan et al., 2018). Data availability is a main challenge in conducting LCA. Furthermore, variations in methodological choices and the definition of the functional unit limit comparability among different studies. Additionally, Data quality and managing uncertainties within life cycle inventories remain a challenge (Pereira et al., 2019; Terlouw et al., 2021).

While LCA offers a powerful tool for environmental decision-making, ongoing efforts are necessary to solidify its role as a robust and effective sustainability assessment tool. These efforts should focus on three key areas: standardization of methodology, enhancing data quality and reconciling top-down and bottom-up approaches, as well as consumption-based and production-based perspectives.

Table 1.1 below presents a comparison of various methods for accounting for GHGEs: bottom-up, top-down, LCA, Production-Based, and Consumption-Based approaches.

Table 1.1: Comparison of various methods for accounting for GHGEs

Method	Emissions Coverage	Pros	Cons
Bottom-Up	Scope 1 & 2 (direct and purchased energy emissions)	• Highly detailed and accurate for specific sources. • Identifies areas for targeted emission reduction.	• Can be time-consuming and data-intensive for complex systems. • Potential for double counting or missing small sources if not carefully treated. • Impacted by the accuracy of activity data and emission factors.
Top-Down	National or regional totals. Scope 1, 2, and potentially 3.	• Provides a comprehensive picture of overall emissions. • Less data-intensive than bottom-up.	• May lack granularity and miss specific sources. • Rely on atmospheric data and complex atmospheric models that require significant computational resources
Production-Based	Scope 1 & 2 emissions generated by domestic production activities.	• Straightforward to implement and monitor. • Aligns with national production statistics.	• Does not account for emissions associated with consumption of imported goods. • Limited in addressing global climate change challenges.
Consumption-Based	Scope 1, 2 & 3 emissions embodied in goods and services consumed within a	• Provides a holistic view of a country's or entity's	• More complex to implement due to

	defined system (e.g., nation).	consumption footprint. • Promotes responsibility for global supply chains.	challenges in tracking embodied emissions. • May not align with national production data.
Life Cycle Assessment (LCA)	Cradle-to-grave or cradle-to-cradle emissions across all stages of the lifecycle.	• Holistic view of environmental impact, including embodied emissions. • Identifies opportunities for eco-design and resource efficiency.	• Can be complex and data-intensive. • Requires expertise in LCA methodology.

To sum up, the previous sections presented the concept of GHGE inventories and discussed different carbon accounting approaches. Highlighting the importance of inventories in providing valuable insights on key contributing sources and tracking variation of emissions over time acting as a tool for climate change mitigation (IPCC, 2014). However, these traditional GHGE inventories typically aggregate emissions at the targeted scale (global, regional, national, or sectoral levels). They often lack the spatial granularity necessary to capture variations in emissions driven by factors such as urbanization, industrial activity, and changes in land use. Accordingly, fails to capture localized emission hotspots, hindering the development of targeted mitigation strategies. Recognizing these limitations in traditional inventories, spatial analysis emerged as a prominent approach.

1.3. Spatial Analysis in GHGE Inventories

Spatial analysis has become increasingly recognized and important in the field of GHGEs inventories, because of its effectiveness in addressing various research questions. This systematic literature review aims to provide a comprehensive overview of the concept, methodologies, advantages, limitations, and key findings of previous studies in this field.

1.3.1. Concept of Spatial Analysis

Traditionally, GHGE inventories have been made at different scales from the global and national levels to city and unit levels, providing valuable insights into the total emissions, for policymakers, stakeholders and international agreements (Bun et al., 2019; Cai et al., 2020). However, these assessments, while comprehensive in scope, lack the level of detail necessary to fully understand the geographical variations in emission patterns, to inform effective and more targeted climate action strategies (Hutchins et al., 2017).

In this context, spatial inventories of GHGE integrate geospatial data, analytical techniques, and spatial analysis allowing the examination of geographic patterns of emissions at various scales (Bun et al., 2019). GHGE is often visualized using a spatial grid system, creating a map-like representation of emissions (Danylo et al., 2019).

Spatial inventories have a wide range of advantages. Firstly, mapping GHGEs provides a quantification assessment of the climate impact of different economic sectors and activities (Bun et al., 2019). In turn, this allows the development of targeted policies and regulations to reduce emissions and prioritise mitigation efforts and the effective allocation of resources (Danylo et al., 2019). Additionally, it serves as a tool for monitoring progress towards reduction targets (K. Wang et al., 2022). Furthermore, spatial analysis helps identify emission hotspots and design localized mitigation strategies(Bun et al., 2019). Finally, integrating these maps with other datasets such as economic activity, population density, and land use helps in identifying the main drivers of GHGEs by location (Su et al., 2020).

Despite these advantages, spatial inventors have some limitations. Spatial inventories are data-intensive, they require a huge dataset that encompasses statistical and spatial data besides data on energy consumption and economic activities (Danylo et al., 2019; X. Zhang et al., 2023). The applicability of this method is subject to data availability while its accuracy depends on uncertainties associated with data quality, and consistency (Danylo et al., 2019). The variation of methods and techniques employed for mapping emissions leads to inconsistencies in spatial emission and limits the comparability of different inventories (Hutchins et al., 2017).

Recognizing these challenges, many efforts have been made to develop methodologies and techniques for mapping emissions. The subsequent section presents these methods and techniques.

1.3.2. Methods and Techniques of Spatial Analysis

Similar to traditional inventories, spatial inventors also have a variety of methodologies for mapping emissions including top-down, bottom-up, and hybrid approaches.

The bottom-up approach is a data-intensive method that relies on activity data, emission factors, and spatial allocation methods to estimate emissions from individual sources (Mateo Pla et al., 2021). This approach relies on collecting data on GHGE from various sectors such as sectoral energy consumption statistics (e.g. electricity and fuel consumption by type of building and industry) and point source data (e.g. power plants, and industrial facilities), and other kinds of data, for example, data on land use, traffic data or road network information and GDP (Cai et al., 2020; Mateo Pla et al., 2021)

In contrast, the top-down approach uses remote sensing, satellite images and atmospheric transport models. This approach disaggregates carbon emissions from a larger geographical scale to smaller scales using proxy data (Cai et al., 2020). Some examples of proxy data that are commonly used in top-down approaches include population, nighttime light imagery, land cover, number of livestock, meteorological data, etc (Danylo et al., 2019). While considered less precise than the bottom-up approach, it is valuable in situations where detailed data on emissions and energy consumption is unavailable.

Involving both top-down and bottom-up approaches creates what is so-called the hybrid approach. This approach uses proxy data like population density and nighttime lights to estimate emissions across areas, similar to top-down methods, additionally, it incorporates information on specific sources like power plants and roads as in bottom-up approaches (Hutchins et al., 2017).

Two primary techniques for spatially representing GHGEs are employed in mapping analysis: vector mapping and grid mapping. Vector mapping offers a dynamic and detailed visualization of emissions by presenting data as a vector unit including polygons, lines and points depending on the size of the emission source. One main advantage of this approach is its flexibility in accommodating complex geometries which enhances the accuracy of spatial emissions and allows the aggregation of data at different scales within administrative boundaries (Bun et al., 2019; Danylo et al., 2019) . Vector mapping excels in providing detailed spatial information; however, this approach is resource-intensive and requires data at the level of individual sources which means substantial effort for data collection (Li et al., 2022).

In contrast to vector mapping, grid mapping of emissions relies on gridded data, where emission data is represented in uniform grid cells, not vector units. Grid mapping also enables aggregating emissions at different geographic scales where the smallest possible scale is the grid or cell (which usually contains a group of emission sources) (Boychuk & Bun, 2014; Hutchins et al., 2017). However, depending on uniform cells in mapping GHGEs may fail to capture fine-scale variations in emission intensity and distribution (Hutchins et al., 2017).

Many techniques and tools are integrated with the spatial analysis of GHGEs. One example is the utilization of Geographic Information Systems (GIS) for mapping emissions. GIS-based approaches provide a variety of spatial analysis techniques that enable researchers to analyze GHG emissions and visualize the results on maps which could be grid-based or vector-based maps (Bun et al., 2019; Hutchins et al., 2017). Remote sensing data, including satellite imagery, nighttime light imagery and aerial photography, are also widely used in spatial analysis particularly in the absence of detailed sector data (Danylo et al., 2019).

Additionally, machine learning algorithms, including random forest, neural networks, and support vector machines, are increasingly used for GHGEs spatial analysis (Li et al., 2022; Lin et al., 2022; Luo et al., 2024). These techniques use large datasets of environmental and socioeconomic variables, and land use characteristics to predict emissions patterns (Lin et al., 2022).

1.3.3. Previous Research in The Field

Many researchers have investigated the spatial distribution of GHGE around the world (Boychuk & Bun, 2014; Bun et al., 2019; Cai et al., 2020; Danylo et al., 2019; Hutchins et al., 2017; Liu & Song, 2020; Mateo Pla et al., 2021; Su et al., 2020; K. Wang et al., 2022; Y. Yang et al., 2020; Zhou et al., 2021). Charkovska et al. (2019) developed a 100-m resolution bottom-up inventory of emissions from industrial processes, focusing on fuel combustion, fugitive emissions, and various industrial activities (Charkovska et al., 2019). The study utilized data from national sectoral inventories and detailed activity data to disaggregate emissions to the level of individual point and area sources. A major limitation of this study is the reliance on detailed national statistics and activity data which may limit its applicability in other areas. Another study by Cai et al. (2020) proposed a new tool for high-resolution urban carbon emission modelling using open urban form data, building attributes, and traffic flow data as inputs for emission modelling. (Cai et al., 2020). The model is based on a hybrid approach and estimated emissions from buildings and transportation sectors in Hong Kong at a 100-meter resolution raster grid. The method's applicability to other cities may depend on the availability of similar urban data.

Hutchins et al. (2016) compared five spatial emission inventories for the United States, including the Emission Database for Global Atmospheric Research (EDGAR), Open-Source Data Inventory for Anthropogenic CO_2 (ODIAC), Carbon Dioxide Information and Analysis Center (CDIAC), Fossil Fuel Data Assimilation System (FFDAS), and Vulcan. The study assessed the impact of different approaches used in these inventories (top-down and bottom-up approaches, nightlight imagery, population proxies, and the inclusion of large-point sources) on the spatial patterns of emissions. The variation in data sources and methodologies to some extent limits the comparability. However, excluding large point sources was found to impact the accuracy of emission inventories.

Danylo et al. (2019) introduced a novel method for mapping GHGE from the residential sector (Danylo et al., 2019). Different from grid-based spatial approaches, this method utilized settlement-level data on population density and other factors to disaggregate regional data more precisely. It accounts for variations in heating demand due to climate (using the heating degree day method) and considers differences in energy sources and consumption patterns between urban and rural areas. This approach can be adapted to other countries with adjustments for local data availability.

At the city scale, Wang et al. (2022) quantified the building energy use and heat emissions in Kuala Lumpur using a hybrid approach (K. Wang et al., 2022). Researchers Integrated building energy models with national statistical data and diurnal temperature profiles to assess the impact of urban heat islands (UHI) on energy use. The complexity of models and datasheets used here may limit the applicability of this approach. Furthermore, the reliance on assumptions, and linear correlations between variables, affects the accuracy of estimates and introduces uncertainties.

A study by Khrystyna Boychuk & Rostyslav Bun (2014) explored a spatial bottom-up approach using GIS for creating GHGE inventories in the energy sector (Boychuk & Bun, 2014). Based on IPCC guidelines, emissions were estimated within individual grid cells (2km x 2km) for various source categories; large-scale point sources, line and area sources like power plants, transportation, and agriculture. Specific emission factors and activity data were considered to account for local variations. Bun et al. (2018) proposed a hybrid approach for creating a high-resolution spatial inventory of GHGE (Bun et al., 2019). Unlike traditional gridded emissions, this approach focuses on building vector maps of emission sources (point, line, and area). Disaggregation algorithms were used to assign emissions to vector elements (emission sources). The approach allows the visualization of emissions at different administrative levels. This flexible approach can be applied to other countries if data is available.

Zheng et al. (2022) employed multi-source data and a novel framework hybrid approach to estimate carbon emissions within Beijing's urban functional zones (UFZs), particularly for residential and urban facility areas. Employing spatial analysis techniques, the study revealed patterns in emission distribution, with peak levels concentrated in areas of high aggregation and outliers predominantly in forested and farmland zones (Zheng et al., 2022). Pla et al. (2020) explored a new, bottom-up methodology for quantifying GHGE emissions from road traffic in cities (Mateo Pla et al., 2021). This approach is based on real-time data from existing urban traffic control and monitoring systems to estimate emissions with high spatial (street level) and temporal (hourly) resolution. A study by Zhang et al. (2023) tried to address the challenge of inaccurate or missing carbon emission data at the municipal and county levels in China (X. Zhang et al., 2023). They proposed a novel method for developing countries lacking robust energy-related data: inverting carbon emissions at the grid level by coupling nighttime light data with energy consumption. This innovative approach offers high accuracy and is particularly suitable for spatial analysis.

In conclusion, spatial analysis techniques provide an in-depth understanding of GHGEs. They offer detailed insights into the spatial distribution and trends of emissions, unveiling the underlying factors driving emissions. However, challenges remain, including data limitations, and methodological uncertainties. Besides the necessity for standardized methods for consistency, comparability, and reliability in emissions analysis and reporting.

1.4. GHGEs Challenges in Developing Countries and Conflict- Areas

This section explores the situations, and challenges associated with GHGEs in developing countries, with a particular focus on conflict areas, highlighting the need for targeted interventions and sustainable solutions.

1.4.1. Key Facts, Current Situations and Challenges

Most developing countries have been described as climate change hot spots in the Scientific literature and official United Nations reports (Murun et al., 2021; Umemiya et al., 2021; UNDP, 2018, 2019; Waha et al., 2017). This is mainly due to the predicted extreme weather events, shifts in precipitation patterns, rising temperatures and sea levels, and changes in ecosystem dynamics (UNDP, 2019; Waha et al., 2017). Overall exacerbates existing vulnerabilities and hinders sustainable development efforts.

In recent years, there has been a growing recognition of the significant contribution of developing countries to global GHGEs. According to estimates by the Center For Global Development, developing countries are responsible for about 63% of total global emissions of GHGs (Jonah Busch, 2015). Emissions in developing countries are influenced by population growth, industrialization, and land-use practices (UNDP, 2018, 2019). Despite the major contribution of developing countries to global emissions, limited studies targeted these countries in the field of GHGEs (Abbass et al., 2018).

Major bottlenecks encountered in developing countries include a lack of prioritization of climate change adaption and mitigation actions, limited monitoring and observation of climate variables, lack of effective cross-sectoral financial system to build climate resilience, and poor awareness of the public and leaders about effective measures to mitigate climate change and cut GHG emissions (UNDP, 2018; Waha et al., 2017). To prioritize adaptation interventions and for effective decision-making and targeted mitigation actions, structural changes should be undertaken in governmental policies (Abbass et al., 2018). To achieve this, emission inventories play a significant role.

In addition to the challenges stated above, conflict areas experience supplementary difficulties, including insecurity and instability, disruptions in infrastructure, displacement of populations, and resource exploitation, leading to socio-economic vulnerabilities and increased emissions and environmental degradation (Michaelowa et al., 2022; Prime Minister's Office & United Nations Population Fund, 2016; Sasmoko et al., 2023). All in all, exacerbates vulnerabilities and hinders progress in emission reduction and climate adaptation. International cooperation and support are a cornerstone in overcoming these challenges for climate resilience in conflict-affected regions (UNDP, 2019). Furthermore, addressing GHGEs in these areas requires a comprehensive and context-specific approach.

1.4.2. Emission Inventories in Developing Countries

Developing countries encounter many challenges in preparing national inventories (Kawanishi & Fujikura, 2018; Perugini et al., 2021). Significant quality and accuracy-related problems exist in national inventories reported by these countries, mainly due to: the absence of a continuous inventory system, as inventories are carried out on a project basis in these countries, and institutional constraints (Kawanishi & Fujikura, 2018; Perugini et al., 2021; Umemiya et al., 2017). Data gaps may arise because of the unavailability of historical data that is essential for the estimation of GHG emissions such as activity data and country-specific emission factors (Murun et al., 2021; UNDP, 2019). Institutional constraints are represented by: a lack of experts who are responsible for the preparation of GHG inventories, the absence of a legal and regulatory basis that identifies the providers of data in ministries, and support data collection, and the insufficient data management and archiving system (ClimaSouth, 2014; Kawanishi & Fujikura, 2018; Umemiya et al., 2017). The climaSouth programme pointed out that, emission inventories in developing countries have limited quality (ClimaSouth, 2014).

Several studies have shed light on the patterns, trends, and drivers of GHGE in developing countries, providing valuable insights into the challenges and opportunities for sustainable development (Abdallah & El-Shennawy, 2020; Aldaihani & Alenezi, 2017; AlRukaibi & AlSalem, 2022; Alzard et al., 2019; Ammar et al., 2020; Ben Azzeddine et al., 2024; Dahmani et al., 2021; Hashim et al., 2020; Hijazi et al., 2014; Khondaker et al., 2016; Nassar et al., 2021; Ogle et al., 2013; Rahman et al., 2017; Ramirez-Contreras et al., 2020; saheb Koussa & Koussa, 2016; Sahnoune et al., 2016; Saidan et al., 2019; Samara et al., 2022; Stephan & Stephan, 2020).

Ogle et al. (2013) identified the challenges faced by developing countries in constructing national inventories of GHGEs (Ogle et al., 2013). The study focused on the agricultural sector, proposing strategies for collecting activity data, measuring emissions, and using advanced software systems through the inventory process. Limitations include potential difficulties that would face developing countries in resource allocation for data collection, accuracy of emissions measurements, and complexities in implementing advanced software systems in developing country contexts. While Meng et al. (2020) introduced a new method to differentiate self-responsibility from shared responsibilities for carbon emissions along global value chains (GVCs) (Meng et al., 2023). The study which is based on input-output analysis revealed that the GVC-based responsibility of developing countries for global emissions has exceeded the responsibility of developed countries since 2012. While providing valuable insights, the study did not account for differences in the actual implementation of policies and actions for emissions reduction. Another study used remotely sensed data supported by ground observations to estimate GHGEs from deforestation activities in developing countries (DeFries et al., 2007). While the study highlighted the importance of remote sensing for monitoring deforestation, it acknowledged challenges in measuring emissions from forest degradation and carbon stocks over large areas. Focusing on the Middle East region, decomposed CO2 emissions using a novel approach based on the Tapio decoupling model (Rajabi Kouyakhi, 2022). The study projected future emissions trajectories and identified potential decoupling opportunities. Furthermore, it highlighted the impact of wars and migration on reducing emissions due to population decline coupled with decreased energy intensity. However, the study overlooked regional variations in GHGEs drivers and acknowledged limitations due to data availability in some countries like Syria and Yemen.

Based on the IPCC methodology, Hashim et al. (2020) estimated GHGEs from energy industries in Iraq over 25 years. The study showed a sharp increase in emissions from the generation of electricity which could be attributed to the poor quality of the electricity generation mix (Hashim et al., 2020). Whereas Hijazi et al. (2014) used the IPCC methodology to evaluate CH4 emissions from different sheep-keeping systems in Syria (Hijazi et al., 2014). A significant variation in emissions from the different was observed. In the same context, Ammar et al. (2020) applied Tier 1 and Tier 2 in the IPCC guidelines to estimate emissions from livestock species in Tunisia over eleven years (Ammar et al., 2020). Abu-Madi & Rayyan (2013) and Hassouna & Al-Sahili (2020) used the IPCC guidelines to estimate GHGE from fuel consumption in the residential and transport sectors in Palestine, respectively(Abu-Madi & Rayyan, 2013; Hassouna & Al-Sahili, 2020b, 2020a; Hassouna & Assad, 2020).

Stephan & Stephan (2020) conducted LCA of GHGEs for apartment buildings in Lebanon (Stephan & Stephan, 2020). The study explored the feasibility of achieving zero emissions; which appeared to be possible at high associated costs. Assumptions about building materials may affect the accuracy of the study findings.

Saidan et al. (2019) assessed GHGEs in water utilities in Jordan, using the Energy Performance and Carbon Emissions Assessment and Monitoring Tool (ECAM) (Saidan et al., 2019). Results revealed that water supply is the largest contributor to GHGEs in water utilities. The study's assessment is based on assumptions that may affect the accuracy of the results. Hussein (2016) investigated the potential for reducing emissions in Jordan through the implementation of wind and solar projects (Hussein, 2016). Renewable energy projects were found to have high reduction potential at the country level. However, the study's reliance on scenario analysis and assumptions may introduce uncertainties, due to limitations in capturing real-world complexities.

Zooming on conflict areas; few scholars covered GHGE in conflict areas with an emphasis on quantifying GHGE from armed conflicts and military operations (Rajabi Kouyakhi, 2022; Sasmoko et al., 2023; C. Zhang et al., 2023)Other scholars focused on emissions from energy generation in conflict areas such as Iraq and Syria, without discussing the implications of the war and conflict on this sector and its associated carbon emissions (AL-wesabi et al., 2022; Hainoun et al., 2014; Hashim et al., 2020).

In terms of responsibility, a few researchers have discussed the responsibility of GHGE in conflict. Michaelowa et al. (2022); and Michaelowa & Koch (2001) (Michaelowa et al., 2022; Michaelowa & Koch, 2001)established a general frame for the primary assignment of responsibility for military and conflict-related emissions in war and peacetime. They distinguished between different types of conflicts, including the occupation, such as the case of Palestine.

1.5. Research Gaps, Objectives and Contribution

The systematic review of literature on carbon accounting inventories, methodologies, and published research, reveals significant gaps and challenges in estimating GHGE in developing countries. One major hurdle is the limited availability of data and resources in these regions, hindering efforts to obtain a comprehensive understanding of emissions dynamics. Additionally, many existing methodologies are frequently data-intensive, requiring comprehensive datasets and tailored to developed countries, where data availability differs, making them less applicable to developing nations.

Moreover, the impact of conflict on emissions in these regions has been largely overlooked. In particular, conflict areas face unique challenges due to the disruptive effects of conflict on GHGEs. The interplay between conflict dynamics and emissions remains poorly understood, limiting the progress towards achieving emission reduction targets in these areas.

Spatial analysis, crucial for understanding emission patterns, is also lacking in developing countries, with virtually no studies focusing on conflict areas. Understanding how conflict affects emissions, such as through population displacement and trade restrictions, is essential for effective emission reduction strategies.

To address these gaps, this research proposes a novel multiscale approach that goes beyond national reports. By employing alternative data sources and innovative methodologies that are less reliant on comprehensive datasets, we aim to bridge the data gap and provide a more in-depth understanding of GHGEs across multiple scales within developing countries and conflict areas.

By providing a spatial distribution of emissions in these conflict areas, the study seeks to shed light on the interaction between conflict and emissions and contribute to a better understanding of emission dynamics in challenging environments. Ultimately, the research aims to facilitate the development of targeted policies and strategies to reduce emissions in conflict areas and support progress towards achieving climate targets.

This research seeks to make several contributions to both academic scholarship and policy-making in the field of GHGEs:

- Theoretical contribution: This study aims to bridge the gap in the scientific research concerning GHGEs in conflict areas, by targeting an interesting case study "Palestine", which presents unique challenges in estimating GHGEs in conflict areas.
- Methodological innovation: The study proposes a novel multiscale approach for multiscale and multisector GHGEs assessment in conflict areas which will provide valuable insights for future research endeavors.
- Policy implications: The findings of this research are expected to inform policy-making and interventions aimed at mitigating GHGEs in conflict areas.

In summary, this research aims to provide a more in-depth understanding of GHGE in conflict areas by developing a hybrid approach for estimating GHGE from various sectors at multiscales, offering insights into the impact of conflict on emissions, while also facilitating the development of targeted policies and strategies to reduce emissions in conflict areas and support progress towards achieving climate targets.

1.6. Conclusion

This chapter presented the state of the art about GHGEs inventories, available methodologies and approaches for carbon accounting, and challenges of GHGEs estimation in developing countries and conflict areas.

Our systematic review has uncovered a notable bias prevalent in the published literature, wherein the predominant focus lies on developed nations and emerging economies such as China and India. Furthermore, the methodologies deployed in these studies are predominantly tailored to environments characterized by abundant big data, financial resources, and readily accessible data acquisition tools and resources. Unfortunately, the applicability of these methodologies to developing nations remains constrained.

Despite the substantial contribution of developing countries to global emissions, they are not adequately targeted in the literature to address the escalating emissions from these regions and assist them in achieving their emission reduction targets outlined in their nationally determined contributions. Furthermore, our review has revealed a striking scarcity of studies that specifically target conflict areas and explore the interactions and impacts of conflict on emission patterns in these regions. Despite their vulnerability, conflict-induced instability and insecurity and the complexities they face, very few studies have addressed these critical areas.

The outcomes of the systematic review serve as a foundation for the formulation of targeted research questions and objectives, and for defining the research gap and prospective contributions. By leveraging the findings and learning from the limitations of prior studies, we aim to develop a tailored method that is suited to the unique context of GHGEs in conflict-affected areas. Ultimately, the objective is to address this gap in the literature for a better understanding of emissions in conflict areas.

Furthermore, the literature review highlighted the significance of adopting a multi-phase approach to construct a comprehensive understanding of emissions from conflict-affected regions. This approach entails progressing from a national scale assessment to pinpoint key contributing sectors, followed by sectoral analysis to define specific emission sources within each sector. Subsequently, spatial analysis is employed to discern emission patterns and evaluate the impact of primary emission drivers on emission distribution. Lastly, particular attention is given to emission trajectories and scenario assumptions to outline pathways for reducing emissions in the targeted area considering the local context.

This chapter sets the stage for the subsequent research by outlining the existing gaps and challenges in GHG emissions estimation and highlighting the need for innovative methodologies tailored to the unique contexts of developing countries and conflict areas. The next chapter will present the methodology adopted in this research for estimating GHGE in conflict areas.

Chapter 2. Research Methodology

2.1. Introduction

2.1.1. Overview

Climate change, driven by rising GHGEs, stands as one of the most pressing challenges facing the planet. Understanding the sources and distribution of these emissions is crucial for developing effective mitigation strategies. However, this task becomes particularly complex in conflict zones and regions with limited data availability where ongoing political instability and disruption often hinder comprehensive data collection efforts. This research delves into a multiscale and multisector analysis of GHGEs in such areas, offering a comprehensive approach to bridge the data gap.

This chapter outlines the general methodological approach employed in this research for the evaluation of GHGEs at multiscale in conflict areas with limited data. Subsequent chapters will delve into the specific methodologies used for each stage of the analysis.

To bridge this critical gap in understanding carbon footprints in developing countries, especially conflict zones, due to limited data, this research focuses on developing a novel carbon accounting methodology based on a hybrid approach. This approach is specifically tailored to address the data limitations and other challenges that hinder GHGEs estimation in developing countries and conflict zones.

While research on GHGEs has grown significantly, a key limitation exists in developing countries. Traditional emission assessments in these regions often prioritize the national scale. This focus is primarily driven by the need to develop National Determination Contribution (NDC) reports submitted to the UNFCCC under the Paris Agreement. While these reports are valuable for understanding national emissions trends, they present a single, homogenized picture. This approach overlooks the significant spatial variations in GHGEs that can occur within developing countries.

This limitation is particularly problematic in conflict zones, where ongoing disruptions can drastically alter emission patterns across different locations. Traditional national inventories fail to capture these crucial spatial variations. While established spatial analysis methods are frequently data-intensive, requiring comprehensive datasets that are often unavailable in developing countries and conflict zones. These methods, typically designed for developed countries with robust data collection systems, are not readily applicable in these challenging contexts.

2.1.2. Research Gap

Recognizing these limitations in capturing the full scope of emissions for developing countries and conflict zones, this research is designed to address the following gaps:

- Focus on developed economies: Existing research on GHGEs estimation has primarily concentrated on developed countries and emerging economies.
- Limited knowledge for developing countries: This has resulted in a significant knowledge gap in understanding carbon footprints within developing countries, particularly at the city and local community level.
- Data scarcity challenges: Due to limited data availability, developing countries often face significant challenges in conducting comprehensive GHGEs inventories to gain an in-depth understanding of their emission sources and distribution. This lack of granularity makes it challenging to develop targeted strategies for reducing emissions effectively and making a more significant contribution to global efforts.

- Limitations of existing approaches in data-scarce environments: As a consequence, existing methodologies and carbon accounting frameworks designed for developed economies, rely on detailed data collection, often requiring breakdowns by sector, activity, or region. These approaches ensure accuracy, but in data-scarce environments like developing countries and conflict areas, it becomes a limitation.
- Unexplored challenges in conflict zones: Furthermore, the unique challenges of data collection and analysis in conflict zones, where political instability and disruptions are commonplace, remain entirely unaddressed in current published studies.

This research addresses this gap by proposing a novel multiscale approach that goes beyond national reports. By employing alternative data sources and innovative methodologies that are less reliant on comprehensive datasets, we aim to bridge the data gap and provide a more in-depth understanding of GHGEs across multiple scales within developing countries and conflict areas. This will ultimately allow for the development of more effective and targeted mitigation strategies.

2.1.3. Research Significance

In line with the research objectives, our case study is "Palestine" a developing country which is also well known as a conflict zone. This case is particularly well-suited for our research because it exemplifies the data scarcity issues and challenges faced by many developing countries and conflict zones.

The significance of this research stems from the originality of the study area; as estimating GHGEs in Palestine presents unique challenges due to several factors:

- Conflict area: the conflict in the area has its roots in the late 19th and early 20th centuries, and it is still ongoing.
- Territorial fragmentation and complex geopolitical context: Palestine consists of two separated land masses; The West Bank and the Gaza Strip. Moreover, the West Bank is divided into three areas A, B, and C as part of the Oslo Accords (EUROPEAN UNION, 2021). The West Bank is under partial Palestinian Authority control (Areas A & B) and Israeli occupation of the larger Area C (UNCTAD, 2015). Additionally, the Israeli settlements in the occupied West Bank, contribute significantly to the pollution of air, soil, and water in the West Bank (Ramahi, 2012; United Nations Environment Programme, 2020).
- Strong dependency and interaction with regional countries: There is a strong dependence of the Palestinian economy on occupation due to economic policies and many restrictions on freedom of movement of goods and people, import and export of raw materials and products, full control of international borders, and the development of domestic and industrial infrastructure. One of the primary challenges Palestine faces in terms of GHGEs lies in its energy sector. The nation relies heavily on imports from Israel, particularly for fossil fuels like petroleum and natural gas derivatives. This dependence not only increases GHGEs but also creates vulnerabilities due to limited storage capacity and potential supply disruptions.
- Data missing: as in the case of other developing countries, Palestine encounters problems in data availability such as activity data and country-specific emission factors due to insufficient data collection, management, and archiving systems.

More details on the case study are presented in the following section.

2.2. Methodology

2.2.1. Case study

This research focuses on a relevant study case, Palestine, a developing country, located in the Levant, between the Jordan River and the Mediterranean Sea. The research covers the West Bank (including East Jerusalem) with an estimated area of 5,660 km^2 and the Gaza Strip covers an area of 365 km^2.

Based on population estimates by the Palestinian Central Bureau of Statistics (PCBS) for 2024, there are about 5.49 million in the State of Palestine, of which 3.2 million are in the West Bank and 2.29 in the Gaza Strip (Palestinian Central Bureau of Statistics, 2021c). The country's average population density is around 790 people per square kilometre. However, this value varies significantly across territories. Gaza Strip boasts a high density of 5200 people per square kilometre, while the West Bank exhibits a much lower density of 510 people per square kilometre (Palestinian Central Bureau of Statistics, 2020a).

In accordance with the Oslo Accords (the Declaration of Principles on Interim Self-Government Arrangements of 1993 (Oslo I) and the Interim Agreement on the West Bank and the Gaza Strip of 1995 (Oslo II)), the West Bank was divided into three non-contiguous regions: A, B, and C (United Nations High Commissioner for Human Rights, 2020). **Figure 2.1** visualizes the jurisdictional areas within the West Bank.

Area A represents 18% of the West Bank, and most affairs in this area are controlled by the Palestinian Authority. Area B comprises 21% of the West Bank. The Palestinian Authority is in charge of civil administration in this area (education, health, and the economy), while Israel has complete control of the security. Area C represents the largest part of the West Bank (60%). It is under the control of Israel. Although the Oslo Accords were agreed to be an interim five-year agreement, they are still in force. Additionally, there are at least 250 settlements in the occupied West Bank, which are home to around 500 thousand settlers (EUROPEAN UNION, 2021), and contribute significantly to the pollution of air, soil, and water in the West Bank (Ramahi, 2012; United Nations Environment Programme, 2020).

The Palestinian economy strongly depends on the occupation due to restrictions on the movement of goods and people, import and export of dual-use materials and equipment, raw materials, and products, complete control of international borders, and the development of domestic and industrial infrastructure. (United Nations High Commissioner for Human Rights, 2020).

Documented by the UN Office for the Coordination of Humanitarian Affairs (OCHA) in early 2023, these limitations severely limited Palestinian mobility and impacted economic activity (OCHA, 2023). Over 645 physical barriers, including checkpoints, roadblocks, and earthen obstructions, fragment the West Bank, representing a disturbing 8% increase compared to 2020. The checkpoints are creating unpredictable delays and disruptions in movement, hindering the Palestinian's access to essential services, agricultural land, and urban centres. Beyond the physical barriers, a more extensive system of control exists. The 712-kilometre Israeli Barrier runs inside the Palestinian territory, further isolating communities and agricultural areas. Most access points through the Barrier remain frequently closed, restricting farmers from tending to their land. Military-designated "firing zones" restrict access to a substantial portion (20%) of the West Bank, hindering land use and economic development (OCHA, 2023). Additionally, Israeli settlements, occupying roughly 10% of the West Bank, further fragment the West Bank. The cumulative effect of these restrictions creates a fragmented and stifled Palestinian economy. Limitations on movement hinder the flow of goods and people, essential for a healthy and functioning market. This disrupts supply chains, inflates transportation costs, and limits access to essential resources.

The illegal settlements, along with the apartheid wall, annexation, fragmentation, checkpoints, unequal status quo, and other discriminatory practices, reduce the adaptation capacity of the Palestinians to climate change. Adaption options that need the import of new technology, dual-use materials, and the development of infrastructure are challenging and require the lifting of these restrictions (Freij, 2021).

Palestine joined the Paris Agreement on climate change in December 2015, as a non-Annex I party, which means it is considered to be more vulnerable to the effects of climate change (Palestine Environment Quality Authority, 2021).

Subsequent chapters will explore deeper into the Palestinian context, providing crucial details that inform the needs and approaches discussed in each chapter.

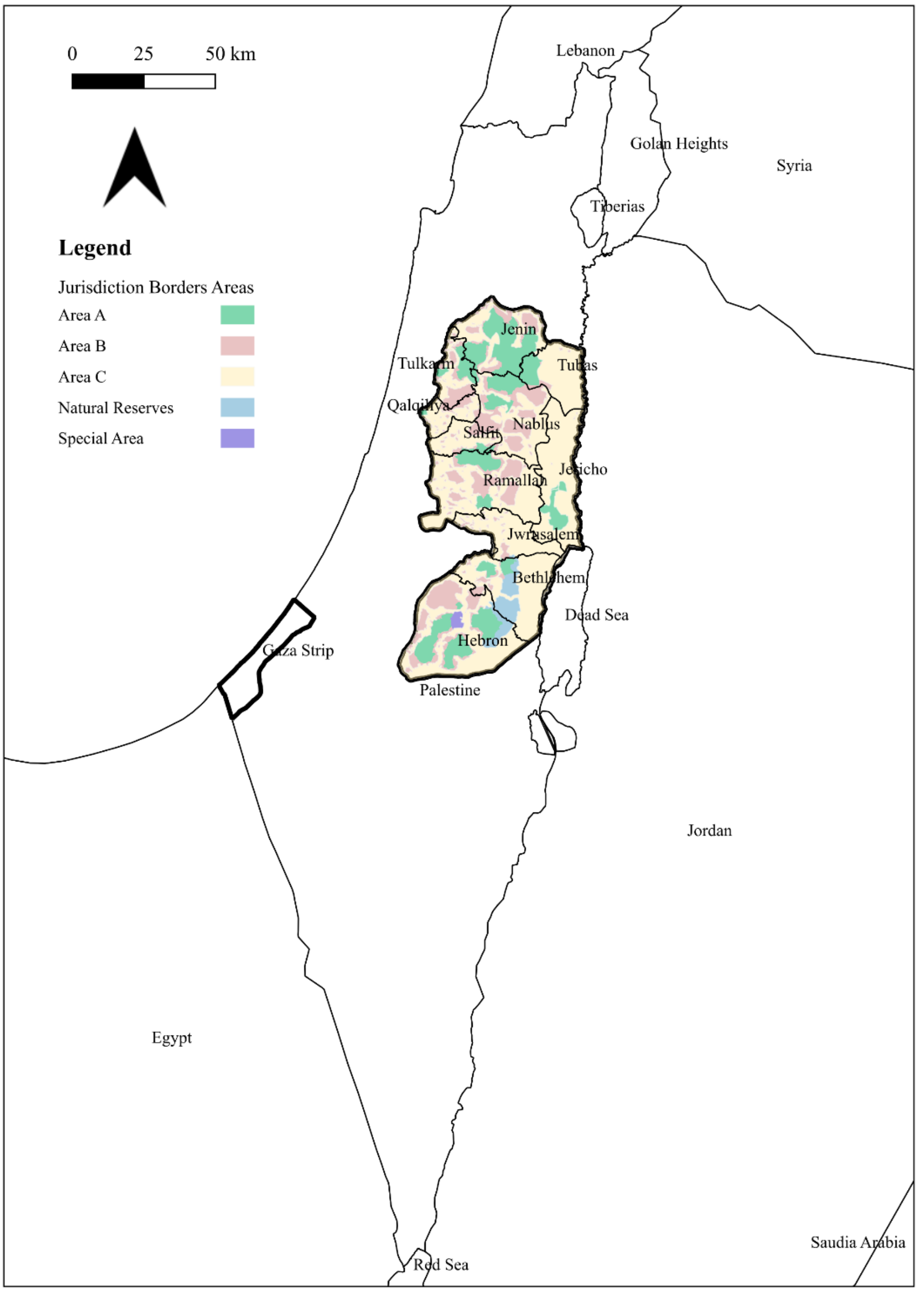


Figure 2.1: The jurisdictional areas within the West Bank, areas A, B and C in accordance with the Oslo Accords

2.2.2. Research Design and Methods

This research starts with establishing the national picture of GHGEs, with a particular focus on the energy sector as a major contributor to carbon emissions. Establishing a national picture is the first crucial step in our multiscale analysis. First, it provides a baseline for understanding the country's or region's role in climate change and facilitates comparisons with other nations. Second, it identifies the key emitting sectors of GHGEs. Finally, the national picture serves as a roadmap for subsequent stages of our research, where it facilitates exploring and investigating spatial variations and conducting a more in-depth analysis of specific sectors with high emissions.

Following the establishment of the national picture, a more in-depth analysis of key sectors (identified as major contributors to GHGEs) will take place. This analysis delves deeper into these sectors to understand the specific drivers influencing emissions within each sector. By identifying the factors responsible for emissions within each key sector, valuable insights will be gained for developing targeted mitigation strategies.

Building upon the national and sector-specific analyses, we implement a spatial analysis approach to map GHGEs across the study area. This approach utilizes a hybrid methodology, drawing on multiple data sources – both national and international – to provide a comprehensive picture of emissions distribution. Employing this innovative approach, will not only allow identifying hotspot areas with high concentrations of emissions but also pinpoint the specific drivers of emissions within each location.

Utilizing the insights and information gained from the national, and sectoral analyses, and spatial mapping of emissions, it is possible to explore pathways for reducing GHGEs within the study area. This stage involves building emission reduction scenarios. Various hypothetical scenarios are developed and analyzed to assess their effectiveness in curbing emissions.

This scenario-based approach allows us to evaluate the potential impact of different mitigation strategies before their actual implementation. By analyzing these scenarios, we aim to identify the most effective and targeted strategies for emission reduction tailored to the spatial needs of the study area. These recommendations will provide a concrete base for reducing emissions and promoting sustainable development in the region, taking into account the specific spatial context of the area.

The general framework for the research methodology is presented in **Figure 2.2**. The following section will delve deeper into each stage of the research process presented in **Figure 2.2**, offering detailed insights into the methods and approaches used.

2.2.3. Multiscale Multisector Analysis of GHGE

This section provides more information on the material and methods applied in this research at the different phases as presented in **Figure 2.2**. As illustrated, the research framework consists of four main phases; national GHGE inventory, Sector specific analysis, spatial analysis, and Scenario-Based Emissions Reduction Pathways

2.2.3.1. Constructing a National Inventory under Data Constraints

Understanding the sources and distribution of GHGEs is crucial for developing effective mitigation strategies. To achieve this goal, the analysis process begins by establishing a national picture of carbon emissions in Palestine. This initial stage focuses on the energy sector, a major contributor to GHGEs in Palestine (Palestine Environment Quality Authority, 2021).

The analysis at this phase delves into the energy sector, to categorize emissions based on two key aspects:

- Type of gas emitted: The analysis differentiates between various GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
- Type of fuel: GHGEs are also investigated by the type of fuel responsible for these emissions; diesel, gasoline, natural gas, kerosene…. .etc.
- Economic activity responsible: The emissions are further categorized by the economic sector generating them, including household activities, commercial establishments, industrial processes, transportation networks, and others. This level of detail allows us to pinpoint emission hotspots within the national energy sector.

Within this sector, the impact of imported electricity (which is not usually accounted for in national inventors) on GHGEs is investigated in this analysis. Understanding the reliance on imported electricity allows us to assess the indirect emissions associated with energy consumption beyond the national borders. Under this context, emission factors for electricity generation and consumption in Palestine are evaluated.

To ensure the accuracy and consistency of our national inventory, we rely on the well-established guidelines provided by the Intergovernmental Panel on Climate Change (IPCC) for national greenhouse gas inventories (IPCC, 2006). These guidelines offer a standardized approach for estimating and reporting GHG emissions, allowing our findings to be comparable with national inventories from other countries. By employing this comprehensive approach, a robust national picture of GHGEs in Palestine is established. This foundational understanding of the energy sector's contribution to national emissions paves the way for subsequent stages of our multiscale analysis, where we go deeper into specific sectors and explore spatial variations across the country.

2.2.3.2. Sectoral Focus Analysis

Following the establishment of the national picture, the research zooms in on a specific sector with a significant contribution to GHG emissions. This phase focuses on the main drivers of GHGEs from the energy sector in Palestine. The application will be on the transportation sector, the first fuel consumer in the country (Palestinian Central Bureau of Statistics, 2019). Here, a hybrid approach is established to evaluate emissions based on vehicle type and fuel. This approach aims to identify the key contributors to total vehicular emissions in the country. As this analysis is data-intensive, it incorporates information from various sources including:

- Fuel consumption and vehicle statistics: This data provides a foundational understanding of the transportation sector.
- Vehicle kilometres travelled (VKT): Understanding how much vehicles are driven is crucial for accurate emissions assessment.
- Average fuel consumption by vehicle type: This data allows us to refine the analysis by considering the specific fuel efficiency of different vehicle categories.

By combining data from surveys, published research, and reports from official bodies with this hybrid approach, it is possible to effectively evaluate fuel consumption across various vehicle categories. This analysis helps in identifying the specific types of vehicles and fuels that contribute the most to overall transportation emissions in Palestine. This information is crucial for policymakers to develop targeted policies.

2.2.3.3. Spatial Analysis

A core aspect of this research lies in its ability to assess emissions across various scales. This phase explores the geographical distribution of GHGE in Palestine. The application here is to GHGE from electricity consumption in different sectors; industrial, residential, commercial, and public sectors**.**

Spatial analysis is the most data-intensive phase. Various data sources are utilized to map GHGEs, including industrial statistics, demographic data, energy-related statistics, commercial and economic activity surveys, and spatial data. Open-source databases, like OpenStreet Maps and GeoMOLG, are also included. To integrate this vast amount of data, different aggregation techniques will be employed. To integrate all of these datasets a hybrid approach based on vector maps will be developed. Ultimately, the developed approach will allow for estimating emissions at different geographical scales. This ability to analyze emissions at various scales is highly valuable for policymakers, as it enables them to develop targeted emission reduction strategies that focus on areas with the highest emissions.

2.2.3.4. Scenario-Based Emission Reduction Pathways

Building upon the insights gained from the national, sectoral, and spatial analyses, this phase constructs various emission reduction scenarios. The focus here is on developing emission reduction pathways for the main contributors to GHGEs within the energy sector in Palestine; the transport and household sectors. This part explores various emission reduction scenarios based on:

- Technological Advancements: Scenarios incorporating advancements like increased adoption of electric vehicles or improved fuel efficiency measures are considered.
- Shifts in Consumption Patterns: Scenarios exploring changes in travel behaviour, such as a modal shift towards public transportation or cycling, are assessed.
- Policy Interventions: The potential impact of policy interventions such as carbon pricing mechanisms or regulations promoting energy-efficient technologies are evaluated.

Trend and regression analysis are utilized here to establish baseline emissions projections; by analyzing historical data and emissions-driving factors (population, GDP, etc.), this analysis establishes a baseline projection of future emissions where no reduction strategies are implemented. A spreadsheet model is developed for simulating the impact of various policy interventions and technological advancements on emissions within targeted sectors. This approach allows policymakers to compare the effectiveness of different mitigation strategies and select the most impactful ones for achieving Palestine's emission reduction goals.

2.2.3.5. Policy Recommendations: Tailored Solutions for Palestine

The final stage involved formulating policy recommendations grounded in the findings from the multiscale analysis and scenario modelling. Considering the specific context of Palestine, these recommendations will prioritize:

- Sector-specific mitigation actions: Based on the sectoral analysis, tailored recommendations for emission reduction within the transportation and household sectors will be proposed.
- Policy Instruments for Change: Policy recommendations will consider effective instruments suitable for the Palestinian context, promoting sustainable transportation practices and fostering low-carbon development in the household sector. This can involve financial incentives, regulations, and awareness campaigns targeting households directly.

The detailed methodology for each stage of this multiscale analysis framework will be presented in subsequent Chapters. This approach, designed to overcome limitations in data availability, provides valuable insights for policymakers and stakeholders in Palestine to chart a course toward a more sustainable future.

2.3. Main Research Tools

This section outlines the various tools and software utilized throughout this research to ensure accuracy, efficiency, and effective data analysis.

- *IPCC Guidelines for National Inventories*: The 2006 IPCC Guidelines for National Greenhouse Gas Inventories provided a robust methodological framework for estimating GHGE in the study area (IPCC, 2006). These guidelines are particularly valuable for ensuring consistency and comparability with international emission reporting standards. The main principle of this method is adapted at different scales in this research.
- *Method for Estimating Electricity-related Emission Factors*: The core methodology for calculating GHGE factors associated with electricity consumption and production in Palestine in this research is derived from the International Energy Agency's (IEA) method (International Energy Agency, 2020).
- *R 4.3.2 Software*: A free and open-source statistical programming language, that facilitates sophisticated data analysis and modelling tasks. R's extensive collection of packages provided a powerful toolkit for addressing the complexities of this study. R is used to perform the following: data processing, time-series trend analysis, regression analysis, and prediction Models.
- *QGIS 3.34.3 Software*: A Geographic Information System software, that plays a crucial role in spatial analysis and data visualization. All the spatial data in this research are incorporated into QGIS. QGIS played a crucial role in spatial calculations and data disaggregation processes. It is also used to create thematic maps that visually represent the spatial distribution of energy consumption and associated emissions across the study area.
- *Microsoft Excel*: This is used for basic data manipulation tasks such as data cleaning, organization, and preliminary calculations related to the application of IPCC guidelines and the IEA methodology. This research utilizes an Excel-based model specifically designed to evaluate the effectiveness of different emission scenarios. In some cases, Excel is also used for the presentation of simpler results like tables and charts.

The various tools and software employed throughout this research play a critical role in ensuring the accuracy, efficiency, and comprehensiveness of the analysis. The combination of established methodologies, the IEA's emission factor calculation approach, and sophisticated statistical techniques enable a deeper understanding of the relationship between energy consumption, electricity imports, and GHGEs within the study region.

2.4. Conclusion

This chapter presented the research methodology employed in this study. The research has developed a novel multiscale approach to estimate GHGEs in conflict areas and developing countries, addressing the limitations identified in existing methodologies and contributing valuable insights to the field of carbon accounting in these areas. By employing alternative data sources and innovative methodologies that are less reliant on detailed datasets, this approach provides a more comprehensive and in-depth understanding of GHGEs across multiple scales within the targeted regions. This will ultimately allow for the development of more effective and targeted mitigation strategies.

The research applies the developed approach to Palestine, a developing occupied country in the Middle East. This case study is particularly well-suited for this research due to its characteristics that mirror the limitations we aimed to address.

The application of the research stages will be presented in the following chapters:

VI. Chapter 3: National GHGE Inventory; this chapter will provide a comprehensive national picture of GHGEs from the energy sector in Palestine, and quantify the emissions embodied in a nation's electricity Imports.

VII. Chapter 4: Sectoral Focus Analysis; this chapter will present a more in-depth analysis of key sectors identified as major contributors to GHGEs in Palestine. The application here is in the transportation sector.

VIII. Chapter 5: Spatial Analysis; this chapter will map GHGEs, providing a comprehensive picture of emissions distribution in the country. The developed approach here is applied to emissions from electricity consumption in Palestine.

IX. Chapter 6: Scenario-Based Emissions Reduction Pathways; utilizing the insights and information gained from previous analysis, this chapter will explore pathways for reducing GHGEs within the study area to develop targeted emission reduction strategies.

By presenting the research process, this chapter provides a clear roadmap for the reader to understand how the research is conducted and how the findings will be presented in subsequent chapters.

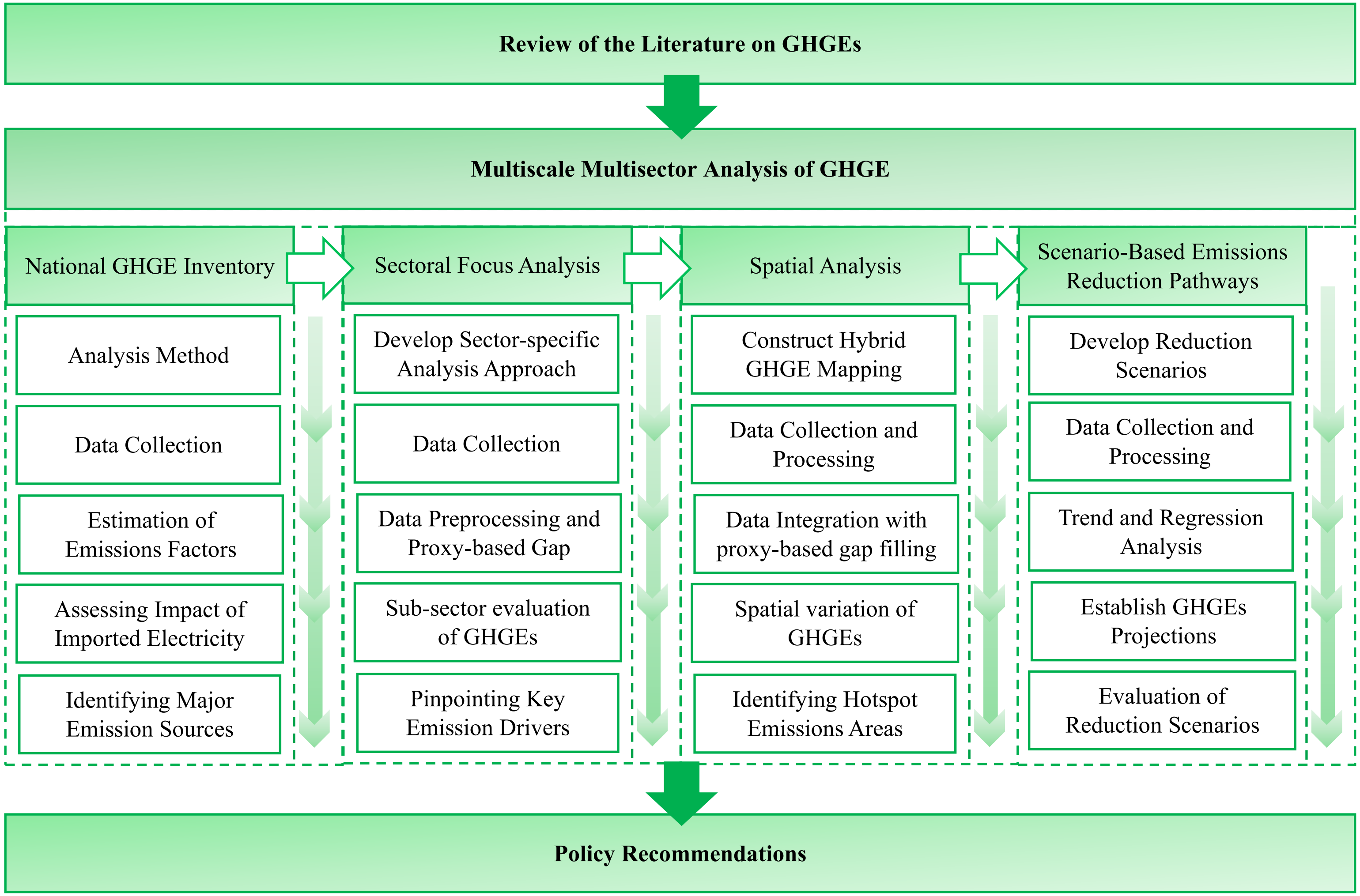


Figure 2.2: General framework for the research methodology

Chapter 3. National Scale Analysis of Greenhouse Gas Emissions From The Energy Sector

3.1. Introduction

This chapter estimates greenhouse gas emissions (GHGEs) from the energy sector in Palestine. Palestine has been deprived of control over its international borders and submitted to discriminatory practices, including restrictions on the movement of people and goods, import of dual-use materials, access to natural resources, and destruction of property and infrastructure (Freij, 2021).

This subject is particularly significant because the consequences of the conflict in Palestine go beyond adding complication to carbon accounting to restricting Palestine's mitigation and adaptive capacities to reduce GHGE. Moreover, it raises complex questions regarding GHGEs: Who is responsible for these emissions? And what is the legal point of view?

Few scholars covered GHGEs in conflict areas with an emphasis on quantifying GHGEs in the context of armed conflicts and military operations (Rajabi Kouyakhi, 2022; Sasmoko et al., 2023; C. Zhang et al., 2023). Other scholars focused on emissions from energy generation in conflict areas such as Iraq and Syria, without discussing the implications of the war and conflict on this sector and its associated carbon emissions (AL-wesabi et al., 2022; Hainoun et al., 2014; Hashim et al., 2020).

In terms of responsibility, a few researchers have discussed the responsibility of GHGEs in conflict areas. Michaelowa et al. (2022); and Michaelowa & Koch (2001) (Michaelowa et al., 2022; Michaelowa & Koch, 2001)established a general frame for the primary assignment of responsibility for military and conflict-related emissions in war and peacetime. They distinguished between different types of conflicts, including the occupation, such as the case of Palestine.

The literature review revealed a lack of published literature on GHGEs in Palestine. Only one paper concerned carbon emissions from the energy sector (Qureitem et al., 2020). In this paper, the emissions from electricity consumption were not considered. These emissions lie under scope 2 emissions since the vast majority of the electricity in the country is imported because of political and logistical factors. Another study focused on emissions from household energy consumption. Abu-Madi & Rayyan (2013) (Abu-Madi & Rayyan, 2013)used emission factors from published literature to estimate GHGEs from fuel consumption in the residential sector, including electricity, due to the unavailability of country-specific data. Other scholars estimated GHGEs from the transport sector (Hassouna & Al-Sahili, 2020b, 2020a; Hassouna & Assad, 2020; Karaeen et al., 2021). These papers did not consider the impact of the conflict on GHGE.

This chapter fills this gap by considering the impact of the occupation on estimating the GHGEs in Palestine. The research question is then to collect available data on GHGEs and the occupation's restrictions on Palestinians to analyse the impact of this occupation on the GHGEs in Palestine with an emphasis on the energy sector.

This chapter is composed of four main sections. It starts with the introduction section, which presents the research gap and the research objective. Then it describes the research methodology, including information on the study area, data collection, and the method of analysis method. After that, it presents the research results supported by a discussion. Finally, the chapter ends up with the conclusions and limitations of this research.

3.2. Materials and Methods

3.2.1. Overview

The main objective of this research is to present the impact of the conflict in Palestine on estimating GHGEs related to the energy sector, which constitutes the most significant contributor to carbon emissions according to the State of Palestine's Initial National Communication Report (INCR) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) (Palestine Environment Quality Authority, 2016).

The methodology adopted in this research is based on the IPCC- 2006 guidelines, considering the 2019 Refinement, which was adopted and accepted in the 49^{th} session of the IPCC in May 2019. This research also covers indirect carbon emissions from imported electricity, unlike the National Inventory Reports (NIR), which only cover the direct emissions following the IPCC guidelines. This production-based carbon accounting method does not require reporting scope 2 emissions. The theoretical framework of this research is presented in **Figure 3.1**.

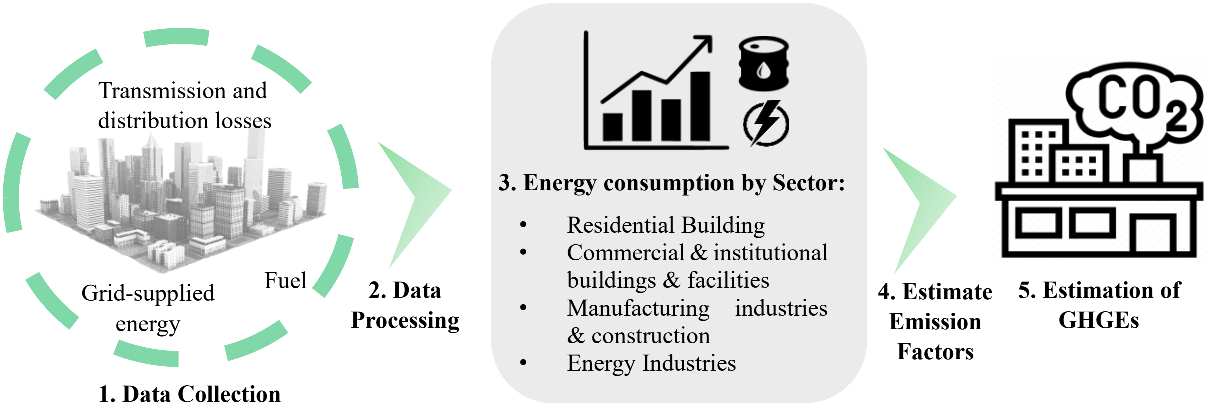


Figure 3.1: Theoretical framework of the study

The first step of this research included a study of the energy sector in Palestine with a focus on the impact of the conflict on GHGEs related to energy.

Data required to estimate GHGEs was defined according to the literature and the 2006 IPCC guidelines. Generally, to quantify CO_2 emissions, two types of data are required: (i) activity data and (ii) emission factors. To reduce climate change caused by carbon emissions, it is imperative to estimate the emissions of GHG (Elahi et al., 2022; Solomon et al., 2009). The emission factors are coefficients that represent the average emission rate of a GHG from fuel combustion in 85 particular activities/processes (Abbas et al., 2022; Drouet et al., 2011).

In the energy sector, the activity data are typically the amounts of fuels combusted in a specific activity/process. The emission factors are coefficients that represent the average emission rate of a GHG from fuel combustion in a particular activity/process. In this study, the activity data are characterized by fuel sales and electricity consumption by different sectors. It was a big challenge to obtain this data for Palestine. Data have been acquired from different governmental and official bodies in the country, such as the Palestinian Energy and Natural Resources Authority (PENRA), the Palestinian Ministry of Transport (MoF), and the Palestinian Central Bureau of Statistics (PCBS). The geopolitical separation between the West Bank and the Gaza Strip created difficulties in data collection.

Regarding emission factors, Palestine lacks country-specific emission factors due to the unavailability of expertise and equipment needed to measure these factors. Consequently, the default emission factors of the 2006 IPCC guidelines were applied. In particular, the emission factors of electricity consumption were estimated based on the electricity generation emission factors. The emission factors for imported electricity were obtained from the Israel Central Bureau of Statistics, the Israel Ministry of Environmental Protection, and the Ministry of Energy and Infrastructure.

The last phase of this research estimates the GHGEs from fuel combustion using the collected data and emission factors based on Tier 1 in the IPCC guidelines and interprets the results in light of the conflict in the country. The use of Tier 1 is justified by data availability in the studied area, which did not allow us to use a higher tier. The following section provides more information about the research methodology.

3.2.2. Study Area

The study area covers the West Bank (including East Jerusalem) and Gaza Strip. Accordance to the Oslo Accords (the Declaration of Principles on Interim Self-Government Arrangements of 1993 (Oslo I) and the Interim Agreement on the West Bank and the Gaza Strip of 1995 (Oslo II)), the West Bank was divided into three non-contiguous regions: A, B, and C (United Nations High Commissioner for Human Rights, 2020). Area A represents 18% of the West Bank, and most affairs in this area are controlled by the Palestinian Authority. Area B comprises 21% of the West Bank. The Palestinian Authority is in charge of civil administration in this area (education, health, and the economy), while Israel has complete control of the security. Area C represents the largest part of the West Bank (60%). It is under the control of Israel.

Although the Oslo Accords were agreed to be an interim five-year agreement, they are still in force. Additionally, there are at least 250 settlements in the occupied West Bank, which are home to around 500 thousand settlers (EUROPEAN UNION, 2021), and contribute significantly to air, soil, and water pollution in the West Bank (Ramahi, 2012; United Nations Environment Programme, 2020).

The Palestinian economy strongly depends on the occupation due to restrictions on the movement of goods and people, import and export of dual-use materials and equipment, raw materials, and products, complete control of international borders, and the development of domestic and industrial infrastructure. Palestine depends strongly on neighbouring countries. For example, more than 95% of the electricity in the country is purchased due to political and logistical factors (United Nations High Commissioner for Human Rights, 2020).

The illegal settlements, along with the apartheid wall, annexation, fragmentation, checkpoints, unequal status quo, and other discriminatory practices, reduce the adaptation capacity of the Palestinians to climate change. Adaption options that need the import of new technology, dual-use materials, and the development of infrastructure are challenging and require the lifting of these restrictions (Freij, 2021) .

3.2.3. Energy Sector

Due to political and logistical factors, Palestine depends primarily on imported energy. Since Israel controls energy imports, the energy sector suffers from an unsecured supply (Qureitem et al., 2020). Figure 2 shows the main energy products, solid and liquid fuel, and electricity consumed by Palestinians in 2019, including and excluding imported electricity. The amounts of diesel and gasoline fuels transformed into electricity in energy industries (electricity power plants) in Palestine were excluded from the total amounts of diesel and gasoline fuels represented in **Figure 3.2** to avoid double counting.

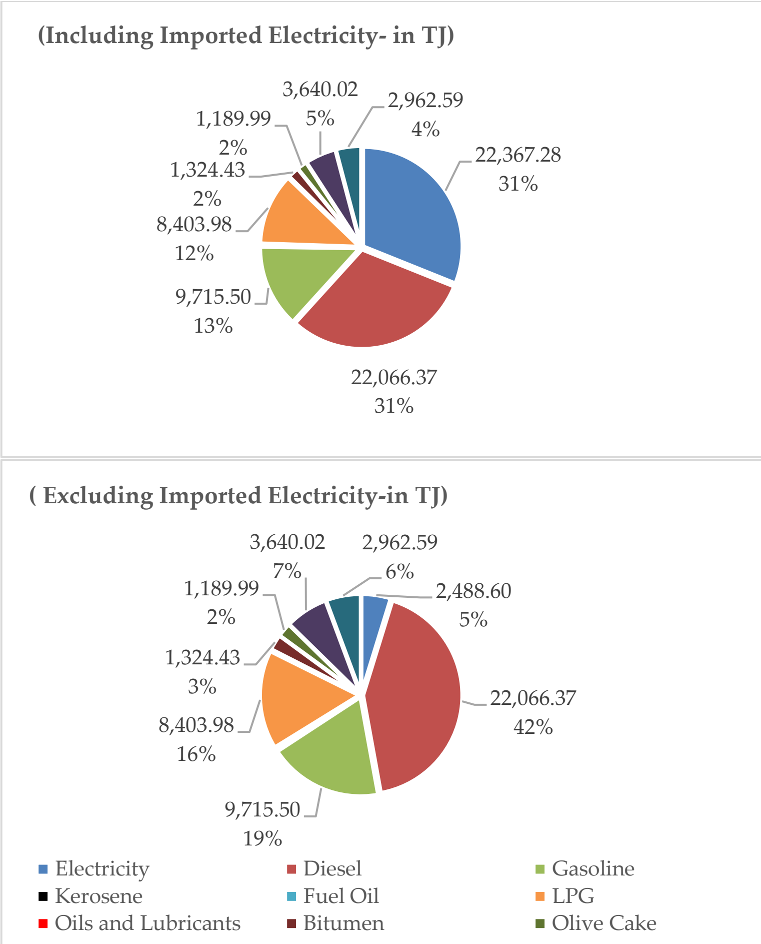


Figure 3.2: Main energy products used in Palestine in 2019, including and excluding imported electricity (in TJ)

The primary fuels in Palestine include diesel, gasoline, LPG, wood, and charcoal. Transport and household sectors are considered the country's largest fuel consumers (Palestinian Central Bureau of Statistics, 2019). Most of the consumed fuels in Palestine are imported except for olive cake, wood, and charcoal (Palestinian Central Bureau of Statistics, 2019). In contrast, all of the liquid fuel is supplied by or via Israel and distributed to the consumers in Palestine by national suppliers (Qureitem et al., 2020).

In terms of electricity, more than 90 % of the total supply is imported from Israel Electric Corporation (IEC) (World Bank Groupe, 2017). Local suppliers and Jordan and Egypt provide the remaining percentage of the supply. **Figure 3.3** illustrates the electricity supply in Palestine in 2019. The Gaza Strip imports represent about 60-65% of the total supply, while the West Bank imports almost 98% of the electrical supply from IEC. This is because Palestine's only generation power plant is located in Gaza. This power plant is diesel-fired with a generation capacity of approximately 60-140 MW (World Bank Groupe, 2017). Palestine is developing a new combined cycle gas-fired power plant with about 450 MW of generation capacity in Jenin City in the West Bank, which is supposed to cover 50% of the current electricity demand in Palestine (Palestine Environment Quality Authority, 2016). The new power plant is expected to operate by the end of 2023.

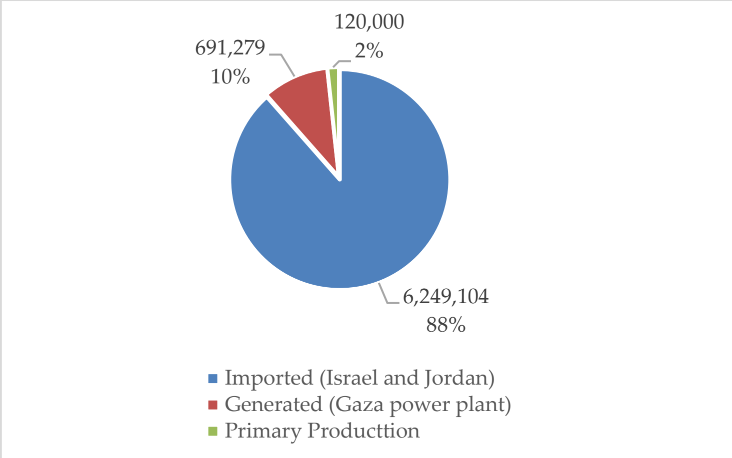


Figure 3.3: Available electricity for consumption in Palestine in 2019 (in MWh)

Electricity represents about 30 % of the total energy consumption in Palestine. It is dominated by the household sector (Palestinian Central Bureau of Statistics, 2019). Up to 2017, electricity has been imported from Israel to Palestine using more than 270 connection points of low and medium voltage. Later, Palestine improved its power supply by adding four higher-voltage substations, which increased the capacity of imported electricity by 550 MW. The first high-voltage substation was implemented in 2017, and the other three substations followed in 2020. Transmitting the power at higher voltage has reduced losses and improved cost recovery by billing for a larger portion of imported electricity (World Bank Groupe, 2017).

In most countries, power generation is a primary source of GHGEs. However, this is not the case in Palestine because a significant ratio of electric power is imported, which makes power generation insignificant for GHGEs (Palestine Environment Quality Authority, 2016). According to the Palestinian references, the associated GHGEs with imported electricity are accounted for in Israel's national GHG inventory (Palestine Environment Quality Authority, 2016)

Different from the national GHG emission inventories submitted to the UNFCCC. This research estimates the GHGEs not only from electricity generation but also from total consumed electricity, locally generated and imported, which means it includes scope 2 emissions associated with the consumption of purchased electricity and heat.

3.2.4. Data Source

The estimation of GHGEs from fuel combustion activities requires (i) emission factors of GHGs, and (ii) detailed activity data on energy consumption in different sectors: energy industries, manufacturing industries and construction, transport, and other sectors (commercial and institutional, residential, and agriculture/forestry/fishing). Therefore, data for this study were collected from different sources, as illustrated in **Table 3.1**.

Table 3.1: Data collected by its source

Data	Source	References
Energy Tables 2011-2020	Palestinian Energy and Natural Resources Authority (PENRA), and Palestinian Central Bureau of Statistics (PCBS)	(Palestinian Central Bureau of Statistics, 2019; Palestinian Energy and Natural Resources Authority, 2023a)

Transportation and Communications Statistics 2011-2020	Palestinian Ministry of Transport in The West Bank and Gaza Strip (MoT)	(Gaza Ministry of Transport, 2020; Palestinian Ministry of Transport, 2020, 2022)
IPCC default emission factors	The 2006 IPCC guidelines for National Inventories	(IPCC, 2006)
Per capita electricity generation	International Renewable Energy Agency (IRENA)	(International Renewable Energy Agency, 2022b, 2022a)
CO_2 emission factor for electricity & heat generation		
Emission Factors for electricity generation and fuel combustion in Israel	Israel Ministry of Environmental Protection	(Gutglick et al., 2020; Israel Ministry of Environmental Protection, 2022)
Guidelines for reporting GHGE		
Fuel quality in gas stations in Palestine (e.g., density and Calorific values)	Published literature	(Abu Hamed et al., 2017; Karaeen et al., 2021; Khraisha, 2022; M. Tawarah & A. Rababah, 2013)

Data on energy consumption was collected from the official reports of energy and energy balance in Palestine published by the PCBS (Palestinian Central Bureau of Statistics, 2022b). The reports provide data on imported energy in Palestine, source and amounts of consumed electrical energy, type and amount of fuel used in electricity generation, and energy balance tables in Palestine, which provide detailed information on the total energy supply and final energy consumption by type of energy (electricity, diesel, gasoline, kerosene, fuel oil, liquefied petroleum gas (LPG), olive cake and wood and charcoal) and energy sub-sectors: (i) energy industries, (ii) manufacturing industries and construction, (iii) transport and households, and (iv) other sectors (households, agriculture and commerce, and public services). The PCBS prepares these reports annually. Data are collected from the Palestinian Energy and Natural Resources Authority (PENRA), the Palestinian General Petroleum Corporation, PCBS Database of Foreign Trade. These data are considered high quality, and wherever any assumptions are made, missing data or parts of the country are not included; such notes are highlighted in the report. For instance, in the energy balance tables, the following assumptions were made:

- The technical losses in electricity in Palestine are considered to be 12%, based on the Palestinian Energy and Natural Resources Authority.
- The efficiency of the solar water heater was considered to be 45%, and the consumed energy is half of the produced quantity.
- In all accounts related to charcoal and wood, a unified calorific value was used for each charcoal and wood based on the weight of each type in the balance. The calorific value for both was considered to be 15.7 gigajoules/ton.

Data on fuel characteristics in Palestine was used to convert the consumed fuel from physical units (kilogram, ton, liter) to energy units (joule). The data was collected from Palestinian published literature (Abu Hamed et al., 2017; Karaeen et al., 2021; Khraisha, 2022; M. Tawarah & A. Rababah, 2013), where different representative samples of fuel were examined, and the results were verified through comparison with standard fuel characteristics and global published literature.

Transportation statistics were obtained from the Palestinian Ministry of Transport (MoT). They provide information on the number of vehicles by type of vehicle and fuel (Palestinian Ministry of Transport, 2022). The data is considered of high quality; however, it does not include Gaza Strip data. Data for the Gaza Strip were obtained from the annual statistical and progress reports of the MoT in the Gaza Strip, which are available on the ministry's official website (Gaza Ministry of Transport, 2020).

To estimate the GHGEs from energy consumption, the default emission factors in the 2006 IPCC guidelines were used due to the unavailability of country-specific emission factors. Emission factors are selected according to the activity data and fuel type, as explained in detail in the 2006 IPCC guidelines. To estimate the emission factors from electricity generation and final consumption, it was necessary to distinguish between two sources of electricity, imported and domestically generated electricity. In the case of locally generated electricity, default emission factors for diesel and gasoline (the electricity generation mix) were used. Regarding imported electricity, it was assumed that all the imported electric power was purchased from Israel (because more than 98% of purchased electricity in 2019 was from Israel) (Palestinian Central Bureau of Statistics, 2019). Israel's electricity generation emission factors were obtained from the official reports on the State of the electricity Sector by the Electricity Authority in Israel (Gutglick et al., 2020). According to the reference, the emission factors of electricity generation in Israel were calculated using country-specific emission factors and considering all suppliers of electric power and the different generation mix at each supplying point.

3.2.5. Estimation of GHGE

The GHGEs from the energy sector were estimated from the primary energy products, including electricity. Since the electricity is transformed/generated from various primary energy sources such as natural gas, gasoline, kerosene, …. Etc., the amounts of primary energy products which are used in the electricity generation were deducted from the total amount of fuel consumed by different sectors in the country, so that no double counting occurs in the estimation of CO_2 emissions. The following sections provide a detailed explanation of the method of GHGEs estimation from energy products starting with primary fuel and then electricity.

3.2.5.1. Fuel

The emissions generated from the combustion of different fuels in each sector were calculated separately. To estimate the emissions from any fuel, it is necessary to convert the amount of fuel from physical units (e.g., litre, kilogram, ton, etc.) to energy units (joule). In this conversion, where possible, country-specific fuel characteristics are used. The density of diesel and gasoline was obtained from a published study that examines the fuel characteristics at nine gas stations in Palestine. The average densities of diesel and gasoline at the nine gas stations were 0.748 kg/l and 0.833 kg/l, respectively (Karaeen et al., 2013). A net calorific value of 19.21 TJ/Gg was used for the olive cake. This value is based on studies in Palestine and Jordan as it is very similar to Palestine (Abu Hamed et al., 2017; Khraisha, 2022; M. Tawarah & A. Rababah, 2013). Default calorific values and emission factors of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories were used for other fuels due to the unavailability of local values.

Due to the need for more data in the study area, the emissions were calculated by applying Tier 1 in the 2006 IPCC guidelines, which requires data on fuel consumption and default emission factors. Emissions from stationary combustion are calculated as follows:

$$Emissions_{GHG,fuel}(kg) = Fuel\ consumption_{fuel}(TJ) \times Emission\ factor_{GHG,fuel}(kg\ gas\ /TJ) \quad (1)$$

$$Emissions_{GHG} = \sum_{fuels} Emissions_{GHG,fuel} \qquad (2)$$

Where:

- *Emissions* $_{GHG.\ Fuel}$: emissions of a specific GHG by type of combusted fuel
- *Fuel consumption* $_{fuel}$: the amount of combusted fuel
- *Emission factor* $_{GHG,\ fuel}$: default emission factor of a given GHG by type of fuel
- *Emissions* $_{GHG}$: Total emissions of a given GHG induced by the combustion of all fuels

GHGEs are also produced as a result of fuel combustion in mobile sources such as road transport, civil aviation, railways, etc. The emissions from these sources are estimated using total fuel sales and default emission factors in the IPCC 2006 guidelines.

3.2.5.2. Electricity

The Palestinian energy balance tables show the total amount of electricity generated locally by fuel combustion in the Gaza power plant and other small generators, the total imported electricity from foreign suppliers, and the final consumption of electricity by different sectors in Palestine, taking into account losses but regardless the source of electricity (imported/generated). An adjusted emission factor for consumed electricity is required to estimate the emissions from electricity consumption. **Figure 3.4** illustrates the adjustment methodology used to estimate the electricity emission factor at the point of final consumption. It is worth mentioning that this methodology is used for the first time in Palestine. This factor should account for:

1. Electricity generation mix: GHGEs from a single electricity generation point depend on the mix used for electricity generation at that point (fossil fuel, biofuels, geothermal, nuclear, solar. etc.,), as a result, the emission factor of electricity generation varies from one year to another with the variation of the generation mix. Based on the 2006 IPCC Guidelines and the IEA World Energy Balances data (International Energy Agency, 2020), the total CO_2 emission factor for electricity generation is calculated as follows:

$$CO_2\ kWh\ for\ electricity\ generation = \frac{\sum_{the\ fuel}\{(Input_{Electricity\ plants} + Input_{CHP\ plants/Ele} + Own\ use_{Plants/Ele}) \times EF_{Fuel}\}}{Ele_{Inland}} \qquad (3)$$

Where:

- $CO_2\,kWh$: carbon dioxide emission factor (in CO_2/kWh) calculated at the generation point
- $\sum_{fuels}$: sum over the different fuels used for electricity generation.
- $Input_{\ plants}$: fuel input into the plants (both main activity and auto producer) expressed in energy unit.
- $Input_{CHP\ plants/Ele} = Input_{CHP\ plants} - \frac{Heat\ output}{\eta_{heat}}$, where CHP: combined heat and power plants.
- η_{heat}: efficiency of heat generation is usually assumed 90% similar to that of a typical heat boiler. Except when the observed efficiency of CHP generation is higher than 90%, in which case emissions are allocated using the proportionality approach such that inputs are allocated based on the output shares of electricity and heat, where equivalent efficiency is used for both electricity and heat (International Energy Agency, 2020).
- $Own\ use_{Plant/Ele} = Own\ use_{\ Plants} \times \frac{Total\ electricity\ output}{Total\ electricity\ output + Total\ heat\ output}$
- EF_{fuel}: default emission factors of the corresponding fuel provided in the 2006 IPCC Guidelines.

- Ele_{Inland}: the electricity generated from all sources including the non-emitting sources.

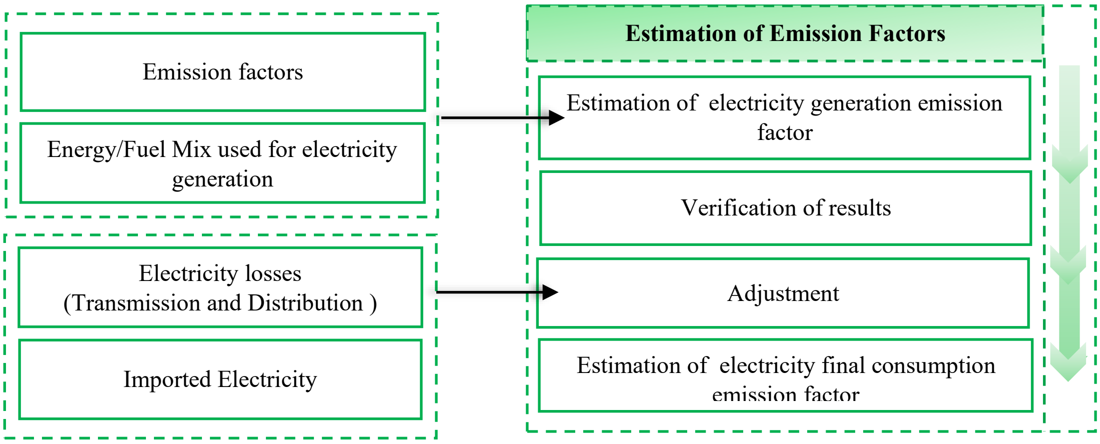


Figure 3.4: The methodology used to estimate the electricity emission factor at the point of final consumption.

2. Electricity trade: a country can either export or import electricity to/from another one. Thus, the emission factor should be adjusted for the trade of electricity; the adjustment can be positive or negative based on the share of electricity exports and imports. It is calculated as follows:

$$CO_2kWh_{trade} = \frac{C_{Indigenous} + C_{Imported} - C_{Exported}}{Net\ electricity} - CO_2kWh \qquad (4)$$

Where:

- $CO_2\ kWh_{trade}$: Adjustment of the carbon factor (in CO_2/kWh) for emissions induced by the trade of electricity with partner countries.
- $C_{Indigenous} = \mathrm{Ele}_{Inland} \times \mathrm{CO_2}\ kWh$
- $C_{Imported} = \sum_{Partner} Ele_{Imports_{Partner}} \times CO_2\ KWh_{Partner}$, where CO_2 kWh Partner is the electricity generation emission factor at the partner country.
- $C_{Exported} = Ele_{Exports} \times \frac{C_{\mathrm{Indigenous}} + C_{Imported}}{Ele_{Inland} + Ele_{Imports}}$
- $Net\ electricity = Ele_{land} + Ele_{Imports} - Ele_{Exports}$

3. Electricity transmission and distribution losses: about 5 to 15% of the electricity transmitted is usually lost through the electricity distribution and transmitting grid, which means for each kWh at the consumption point, a higher amount of electricity has to be generated to account for these losses. In the case of Palestine, the technical losses in electricity are considered to be 12% according to PENRA (Palestinian Central Bureau of Statistics, 2019).

The emission factor is adjusted to account for these losses as follows:

$$CO_2kWh_{loss} = Co_2kWh \times loss\ fator \qquad (5)$$

Where:

- CO_2kWh_{loss}: in the adjustment (in CO_2/kWh) for emissions induced by electricity transmission and distribution losses.
- $Loss\ factor = \frac{Transmission\ and\ distribution\ losses\ in\ the\ grid}{Total\ grid}$, where the total grid is the electricity transmitted through the country grid which equals the gross generation and imports of electricity minus plants' own use.

By adding the adjustments for electricity trade and losses to the calculated electricity emission factor at the generation point the emission factor for electricity final consumption in Palestine was obtained. The same methodology was used to calculate the N_2O and CH_4 emission factors at the consumption point. Then, these factors were used to estimate the emissions from the final consumption of electricity by different sectors in Palestine.

GHGEs induced by the consumption of electricity by different sectors in Palestine were calculated using the following equation:

$$GHG\ emissions_{sector}\ (kg) = Electricity\ consumption_{sector}(kWh)\ Emission\ factor\ of\ electricity\ consumption\ (kg/kWh) \quad (6)$$

Where:

- GHG emissions sector: the emissions of a specific GHG (CO_2, N_2O, etc.) from a specific sector (households, commerce, public services, etc.) in Kg.
- Electricity consumption sector: the consumption of electricity in a specific sector.

To convert the emissions from (g) N_2O and CH_4 to (g) of CO_2 equivalent (CO_2eq) the 100-year Global Warming Potential (GWP) in the 4th Assessment Report of the IPCC was used. The 100-year GWP for CH_4 and N_2O is 25 and 298, respectively. After converting all emissions to (g) CO_2eq the total GHG emissions from electricity consumption were calculated.

3.3. Results and Discussion

3.3.1. Fuel

GHGEs from fuel combustion were estimated using local fuel characteristics in Palestine and the default emission factors in the 2006 IPCC guidelines as explained in the methodology section. The total GHGEs from fuel consumption in 2019 were estimated around 3,912,566 tons of CO_2 eq, which is close to the emissions estimated by the PCBS (3,457,410 tons of CO_2 eq) (Palestinian Central Bureau of Statistics, 2022b). The difference is attributed to the use of country-specific fuel characteristics in this study instead of the standard values.

The emissions were classified by type of fuel as shown in **Figure 3.5**. The largest share was for diesel fuel, which is responsible for 2,021,829 tons of CO_2eq, representing more than half (52%)of the total GHGEs resulting from fuel combustion in 2019. Gasoline fuel contributed to approximately 18% of the total GHGEs (725,032 tons CO_2eq). These values include the amount of diesel and gasoline which were transformed into electricity at the Gaza power plant and other small electricity generators. Wood, charcoal, and LPG accounted for 11% (439,338 tons of CO_2eq) and 14% (531,812 tons of CO_2eq) of total emissions, respectively. Other fuels, such as olive cake and fuel oil, had modest amounts of emissions. Since this research is focused on emissions from the energy sector, the emissions from oils and lubricants were not included because they are accounted for the emissions from industrial processes according to the 2006 IPCC guidelines. Concerning bitumen, the use of bitumen does not create emissions of CO_2; because all carbon in bitumen is stored permanently (Krtková et al., 2019).

Even with including the amount of diesel and gasoline which were used in electricity generation in Palestine during 2019 (the imported electricity was not included), the transport sector was found to be the biggest source of GHGEs with about 56% (2,207,834 tons of CO_2eq) of total emissions as illustrated in **Figure 3.6**. This sector is responsible for more than 95% (1,505,282 tons of CO_2eq) of the emissions resulting from diesel combustion and around 97% (690,308 tons of CO_2eq) of gasoline emissions. The total vehicular emissions were very close to those published by the PCBS in 2019 (2,255,170 tons of CO_2eq) (Palestinian Central Bureau of Statistics, 2022b). The small difference is attributed to using fuel characteristics in Palestine in the current study instead of the standard values used in the PCBS reports. Another study (Hassouna & Al-Sahili, 2020a) predicted the emissions from the transport sector in Palestine in 2020 based on data from 2014 and the predicted emissions (4,917,021.907 tons of CO_2eq) were double the actual emissions estimated by the PCBS in 2020 which is 2,293,060 tons of CO_2eq (Palestinian Central Bureau of Statistics, 2022b), which could be attributed to the accuracy of the model used to predict the number of vehicles and kilometres travelled, and the use of emission factors different from the default in the IPCC guidelines.

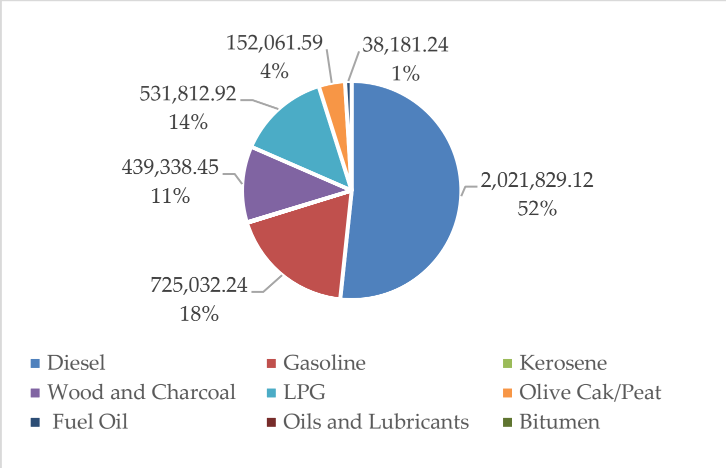


Figure 3.5: GHGEs from the energy sector by fuel type, 2019 (ton CO_2eq)

The household sector is the second emitter, which is responsible for around 25% (969,132 tons of CO_2eq) of the GHGEs as shown in **Figure 3.6** This sector is the main consumer of kerosene, wood, charcoal, and olive cake, used for heating houses and water heating, and the LPG, used for cooking. The household sector contributes to more than 70% of the GHGEs resulting from the consumption of these fuels.

Not surprisingly, the energy industries' share of total emissions represented by electricity generation is very low (only 11%, 446,470 tons CO_2eq) compared to other countries worldwide. This result is due to the low capacity of electricity generation in Palestine, which is due to the occupation's practices including (i) the Israeli control of the Palestinian borders for logistical and political reasons; thus, all types of liquid fuel available for consumption in Palestine, especially diesel and gasoline are either imported from or via Israel, even the amounts of the fuels are controlled and sometimes banning fuel imports, particularly of Gaza Strip where the power plant exists, (ii) the deprive of the Palestinian from their rights to benefit from the available energy sources such as Gaza's offshore natural gas field, (iii) inability of Palestinians to develop the energy infrastructure and built new power plants without the Israel approval, which all together aimed to enforce the Palestinian dependency.

The industry/commerce and public services sectors contributed to about 4% (136,920 tons of CO_2eq) and 3% (112,771 tons of CO_2eq) of the GHGE, respectively (**Figure 3.6**). This result is expected because Palestine is not considered an industrial country. Banning the Palestinians from importing many equipment, machines, and dual-use materials has a significant impact on limiting the ability of the Palestinian economy to improve and grow up and has made the Palestinian economy dominated by internal trade at the expense of productive and manufacturing sectors (Shikaki, 2021). Whereas in neighbour countries with a similar situation but without any restrictions such as Lebanon the share of the manufacturing and commerce sectors to total emissions from the energy sector is more than 20% and 10% respectively (MoE/UNDP/GEF, 2017). Similar results for the contribution of different sub-sectors to total GHGEs from the energy sector in Palestine in 2016 were recorded by Qureitem et al. (2020). The transport sector dominated emissions from the energy sector with 58% followed by the households which contributed to 29%, electricity generation with 8%, commerce and public services

2%, manufacturing industries share was 2%, and the last 1% was for the agriculture (Qureitem et al., 2020). However, even though the percentages are very close, the total GHGEs from the energy sector in 2016 was 4,131,550 tons of CO_2eq, which is greater than the emissions in 2016 published by the PCBS in the reports of emissions to air tables (3,381,790 tons of CO_2 eq) (Palestinian Central Bureau of Statistics, 2022b) and total GHGEs in 2019 estimated in this research (3,912,566 tons of CO_2 eq). The emissions of 2019 are supposed to be higher than those estimated in 2016 by Qureitem et al. (2020) due to the naturally expected increasing consumption of energy as a result of population growth, and the growing use of transportation, however, this is not the case. Simultaneously Qureitem et al. (2020) results were slightly higher than those estimated by the PCBS for the same year (2016) for no clear reason, despite the fact that both references used the same emission factors and energy tables in their estimations (energy consumption data).

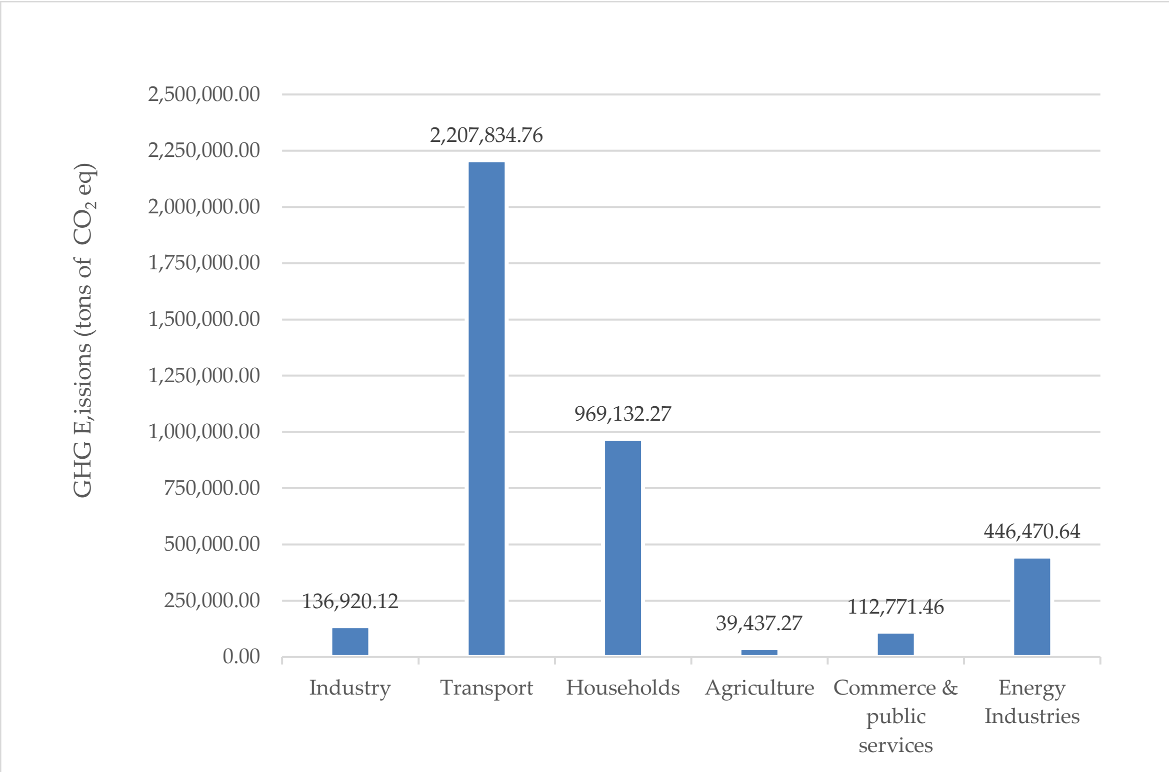


Figure 3.6: GHGEs from final consumption of fuel in 2019, by economic activity -Including fuel used for domestic electricity generation- (ton CO_2 eq).

3.3.2. Electricity

The emission factors of GHGs for electricity generation were calculated for the period 2011 to 2020 based on the IPCC 2006 guidelines using fuel default emission factors presented in **Table 3.2**. **Table 3.3** shows that the emission factor of CO_2 and other GHGs varies from year to year, which is due to the variation of the fuel mix i.e., the amount and type of fuel used to generate electricity from one year to another. Here, other factors that affect GHGE factors for electricity generation such as quality of fuel, pollution control technologies, power plant efficiency, etc., were not taken into account due to a lack of information in the study area.

Table 3.2: Default GHGE factors for fuel combustion according to the 2006 IPCC guidelines

Gas	CO_2 (Kg/TJ)	N_2O (Kg/TJ)	CH_4(Kg/TJ)
Diesel	74100	0.6	3
Gasoline	69300	0.6	3

The results were compared to published reports and literature, such as the Palestinian national inventory and the statistics of the International Renewable Energy Agency (IRENA) (International Renewable Energy Agency, 2022b, 2022a; Palestinian Central Bureau of Statistics, 2022b). The small differences between the estimated emission factors and emission factors in other references are attributed to using the density of diesel and gasoline fuel in Palestine in this research in converting the amount of fuel from physical units to energy units instead of using standard values.

Table 3.3: GHGEs factors of electricity generation, total emissions from electricity generation, and per capita electricity generation in Palestine for the period 2011-2020

Year	Amount of generated electricity (MWh)	Emission Factors of Electricity Generation in Palestine (Kg /MWh or g/kWh)			GHG emissions (Ton CO_2 eq)	Per capita electricity generation (kWh/capita)
		CO_2	CH_4	N_2O		
2011	569,332	659	0.0270	0.0050	376,422	138
2012	461,112	640	0.0260	0.0050	296,098	109
2013	537,097	634	0.0260	0.0050	341,669	124
2014	336,587	699	0.0290	0.0060	236,120	76
2015	505,367	614	0.0250	0.0050	311,364	112
2016	494,574	644	0.0260	0.0050	319,564	107
2017	500,852	701	0.0280	0.0060	352,343	106
2018	360,427	644	0.0260	0.0050	232,886	74
2019	691,279	643	0.0261	0.0052	446,015	139
2020	661,556	633	0.0260	0.0050	420,181	130

The calculated emission factors were used to estimate GHGEs from the electricity generation in Palestine during the same period, as shown in **Table 3.3**. The per capita electricity generation was also estimated. There is a variation in the total GHGEs and, accordingly, the emissions per capita, from one year to another, which could be attributed to the variation in the amount of fuel used in electricity generation. This is mainly a result of the blockade and the control of Israel over the fuel supply (reducing/cutting off the diesel supply). For instance, in 2014 and 2018 when the lowest emissions were recorded, the Gaza power plant was hit several times by Israeli shelling during the 2014 war. It was temporarily forced to shut down (Euro-Mediterranean Partnership Unit, 2019). While in 2018, Israel banned the entry of gas and fuel to the Gaza Strip (Martin et al., 2018).

Since the electricity generation in Palestine represents an insignificant percentage of the total electricity supply (about 10%), Palestine's per capita electricity generation is highly below other countries in the area, as illustrated in **Figure 3.7**. The capacity of electricity generation is limited in Palestine because the only current significant electricity domestic supply; the Gaza power plant, has been facing major hindrances apart from the occupation control on the fuel supply, it faces financial problems in covering the high cost of diesel fuel by the Palestinian institutions without the support of international donors which has been declining in the past few years, and the repeated damage of many facilities of the power plant during the armed conflict (World Bank Groupe, 2017). All together has led to operating the power plant normally at less than 50% of its capacity.

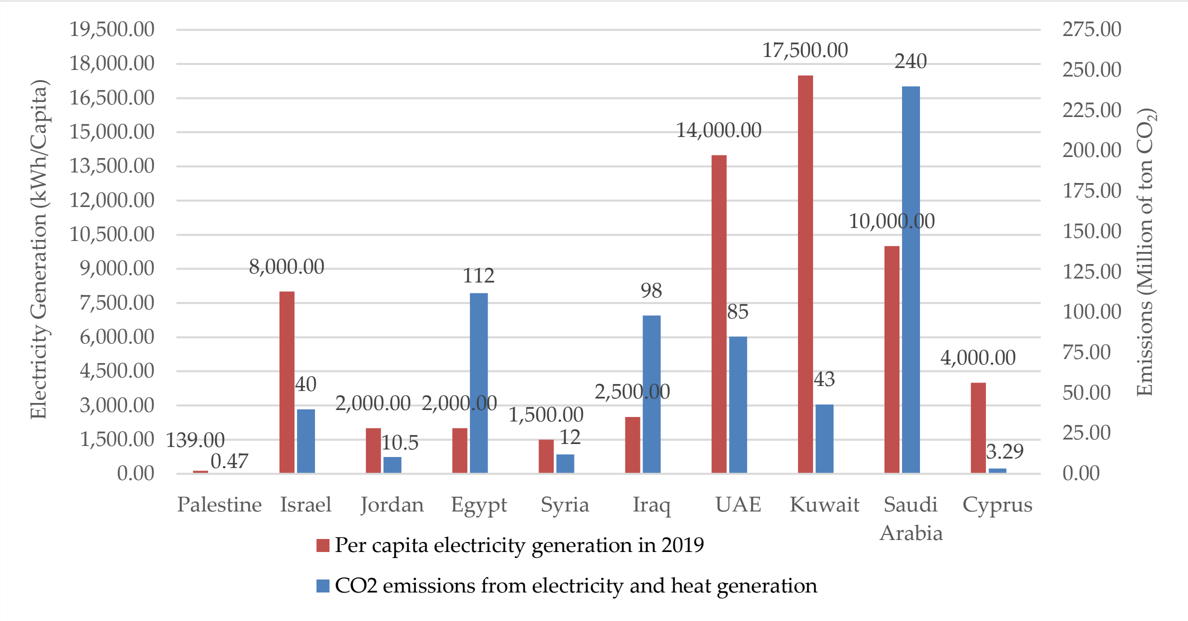


Figure 3.7: GHGEs from electricity generation and electricity generation per capita in Palestine and other countries in 2019.
Data for other countries were obtained from IRENA Ref: (International Renewable Energy Agency, 2022b)

The calculated electricity generation factors for the period 2011-2020 were adjusted for electricity trade and losses to estimate the electricity emission factors at the final consumption point. As shown in **Table 3.4**, the factor varies from year to year due to the variations in the energy mix used for electricity generation.

Table 3.4: Emission factors of electricity consumption in Palestine for the period 2011-2020

Year	Emission factors of electricity consumption in Palestine (Kg /MWh or g/kWh)		
	CO_2	CH_4	N_2O
2011	804	0.0153	0.0094
2012	848	0.0175	0.0104
2013	769	0.0142	0.0087
2014	770	0.0133	0.0092
2015	760	0.0132	0.0089
2016	681	0.0192	0.0080
2017	662	0.0128	0.0060
2018	621	0.0113	0.0065
2019	630	0.0121	0.0065
2020	589	0.0119	0.0049

The Mann-Kendall test was used to check whether the decreasing trend in the electricity generation factors in Palestine and Israel over 2011-2021 was statistically significant. The result of the test is illustrated in **Figure 3.8**. It shows that the decreasing trend is statistically significant at the 0.001 level. On the Israeli side, this decrease is due to the major shift in the electricity generation mix from coal to natural gas in Israel (**Figure 3.9**); the share of natural gas in the fuel mix has increased over the years from 35% in 2011 to 67% in 2020 (Gutglick et al., 2020). On the other hand, the fuel mix for electricity production in Palestine has not changed significantly over the past years. The decreasing trend in the electricity generation emission factor is attributed to the amount of generated electricity (see **Table 3.3**) which depends on the fuel supply allowed to enter the country.

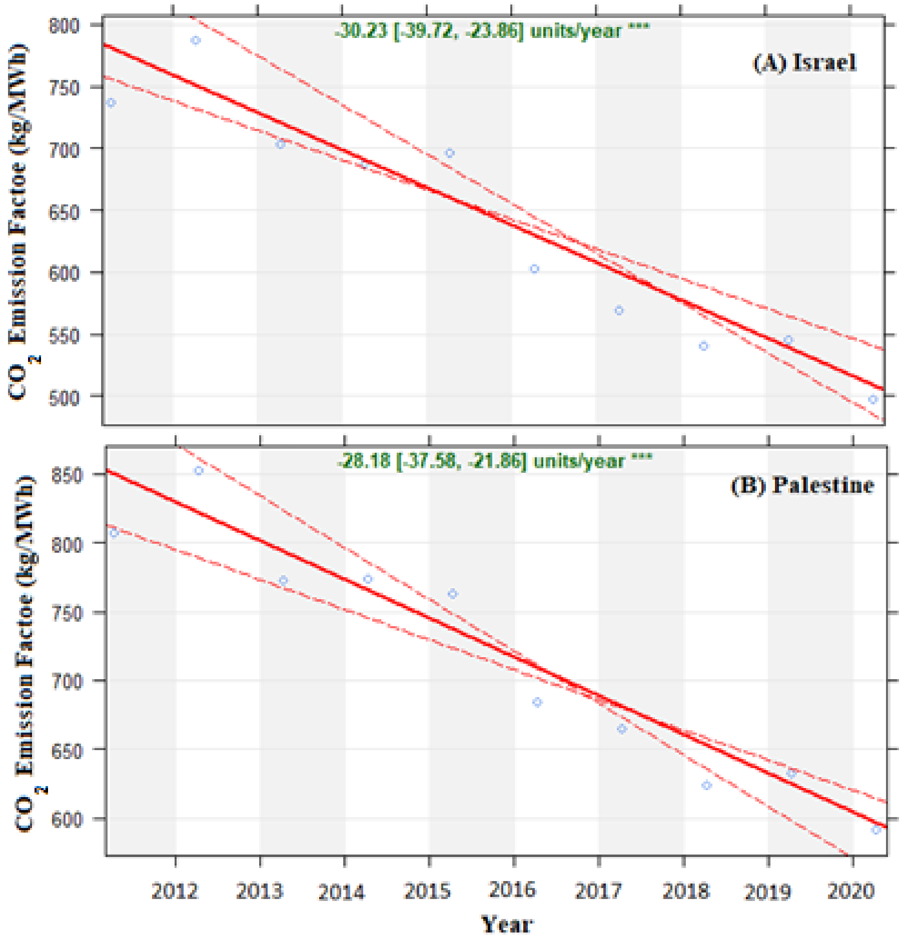


Figure 3.8: Trend in the CO_2 electricity generation emission factors in (A) Israel, and (B) Palestine during the period 2011-2021.

Note:(The solid red line represents the mean trend and the dashed lines represent the 95% confidence interval. The trend and confidence interval are shown at the top as vehicle /year. The *** show that the trend is significant at 0.001 level).

GHGEs from the electricity sector were estimated for 2019 using the electricity generation emission factors for the country where the electricity was produced. The vast majority of the emissions (about 3,405,441.36 tons of CO_2eq - 88%) was from imported electricity, while less than 12 % (446,470.64 tons of CO_2eq) were from domestically generated electricity, mainly from the Gaza power plant (**Figure 3.10**).

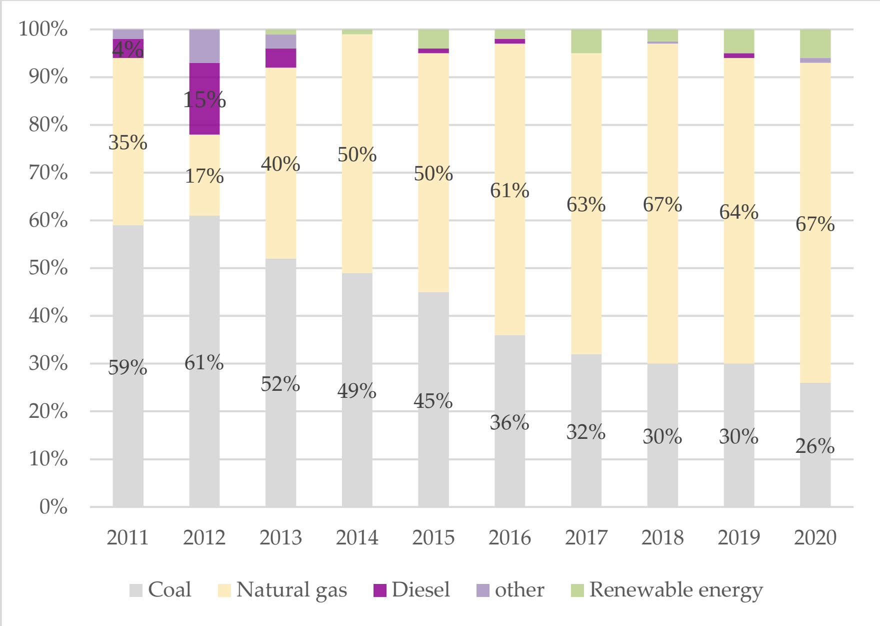


Figure 3.9: Composition of the electricity generation mix in Israel during 2011-2020
Reference*:* (Gutglick et al., 2020)

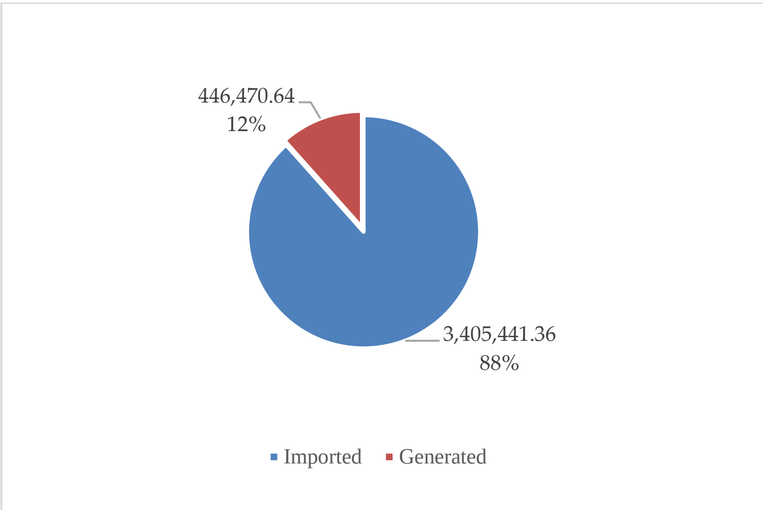


Figure 3.10: GHGEs from the electricity sector, 2019 (tons of CO_2eq)

The electricity emission factors at the final consumption point were also estimated by economic activity for the year 2019. The results are presented in **Figure 3.11**. The total GHGEs from electricity consumption was 3,929,829 tons of CO_2eq. The highest emissions from electricity consumption were from the households sector (about 59% of electricity consumption emissions- 2,316,465 tons of CO_2eq) which is the largest electricity consumer in Palestine, where electricity is used for lighting, heating, cooling, appliances, cooking, etc. The only available study concerns GHGEs from electricity consumption (including imported electricity) by the household sector in Palestine estimated that about 1,512,791 tons of CO_2eq were associated with electricity consumption in 2010 (Abu-Madi & Rayyan, 2013). The estimation of GHGEs was based on the average household energy consumption and the number of households in the West Bank, and emission factors in China, e.g the emission factor of CO_2 electricity consumption was 307 Kg /MWh (Abu-Madi & Rayyan, 2013). The calculated emissions from electricity consumption in this study in 2019 are 3 times greater than those estimated in 2010 by Abu-Madi et al. (2013) (Abu-Madi & Rayyan, 2013), which is reasonable as a result of increasing electricity consumption due to population growth and higher estimated values of electricity consumption emission factors in Palestine as illustrated in **Table 3.4**.

The household sector is followed by the commerce and public services sector, which accounts for around 29% (1,156,091tons of CO_2eq) of the total GHGEs from consumed electricity, and includes commercial buildings such as shops, offices, restaurants, and public buildings and services such as hospitals, schools, universities, street lighting, etc.

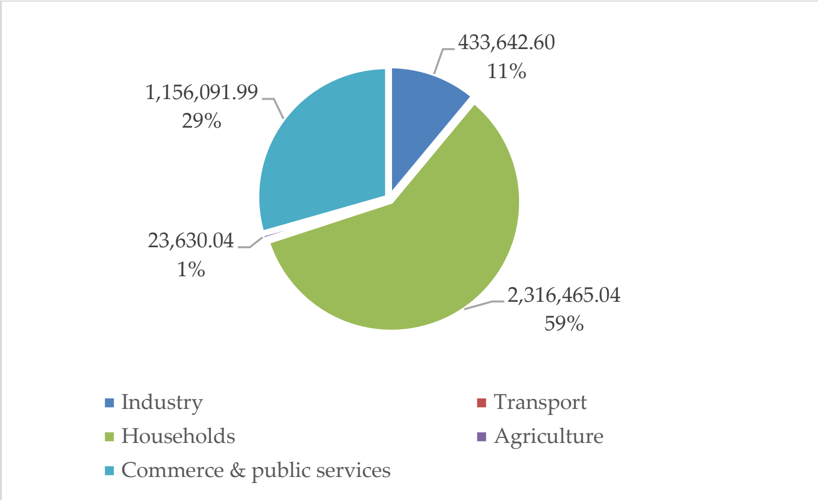


Figure 3.11: GHGEs from electricity consumption, 2019 (ton CO_2eq)

The industrial sector accounts for only 11% (433,642 tons CO_2eq) of the emissions from electricity consumption, while the agricultural sector accounts for only 1% (23,630 tons of CO_2eq). It is obviously seen that the emissions from the transportation sector due to electricity consumption are negligible because the percentage of electrical and hybrid vehicles in Palestine in 2019 was less than 0.5% of the total vehicle fleet (Palestinian Ministry of Transport, 2020).

3.3.3. Total GHGE

Usually, the emissions from purchased electricity and heat which are covered under scope 2 emissions are not considered in national inventories of GHGE. In the case of Palestine's national inventory, even though most of the electricity is purchased, the national inventory only accounts for domestic electricity generation. The emissions associated with imported electricity reside on the supplier side, mainly, on the Israeli side as referenced in the Palestinian national inventory report (Palestine Environment Quality Authority, 2016). This research analyses the impact of including imported electricity on the estimation of GHGE.

Without taking the imported electricity into account, the total emissions from the energy sector in Palestine during 2019 were 3,912,566 tons of CO_2eq. Diesel fuel had the largest share (above 40%; 1,591,030 tons of CO_2eq) of the total emissions, followed by gasoline and LPG fuels as shown in **Figure 3.12**. Electricity accounted for only 11% (446,470 tons of CO_2eq) of the GHGE. Including the imported electricity in the estimation of the GHGEs doubles the total emissions of the energy sector to reach 7,395,925 tons of CO_2eq. Consequently, the electricity share grows from 11% to more than half of the total GHGEs from the energy sector (53%, 3,929,829 tons of CO_2eq) which makes electricity consumption the main source of GHGEs in Palestine. The shares of diesel and gasoline fuels fall to 21% (1,591,030 tons of CO_2eq) and 10% (709,359 tons of CO_2eq), respectively, as illustrated in **Figure 3.12**.

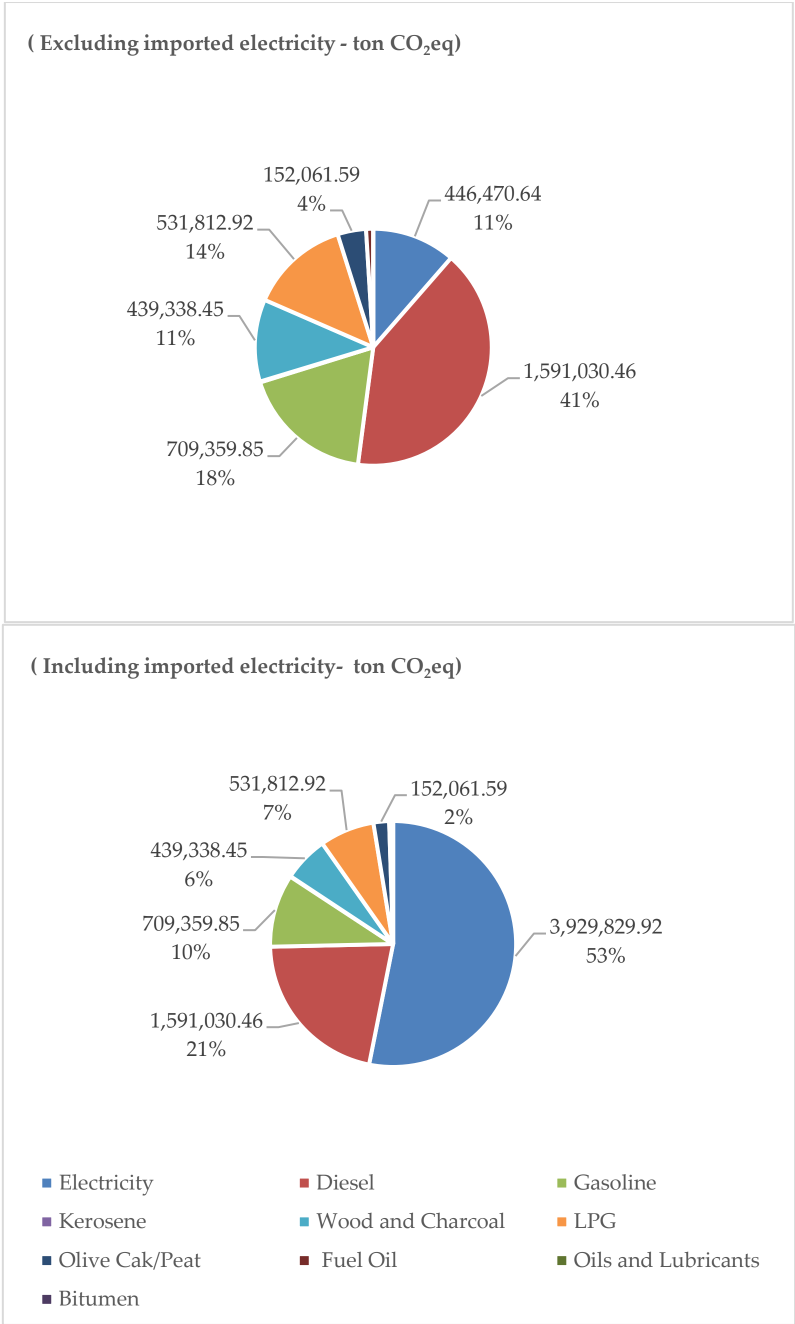


Figure 3.12: Total GHGEs from the energy sector in 2019 'Energy industries, industry, transportation and households and other sectors ' including and excluding imported electricity (in tons of CO_2eq)

Including the imported electricity also affects the contribution of economic activities to the total GHGEs as illustrated in **Figure 3.13**. The household sector contributes to approximately 45% (3,285,597 tons of CO_2eq) of the total emissions. The second top emitter is the transport sector which represents a share of 30% (2,207,834 tons of CO_2eq). The shares of other sectors had also increased at the expense of the transport sector.

In terms of the type of GHGs, the vast majority of emissions from the energy sector are released as CO_2 (98% of total GHGE- 7,259,947 tons of CO_2eq) as shown in **Table 3.5**.

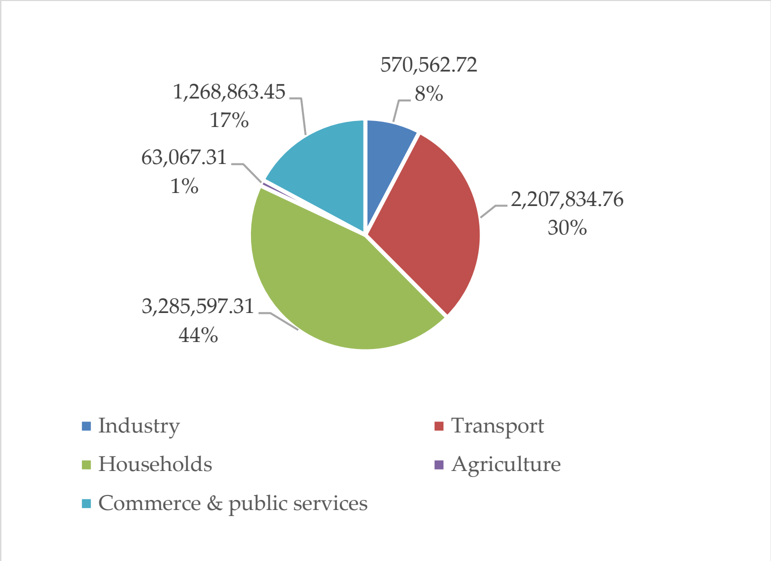


Figure 3.13: Total GHGEs from final consumption of energy in 2019 by economic activity -including imported electricity (in ton CO_2 eq).

Table 3.5: Total emissions from final consumption of energy in 2019 by the type of GHG -including imported electricity

GHG	Emissions (ton)	Tons of CO_2eq	Percent (%)
CO_2	7,259,947.38	7,259,947.38	98.16%
N_2O	302.29	90,082.42	1.22%
CH_4	1,835.84	45,896.00	0.62%
Total		**7,395,925.80**	**100.00%**

3.3.4. GHGEs Per Capita

The per capita emissions are calculated by dividing the emissions of a country by its population. **Figure 3.14** shows the emissions per capita from the energy sector and by economic activity in Palestine and other countries in 2019. To make the results comparable across countries, scope 2 emissions resulting from imported electricity were not included.

The highest per capita emissions are recorded in oil-producing countries such as Saudi Arabia, Kuwait, and UAE. While Palestine shows the lowest emissions per capita the emissions from the energy sector are less than 0.8 tons of CO_2eq/capita.. Contrary to all other countries, the per capita emissions from electricity generation in Palestine are the lowest among other economic activities due to the limited capacity of electricity generation.

The effect of including scope 2 emissions in the calculations is also analysed. As illustrated in **Figure 3.15**, the emissions from imported electricity increase the per capita emissions related to energy from 0.79 to 1.49 tons CO_2eq/capita, which is approximately twice the GHGE. On one hand, emissions from the electricity generation and transport sector were not affected, while on the other hand, the per capita GHGEs from the households sector and commerce and public services increased by more than 3 times and 12 times, respectively.

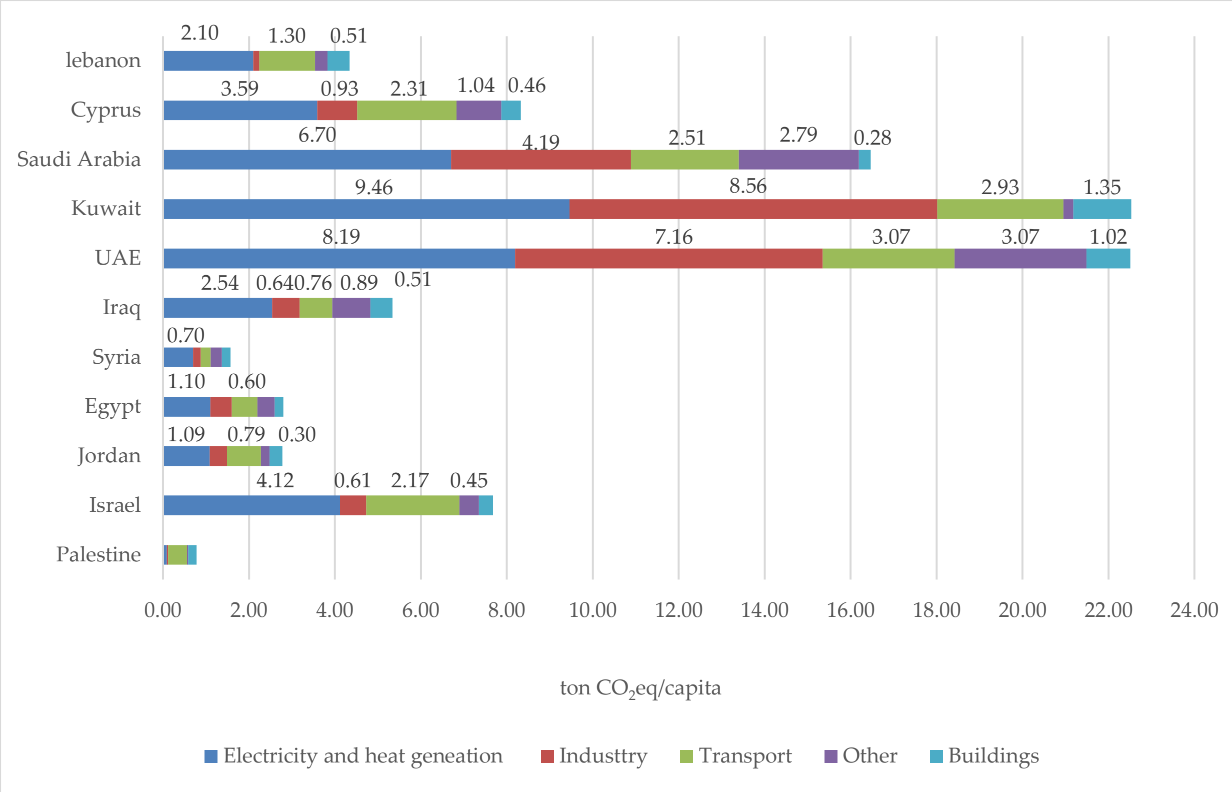


Figure 3.14: Per capita GHGEs from the energy sector in Palestine and other countries during 2019.
Note: Data for other countries on total emissions from the energy sector were obtained from IRENA- Energy Profiles (International Renewable Energy Agency, 2022b)

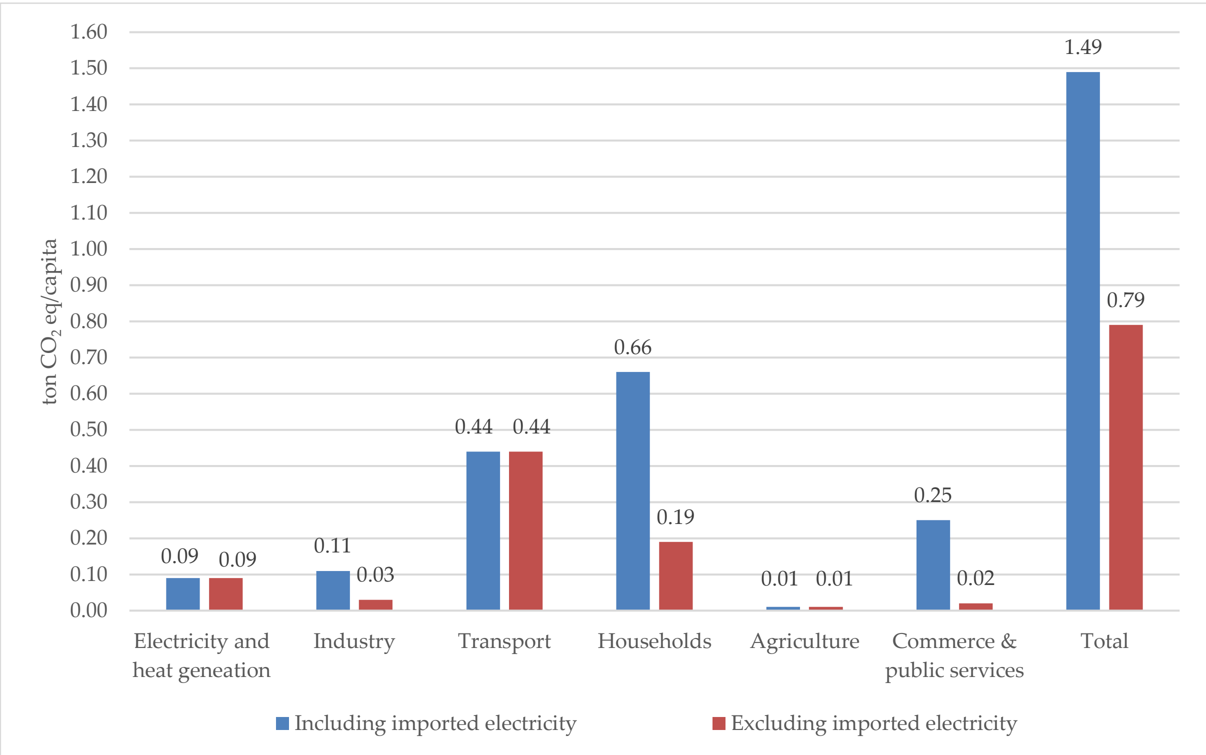


Figure 3.15: Per capita GHGEs from the energy sector in Palestine including and excluding imported electricity in 2019

3.4. Conclusion

This research aimed at investigating the GHGEs of the energy sector in a territory suffering from geopolitical tension, Palestine. The methodology for estimating the carbon emissions is based on the 2006 IPCC guidelines, more precisely, the Tier 1 approach, because the country-specific emission factors were unavailable.

Analysis showed that the Israeli occupation influenced the Palestinian GHGEs as follows : (i) the Israeli control of the Palestinian borders and import of fuel, (ii) depriving of the Palestinians of their rights to benefit from the available energy sources, and (iii) the inability of Palestinians to develop the energy sector, which has limited the capacity of electricity generation and consequently affected the emission factors of electricity generation and consumption.

The impact of the imported electricity in estimating GHG emissions was assessed. It has doubled the total emissions of the energy sector. The households sector became the largest contributor to the GHG emissions instead of the transport sector. The dependency of Palestine on imported electricity has led to reducing the emissions from electricity consumption since the electricity consumption emission factors on the Israeli side are lower than the Palestinian one due to the use of emission control technology and a less polluted electricity mix, which is not possible in Palestine because of discriminatory practices.

Furthermore, banning the Palestinians from importing necessary equipment, machines, and dual-use materials has a significant impact on limiting the ability of the Palestinian economy to improve and grow up, which in turn reduces the CO_2 emissions from industry/commerce and public services sectors (about 4% and 3% of the GHGE, respectively), whereas in neighbor countries with a similar situation but without any restrictions such as Lebanon the share of these sectors accounts for more than 20% and 10% respectively.

The main limitation of this research is related to data availability, as country-specific emission factors are not available. Moreover, other data are missing, such as fuel consumption and vehicle kilometers travelled by type of vehicle, due to poor data collection and archiving systems in the country. Consequently, it was necessary to make assumptions about some missing information, as detailed in the methodology section.

Reducing the GHGEs in Palestine should focus on the transport and household sectors, which constitute the major contributors to these emissions. This objective requires a public policy, international support and private and public efforts to (i) increase the production of solar-based renewable energy for hot water and electricity generation (ii) improve the buildings' energy performances, (iii) improve the public transport and the quality of vehicles in Palestine, and (iv) and reduce the dependency on the imported electricity by developing through public-private partnership electricity generation capacity from green source

Chapter 4. Sectoral Analysis: Use of a Hybrid Approach to Estimate Greenhouse Gas Emissions from the Transport Sector

4.1. Introduction

The transport sector is one of the main emitters of greenhouse gas emissions (GHGEs) from the energy sector (Ministry of Ecological Transition and Territorial Cohesion, 2017; U.S. Environmental Protection Agency, 2020; C. Wang et al., 2020b). World Resources Institute (WRI) data showed that the transport sector is the second largest contributor to GHGEs after electricity production (World Resources Institute, 2020). This is also true at the country scale, the transport sector is considered a significant emitter of GHGEs in many countries, including but not limited to the United States, United Kingdoms, France, Belgium, Italy, Lebanon, Jordan, Palestine, Egypt, United Arab Emirates, Saudi Arabia, and Kuwait (Belgian Interregional Environment Agency, 2022; Department for energy security & net zero, 2023; Designated National Authority, 2022; Egyptian Environmental Affairs Agency, 2018; Jordan Ministry of Environment, 2021; Kuwait Environment Public Authority, 2019; Ministry of Ecological Transition and Territorial Cohesion, 2017; Ministry of Energy and Industry UAE, 2018; Palestine Environment Quality Authority, 2016; The Ministry of Environment-Lebanon, 2017; U.S. Environmental Protection Agency, 2020) The reduction of the emissions related to this sector requires policies, which should be guided by detailed data about the emissions of this sector mainly, by vehicle type and traveled distance.

Vehicular emissions can be estimated using either a bottom-up or a top-down approaches depending on data availability and geographical scope (European Environment Agency, 2019). Top-down approaches are based on fuel consumption data. In contrast, bottom-up approaches require higher levels of detailed data such as the number of vehicles, total kilometers traveled, characterization of vehicles, etc (Arioli et al., 2020; Sim et al., 2015). The combination of the two approaches creates the so-called hybrid methodology or approach (IPCC, 2006).

Scholars used the top-down approach to estimate GHGEs at large geographical scales, such as national and country scales, which could be downscaled to finer scales based on proxy data (Charabi et al., 2020; Engo, 2019; Huo et al., 2012; Ma et al., 2012; Pulselli et al., 2019; Sówka & Bezyk, 2018). Charabi et al. (2020) assessed the emissions from the transport sector in Oman by transportation categories using on the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines and the default emission factors and fuel consumption data (Charabi et al., 2020). Engo (2019) applied a top-down approach to perform a decoupling analysis of GHGEs from the transport sector in Cameroon (Engo, 2019). At the local level, Sówka & Bezyk (2018) used the territorial principle to account for GHGEs from the major sectors in Wroclaw, Poland. Concerning the transport sector, carbon accounting was based on average fuel consumption values for each vehicle category and average vehicle kilometers traveled (VKT) value driven from data available at the country scale(Sówka & Bezyk, 2018) .

The bottom-up approach was applied at lower scales (e.g. city scale). (Mateo Pla et al., 2021) applied a bottom-up approach to quantify spatial urban traffic emissions in Valencia City based on information gathered from traffic management and control systems (Mateo Pla et al., 2021). Using these traffic monitoring systems has allowed the researchers to estimate the emissions in the city at a high temporal and spatial resolution. However, the applicability of this novel approach is subject to the availability of traffic monitoring sensors. Some bottom-up approaches consider the operational environment and transportation modes for higher accuracy in GHGEs accounting (Sim et al., 2015). For instance, a study carried out in Korea proposed a methodology that analyzes the emissions for each transport mode taking into account the transportation environments, which require more detailed activity data (Sim et al., 2015). Other bottom-up models used vehicle ownership and VKT data in carbon accounting, such as Zeng et al. (2016), who used this approach to estimate vehicular emissions from four major Chinese cities (Zeng et al., 2016).

Hybrid models were used to estimate emissions at different spatial scales (Baayoun et al., 2019; Ma et al., 2012). For example, Baayoun et al. (2019) estimated GHGEs from light-duty vehicles in Lebanon according to Tier 2 methodology in the European Monitoring and Evaluation Programme/European Environmental Agency (EMEP/EEA) air pollutant emission inventory guidebook (European Environment Agency, 2019). In this study, the emission factors reported by the manufacturer for each vehicle model were used to estimate the emissions beside VKT (as activity data) (Baayoun et al., 2019). The distance travelled was estimated from the fuel consumed, where the fuel efficiency of a vehicle was considered constant and equal to the value reported by the manufacturer.

Despite the variety in vehicular emissions estimation methods, some countries, particularly developing countries, face difficulties estimating these emissions at a higher classification level (by vehicle and fuel type) due to a lack of required data. This chapter presents a hybrid approach to estimating these GHGEs in these countries. The capacity of this method is illustrated through its application for the first time to the Palestinian territory.

The contribution of this research stems from estimating GHGEs related to fuel combustion in mobile sources at a higher level of detail under limited data. It provides policymakers with detailed information to help establish policies to reduce vehicular emissions. Data availability in Palestine constitutes a significant barrier to the use of the previous models to estimate detailed vehicular emissions. Published literature on GHGEs from the transport sector in Palestine is very limited.

Few articles used top-down approaches to estimate the GHGEs related to the transport sector at the national scale. Some scholars (Aburas & Shahrour, 2021; Qureitem et al., 2020) estimated the emissions from the entire vehicle fleet in Palestine by the type of fuel (diesel and gasoline), while (Hassouna & Al-Sahili, 2020b, 2020a; Hassouna & Assad, 2020) assessed the environmental impact of introducing hybrid and electric vehicles to the vehicle fleet in Palestine. Qureitem et al. (2020) investigated the GHGEs from on-road vehicles using the IPCC 20016 guidelines emission factors and estimated the emissions as national totals from diesel and gasoline vehicles (Qureitem et al., 2020). Aburas, H., & Shahrour, I. (2021) analysed the impact of mobility restrictions in Palestine on the environment and public health in terms of energy consumption and GHGE (Aburas & Shahrour, 2021).

A study by Hassouna, F. M. A., & Al-Sahili, K (2020) assessed the environmental impact of introducing hybrid vehicles to the vehicle fleet in the West Bank (Hassouna & Al-Sahili, 2020a). The predicted emissions in this study for 2020 were double the actual emissions estimated by the Palestinian Central Bureau of Statistics (PCBS) from the transport sector (Palestinian Central Bureau of Statistics, 2022b), which could be attributed to the accuracy of the model used to predict the number of vehicles and kilometres travelled (Hassouna & Pringle, 2019), and the use of emission factors (Razif & Santoso, 2016)different from the default in the IPCC guidelines. A second study by Hassouna, F. M. A., & Al-Sahili, K. (2020) investigated another alternative to reduce the environmental impact of the transport sector; this time, they assessed the implication of replacing 10% of traditional vehicles with electric vehicles by 2030 (Hassouna & Al-Sahili, 2020b). In estimating the GHGEs from electric vehicles in 2030, they assumed the emission factors of electricity genera-tion would be constant for the next ten years. This is inaccurate as the electricity generation mix varies from one year to another (Gutglick et al., 2020). Another study tried to introduce a sustainable public transportation system by replacing traditional taxi fleets (entirely composed of diesel vehicles) with hybrid ones under two scenarios: 10% and 50% hybrid taxi penetration (Hassouna & Assad, 2020). A similar methodology and emission factors to the previously presented studies were used.

Since road transport constitutes a significant contributor to the GHGEs in Palestine, it is necessary to analyze these emissions by type of vehicle (private cars, taxis, buses, trucks…etc.) and fuel to establish more targeted policies to reduce the national GHGEs. This research contributes to this goal by estimating the GHGEs by type of vehicle and fuel. The proposed hybrid approach based on the 2006 IPCC guidelines is used for this estimation using data collected for the transport sector in Palestine over the period 2011-2021. The general framework of this research is presented in **Figure 4.1**.

The chapter presents successively (i) a description of the research methodology and data collection and analysis, (ii) a presentation and discussion of the GHGEs related to road transport in Palestine, and finally, (iii) a presentation of the main findings and research limitations.

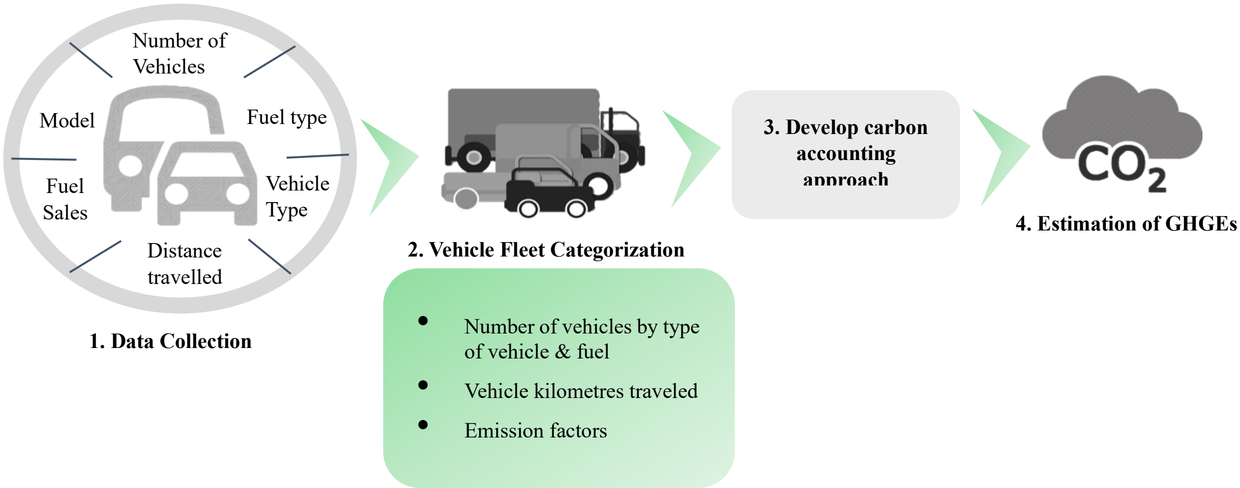


Figure 4.1:General framework of the study

4.2. Materials and Methods

4.2.1. Overview

This research aims at estimating GHGEs from the transport sector in Palestine, which suffers from a lack of detailed data about this sector. The GHGEs are estimated using a hybrid method combining bottom-up and top-down approaches.

The transport system in Palestine is based on the use of road vehicles. It is one of the main sources of GHGEs in the country (Palestine Environment Quality Authority, 2016). The tier 1 method is used to estimate vehicular emissions. It combines two methodologies presented in the IPCC guidelines: (i) fuel consumption method representing a top-down approach, and (ii) vehicles kilometers travelled, which is a bottom-up approach.

To estimate GHGEs by the type of vehicle and fuel, which has not been estimated before For Palestine, it was necessary to collect the data according to the IPCC guidelines. The following section presents data collection.

Table 4.1 summarizes the characteristics of the vehicle fleet in Palestine in 2019 as provided by the administration.

Table 4.1: Classification of the vehicle fleet in Palestine in 2019 by type of vehicle and fuel

Type of Vehicle	Total Number	Fuel					
		Diesel	Gasoline	Electric	Hybrid diesel	Hybrid gasoline	Unclassified
Bus	2,912	2,912					
Tractor	703	703					

Public Taxi	12,219	12,157	29			32	
Private Cars	249,637	115,083	131,758	66		624	1,947
Commercial Vehicles	15,921	15,380	541				
Commercial Trucks < 4.5 ton	10,807	10,685	16				
Other Trucks > 4.5 ton	4,127	4,122					
Motorcycles	1,212		1,212				
Trailers and Semi-Trailers	3,757	601					
Other Vehicles	820	820					
Grand Total	302,115	162,463	133,556	66		656	1,947

4.2.2. Data Collection

The data required to estimate GHGEs from on-road vehicles include (i) activity data (fuel sale, VKT, etc.) and (ii) emission factors of GHGs from the combustion of fuel. Other proxy data were used to fill the gaps and estimate the VKT and fuel sales by the type of vehicle and fuel. **Table 4.1** and **Table 4.2** summarize the data used in this research, and the sources, respectively.

Table 4.2: Data collected by its source

Data	Source	Reference
Number of vehicles by the type of vehicle and fleet	Palestinian Ministry of Transport in The West Bank and Gaza Strip (MoT)	(Palestinian Ministry of Transport, 2022)
Vehicles kilomaters travelled by type of vehicle	Published literature	(Shalabe et al., 2017)
Vehicles' kilomaters travelled by type of fuel	Energy consumption in the transport sector and fuel economy in Palestine from PCBS	(Palestinian Central Bureau of Statistics, 2015a)
Fuel sales by type of fuel	Palestinian Energy and Natural Resources Authority (PENRA), and Palestinian Central Bureau of Statistics (PCBS)	(Palestinian Central Bureau of Statistics, 2019; Palestinian Energy and Natural Resources Authority, 2023a)
Typical fuel consumption figures, per km, by category of the vehicle	European Environment Agency (EEA)	(European Environment Agency, 2019)
Fuel economy by type of vehicle in Palestine	Energy consumption in the transport sector and fuel economy in Palestine from PCBS	(Palestinian Central Bureau of Statistics, 2015a)
Fuel quality in gas stations in Palestine	Published literature	(Karaeen et al., 2013; Shalabe et al., 2017b)

Vehicle statistics (number of registered/licensed vehicles, type of vehicles by fuel) were obtained from the official statistical reports published by the Ministry of Transport (MoT) annually. The report provides information on the transport fleet in Palestine regarding vehicle fleet composition, number of registered and licensed vehicles, driving licenses, and car rental and sale companies (Gaza Ministry of Transport, 2020; Palestinian Ministry of Transport, 2022). Data quality is high because it is collected from vehicle drive and license offices, official units, and the Palestinian Central Bureau of Statistics (PCBS).

Data on the VKT were available separately by type of fuel (diesel, gasoline, etc.) and type of vehicle (private car, taxi, truck, bus, etc.). The data on VKT by type of fuel were obtained from the PCBS, through a survey that used to be carried out annually until the year 2015; the report of this survey is available under the name: 'Energy consumption in the transport sector and fuel economy in Palestine' (Palestinian Central Bureau of Statistics, 2015). The report also provides data on fuel economy by type of vehicle in Palestine. On the other hand, the VKT by type of vehicle was obtained from (Shalabe et al., 2017). The data is considered accurate since representative sample sizes were used.

Fuel sales were collected from the Palestinian Energy and Natural Resources Authority (PENRA), and PCBS (Palestinian Central Bureau of Statistics, 2022a; Palestinian Energy and Natural Resources Authority, 2023a). This data is highly accurate as it is collected at the country scale from imports and local and national suppliers. Fuel quality in gas stations was obtained from (Karaeen et al., 2013; Shalabe et al., 2017b), where representative fuel samples from different gas stations in Palestine were tested for quality and characteristics. Concerning GHGs emission factors, the default emission factors for mobile sources in the IPCC guidelines were used due to the unavailability of country-specific emission factors (IPCC, 2006).

4.2.3. Trend Analysis

Mann Kendall non-parametric test (M-K test) is applied using R software to check consistently increasing or decreasing trends in the total number of vehicles and the number of diesel and gasoline vehicles in the West Bank from 2011-2021. The restriction to the West Bank is due to a lack of data on the vehicle fleet in the Gaza Strip. However, the data from the West Bank could be considered representative of the national scale because the vehicle fleet in the Gaza Strip accounts for only 15% of the national fleet (Al Madhoun et al., 2016).

4.2.4. Estimation of GHGEs

Since this research aims to estimate the emissions from the transportation sector by the type of vehicle and fuel, it is necessary to know the amount of fuel consumed by each type of vehicle. A hybrid approach of the two methodologies mentioned in the 2006 IPCC guidelines for emission estimation from the transport sector is used in this study. This approach is based on fuel consumption and the distance travelled by vehicles. The first method; fuel sold is a good approach to estimating road traffic's emissions at the national or country scale, whereas, the vehicle kilometerstravelledd could be applied at smaller scales, but request more data regarding the number and characteristics of vehicles, distance traveled, etc… Both approaches were combined together to estimate GHGEs from on-road vehicles in Palestine by type of vehicle and fuel, **Figure 4.2** explains the methodology of estimating GHGEs in this research.

Data collected included the vehicle fleet composition by the type of vehicle and fuel (private car, taxi, bus, motorcycle, trucks, trailers and semi-trailers, and other vehicles), and total fuel consumption by type of fuel (diesel, gasoline) (Palestinian Central Bureau of Statistics, 2019). The vehicle distance traveled in Palestine was collected from the survey on energy consumption in transport by the PCBS (Palestinian Central Bureau of Statistics, 2015b). The survey included 6,947 vehicles in Palestine. In this survey, vehicles were classified based on the type of vehicle and fuel. Three categories of vehicles were identified:

- Passenger vehicles, including private cars, taxis, motorcycles, and buses
- Goods vehicles, including trucks and commercial cars.

- Other vehicles, including ambulances, mobile cranes, self-propelled rollers, bulldozers with metallic wheels ...etc.

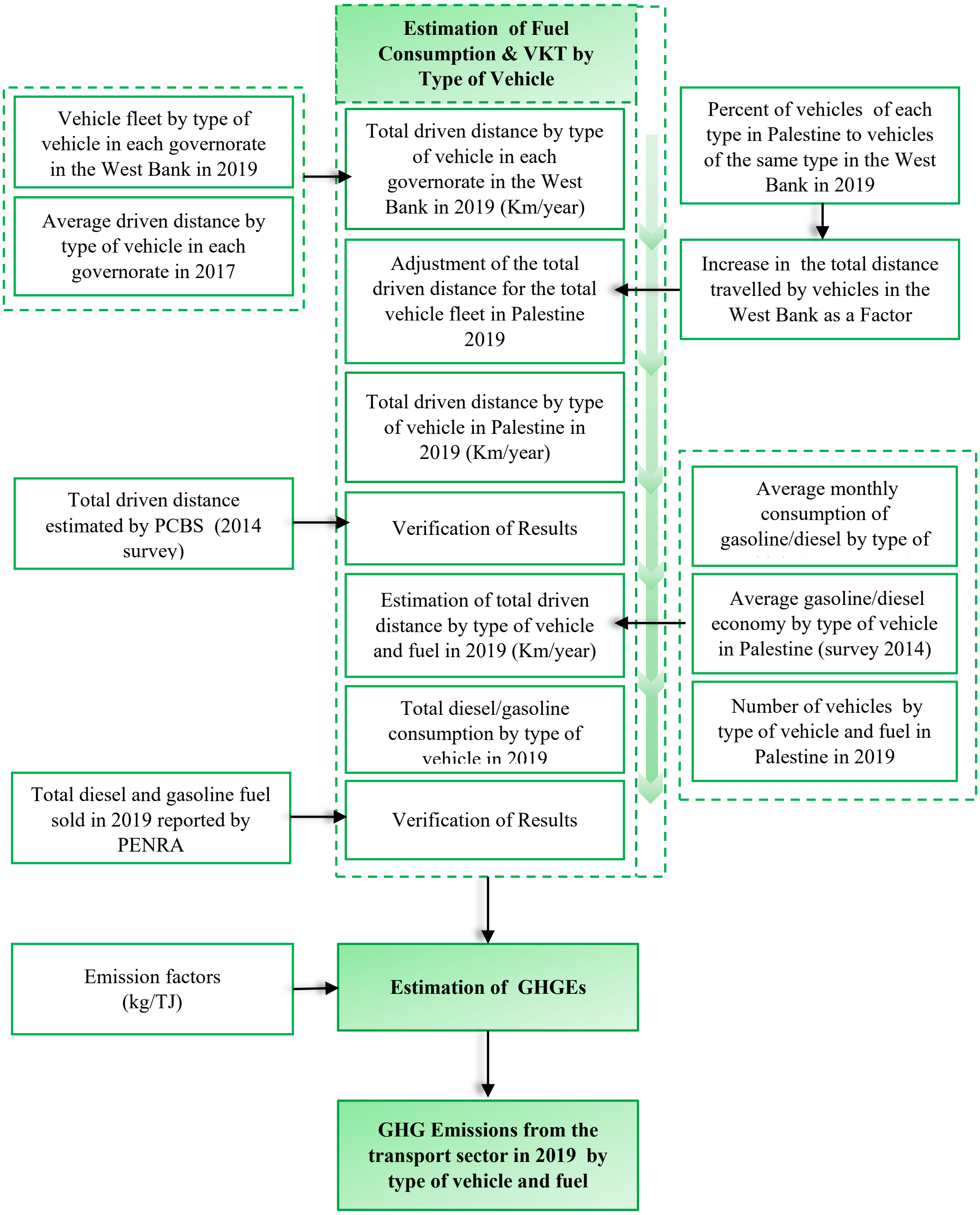


Figure 4.2: Methodology of estimating GHG emissions from on-road vehicles in Palestine by type of vehicle and fuel.

The results of a survey carried out by the Palestine Polytechnic University in 2017 were used (Shalabe et al., 2017) to estimate the average distance traveled by different types of vehicles. The estimation of the amount of fuel consumed by each type of vehicle is based on data collected in 2017. After obtaining the total driven distance by type of vehicle in Palestine in 2019 (Km/year), the result was compared to those in the 2014 survey and published literature (Hassouna & Al-Sahili, 2020a, 2020b; Hassouna & Assad, 2020; Palestinian Central Bureau of Statistics, 2015a; Qureitem et al., 2020;

Shalabe et al., 2017b) for verification. This result and other information obtained from the 2014 survey and data on vehicle fleet in 2019 by type of vehicle and fuel were used to estimate the total driven distance by type of vehicle and fuel.

The result was verified using the total diesel and gasoline sold in 2019 reported by PENRA (Palestinian Central Bureau of Statistics, 2019). The GHGEs were estimated according to Tier 1 as follows:

$$Emissions_{GHG,Fuel,vehicle}(kg) = Fuel\ consumption_{fuel,vehicle}(TJ) \times EF_{GHG,fuel}(kg/TJ) \quad (1)$$

Where:

- $Emissions_{GHG,\ Fuel,\ Vehicle}$: emissions of a GHG by type of fuel (diesel, gasoline, etc.) and vehicle (private cars, taxis, etc.).
- $Fuel\ consumption_{fuel,\ vehicle}$: the amount of a specific fuel consumed by a specific type of vehicle.
- $EF_{GHG,\ fuel,}$: emission factor of a GHG due to combustion of a specific fuel type in a specific vehicle category.

The density of diesel and gasoline used in this research to convert the fuel from physical units to energy units to estimate GHGEs was adapted from a published article that examines the gasoline and diesel characteristics at nine gas stations in Palestine. The used densities of diesel and gasoline are 0.748 kg/l and 0.833 kg/l, respectively (Karaeen et al., 2013).

4.3. Results and discussion

4.3.1. Trend of Vehicle Fleet and GHGEs from the Transport Sector 2011-2021

Results show a significant increasing trend in the vehicle fleet in Palestine during the study period of about 18260 vehicles/year as illustrated in **Figure 4.3**. This increase is significant to the 0.001 level. The growing number of vehicles is a result of demographic growth and the weak public transportation system in the country (Hassouna & Assad, 2020).

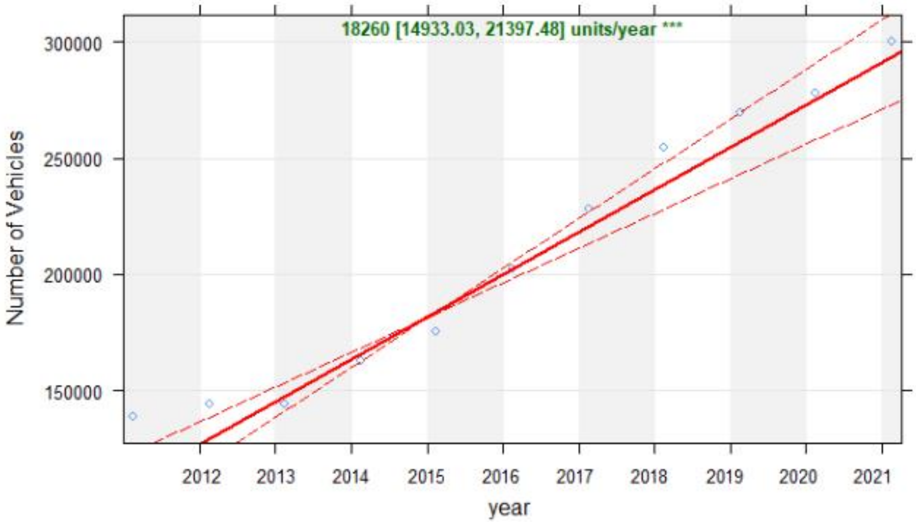
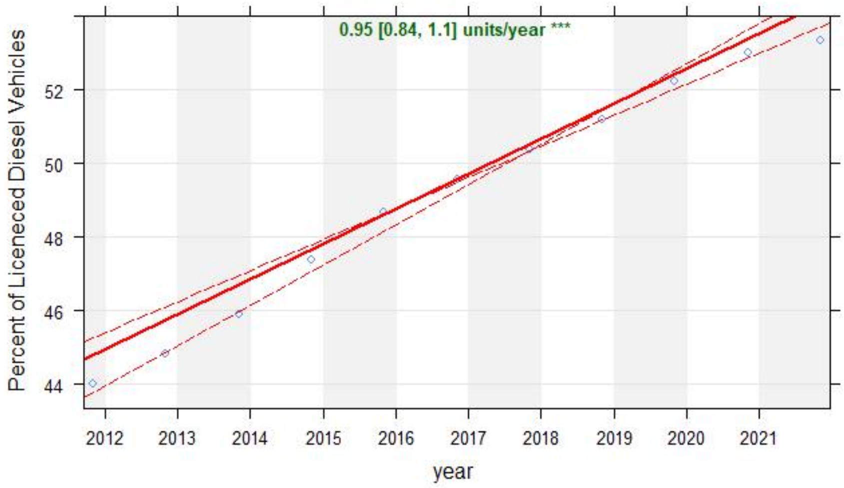


Figure 4.3: Trend in the total number of vehicles in Palestine during the period 2011-2021.
Note:(The solid red line represents the mean trend and the dashed lines represent the 95% confidence interval. The trend and confidence interval are shown at the top as vehicle /year. The *** show that the trend is significant at 0.001 level).

Figure 4.4 shows a decreasing trend in the number of gasoline vehicles in Palestine by about 1.05% /year. This result is significant at 0.001 level. The number of diesel vehicles grew over the same period by 0.95% /year. The increase in diesel vehicles could be attributed to the fact that diesel vehicles give better mileage than gasoline ones and lower diesel prices in Palestine than gasoline prices.

(A) Diesel



(B) Gasoline

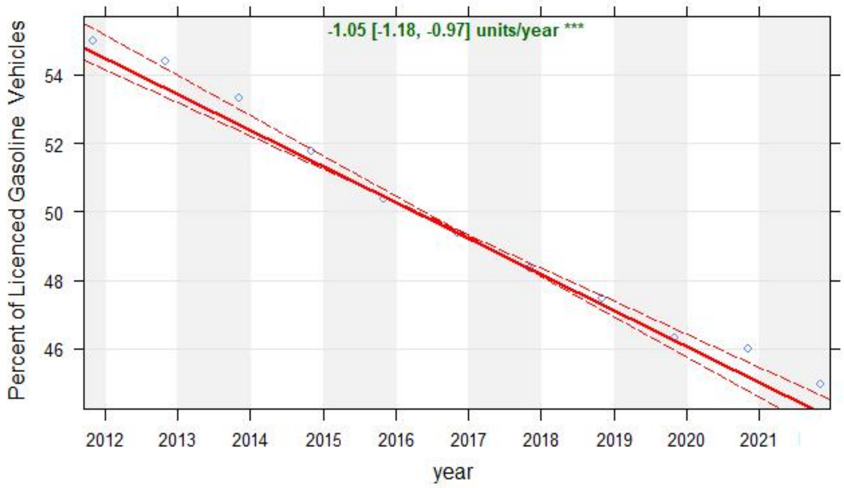


Figure 4.4: Trend in the percentage of (A) diesel and (B) gasoline vehicles from the total fleet in Palestine during the period 2011-2021.
Note: (The solid red line represents the mean trend and the dashed lines represent the 95% confidence interval. The trend and confidence interval are shown at the top as Percent /year. The *** show that the trend is significant to 0.001 level)

GHGEs from the transport sector for the period 2011-2021 were estimated using the IPCC 2016 guidelines as explained in the methodology section. **Figure 4.5** illustrates the variation in the GHGEs during the study period. The highest GHGEs were recorded in 2021. As the emissions do not show a clear trend at first glance, the Mann-Kendall test was also used to check significant trends in vehicular emissions. **Figure 4.6** shows an increasing trend of about 135,737 tons of CO_2eq /year. However, this trend is statistically not significant.

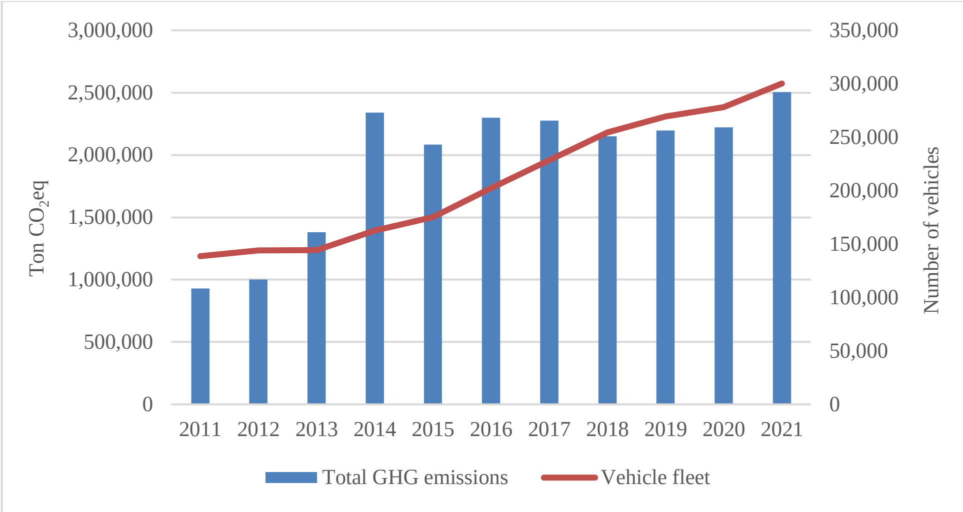


Figure 4.5: GHGEs from the transport sector and the vehicle fleet in the West Bank during the period 2011-2021

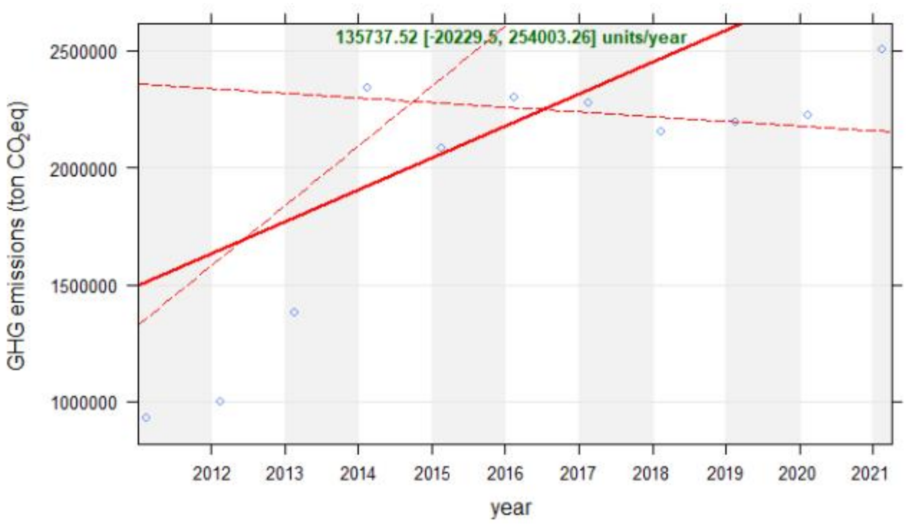


Figure 4.6: Trend in road transport GHGEs in the West Bank during the period 2011-2021.
Note: (The solid red line represents the mean trend and the dashed lines represent the 95% confidence interval. The trend and confidence interval are shown at the top as ton CO_2eq /year).

4.3.2. GHGEs from the Transport Sector in Palestine, 2019

The total emissions from the transport sector in 2019 in Palestine were 2,207,834 tons of CO_2eq, where CO_2 accounts for 98% of these emissions (**Figure 4.7**). Diesel vehicles contribute to around 75% of total GHGEs, as shown in **Figure 4.8**. This result is reasonable because about 55% of the fleet in 2019 was diesel vehicles. Additionally, the amount of diesel fuel consumed by on-road transport in 2019 was twice that of gasoline fuel, which is not only attributed to a larger number of diesel vehicles. Indeed, public taxis, buses, and most commercial vehicles and trucks are diesel-based vehicles (Palestinian Ministry of Transport, 2020). The fuel consumption of these vehicles is usually higher than gasoline vehicles (Palestinian Central Bureau of Statistics, 2015).

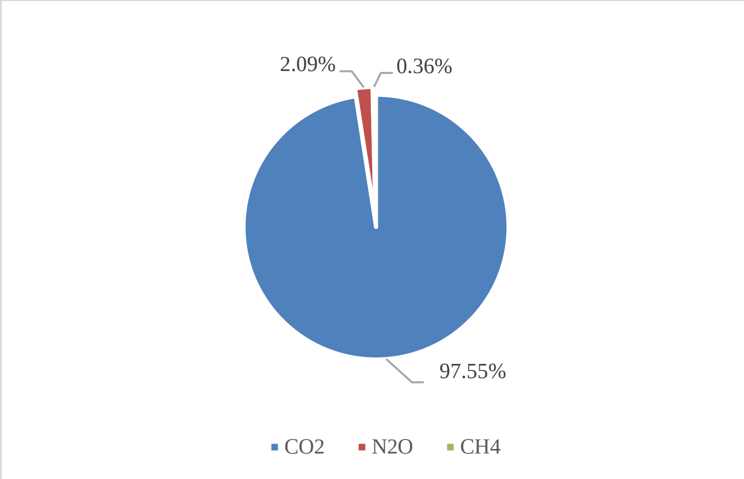


Figure 4.7: GHGEs from the transportation sector in Palestine, 2019 by type of GHGs

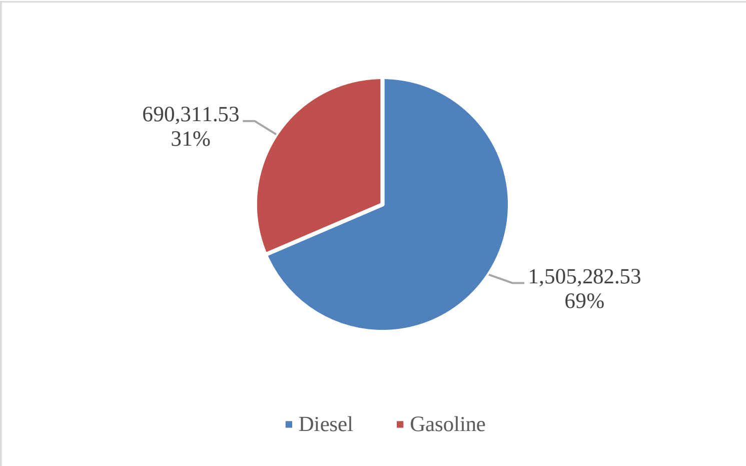


Figure 4.8: Total GHGEs from the transport sector in Palestine by type of fuel, 2019 (in tons of CO_2eq)

Vehicular emissions were estimated and classified by the type of vehicle for 2019, as presented in **Figure 4.9**. Private cars were the biggest contributor to GHGEs in the transport sector, with a share exceeding half of the total on-road emissions (1,207,169 tons of CO_2eq /year, equivalent to 55% of transport sector emissions). This result is expected as the private cars category has the highest vehicle population. The second top emitter is the commercial vehicles and light trucks, with a share of about 20% of the total vehicular emissions (437,138 tons of CO_2eq /year). Public taxis come in third place with around 9% (203,703 tons of CO_2eq /year) of the total emissions, followed by buses with 7% (161,917 tons of CO_2eq /year) of the total transport emissions.

The heightened emissions from private cars are primarily attributed to factors associated with occupation, compounded by restrictions on infrastructure development within the transportation sector. These constraints not only limit the availability of alternative transportation modes like trains, metro systems, and planes but also hinder the necessary infrastructure development for supporting electric and plug-in vehicles. Specifically, the absence of adequate charging stations further diminishes the viability of electric and hybrid vehicles within the country. Furthermore, the fragmentation of the West Bank and the presence of occupation-controlled checkpoints impede Palestinian movement. This discourages public transportation use and fuels preference for private vehicles.

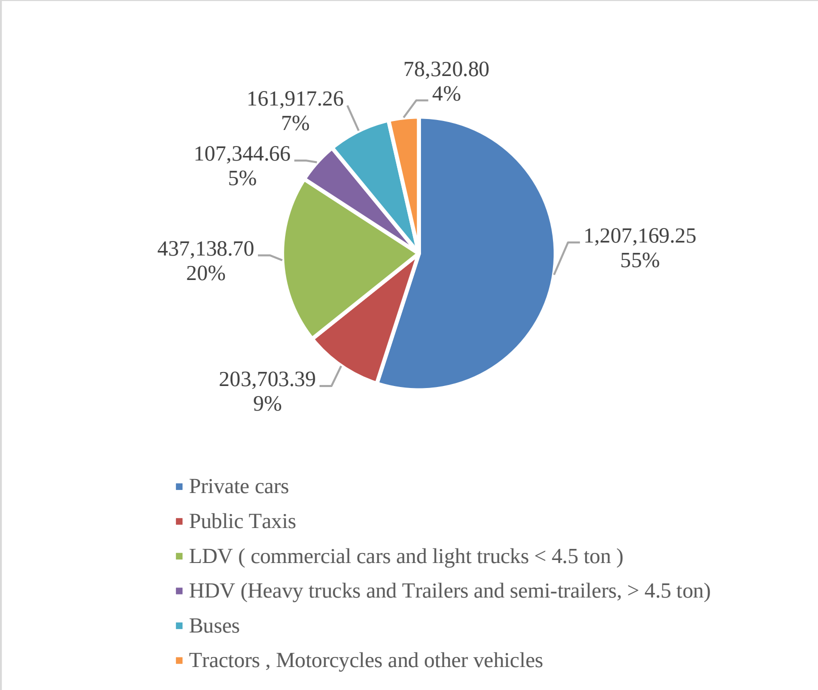


Figure 4.9: GHGEs from the transportation sector in Palestine by the type of vehicle, 2019 (tons of CO_2eq)

Figure 4.10 shows the GHGEs by type of vehicle and fuel. The largest share of GHGEs is attributed to private cars for both diesel and gasoline-based vehicles (593,447 and 613,721 tons of CO_2eq /year, respectively). Gasoline emissions are higher due to the larger number of private gasoline cars. Modest amounts of gasoline-related emissions are released from commercial vehicles, trucks, gasoline, and other vehicles (this category includes tractors, motorcycles, ambulances, etc.).

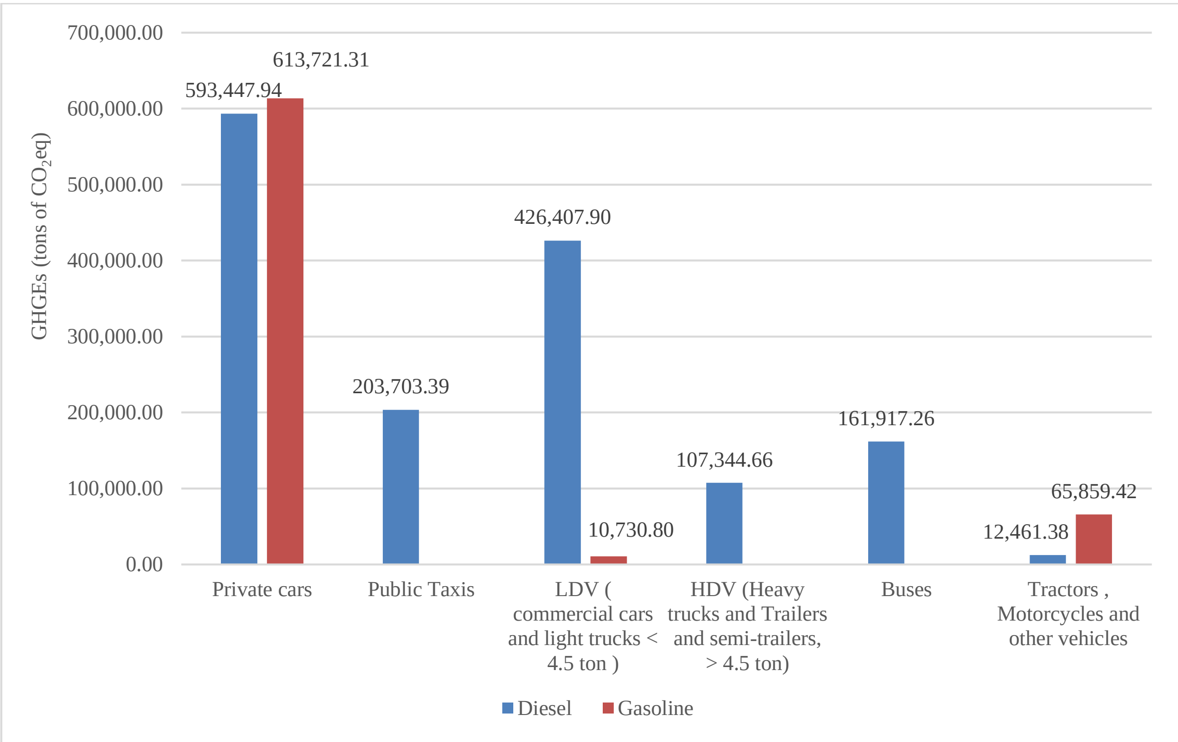


Figure 4.10: GHGEs from the transportation sector in Palestine by the type of vehicle and fuel, 2019 (ton CO_2eq)

The estimated GHGEs from the transport system are compared to the National Greenhouse Gas Inventory for 2019, the result is presented in **Figure 4.11**. Unfortunately, the comparison was only possible for the total GHGEs because the national inventory does not provide any information on emissions from different types of vehicles. The relative differences between results in this research and national inventory in the total GHGEs (CO_2eq) and CO_2 emissions were approximately 3.00% and 2.61%, respectively, while differences in N_2O and CH_4 emissions were higher: around 36% for N_2O and 16% for CH_4. This difference could be attributed to (i) the use of fuel characteristics Palestine instead of standard values and (ii) the use of default emission factors for N_2O and CH_4, as two values are available for gasoline vehicles based on control technology (motor gasoline uncontrolled and oxidation catalyst), which directly affect the N_2O and CH_4 but not CO_2 emissions. According to the IPCC guidelines, in the case of motor gasoline-uncontrolled vehicles, the default emissions factors of N_2O and CH_4 are 3.2 kg/TJ, and 33 kg/TJ, respectively. While for motor gasoline vehicles with oxidation catalysts, the emission factors are 8.0 kg/TJ for N_2O, and 25 kg/TJ for CH_4.

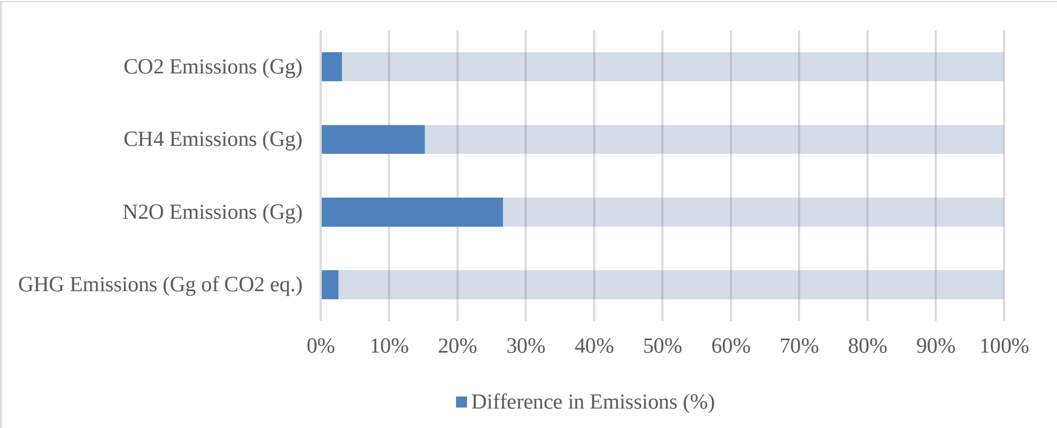


Figure 4.11: Difference between emissions of the transport sector in this research and the National Greenhouse Gas Inventory of Palestine for the same study year, 2019

The emissions of passenger cars are equal to 4.84 tons CO_2eq, which is slightly higher than the value for a typical passenger car which is 4.60 tons CO_2eq (U.S. Environmental Protection Agency, 2018)This result could be attributed to the poor fuel quality and the aged vehicles fleet in Palestine.

4.4. Conclusion

The transport sector is considered a major contributor to GHGEs from fuel combustion activities in the energy sector. This chapter presented a hybrid method to estimate GHGEs from the on-road transport system, with application to Palestine; which constitutes a study area with limited data availability. This method combines bottom-up and top-down approaches to estimate GHGEs using detailed vehicle data, including vehicle type, fuel consumption, and traveled distances. It provides information that helps policymakers to establish more targeted environmental policies that help the country to reduce its GHGEs and achieve the goals set at the country's nationally determined contribution.

The vehicle fleet was assessed for the period 2011-2021. Data analysis indicates a significant increase in vehicles in the country of about 18260 vehicle/year, with a clear preference for diesel vehicles since the share of diesel vehicles is growing by 0.95 %/year on the account of gasoline vehicles. In terms of GHGEs over the same period, the emissions showed an increasing trend, however, this trend is statistically insignificant.

The GHGEs from vehicles were approximately 2,207,834 tons of CO_2eq in 2019. About 75% of these emissions are due to diesel vehicles. Private cars constitute the biggest contributor to the GHGE in the transport sector, with a share exceeding 50% of the total vehicle emissions, followed by commercial vehicles and light trucks (20%), public taxis (9%), and buses (7).

These results show clearly that the GHGEs reduction policy should focus on diesel and private vehicles by developing public transport systems and replacing diesel and gasoline vehicles with environmentally friendly vehicles such as electric and hybrid cars.

The main limitation of this study is the absence of country-specific emission factors and some data for the Gaza Strip.

Chapter 5. Spatial Inventory of GHGE From Electricity Consumption: A Vector Map-Hybrid Approach

5.1. Introduction

Mitigating the impact of greenhouse gas emissions (GHGE) is a critical global challenge facing our planet today. Traditionally, GHGE estimates have been made at different scales from the global and national levels to city and unit levels, providing valuable insights into the total emissions, for policymakers, stakeholders and international agreements (Bun et al., 2019; Cai et al., 2020). However, these assessments, while comprehensive in scope, lack the level of detail necessary to fully understand the geographical variations in emission patterns, to inform effective and more targeted climate action strategies (Hutchins et al., 2017).

Into this gap, spatial inventories of GHGE allow for a more in-depth understanding of emission patterns, enabling the identification of hotspot areas, main sources of CO_2 emissions and their relative impact, and types of GHG being released (Bun et al., 2019). GHGE is often visualized using a spatial grid system, creating a map-like representation of emissions (Danylo et al., 2019). There are two primary methods employed for spatial modelling of carbon emissions: bottom-up and top-down approaches. The bottom-up approach is a data-intensive method that offers a high degree of accuracy. This approach relies on collecting data on GHGE from various sectors such as sectoral energy consumption statistics (e.g. electricity and fuel consumption by type of building and industry) and point source data (e.g. power plants, and industrial facilities), and other kinds of data, for example, data on land use, traffic data or road network information and GDP (Cai et al., 2020; Mateo Pla et al., 2021).

In contrast, the top-down approach disaggregates carbon emissions from a larger geographical scale to smaller scales using proxy data and atmospheric transport models (Cai et al., 2020). Some examples of proxy data that are commonly used in top-down approaches include population, nighttime light imagery, land cover, number of livestock, meteorological data, etc (Danylo et al., 2019). While considered less precise than the bottom-up approach, it is valuable in situations where detailed data on emissions and energy consumption is unavailable. Involving both top-down and bottom-up approaches creates what is so-called the hybrid approach. This approach uses proxy data like population density and nighttime lights to estimate emissions across areas, similar to top-down methods, additionally, it incorporates information on specific sources like power plants and roads as in bottom-up approaches (Hutchins et al., 2017).

Many researchers have investigated the spatial distribution of GHGE around the world (Boychuk & Bun, 2014; Bun et al., 2019; Cai et al., 2020; Danylo et al., 2019; Hutchins et al., 2017; Liu & Song, 2020; Mateo Pla et al., 2021; Su et al., 2020; K. Wang et al., 2022; Y. Yang et al., 2020; Zhou et al., 2021). Cai et al. (2020) proposed a new tool for high-resolution urban carbon emission modelling using readily available urban data (building attributes including type of use and morphological attributes such as building volume, walls, window, and traffic flow data) (Cai et al., 2020). The model is based on a hybrid approach and estimated emissions from buildings and transportation sectors in Hong Kong at a 100-meter resolution raster grid. Hutchins et al. (2016) studied how various approaches used to create spatial maps of GHGE impact the resulting distribution and total emissions (Hutchins et al., 2017). The study compared five existing inventories (at 0.1° resolution): Emission Database for Global Atmospheric Research (EDGAR), Open-Source Data Inventory for Anthropogenic CO_2 (ODIAC), Carbon Dioxide Information and Analysis Center (CDIAC), Fossil Fuel Data Assimilation System (FFDAS), and Vulcan. The researchers investigated the influence of factors like analysis method (top-down vs. bottom-up), proxy data (nightlights vs. population), and inclusion of large point sources. The analysis showed that chosen methods significantly affect emission distribution patterns highlighted the importance of large point emission sources, and emphasized the link between spatial resolution (grid size) and uncertainty. Danylo et al. (2019) introduced a novel method for mapping GHGE from the residential sector (Danylo et al., 2019). Different from grid-based spatial approaches, this method utilized settlement-level data on population density and other factors to disaggregate regional data more precisely. It accounts for variations in heating demand due to climate (using the heating degree day method) and considers differences in energy sources and consumption patterns between urban and rural areas. This approach can be adapted to other countries with adjustments for local data availability. A study by Khrystyna Boychuk & Rostyslav Bun (2014) explored a spatial bottom-up approach using Geographic Information Systems (GIS) for creating GHGE inventories in the energy sector (Boychuk & Bun, 2014). Based on IPCC guidelines, emissions were estimated within individual grid cells (2km x 2km) for various source categories; large-scale point sources, line and area sources like power plants, transportation, and agriculture. Specific emission factors and activity data were considered to account for local variations. Bun et al. (2018) proposed a hybrid approach for creating a high-resolution spatial inventory of GHGEs (Bun et al., 2019). Unlike traditional gridded emissions, this approach focuses on building vector maps of emission sources (point, line, and area). Disaggregation algorithms were used to assign emissions to vector elements (emission sources). The approach allows the visualization of emissions at different administrative levels. This flexible approach can be applied to other countries if data is available. Zheng et al. (2022) employed multi-source data and a novel framework hybrid approach to estimate carbon emissions within Beijing's urban functional zones (UFZs), particularly for residential and urban facility areas. Employing spatial analysis techniques, the study revealed patterns in emission distribution, with peak levels concentrated in areas of high aggregation and outliers predominantly in forested and farmland zones (Zheng et al., 2022). Pla et al. (2020) explored a new, bottom-up methodology for quantifying GHGE emissions from road traffic in cities (Mateo Pla et al., 2021). This approach is based on real-time data from existing urban traffic control and monitoring systems to estimate emissions with high spatial (street level) and temporal (hourly) resolution. A study by Zhang et al. (2023) tried to address the challenge of inaccurate or missing carbon emission data at the municipal and county levels in China (X. Zhang et al., 2023). They proposed a novel method for developing countries lacking robust energy-related data: inverting carbon emissions at the grid level by coupling nighttime light data with energy consumption. This innovative approach offers high accuracy and is particularly suitable for spatial analysis.

While previous studies offer valuable methods for spatial inventories of GHGE, they have primarily focused on developed countries, where data resources are often available. This focus on developed countries has limited their applicability to data availability, particularly in developing countries and conflict zones where data availability remains a significant challenge. These limitations often stem from a lack of detailed spatial data, sector-specific activity data, or robust national emission inventories.

This chapter builds upon the strengths of these existing studies, acknowledging the data constraints often faced in developing countries. A novel hybrid vector map method is proposed here, specifically tailored for Palestine. This method focuses on the electricity sector, the primary contributor to GHGE emissions in the country. This will provide crucial insights for policymakers and stakeholders to develop targeted emission reduction strategies.

5.2. Methodology

The main objective of this research is to create a vector map that shows the spatial distribution of GHGE from electricity consumption in Palestine and identify hotspot areas with high emissions. The method used here is focusing on specific emission sources rather than a grid-based system. The digital maps created will retain information about the administrative location of each emission source. This enables spatial analysis at various administrative levels, including municipalities. This section outlines the methodological approach employed for the spatial analysis.

5.2.1. Overview

Mapping GHGE is a data-intensive process. Investigating the spatial distribution of these emissions necessitates the acquisition and integration of multiple statistical and spatial datasets (Zheng et al., 2022). These include but are not limited to demographics (population, households, housing units), electricity consumption by economic sectors, industrial activity data, administrative boundaries, community maps, building data, land cover/use data, and others. While some data are available from Palestinian authorities, others require utilizing global datasets like OpenStreetMap (OSM) (OpenStreetMap Foundation (OSMF), 2024). The methodology acknowledges the challenges associated with data availability, particularly in developing regions like Palestine. These challenges are addressed through data preparation techniques like proxy data to refine the data scale and provide the necessary level of detail for analysis.

Following data preparation, QGIS software (version 3.34.3), a free and open-source Geographic Information System (GIS) platform, is used for spatial modelling. This involves integrating all prepared data layers and utilizing QGIS functionalities for spatial analysis.

Our approach for spatial analysis is based on utilizing the available spatial data (emission sources) in the form of elementary objects or vector map units while retaining the administrative location of each emission source. In this research emission sources are defined as polygons or area units since the focus is on electricity consumption. By considering administrative boundaries, this method avoids limitations associated with traditional grid-based approaches. These limitations include: disregarding administrative boundaries, leading to inaccurate emission estimates for municipalities; strong dependence on chosen grid size, with coarse grids missing details and fine grids being computationally expensive (Bun et al., 2019).

While our spatial model is designed to present emissions at various levels of detail, data availability in Palestine limits the finest resolution to the built-up area level. This means we cannot account for variations within individual buildings due to limitations in information on building morphology (structure) and elevation. "Built-up area" is defined as the presence of buildings (roofed structures). This definition largely excludes other parts of urban environments or human footprints such as paved surfaces (roads, parking lots), commercial and industrial sites (ports, landfills, quarries, runways) and urban green spaces (parks, gardens) (OECD, 2024). For the purpose of this study, small communities and towns are represented by a single built-up area, while cities are composed of a collection of built-up areas. The character of each built-up area is shaped by its dominant land use (and type of buildings). This can be residential, featuring primarily homes and associated infrastructure; commercial, with a concentration of shops, offices, and businesses; industrial, characterized by factories and warehouses; or public, containing government and public buildings, and educational institutions. The mix of buildings and facilities within a built-up area determines its function and its contribution to overall electricity consumption. Understanding this hierarchy of built-up areas is crucial for interpreting the spatial patterns of GHGEs revealed by the analysis. By acknowledging the range of sizes and complexities, we can gain a more in-depth understanding of how urban form influences electricity consumption and associated emissions.

Using the detailed spatial data available (polygon data), areas are classified based on their electricity consumption. To obtain this, the urban masterplan of Palestine alongside maps on land use and cover are utilized to identify zones of electricity consumption including; industrial zones, commercial areas, residential, and public buildings and services. This detailed approach ensures we capture the varying consumption patterns across different areas, from densely populated city centres to sprawling suburbs. Finally, these classifications are turned into digital maps. Each polygon on these maps represents a specific consumer category (industrial, commercial, residential) and visually depicts the spatial distribution of electricity consumption across Palestine. Emission factors for electricity consumption in Palestine are employed to convert electricity consumption into GHG emissions. Finally, QGIS's mapping functionalities are used to create thematic maps visualizing the spatial distribution of GHGEs. By emphasizing the data-intensive nature of spatial analysis and outlining the specific data requirements, this methodology establishes a robust framework for analyzing the spatial distribution of GHG emissions arising from electricity consumption in Palestine. **Figure 5.1** shows the general framework of the analysis, the following sections provide a more comprehensive explanation.

5.2.2. Data Acquisition

This section details the data collection process followed for the spatial analysis of electricity consumption and associated GHGEs in Palestine. Data are gathered from a variety of sources, categorized as follows:

5.2.2.1. Statistical and Electricity Consumption Data

Demographic data including data on population, number of households and housing units is collected from the Palestinian Central Bureau of Statistics (PCBS) (Palestinian Central Bureau of Statistics, 2018, 2020a, 2020b). This data is crucial for estimating electricity consumption based on population density and housing units. To estimate electricity consumption data is obtained from various sources including national energy balance tables which give valuable insights into the overall energy consumption patterns within Palestine, these tables are published by PCBS and Palestinian Energy and Natural Resources Authority (PENRA) (Palestinian Central Bureau of Statistics, 2019, 2021a, 2022b, 2022a). Annual reports published by the Palestinian Electricity Regulatory Council (PERC) (Palestinian Electricity Regulatory Council, 2021) and electricity distribution companies provide a vital source of data on overall electricity consumption within Palestine (GEDCO, 2020; HEPCo, 2020; JDECO, 2020; NEDCO, 2020). These reports are essential for understanding the current state of electricity usage. In addition to these reports, data from municipalities' annual reports on electricity consumption is also collected (Qalqilya Municipality, 2020; Tulkarm Municipality, 2020). While not universally available, such municipal reports offer valuable insights into local consumption patterns.

Furthermore, data from the PCBS's household survey on energy consumption from 2001-2015 is also utilized (Palestinian Central Bureau of Statistics, 2023a). This survey offers information on consumption habits at the residential level considering spatial variation. Industrial statistics from PCBS are used to understand electricity consumption within the industrial sector and collect data on the number and type of industrial facilities (Palestinian Central Bureau of Statistics, 2020c).

5.2.2.2. Spatial Data

To delve into the spatial distribution of electricity consumption across Palestine, a variety of geospatial datasets are collected. The primary source for this data is GeoMOLG, the first-ever integrated spatial information system in Palestine, developed by the Palestine Ministry of Local Government (MOLG) in partnership with German International Cooperation (GIZ) through the Local Governance and Civil Society Development Programme (LGP) (Palestine Ministry of Local Government, 2024). GeoMOLG provides a detailed picture of land use and administrative boundaries, essential for our analysis. This includes core data like land cover and land-use maps, which allow us to classify areas based on their electricity consumption patterns (industrial zones, commercial areas, residential areas). Additionally, data on approved urban master plans, communities, and built-up areas, all accessible through GeoMOLG, provide further context for understanding electricity usage within specific locations and are used in the classification process of consumption zones.

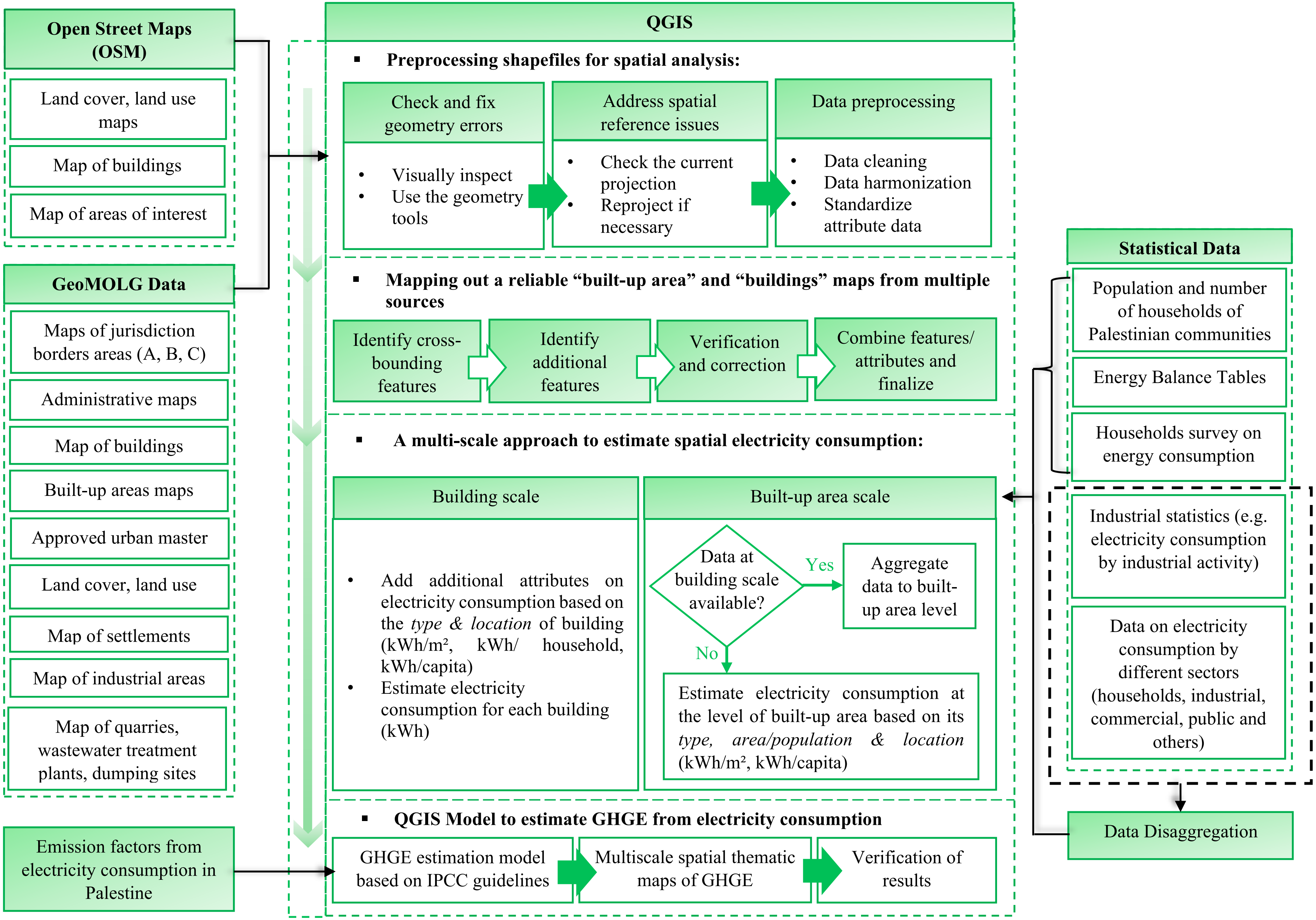


Figure 5.1: Framework for Spatial Analysis of Electricity Consumption in Palestine

Furthermore, information on governorates and jurisdictional borders (Areas A, B, C) is crucial for analyzing consumption patterns across different administrative units. While not directly related to electricity use, data on Israeli settlements is included, as it can potentially shed light on spatial disparities in electricity access or infrastructure.

OSM is used as a valuable complementary source, offering additional land-use/cover data and building information, particularly in cases where Palestinian geospatial data might be limited. By integrating these diverse spatial datasets, we can create a comprehensive picture of electricity consumption patterns across Palestine.

5.2.2.3. Emission Factors

Emission factors from electricity consumption in Palestine are employed to convert electricity consumption into emissions. These factors were previously estimated and presented in detail in Chapter 3. This ensures consistency in the estimation of GHGE.

5.2.2.4. Other Data for Comparative Analysis

In addition to the core data sets used for the spatial analysis within Palestine, additional data sources are utilized. Data on electricity generation emission factors from the supplier are obtained (Electricity Authority, 2023; Gutglick et al., 2020). Data on primary energy supply and final energy

5.2.3. Disaggregating Electricity Consumption by Sector

Accurately estimating electricity consumption across different sectors (residential, commercial, industrial, and public) is crucial for GHGE from electricity consumption. This section outlines the methodology employed to disaggregate the total electricity consumption data in Palestine into these key sectors.

Disaggregating electricity consumption data in Palestine necessitates a thorough understanding of the data currently available from distribution companies. The electricity sector in Palestine is a complex system with a mix of distribution entities. Six electricity distribution companies operate in Palestine (Palestinian Electricity Regulatory Council, 2021), each serving specific governorates. For instance, the Jerusalem District Electricity Company (JDECO) serves Jerusalem, Jericho, Ramallah, and Bethlehem. The North Electricity Distribution Company (NEDCO) primarily serves the Nablus governorate and certain areas of the Jenin governorate, while Tubas Electricity Distribution Company (TEDCO) focuses on the Tubas governorate. Similarly, the Hebron Electric Power Company (HEPCO) and the Southern Electric Company (SELCO) cater Hebron governorate. Gaza Electricity Distribution Company (GEDCO), is the official body in charge of electricity supply in the Gaza Strip. It's important to note that the rest of the governorates and communities like Tulkarm and Qalqilya governorates and parts of Jenin governorate receive electricity directly from the supplier, bypassing the distribution companies.

Disaggregating electricity consumption data to the governorate level can be complicated by the presence of distribution companies. While these companies may report total consumption by sector (residential, commercial, industrial) for the entire governorate they serve, this data doesn't provide a breakdown by location within the governorate (GEDCO, 2020; HEPCo, 2020; JDECO, 2020; NEDCO, 2020). Additionally, distribution company service areas often don't perfectly align with governorate boundaries (NEDCO, 2020), further complicating the picture. Understanding these limitations of distribution company data is essential for the methodology employed to disaggregate the total electricity consumption data in Palestine into the key sectors of residential, commercial, industrial, and public, which directly impacts GHGEs from electricity consumption. This next section outlines the specific approach used for disaggregation.

The data on electricity consumption obtained in the data collection process is modified to account for grid losses. Grid loss data for each governorate is factored into the calculations to provide a more accurate picture of sectoral electricity consumption.

In the industrial sector; ideally, we would have data on the type and size of industrial facilities to estimate electricity consumption per facility. However, in this case, the available data consisted only of facility locations and total electricity consumption for each governorate. To address the data gap, a rough estimate of electricity consumption within each governorate is made. This involved dividing the total industrial sector consumption by the total area designated as industrial in the master plan of that governorate. While this provides a starting point, it may not capture the variations in consumption between different types of industries.

In terms of commercial sector and public buildings, building locations and commercial areas are known. Similar to the industrial sector, data on the location of commercial buildings and commercial areas is available. Unfortunately, crucial data on building elevation height and number of stories is not available. This information would have been essential for estimating electricity consumption per commercial and public building or average consumption per square meter. Due to the data limitations, a similar approach to the industrial sector is adopted.

In contrast to the other sectors, a more detailed estimation of electricity consumption is possible for the residential sector. Utilizing data on total residential consumption of electricity in each governorate, alongside population data and number of households we could obtain the average electricity consumption per household and capita in each governorate. The detailed disaggregation process is shown in **Figure 5.2**.

By employing these disaggregation techniques and acknowledging data limitations, this methodology provides a framework for estimating electricity consumption across different sectors in Palestine. This sectoral breakdown serves as valuable input for electricity consumption mapping.

5.2.4. Mapping GHGE from Electricity Consumption

Building upon the robust data collection and preparation efforts outlined in the previous section, this section details the methodological framework employed to generate spatial visualizations of electricity consumption across Palestine.

5.2.4.1. Preprocessing shapefiles for spatial analysis:

The initial stage of the methodological framework involves ensuring the accuracy of the geospatial data. This step focuses on checking and fixing geometric errors within the shapefiles utilized for the analysis. Geometric errors encompass any inconsistencies or inaccuracies in the way the shapes (geometry) of features are represented within a shapefile. These errors can exist in various forms, such as misplaced points, lines that don't connect properly at endpoints, invalid polygons with self-intersections or areas that are not entirely enclosed.

The presence of geometric errors can have a significant impact on the subsequent spatial analysis. Inaccurate geometries can lead to misleading results. For instance, if an area is misplaced due to a geometric error, it might be excluded from calculations for a specific zone, leading to an underestimation of electricity consumption in that location. Furthermore, geometric errors can hinder the integration of data from different sources, as inconsistent geometries can make it difficult to overlay or merge datasets accurately.

To mitigate these issues, a process of checking and fixing geometric errors is carried out using QGIS. This process involves several key steps: the initial step involves a visual inspection of the data upon loading the shapefile into QGIS. Zooming in and out on the map allows for the identification of any obvious geometric issues. Following that, vector generalization tools are utilized such as snap, vertex tool, buffer and simplify geometry.

It is crucial to ensure data consistency across the various shapefiles. This step focuses on verifying and potentially rectifying inconsistencies in the spatial reference system (projection) and units employed by the different shapefiles and data sources. Incompatibility between the projections and units used by different data sources can lead to significant issues including misalignment of features (inaccurate measurements, misleading interpretations, and difficulties in spatial analysis.), and unit misinterpretations.

Once any inconsistencies are identified between the projections and units of data sources, data cleaning and harmonization become necessary. Here's a breakdown of the process: choose a suitable target projection for analysis, reproject layers from their original projection to the chosen target projection, and convert all layers to a consistent unit system.

This process ensures that all the data sources are consistent, allowing for accurate spatial analysis and meaningful comparisons between different datasets.

5.2.4.2. Mapping out a Reliable Built-Up Area/Buildings layer

This step focuses on constructing a comprehensive and reliable map (single shapefile) of built-up areas and buildings across Palestine. Since data availability is limited, here we integrate data from various sources to achieve the most accurate representation possible. The explanation here is focused on the built-up area, but the same process is applied to buildings as well. Starting with identifying the core built-up area; this involves pinpointing areas consistently identified as built-up across all collected "built-up area" shapefiles, regardless of their source. Techniques like the "Intersection" tool in QGIS are employed to identify these overlapping regions, forming the foundation for a built-up area map.

While the core areas provide a solid base, they might not capture the full extent of built-up zones. Here, we identify additional built-up areas present in individual source data. This might involve utilizing the "Difference" tool in QGIS to create separate layers highlighting potential "additional built-up areas" specific to each data source.

The additional built-up areas require verification to ensure accuracy. This stage involves using additional data sources like "buildings" and "urban master plan" shapefiles for confirmation. Visual inspection, attribute data analysis, and potentially manual editing within QGIS are employed to refine the accuracy of the identified built-up areas.

Creating the final map; once the additional built-up areas are verified, they are merged with the core areas to create a final comprehensive map. Tools like the "Union" function within QGIS will be instrumental in combining these layers into a single shapefile representing the final built-up area data for Palestine.

By following these steps this multi-source approach facilitates the creation of a reliable built-up area and building maps, laying the groundwork for the subsequent stages of analyzing electricity consumption across Palestine.

5.2.4.3. Creating Electricity Consumption Maps for Residential Sector

Having constructed a reliable built-up area and building layers, it is possible now to visualize electricity consumption patterns across Palestine. This sub-section outlines two scenarios for map creation, depending on data availability.

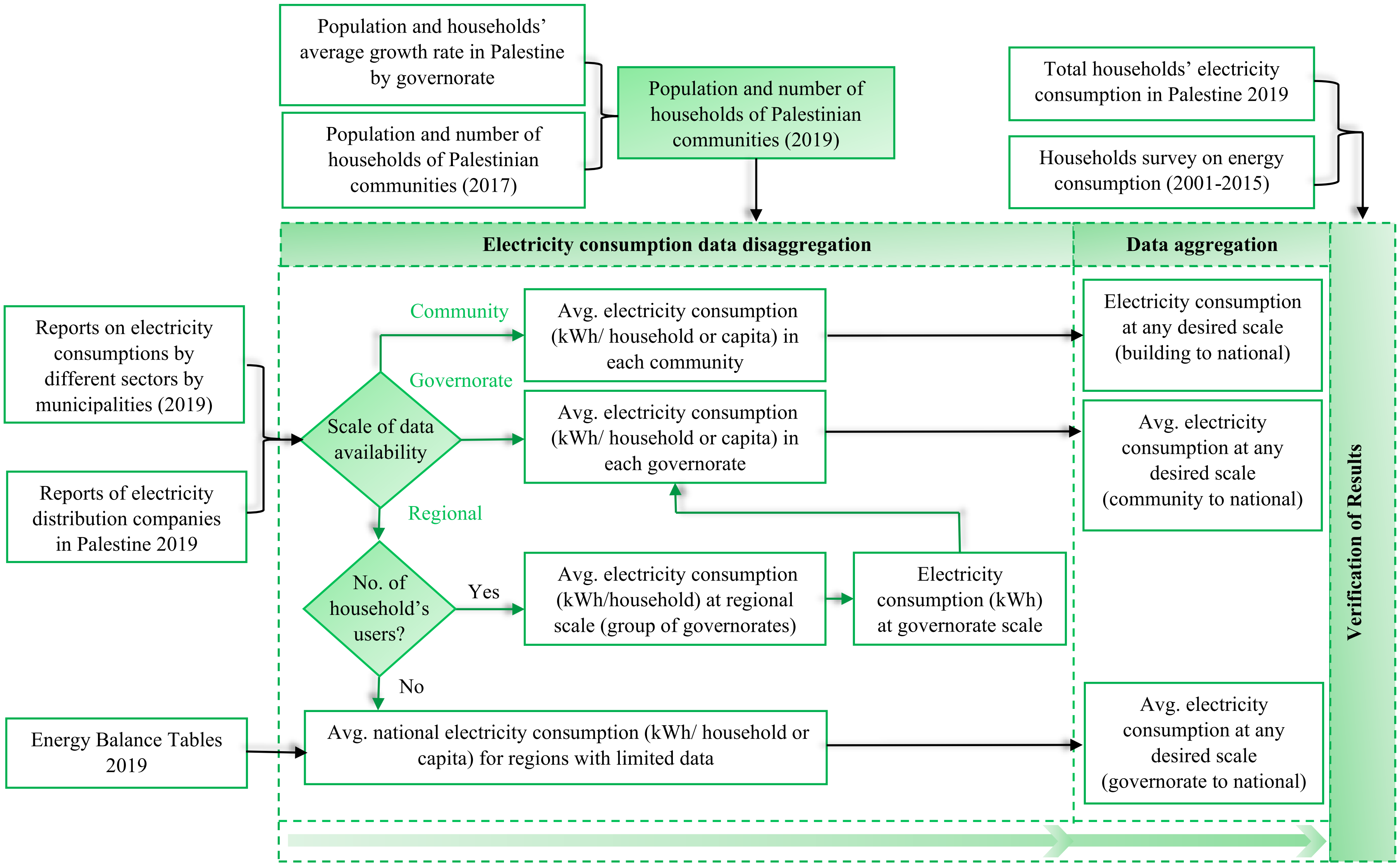


Figure 5.2: Residential electricity disaggregation process at different scales

- Scenario 1. Electricity Consumption at Building Scale:
  In this ideal scenario, where data on the number of stories per building or building height is available, it is possible to estimate electricity consumption at the individual building level. Using QGIS tools we combine the buildings shapefile (containing building locations) with the data source that provides the number of stories for each building. To estimate the consumption at the building level, a model builder in QGIS is utilized. A formula or expression is defined to do the estimation. This formula considers the number of stories for each building and a pre-defined value for electricity consumption. This value, expressed either per story or per square meter of floor area, is estimated in section 5.2.3. Disaggregating Electricity Consumption by Sector. It is important to highlight that the average electricity consumption estimated has a spatial variation at the governorate level. The calculated building electricity consumption data is then used to create a thematic map within QGIS. Thematic maps effectively communicate spatial patterns. This map will serve as a valuable tool for initial analysis.
- Scenario 2. Built-up Area Level Analysis - When Building Story Data is Limited:
  In circumstances where data on building stories is unavailable as in the current case, it is possible to estimate electricity consumption, at the built-up area level. By incorporating population data for each built-up area, we can integrate it with the built-up area data using a similar approach as employed in Scenario 1. This enriches the data available for analysis. The formula in this case considers the population (or number of households) in each built-up area and an average electricity consumption value per capita (or per household in case the number of households is used). This value varies from one governorate to another as illustrated in **Figure 5.2**.

The estimated electricity consumption data, derived either from households' numbers or population figures, is used to create a thematic map for the built-up areas. This map allows us to analyze potential spatial patterns in electricity consumption at a broader level.

Concerning other sectors, the rough estimated electricity consumption per squared meter is used for mapping electricity consumption from these sectors.

5.2.4.4. Estimating GHGE

Following the creation of electricity consumption maps, the process of estimating and visualizing associated greenhouse gas emissions (GHGE) using QGIS takes place. A model based on IPCC guidelines is employed here. The model is based on multiplying the estimated electricity consumption (obtained from the previous step) by an emission factor for electricity consumption in Palestine.

Once the GHGE values are calculated for each building (in Scenario 1) or built-up area (in Scenario 2), spatial thematic maps of GHGE are created. Similar to the electricity consumption maps, these thematic maps will effectively visualize the spatial distribution of estimated GHGE across Palestine.

5.2.4.5. Verification of Results

Verifying the estimated GHGE values is crucial for ensuring the accuracy of the analysis. For verification, the emissions are aggregated to the national level allowing the comparison with existing studies or reports on GHGE emissions in Palestine.

The following section presents the results of these analyses, exploring spatial patterns of emissions across Palestine.

5.3. Results and Discussion

The spatial analysis in this study has revealed a distinct pattern in GHGEs arising from electricity consumption across Palestine. This section delves into the key findings, presenting the results of mapping GHGEs at two crucial geographic scales: governorate level and built-up area.

5.3.1. Built-Up Area Scale

5.3.1.1. Identifying Emissions Hotspots within Built-up Areas

The vector map of GHGE from total electricity consumption by different sectors in Palestine is presented in **Figure 5.3**. At this scale, each built-up area has a specific type, either representing residential, commercial, industrial or public zone, according to the buildings and facilities within this segment. The mix of buildings and facilities within a built-up area determines its function and its contribution to overall electricity consumption.

The analysis at this scale focuses on emissions within built-up areas. These areas, characterized by a concentration of buildings and electricity-consuming facilities, are where the majority of emissions originate. The white areas on the map **in Figure 5.3** represent regions outside the built-up areas. These typically encompass agricultural lands, forests, natural reserves, grazing lands, and other environments with minimal permanent structures and consequently, little to no electricity consumption and associated emissions.

As shown in **Figure 5.3**, Gaza City exhibits the highest concentration of electricity-related GHGEs in Palestine, approximately 266,000 tons of CO_2eq. This hotspot coincides with a densely populated urban area with a population of about 678,700 residing within a compact 70 square kilometres (Palestinian Central Bureau of Statistics, 2020b). This translates to a population density of approximately 9,700 capita/km^2, making it one of the most densely populated urban centres globally. High population density undoubtedly contributes to the elevated emissions, emphasizing Gaza's position as the region with the highest concentration of electricity-related GHGEs in Palestine.

Despite this high population density, Gaza faces significant energy challenges. In 2019, the study year, the Gaza GEDCO reported a substantial energy deficit of 68% (GEDCO, 2020). Furthermore, our analysis estimated the per capita electricity consumption in 2019 of only around 690 kWh, reflecting only residential use. This low consumption figure, excluding industrial, commercial, and public uses, suggests limitations in accessing electricity from the grid (Palestinian Electricity Regulatory Council, 2021). The geopolitical context in Gaza contributes to these limitations.

This situation presents a fascinating puzzle. While the analysis reveals the highest total electricity-related GHGEs in Palestine for Gaza, the per capita electricity consumption is surprisingly low. This contradictory situation can be explained by the high population density. Even with limited grid access, a large number of people concentrated in a small area can generate significant electricity-related emissions.

Within the West Bank, spatial variations in emissions were evident. Residential built-up areas within Hebron City emerge as the regions with the highest concentration, 125,000 tons of CO_2eq. Following closely behind is residential areas in Nablus City, exhibiting emissions of about 79,400 tons CO_2eq. It's important to note that these hotspots are primarily concentrated within the residential areas of both Hebron and Nablus. In contrast, commercial and industrial zones within these cities generally showed significantly lower emissions, sometimes dipping below 7,500 tons CO_2eq. This pattern of higher emissions in residential areas holds true across other West Bank cities as well, suggesting a strong correlation between population density and electricity use in these areas.

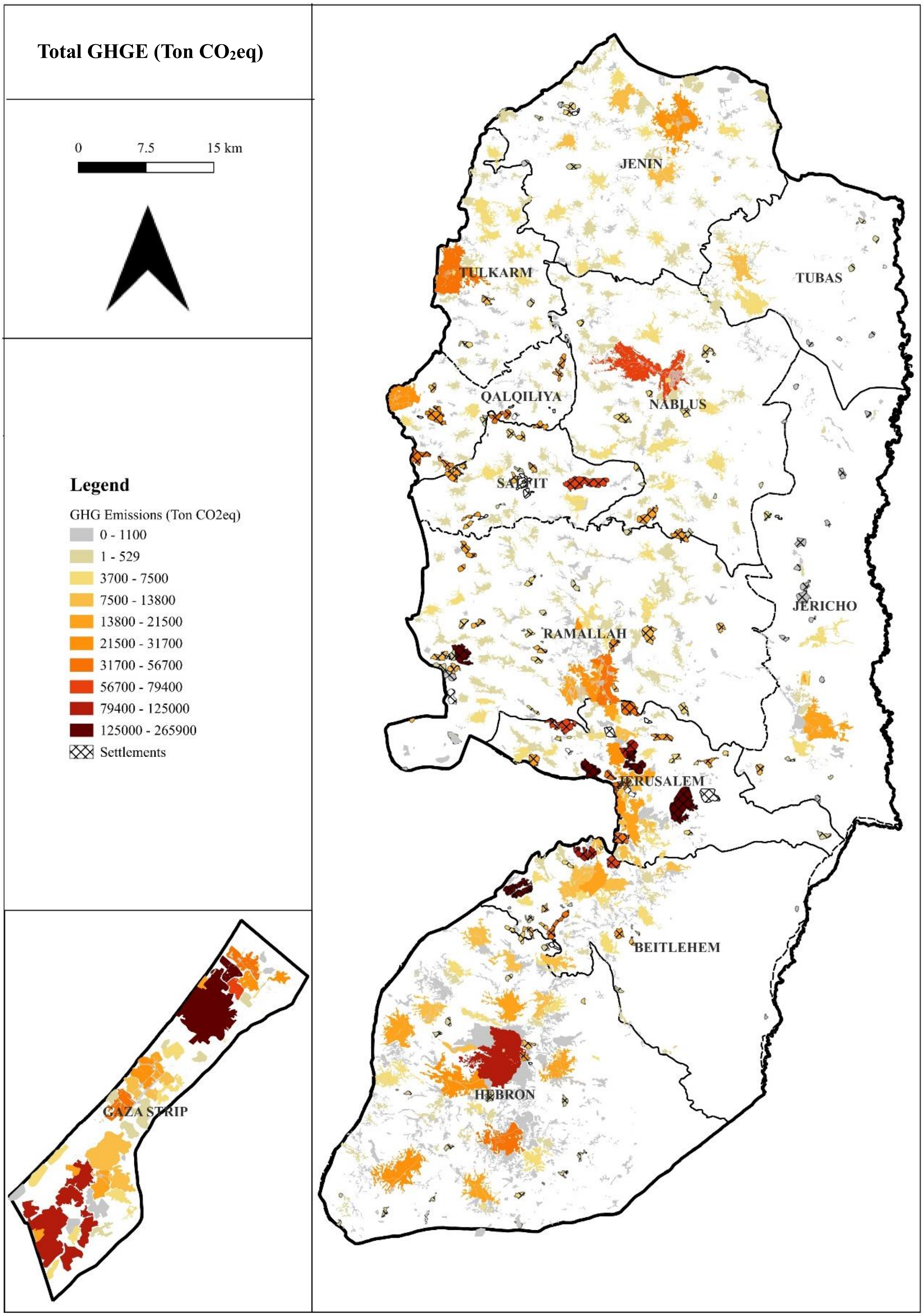


Figure 5.3: Spatial distribution of GHGE from electricity consumption in Palestine in 2019 at the built-up area level

Concerning the emissions in smaller communities and towns; small communities and towns were typically represented by a single unit of built-up area on the map. Within these smaller settlements, emissions are likely driven by two key factors: (i) population; communities and towns with higher populations tend to have increased total electricity consumption. This higher consumption translates into higher emissions compared to areas with lower population d. (ii) average electricity consumption; the average amount of electricity consumed per person within a community also influences overall emissions. Communities, where residents use more electricity per capita, exhibit higher emissions compared to those with lower per capita consumption.

To illustrate the influence of per capita electricity consumption on emissions, consider four towns with similar populations of around 7,250: Qalandia in Jerusalem governorate, Awarta in Nablus governorate, Dier Abu Da'if in Jenin governorate, and Husan in Bethlehem governorate. Despite their similar population sizes, these towns exhibit varying levels of GHGEs of approximately: 6,000, 3,500, 4,000, and 5,000 tons CO_2eq, respectively. This significant variation is attributed to differences in per capita electricity consumption across the governorates where these towns are located.

Figure 5.3 also highlights electricity-related GHGEs within settlements located in the West Bank for which population data is available. It's important to note that these estimations rely on an average per capita electricity consumption value for Israel in 2019 (0.577 metric tons of oil equivalent, or 6,710 kWh/capita) reported by the Ministry of Energy (Fuel and LPG Authority and Ministry of Energy., 2021).

Among these settlements, one location (Maccabim near Ramallah) stands out with the highest recorded emissions, reaching approximately 297,000 tons of CO_2eq. While the population of this settlement is around 81,000, this translates to an emission intensity of 3.66 tons CO_2eq/ capita. This intensity is significantly higher than Hebron City in the West Bank, which has the highest emissions overall (210,000 population) but an emission intensity of 1.69 tons CO_2eq/capita. In fact, the settlement's emission intensity is more than double that of Hebron and nearly ten times higher than Gaza City.

Understanding these spatial variations and the factors that contribute to them is crucial for developing targeted strategies to reduce electricity-related GHGEs across the West Bank. By focusing on areas with high population density and analyzing consumption patterns within different built-up area types, we can create more effective approaches to promoting energy efficiency and reducing emissions.

5.3.1.2. Exploring Emissions Across Jurisdictional Areas

This analysis utilizes the same built-up area scale as the previous map. However, to further understand variations in emissions across locations, an additional layer was incorporated showing jurisdictional borders: Areas A, B, and C as illustrated in **Figure 5.4**.

In accordance with the Oslo Accords, The West Bank was divided into three non-contiguous regions; A, B and C. Area A represents 18% of the West Bank (United Nations High Commissioner for Human Rights, 2020). Most affairs in this area are under the control of the Palestinian Authority. Area B comprises 21% of the West Bank. The Palestinian Authority is in charge of civil administration in area B (education, health and the economy), while the Israeli occupation has full control of security. Area C represents the largest part of the West Bank (60%) and it's under the control of the Israeli occupation. The control of the area was supposed to be transferred to Palestinians, but that has never happened.

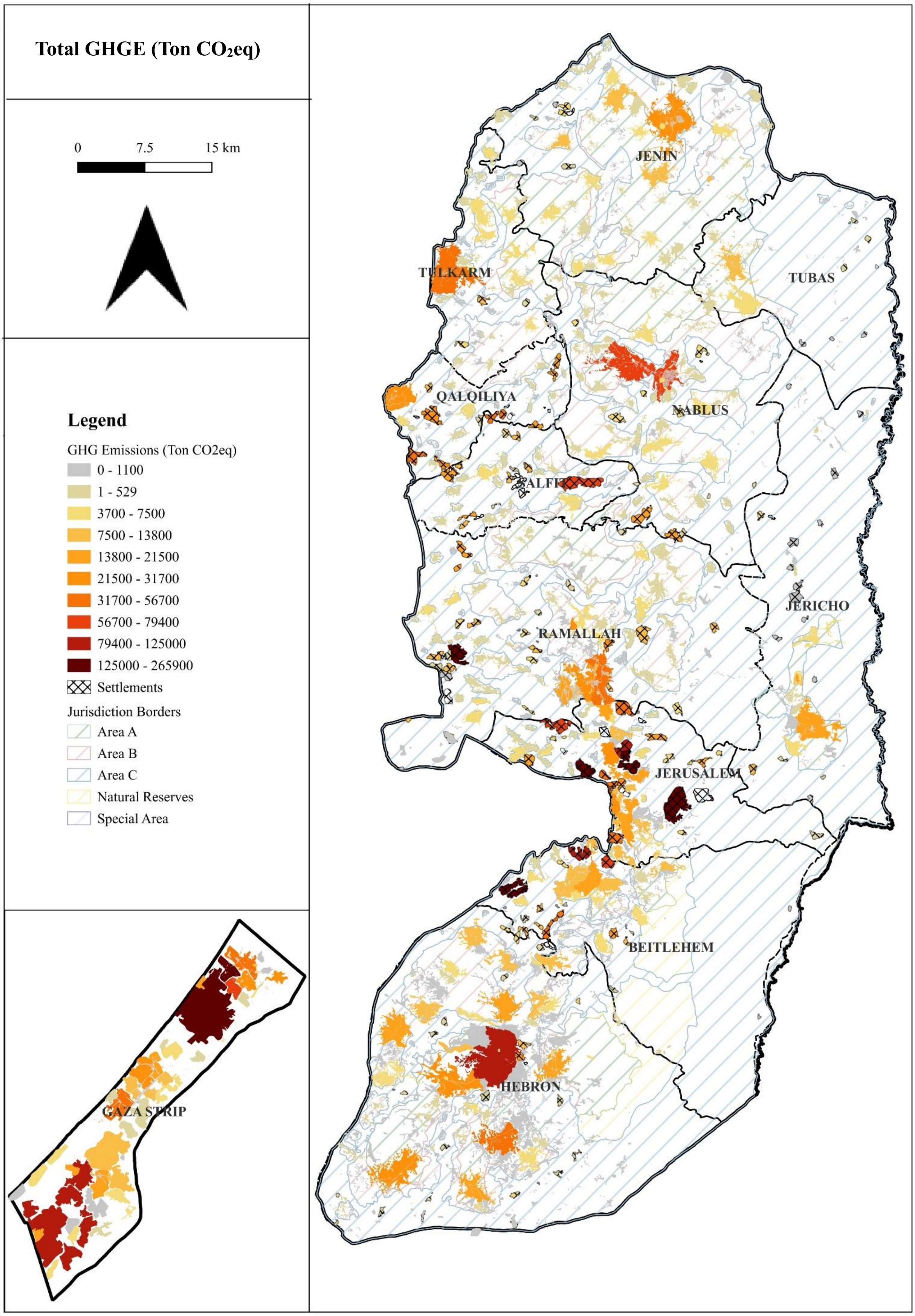


Figure 5.4: Spatial distribution of GHGE from electricity consumption in Palestine in 2019 at the built-up area level across jurisdictional areas

Having identified hotspots within built-up areas, it's crucial to consider the impact of jurisdictional control. Areas A, B, and C, as defined by the Oslo Accords, create distinct contexts for development and energy use.

A clear spatial pattern appears when examining emissions in relation to these jurisdictional areas as illustrated in **Figure 5.4**. The analysis revealed that most high-emission built-up areas are concentrated within Area A, where major cities and large communities exist, while areas with the lowest emissions tend to be located in Area C. Area C presents a contrasting picture compared to Area A in terms of both population size and electricity-related emissions. This disparity can be attributed to the extensive restrictions imposed by the occupation control over the region.

The occupation restrictions have severely impacted Palestinian development opportunities in Area C (United Nations Development Programme, 2016). Access to agricultural land, natural resources, and trade opportunities are all subjected to significant limitations, hindering the establishment of industries and commercial enterprises that would typically contribute to higher energy consumption. Furthermore, the large-scale construction of Israeli settlements fragments the territory, further restricting Palestinian access to resources and constraining economic potential (Ghattas et al., 2017).

Perhaps the most critical factor influencing emissions in Area C is the strict control over building permits. Palestinians face a considerable challenge in obtaining authorization to construct new dwellings or commercial structures. With a mere 1.5% of permit applications receiving approval (United Nations Development Programme, 2016), most Palestinians are forced to reside in rudimentary, unauthorized structures. This limited development translates to a lower overall population density in Area C compared to Areas A and B. As a consequence, with fewer buildings and a smaller population, the total electricity consumption and associated emissions in Area C are lower than in Area A and B.

5.3.2. Governorate Scale

This section aggregates the GHGEs from the built-up area scale to the governorate scale. The analysis considers emissions from all sectors, providing a more comprehensive picture of Palestine's GHGEs.

GHGEs from electricity consumption revealed a clear spatial variation across governorates as seen in **Figure 5.5**. Gaza Strip, showed the highest emissions of approximately 1,084,700 tons of CO_2eq followed by Hebron governorate with 709,170 tons of CO_2eq, while Tubas Governorate showed the lowest (80,300 tons of CO_2eq). Understanding the reasons behind these variations requires delving into potential contributing factors such as population and industrial activity. Governorates with higher population tend to have increased overall energy consumption due to a larger number of residents and associated activities. Whereas the presence of industrial facilities within a governorate can significantly contribute to its total GHGEs. Governorates with a higher concentration of industrial activity are likely to have higher emissions compared to those with a primarily agricultural or service-based economy.

To comprehensively understand the variations in emissions from electricity consumption observed across governorates, a sector-by-sector breakdown analysis of GHGEs is presented in **Figure 5.6**. This approach helps in identifying the specific sectors within each governorate that contribute most heavily to overall emissions. It also reveals potential interdependencies between sectors and their combined impact on GHG footprint.

Disaggregating emissions data by sector gives valuable insights into the specific activities contributing most significantly to electricity consumption within each governorate. This section will focus on the West Bank, Gaza Strip governorates were excluded due to limited data availability.

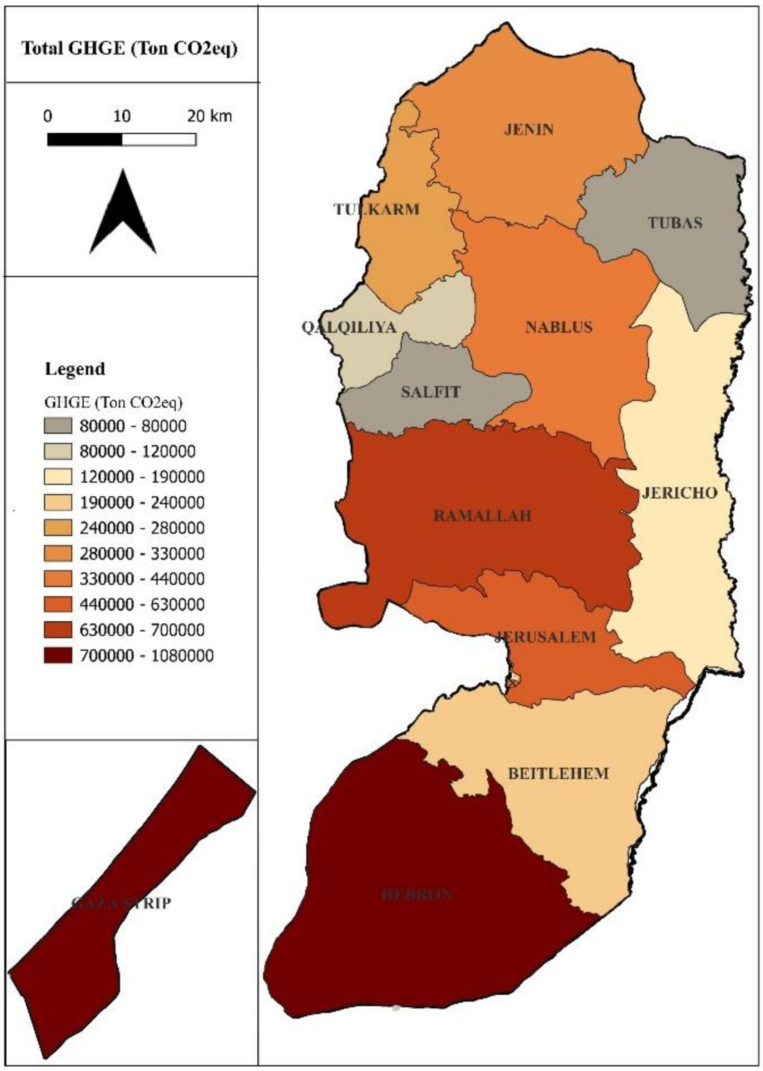


Figure 5.5: Spatial distribution of total GHGEs from electricity consumption in Palestine in 2019 at the governorate level

The analysis of electricity consumption-related GHGEs revealed an interesting variation between sectors and governorates. While Hebron governorate ranked first in total electricity consumption-related GHGEs, the breakdown analysis revealed the residential sector as the primary contributor. Hebron governorate showed the highest residential sector emissions, significantly exceeding those of other governorates. With these significantly higher emissions, Hebron takes the lead as the largest emitter in the residential sector. This could be attributed to the fact that Hebron is the most populous governorate in the West Bank, with an estimated population of 743,121in 2019 and an average electricity consumption per capita of around 1000 kWh which is on average compared to other governorates.

However, Hebron's dominance extends beyond the residential sector. It also boasts one of the highest emissions from other sectors (commercial, public, and industrial), ranking second, just behind Ramallah governorate. While Hebron boasts the highest number of operating industrial enterprises in Palestine according to the 2019 industrial survey, with a robust annual operation rate of 83% of production capacity (Palestinian Central Bureau of Statistics, 2020c), Ramallah emerges as the leader in industrial sector electricity consumption. Despite Hebron's substantial industrial presence, Ramallah has a higher level of electricity consumption per square meter of industrial space compared to Hebron.

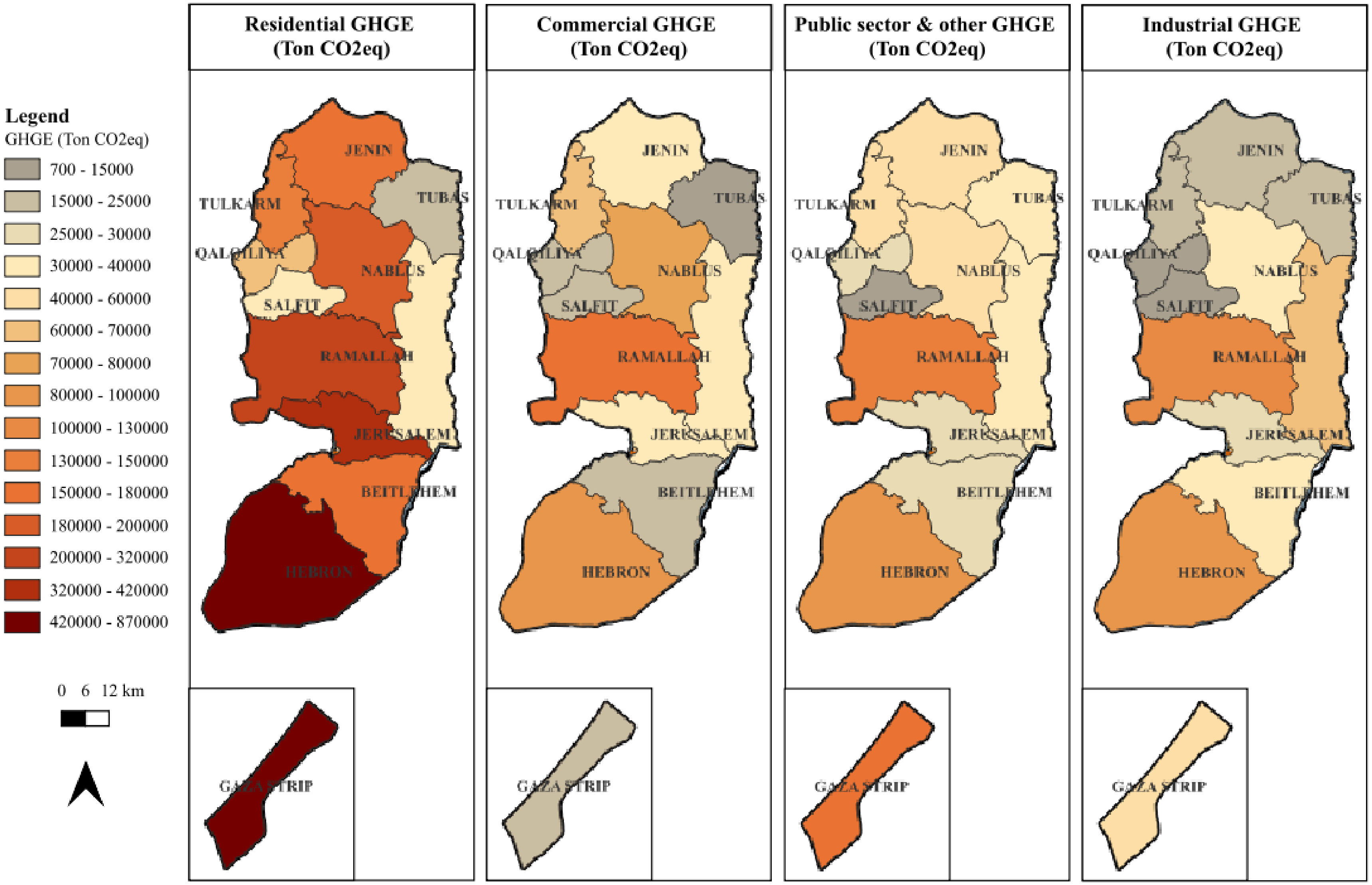


Figure 5.6: Spatial distribution of GHGEs from electricity consumption in Palestine in 2019, a break-down-analysis by sector at the governorate level

This trend of the residential sector leading the way, followed by commercial, public, and industrial sectors respectively, is also observed in the northern governorates of Jenin, Nablus, and Tulkarm.

Focusing deeper on the residential sector, which has the highest share of total electricity-related emissions, a clear geographic pattern emerges. Hebron led the pack with the highest emissions at 440,550 tons of CO_2eq, followed by Jerusalem at 391,600 tons and Ramallah at 231,760 tons. Nablus and Jenin come in fourth and fifth, respectively, with emissions of 195,690 tons and 177,200 tons of CO_2eq. In contrast, Tubas Governorate exhibits the lowest emissions in this sector, at 23,940 tons of CO_2eq.

The analysis also revealed interesting variations in emissions from other sectors across governorates. Qalqilya and Salfit exhibit the lowest industrial sector emissions below 15,000 tons of CO_2eq. In contrast, the majority of governorates display public sector emissions within a relatively narrow range, typically between 30,000 and 60,000 tons of CO_2eq. Finally, the commercial sector witnessed the highest emissions in Ramallah, Hebron, and Nablus, with Ramallah taking the lead with 176,360 tons of CO_2eq. In contrast, Tubas recorded the lowest emissions from this sector of about 8,220 tons of CO_2eq.

The previous analysis has highlighted the variations in total GHGEs and the contributions from different sectors across governorates. To further explore this spatial distribution, **Table 5.1** is presented below. This table shows the emissions per square meter from various sectors within each governorate.

Table 5.1: Electricity consumption-related GHGE per square meter by sector and governorate during 2019

Governorate	GHGEs (kg CO_2eq/m^2)					GHGEs (ton CO_2eq/capita)
	Industrial	Commercial	Public	Residential	Total	
Gaza Strip	0.131	0.066	0.410	2.348	2.955	0.545
Jenin	0.029	0.068	0.101	0.305	0.503	0.900
Tulkarm	0.101	0.252	0.166	0.538	1.058	1.342
Tubas	0.046	0.022	0.083	0.064	0.214	1.272
Nablus	0.064	0.130	0.077	0.324	0.590	0.895
Qalqiliya	0.004	0.109	0.149	0.363	0.625	0.929
Jericho	0.109	0.053	0.061	0.058	0.280	3.449
Salfit	0.016	0.118	0.071	0.197	0.402	1.037
Ramallah and Albireh	0.147	0.212	0.161	0.280	0.800	1.952
Jerusalem	0.077	0.107	0.081	1.170	1.434	1.067
Bethlehem	0.055	0.036	0.044	0.248	0.382	1.047
Hebron	0.082	0.082	0.092	0.424	0.680	0.954

By comparing values across the different sectors within each governorate, we can identify which sectors contribute the most emissions per square meter of space they occupy. This metric, known as emission intensity, provides valuable insights into the relative efficiency of different sectors in each region.

The residential sector often emerges as a leader in emission intensity, particularly in densely populated areas. Take, for instance, the Gaza Strip. With a residential sector emission intensity of 2.348 kg CO_2eq/m^2, Gaza showed the highest value in this category across all governorates. This high intensity likely stems from its very high population density. More people residing in a smaller area translates to a higher concentration of residential emissions per square meter. Jerusalem Governorate followed closely behind with an emission intensity of 1.170 kg CO_2eq/m^2 in the residential sector, potentially reflecting its significant population density.

The commercial and industrial sectors also play a role in shaping emission intensity across governorates. In the commercial sector, Tulkarm ranked top with an emission intensity of 0.252 kg CO_2eq/m^2, closely followed by Ramallah at 0.212 kg CO_2eq/m^2. This could be due to factors like the types of businesses present in each governorate or the efficiency of their commercial buildings. For the industrial sector, Ramallah came in the top place with an emission intensity of 0.147 kg CO_2eq/m^2. This might be related to the specific types of industries concentrated within Ramallah compared to other governorates.

When considering the total emission intensity across all sectors, the Gaza Strip again led with a value of 2.955 kg CO_2eq/m^2. This aligns with its high residential sector intensity and likely reflects the overall pressure on resources within a densely populated area. Jerusalem (1.424 kg CO_2eq/m^2) and Tulkarm (1.058 kg CO_2eq/m^2) follow Gaza in total emission intensity.

An interesting pattern emerged when examining total emissions per capita at the governorate level. Jericho governorate, despite having the lowest emissions per square meter right after Tubas governorate, records the highest emission per capita at 3.449 tons of CO_2eq/capita. This is surprisingly six times higher than the Gaza Strip, which has the highest emissions per square meter.

This seemingly contradictory finding can be explained by the significant difference in population densities between the two governorates. The Gaza Strip, with a population of around 2 million people and an area of 365 km^2, boasts a very high population density. Conversely, Jericho governorate has a much smaller population of approximately 51,400 people spread across a considerably larger area of about 580 km^2.

The metric of "emissions per square meter" reflects the overall level of economic activity and energy consumption concentrated within a specific area. In Gaza's case, the high population density and intense industrial activity lead to a larger total amount of emissions per unit area. On the other hand, "emissions per capita" provides a different perspective. It reveals the average emissions produced by each individual within a particular area. Jericho's smaller population, despite having lower overall emissions, translates to a higher average emission per person compared to the densely populated Gaza Strip.

While the Gaza Strip has a higher overall level of emissions per unit area, Jericho's smaller population size results in a higher average emission per capita. This highlights the importance of considering both metrics when analyzing emission data to gain a comprehensive understanding of environmental impact across different regions.

This analysis of emission intensity highlights the importance of considering both the total emissions and the spatial distribution across sectors within a region. By understanding the leading contributors in each area, policymakers can develop targeted mitigation strategies to address emissions and promote sustainable development.

5.3.3. Limitation of the Work

It is important to acknowledge the limitation of this work. A crucial limitation of this research is the difficulty in obtaining disaggregated electricity consumption data at the city level from relevant authorities. To address this challenge, we employed proxy techniques for data disaggregation at the city scale relying on the number of households, housing units and population for the residential sector. However, it's important to acknowledge that the accuracy of these estimates can be influenced by the quality of proxy data. We mitigated this concern to the greatest extent possible by utilizing high-quality data from the Palestinian Central Bureau of Statistics (PCBS).

It's noteworthy that our estimations of electricity emissions from the residential sector are of a higher quality compared to other sectors at the scale of built-up area. This arises from the unavailability of detailed data on specific commercial and public buildings, as well as industrial facilities. For these sectors, we were required to estimate consumption based solely on the area classified as commercial, industrial or public. The primary reason for this limitation is the lack of comprehensive spatial and statistical data on the location and elevation of industrial and commercial buildings, besides the type of industrial activity in a specific location. It's important to emphasize that this limitation applies only to the built-up area analysis. At the governorate level, where data is more readily available, our estimations possess a higher degree of accuracy.

5.4. Conclusion

This chapter presented a novel approach for spatial analysis of GHGEs from the electricity sector in Palestine based on a vector mapping approach, where data was disaggregated to the level of built-up area (mapping unit). Our investigation revealed a dynamic variation between the sectors contributing to these emissions and the geographic locations where they occur. the flexibility of our method allows for the aggregation of results across different scales. Emissions can be analyzed at various levels, ranging from individual built-up areas to entire cities, governorates, regions, and national scales. This scalability provides policymakers with a powerful tool for understanding the spatial distribution of emissions and developing targeted mitigation strategies. In this context, the model was applied at both the built-up area and governorate scales.

At the built-up area scale; Gaza City was found as the region with the highest concentration of electricity-related GHGEs in Palestine. Within the West Bank, analysis revealed further spatial variations. Residential areas within Hebron City emerged as the region with the highest concentration.

When exploring the jurisdictional areas, a distinct pattern emerges in electricity consumption emissions. Densely populated urban centres within Area A, where major cities and large communities exist, tend to be hotspots for emissions. This likely stems from factors like higher energy consumption and limited space for renewable energy infrastructure within these densely developed areas. Conversely, areas with the lowest emissions tend to be located in Area C, which is characterized by less development due to high restrictions.

On the governorate level, the analysis confirmed the previous trend at the built-up area scale, with the Gaza Strip exhibiting the highest emissions, followed by Hebron Governorate. Tubas Governorate, with its lower population density, displayed the lowest emissions.

A deeper analysis revealed the residential sector as the primary contributor to emissions across most regions. The analysis of emission intensity per square meter further emphasized this trend. Gaza Strip, with its very high population density, displayed the highest residential sector emission intensity across all governorates. Surprisingly, Jericho governorate stands out with the highest emissions per capita among all governorates, its emissions per capita is six times greater than Gaza Strip.

5.4.1. Implications and Future Research

Understanding these spatial variations and the dominance of the residential sector is crucial for developing targeted mitigation strategies. Focusing on promoting energy-efficient appliances and practices in densely populated areas like Hebron and Gaza City could yield significant reductions in emissions. Additionally, exploring renewable energy sources could be a valuable strategy for reducing reliance on fossil fuels and their associated emissions.

Further research is necessary to gain a more comprehensive picture. Investigating aspects like building efficiency standards, population density distribution within built-up areas, and the specific energy sources utilized in different regions will provide valuable insights. By building upon this knowledge base, policymakers can create data-driven policies and initiatives that effectively address the specific challenges faced by each region. This approach will be instrumental in promoting sustainable development and reducing the overall environmental footprint of electricity consumption across Palestine.

Chapter 6. Evaluating Emission Reduction Pathways in Palestine's Transport and Household Sectors: A Scenario-Based Approach

6.1. Introduction

Despite its relatively low per capita emissions, the Palestinian government demonstrates strong dedication to contributing to global efforts to mitigate climate change (Palestine Environment Quality Authority, 2021). To effectively contribute to global mitigation efforts, charting a clear path forward is crucial. By identifying key sectors with the highest impact on carbon emissions, targeted mitigation strategies can be established.

The largest contributors to GHGEs in Palestine are the transportation sector which stands out as the top consumer of fuel, and the household sector which ranks second in fuel consumption and leads in electricity consumption (Jafar et al., 2023a). Building on the prior analyses in Chapter 3 and Chapter 4 the electricity consumption including imported electricity (which constitutes more than 90% of the total supply) was found to be responsible for more than half of the total GHGEs from the energy sector in 2019. Furthermore, the household sector contributed to approximately 45% of the total emissions primarily through energy consumption for space cooling/heating, water heating, and cooking. Meanwhile, the transport sector was estimated to contribute to 30% of total emissions in 2019. The analysis revealed that diesel vehicles were the primary contributor, responsible for about 75% of these emissions. Furthermore, private cars emerged as the most significant source within the transport sector in Palestine, contributing over 50% of the total emissions (Jafar et al., 2023b). Building upon these insights, it is crucial to reduce GHGE from these sectors, which necessitates the development of effective mitigation strategies. These pathways or strategies provide valuable insights to guide future policy and develop decisions, ensuring sustainable growth while limiting the environmental footprint.

To formulate these strategies, estimations of future GHGEs are essential. While not predicting the exact future, GHGEs projections offer valuable insights based on a set of assumptions about economic growth, technological advancements, and policy changes (Wartmann et al., 2021). These assumptions are dynamic, requiring periodic updates to the projections to reflect evolving circumstances (Organisation for Economic Co-operation and Development, 1998). The basic approach to estimating GHGEs projections is presented in **Figure 6.1** below. The milestone in GHGEs projections is establishing a baseline for the reference year, this involves calculating GHGEs to the year with the most recent GHG inventory data available (IPCC, 2006; Organisation for Economic Co-operation and Development, 1998). To project future emissions, these baseline emissions are modified utilizing activity drivers such as electricity consumption growth rate (Wartmann et al., 2021). This activity driver represents the anticipated growth or decline in the activity data over time. By incorporating this factor, GHGEs projections can be estimated.

No standardized methodologies or tools exist to estimate projections of GHGE (Wartmann et al., 2021). Depending on the existing capacities and aim of projections, different modelling approaches are available. Top-down approaches offer a holistic view, analyzing the system through aggregate economic variables like energy demand and supply (Massachusetts Institute of Technology, 2024; Stockholm Environment Institute, 2022). Conversely, bottom-up models focus on specific technological options or project-level mitigation policies (ENERdata, 2024; Loulou et al., 2005). They utilize disaggregated data, while top-down models rely on aggregated data. Some models combine both approaches for greater flexibility (hybrid models) (European Commission, 2024). Accounting models provide a simpler framework, outlining key performance characteristics of a system (e.g., energy) and allowing users to explore the implications of resource, environmental, and social cost decisions

(NewClimate Institute, 2019; UNEP Copenhagen Climate Centre, 2024). Their relative simplicity makes them a potential starting point for countries with limited experience. Regardless of the chosen method, all GHG projections rely on multiplying activity data (often estimated within the model itself) by an emission factor (representing emissions associated with specific activities or fuels).

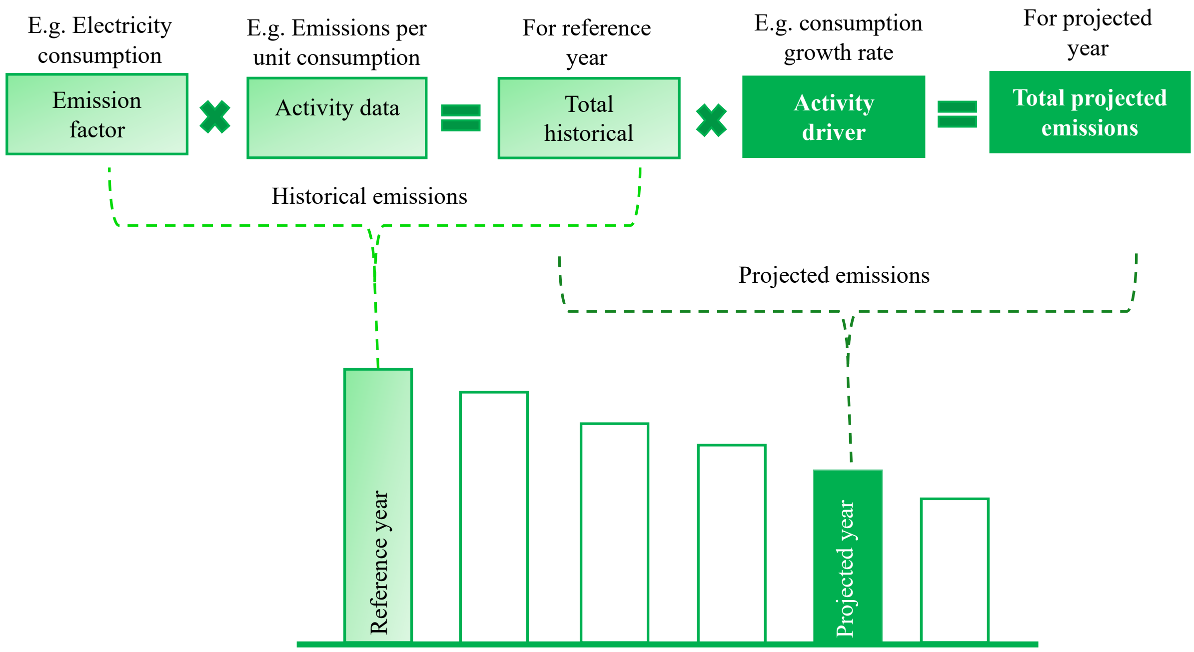


Figure 6.1: The basic approach to estimating GHGEs projections
Reference: (Wartmann et al., 2021)

Forecasting emissions necessitates an understanding of potential future developments. Scenarios, encompassing economic, social, and technological trends, provide this crucial "big picture" perspective. Scenarios, as defined by the IPCC Data Distribution Centre Glossary, are not predictions of the future. Instead, they serve as internally consistent descriptions of plausible future states of the world (IPCC, 2006). These scenarios provide a range of possibilities, allowing countries to explore the potential consequences of different development pathways.

When developing Nationally Determined Contributions (NDCs), countries utilize various scenarios (UNFCCC, 2024). A common scenario is the "Business-as-Usual" (BAU) scenario, reflecting a future with no additional climate policies beyond current ones. Additionally, mitigation scenarios are also employed, these scenarios explore potential strategies for reducing emissions. The strategies can range from modest enhancements of existing actions to highly ambitious, transformative policies (Wartmann et al., 2021). By exploring this spectrum of possibilities, countries can build a strong foundation for refining and developing their emission reduction plans and NDCs' targets.

Understanding the potential impact of different mitigation pathways is crucial for Palestine, as the country seeks to curb GHGEs effectively. Effective mitigation strategies require a clear understanding of their potential impact on emissions. This chapter addresses this critical gap by focusing on the transport and household sectors in Palestine, key contributors to the country's GHGEs.

This chapter explores different pathways to reduce GHGEs in Palestine's transport and household sectors, considering official strategies and plans outlined by the Ministry of Transport, Energy and Natural Resources Authority, Environment Quality Authority, and other relevant bodies. The primary focus is not on developing a GHG projection model, but rather on quantifying the impact of various mitigation scenarios. By analyzing these scenarios, the aim is to equip policymakers with valuable insights into the effectiveness of different strategies in curbing emissions. Financial estimations of mitigation measures i.e. cost of mitigation options fall outside the scope of this chapter, allowing us to concentrate on providing a clear picture of the environmental impact of potential actions. Following the introduction, this chapter will outline a general methodology evaluating emission reduction pathways in Palestine's transport and household sectors. This methodology will serve as a foundation for the subsequent parts of this chapter, which will be divided into two parts.

- Part 1: This section focuses on the specific methodology and results of the transportation sector.
- Part 2: This section will mirror Part 1, focusing on the household sector.

By employing this consistent structure, we can ensure a clear understanding of the evaluation process for both sectors.

6.2. General Methodology

This chapter aims to explore various options (pathways) for curbing GHGEs in Palestine's transport and household sectors. The chapter leverages existing national strategies and plans from relevant ministries (Transport, Energy, etc.) to identify potential mitigation strategies. Our primary focus is to analyze the environmental impact of these strategies, not on financial costs. By quantifying the effectiveness of different scenarios on GHG reductions, we aim to equip policymakers with valuable insights for crafting effective emission reduction policies.

Tailored to the specific challenges and opportunities of Palestine's transport and household sectors, this section outlines the general methodology used to develop and analyze the environmental impact of various emission reduction scenarios achievable by 2040, aligned with Palestine's NDC targets (Palestine Environment Quality Authority, 2016, 2021).

Emission reduction strategies can be categorized into several key approaches (HAN & LUO, 2022; Hao et al., 2015; Palestine Environment Quality Authority, 2016; Pleßmann & Blechinger, 2017). One key strategy is to minimize energy consumption through improvements in energy efficiency. This can be achieved in buildings through advancements in insulation and appliance technology and transportation through vehicle fuel efficiency standards and the promotion of public transit and cycling (L. Zhang et al., 2022). Another strategy involves transitioning to cleaner energy sources. Replacing fossil fuels with renewable energy resources like solar and wind power. Additionally, substituting cleaner fuels like natural gas for coal can offer significant environmental benefits (Kabeyi & Olanrewaju, 2022; Murshed et al., 2021). Carbon capture and storage (CCS) technology holds promise for mitigating emissions by capturing them from power plants and industrial facilities and storing them underground. However, this technology is still in its early stages of development (Paltsev et al., 2021; Yadav & Mondal, 2022). Replacing high-global warming potential (GWP) gases with less potent alternatives is another option. These high-GWP gases are often used in refrigeration and industrial processes (Bahrami et al., 2022; Z. Yang et al., 2021). Finally, changes to land use and agricultural practices can also contribute to emission reduction (Haider et al., 2020). Techniques like improved manure management and sustainable farming practices can significantly reduce emissions from the agricultural sector (Adame et al., 2021; Haider et al., 2020).

While the choice of any emission reduction strategy depends on a region's specific needs, capacity, and context, some pathways offer greater potential than others. Strategies like promoting energy efficiency, transitioning to renewable energy sources, and utilizing cleaner fuels are all considered, but their applicability can vary. For example, electric vehicles (EVs) could be a promising long-term solution for Palestine, given the country's relatively small size and short travel distances (Palestine Environment Quality Authority, 2021). Tax incentives for EVs and hybrids are already in place. However, high upfront costs and limited electricity grid reliability currently pose barriers to widespread the adoption of EVs. While energy efficiency improvements are a universal goal, their implementation in Palestine faces unique challenges due to administrative complexities arising from the ongoing occupation (Palestine Environment Quality Authority, 2021). However, Palestine boasts significant potential for other strategies, particularly those focused on renewable energy generation, especially solar power, due to its high solar radiation levels (Khaldi & El Musa, 2022; Palestinian Investment and Promotion Agency, 2017).

Aligned with the strategic and national plans for climate change mitigation, this chapter focuses on identifying the emission reduction scenarios that hold the greatest promise for Palestine. Into this context, scenario development requires a comprehensive review of literature on GHGE in Palestine, and an in-depth study of strategies and plans for the targeted sector set by the Palestinian Ministry of Transport, the Palestinian Energy and Natural Resources Authority (PENRA), Palestinian Investment and Promotion Agency (PIPA), the World Bank, Palestine's NDC, and other relevant bodies. Building upon this comprehensive review of existing policies and strategies for both targeted sectors, a general framework for emission reduction scenarios is established. This framework outlines general pathways for reducing emissions in these sectors. Following this, the data collection process takes place to provide the necessary data for subsequent analysis to evaluate the environmental effectiveness of these scenarios. The specific data requirements depend on the chosen scenarios, while data availability influences the choice of methodology and analytical tools (Wartmann et al., 2021). In other words, there's a two-way street: scenarios influence data needs, and available data guides tool selection.

To obtain emission predictions for each developed scenario, the emissions for the baseline year (reference year) should be estimated. This involves investigating historical trends and projections of activity drivers, such as growth in electricity consumption, population, and GDP. These activity drivers can be derived from various sources, including reference materials, analytical tools, and regression analysis using machine learning techniques. In this work, the last method is applied to find the key activity drivers such as rates of electricity and fuel consumption. By obtaining a clear picture of these drivers, it is possible to estimate future emissions under a specific scenario. For instance, a scenario focusing on increased energy efficiency in buildings would likely project lower future emissions compared to a scenario with continued reliance on conventional energy sources.

The detailed process is presented in **Figure 6.2** and will be explained in the following sections, starting with scenario development, followed by data acquisition, and details of the process of GHGE projections under different scenarios.

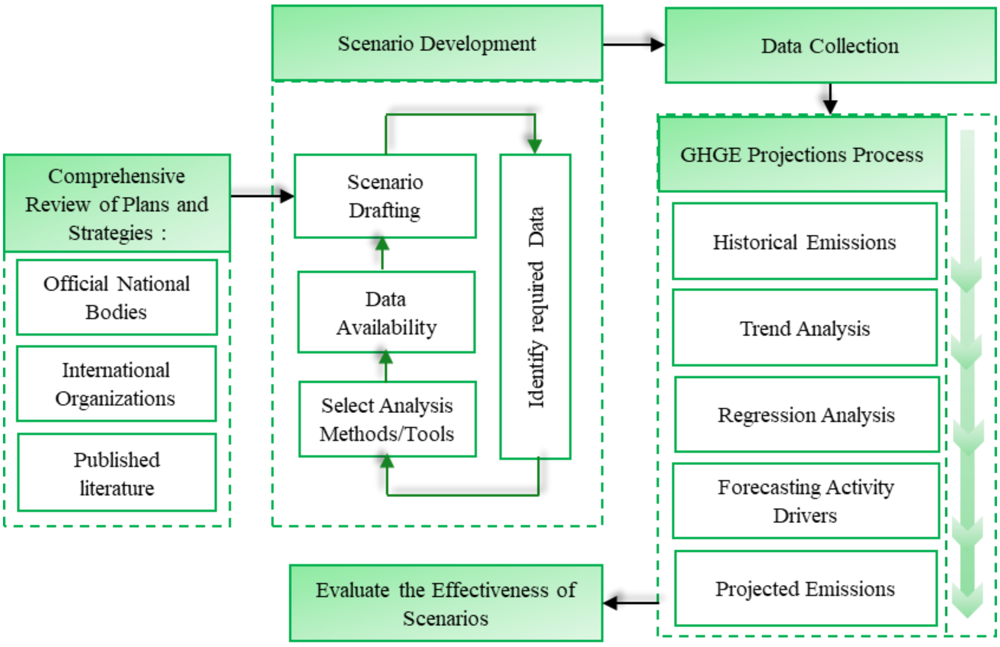


Figure 6.2: Framework of the general methodology for GHGE projections under different reduction scenarios

6.3. Part 1: Transportation Sector

Having established the general methodology to predict future GHGE under different scenarios, this part dives deeper into its application for the transportation sector. Here, we'll detail the specific methods used and present the resulting data, providing a clear picture of the transportation sector.

6.3.1. Methodology

Building upon the general methodology outlined previously, this section details the specific approach used for the transportation sector. As with the general approach, scenario development here relies heavily on an extensive review of plans and strategies for the transport sector in Palestine established by relevant bodies, such as the Ministry of Transport and Palestinian Energy Regulatory Authority (PENRA), in addition to the published work (Ersoy et al., 2022; Hassouna & Al-Sahili, 2020b, 2020a; Hassouna & Assad, 2020; Jafar et al., 2023a; Palestine Environment Quality Authority, 2016, 2021; Palestinian Energy and Natural Resources Authority, 2014, 2016, 2020, 2023b, 2023a; Palestinian Investment and Promotion Agency, 2020; Palestinian Ministry of Transport, 2009, 2021a, 2021b; Qureitem et al., 2020; World Bank Groupe, 2017).

Our extensive review of relevant plans and strategies, particularly those from the Ministry of Transport, reveals that the transportation sector plans and initiatives focused on: (i) developing a robust public transportation system, which involves improvements to bus networks, stations, and infrastructure to make public transit a more attractive and viable alternative to private vehicles, (ii) developing a comprehensive National Strategy for Traffic Safety, (iii) implementing the action plan of the strategic framework for Intelligent Transport Systems (ITS) in Palestine (2019-2029), where ITS refers to technologies that improve the efficiency and safety of transportation systems., (iv) approving the import of additional new vehicles to meet the market need, (v) promoting the adaption of hybrid electric vehicles, especially for high-mileage fleets like taxis to reduce GHGE from the transport sector in Palestine, (vi) prioritizing energy efficiency and consumption rationalization, in addition to, (vii) shifting to the use of natural gas in goods and public transport vehicles.

the subsequent sections will delve into the detailed process for projecting emissions under different reduction scenarios. We'll begin by outlining the development of these scenarios, building upon the insights gleaned from the review.

6.3.1.1. Scenario Development and Policy Assumptions

Building on the comprehensive review of published literature and official strategic plans and reports, this subsection presents the developed scenarios for emission reduction in the transport sector in Palestine

Considering the dominant role of diesel vehicles and private car usage in Palestine's transport sector (Hassouna & Al-Sahili, 2020b, 2020a; Hassouna & Assad, 2020; Jafar et al., 2023b; Karaeen et al., 2013, 2021; Shalabe et al., 2017b), plans and strategies of the Palestinian Ministry of Transport and PENRA (Palestinian Energy and Natural Resources Authority, 2011, 2014, 2016, 2020, 2023c; Palestinian Ministry of Transport, 2009, 2020b, 2021a, 2021b), and actions recommended in the Palestine NDC to reduce emissions from this sector (Palestine Environment Quality Authority, 2016, 2021), five targeted scenarios are developed to address these key contributors and explore their potential for emission reduction by 2040. This year is chosen because the NDC goals are set for the target year 2040 (Palestine Environment Quality Authority, 2016, 2021). Each scenario incorporates specific policy assumptions tailored to the Palestinian context. The proposed scenarios are explained below.

Scenario 1; Business-As-Usual (BAU) baseline. The BAU scenario represents a future where no significant changes are made to current policies, technologies, or economic and social activities that influence emissions. This scenario serves as a reference point, projecting future emissions based on historical trends in activity data (e.g. fuel consumption and vehicle population growth). This scenario acts as a benchmark, representing the projected state of the sector if no changes are made (no policy interventions are implemented here). Many countries, when formulating their NDCs under the Paris Agreement, utilize the BAU scenario as a baseline for comparison (Organisation for Economic Co-operation and Development, 1998; Wartmann et al., 2021). This baseline allows them to demonstrate the potential impact of their proposed emission reduction strategies. By comparing their NDC targets with the projected emissions under a BAU scenario, they can quantify the expected level of emission reduction achievable through their proposed actions.

Scenario 2; Increased hybrid vehicle adoption. This scenario is supported by the existence of tax incentives currently offered by Palestine for both electric and hybrid-electric vehicles. Given Palestine's current limitations with high upfront costs for EVs and potential grid instability, hybrid vehicles offer a more achievable and adaptable solution for near-term emission reduction in the transport sector. Scenario 2 explores the potential emission reduction achievable by reaching a target of 10% hybrid vehicle market share by 2040. This proposed percentage takes into account the current percentage of hybrid vehicles in Palestine which is below 0.5% (Palestinian Ministry of Transport, 2020b, 2022b), and the promotion of the use of these vehicles in the sectoral strategy for the transport sector (Palestinian Ministry of Transport, 2021a). Significantly, the 10% target for hybrid vehicle penetration aligns with research on emissions reduction in Palestine. Studies by Fady M.A. Hassouna and other researchers (Hassouna & Al-Sahili, 2020b, 2020a; Hassouna & Assad, 2020) explored the impact of hybrid and electric vehicles. These studies considered scenarios with 10% and 20% hybrid vehicle penetration by 2030, alongside replacing 50% of conventional taxis with hybrids.

Specific policy measures to achieve this target are not analyzed in detail here. This scenario provides a framework for exploring the potential benefits of increased hybrid vehicle adoption on emission reduction.

Scenario 3; Multimodal transportation (15% VKT reduction). This scenario assumes a hypothetical 15% reduction in VKT for gasoline and diesel vehicles by 2040. This reduction represents a projected shift towards more sustainable modes of transportation like public transport, cycling, and walking. This scenario serves as a key tool for the Palestinian Ministry of Transportation's strategy plan (Palestinian Ministry of Transport, 2009, 2021b, 2021a). It specifically evaluates the potential emission reductions achievable through a modal transport shift. This aligns with the Ministry's efforts to develop infrastructure and improve public transportation, which involves improvements to bus networks, stations, and infrastructure. Ultimately, the goal is to make public transit a more attractive and viable alternative to private vehicles, further complemented by the implementation of the ITS Action Plan.

Scenario 4; Biofuel adoption (B20 Biodiesel blend mandate). This scenario explores the potential emission reduction achievable by 2040 through B20 (20% biodiesel with 80% petroleum diesel) biodiesel adoption. Assuming B20 biodiesel provides a reasonable realistic scenario representing potential real-world use of biodiesel. This is because B20 is widely available, it is one of the most common biodiesel blends in the markets, and most modern diesel engines are compatible with B20 blends without requiring modifications to the engine or fuel system (European Environmental Agency, 2023; Putzig, 2017; U.S. Department of Energy, 2024). However, using B20, the overall fuel efficiency might see a slight decrease, as biodiesel has a slightly lower energy density (1-2% less energy per litre) compared to petroleum diesel (U.S. Department of Energy, 2024). This scenario provides a framework for exploring the potential benefits of biofuels alongside advancements in vehicle technology. Scenario 4, is aligned with the Palestinian Ministry of Transport and the Energy Ministry's plans for prioritizing energy efficiency and consumption rationalization. Firstly, it directly reduces transportation emissions, secondly, this scenario promotes a more sustainable transportation sector. While Scenario 3 focuses on reducing vehicle usage through a shift towards multimodal transportation, Scenario 4 explores reducing emissions from the fuel itself. Furthermore, it explored and shed light on a new path for emission reduction that has not been explored yet by other researchers in the Palestinian context.

Scenario 5; Targeted policy focus on high-emission vehicles. This scenario explores the potential emission reduction achievable through a targeted policy aimed at accelerating the retirement of older, high-polluting vehicles. This scenario assumes the implementation of a scrappage program designed to remove 30% of old diesel and gasoline vehicles aged 15 years or older from the Palestinian transport sector by 2040. This scenario provides a framework for exploring the benefits of targeted interventions to address a significant portion of the high-emitting vehicle population. Scenario 5 complements the promotion of hybrid electric vehicles by creating space for cleaner alternatives and accelerating the shift towards a sustainable transportation sector. Furthermore, by tackling a significant portion of high-emitting vehicles, Scenario 5 can indirectly contribute to improved traffic safety and potentially reduce the pressure to approve large numbers of new vehicle imports, aligning with other aspects of the strategy plans of the Palestinian Ministry of Transport, PENRA and NDC.

Table 6.1 summarizes the five potential emission reduction scenarios for Palestine's transport sector, outlining their key targets and assumptions.

Table 6.1: Emission Reduction Scenarios for Palestine's Transport Sector (2040)

Scenario/ Strategy	Policy Goal /Target	Assumptions
Scenario 1: Business-As-Usual (BAU) Baseline	This scenario assumes a continuation of current trends in emissions growth.	The number of vehicles, fuel consumption, and fleet composition continue to grow along the historical trends.
Scenario 2: Increased Hybrid Electric Vehicle Adoption	Increased Hybrid Adoption; 10% penetration by 2040	• fuel consumption rates of hybrid vehicles (0.055 L/km) • emission factors for hybrid vehicles of 50 g CO_2/km
Scenario 3: Multimodal Transportation	Modal Shift: A 15% reduction in gasoline and diesel vehicle kilometres travelled (VKT)	Reduction in fuel consumption is equal to the reduction in VKT
Scenario 4: Biofuel Adoption	B20 Biodiesel Blend Mandate: 30% of diesel vehicles run on B20	• 30% of diesel vehicles running on B20 by 2040 • B20 blend emission factor equals 2.14 kg CO_2/litre
Scenario 5: Targeted Policy Focus on High-Emission Vehicles	Removal of 30% of old diesel and gasoline vehicles aged 15 years or older	No changes in fuel efficiency

6.3.1.2. Data Acquisition and Preparation

The specific data requirements vary depending on the chosen scenarios. Recognizing this, data collection efforts targeted the transport sector. Data collection focuses on the following elements:

Historical vehicular emission data; GHGE data from the transport sector is obtained for the period 2011-2021 from the national inventory reports published by the PCBS and EQA (Palestinian Central Bureau of Statistics, 2021a, 2022b). This data provides a historical perspective on emissions patterns within the sector. In addition, data from the hybrid approach (GHGE from the transport sector in Chapter 4) classifies emissions by fuel type and vehicle category is utilized offering a more in-depth understanding of emission sources within the transport sector.

Transportation statistics; data on vehicle registrations by category (cars, motorcycles, trucks, buses, etc.) for the same period (2011-2021) is procured from the PCBS and the Ministry of Transport (Gaza Ministry of Transport, 2020; Palestinian Ministry of Transport, 2020b, 2022b). Additionally, vehicle age distribution data (2019-2022) is included to understand the composition of the vehicle fleet (Palestinian Ministry of Transport, 2022b).

Activity data; historical diesel and gasoline fuel consumption in the transport sector are obtained from national energy balance tables published by PCBS and PENRA (Palestinian Central Bureau of Statistics, 2022a) For VKT data, due to limitations in data availability, two approaches are considered: (i) if VKT data exists; data is obtained from PCBS or related studies (Hassouna & Al-Sahili, 2020b, 2020a; Jafar et al., 2023a; Karaeen et al., 2021; Palestinian Central Bureau of Statistics, 2015a; Shalabe et al., 2017b), ensuring transparency about any limitations associated with its use. (ii) in case VKT data is unavailable, national fuel sales data is used along with established conversion factors from a reputable source (Palestinian Central Bureau of Statistics, 2019, 2022a) to estimate VKT.

Emission factors for different fuel types (gasoline, diesel, biofuels) and vehicle categories are obtained from IPCC guidelines and GHG Protocol (GHG Protocol, 2017; IPCC, 2006).

To enrich the analysis and for emission projections, additional statistical data is collected from official sources. This data encompasses demographics (e.g. population, age group, education), economic indicators (GDP, GDP/capita, electricity and fuel prices), and health statistics (fertility rate, mortality rate, and death rate). The data is used for historical trends analysis and projections of activity key drivers which is the milestone for GHGE projections. Data is collected from various sources including PCBS, the Prime Minister's Office, the Ministry of Health, the United Nations and the World Bank (Palestinian Central Bureau of Statistics, 2020a, 2021b, 2021c, 2022a, 2023b; Palestinian Electricity Regulatory Council, 2024; Prime Minister's Office & United Nations Population Fund, 2016; The World Bank Group, 2024).

6.3.1.3. GHGE Projection Analysis

6.3.1.3.1. Historical Emission

The initial step in GHG emission projections involves establishing a baseline by calculating historical emissions in the transport sectors. These calculations, as detailed in previous chapters (Chapter 3 and Chapter 4), rely on activity data specific to the transport sector and corresponding emission factors. The activity data includes fuel consumption, data on VKT and vehicle characteristics.

While a comprehensive examination of historical emissions can be found in those earlier sections, the primary focus here is on (i) emission trends to understand the historical trajectory of emissions in both sectors since analyzing these trends helps in predicting potential future patterns. (ii) Baseline emissions for 2019, Determining the total GHG emissions for the chosen reference year, which in this case is 2019. This baseline serves as a crucial starting point for projecting future emissions under different scenarios.

6.3.1.3.2. Trend Analysis

TheilSen function within R (4.3.2) software is used to investigate potential trends in historical GHGE from the transport sector during the period 2011-2021. This non-parametric method does not require normality, and it is resilient to outliers because it estimates the median slope of the data not the mean as other regression methods, and it relies on pairwise comparisons emphasizing the central tendency of the data and eventually providing insights into potential upward or downward trends. Uncertainty in slopes is calculated using bootstrap methods.

The analysis revealed scattered data as presented in **Figure 6.3**. While a very weak increasing trend is observed in GHGE, the trend is not statistically significant. This suggests that there's no clear relationship between the variation in emissions over time. Consequently, emission projections cannot solely rely on this approach. Trends in activity data are also explored using this technique. The analysis showed that the number of vehicles in the transport sector showed a strong increasing trend during the study period, and this trend is statistically highly significant ($p < 0.001$)

Due to the limitations of this approach, emission projections will shift focus towards predicting fuel consumption. By understanding and predicting how fuel consumption changes based on various factors (e.g., vehicle, distance travelled, population, GDP, price of fuel), it is possible to indirectly estimate the associated GHG emissions. This approach requires analyzing the relationship between fuel consumption and relevant variables using various regression models, including linear regression, non-linear regression, and multiple regression.

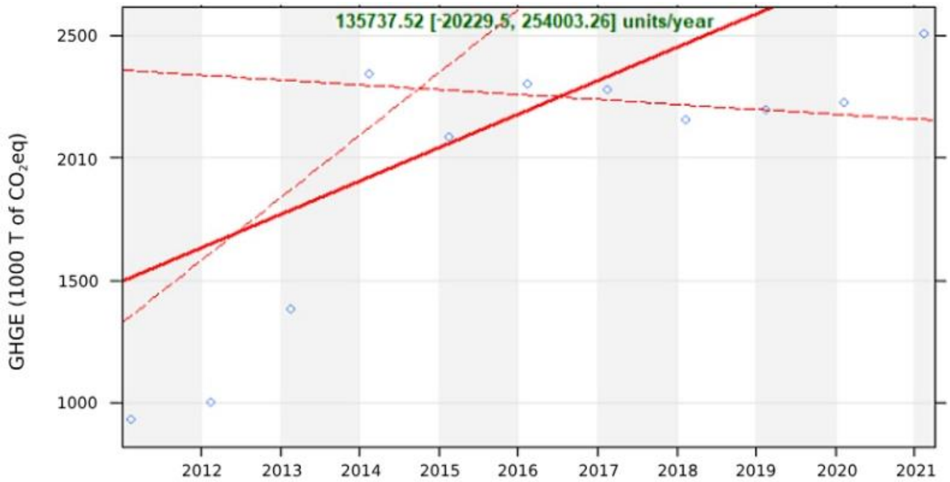


Figure 6.3: Trends in GHGE from the transport sector in Palestine during the period (2011-2021)

6.3.1.3.3. Regression Analysis

To understand how different factors influence activity data (e.g., fuel consumption) in the transportation sector, we employ various regression analyses. This includes linear regression for straightforward relationships, non-linear regression for more complex associations, and multiple regression to analyze the combined effect of multiple factors.

Throughout this analysis, we investigate the relationships between several key variables. It's important to note that the designation of a variable as dependent or independent can depend on the specific relationship being explored. For instance, if the aim is to predict or understand outcomes like the total number of vehicles, and the consumption of diesel and gasoline fuel. These will be the dependent variables. Factors that potentially influence these outcomes, such as population, GDP, time, and even the number of existing diesel and gasoline vehicles (in a separate analysis), will be considered independent variables.

Linear regression formed the foundation for initial analyses. It assesses the strength and direction of the linear relationship between a dependent variable (e.g., total number of vehicles) and other independent variables (e.g., population, GDP). This provides a baseline understanding of the associations between the variables. A general equation for the linear regression model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta n X n + \varepsilon$$

Where:

- Y: Dependent variable (e.g., total number of vehicles)
- X_1 to Xn: Independent variables (e.g., population, GDP, time)

- β_0: Intercept (constant term)
- β_1 to βn: Regression coefficients representing the impact of each independent variable on Y
- ε: Error term (represents unexplained variance)

The coefficients (β) indicate the magnitude and direction of the influence each independent variable has on the dependent variable.

To explore potential non-linear relationships, polynomial regression models are employed. These models incorporate squared and potentially cubed terms of the independent variables, allowing for the capture of more complex trends in the data. polynomial regression introduces squared (X^2) and potentially cubed (X^3) terms of the independent variables:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_1^2 + \beta_3 X_2 + \beta_4 X_2^2 + ... + \beta n X n + \varepsilon$$

Additionally, logarithmic regression is used in specific cases, where the relationship between the independent and dependent variables might be exponential or power-law in nature. A general formula for these models is:

$$\text{Ln}(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta n X n + \varepsilon$$

Powerful statistical techniques like the Generalized Additive Model (GAM) are used to capture non-linear relationships between various factors and the outcome of variables (e.g., total vehicles). Unlike traditional linear regression, GAMs allow for more flexibility by incorporating smoothing terms. a GAM replaces the linear terms ($\beta j X j$) in the traditional model with smooth functions $fj(Xj)$ that capture the non-linear relationship between Y and each independent variable Xj. The resulting general form of a GAM becomes:

$$Y = \beta_0 + f_1(X_1) + f_2(X_2) + ... + fp(Xp) + \varepsilon$$

Here, β_0 remains the intercept, and ε represents the error term.

R 4.3.2 software and statistical techniques are employed for this analysis. R offers a rich collection of packages specifically designed for statistical modelling. Such as lm( ) function for linear regression, and logarithmic regression with a log-transformed dependent variable, the poly( ) function for creating polynomial terms, the gam( ) function from the mgcv package is used for its statistical modelling capabilities to capture potentially complex, non-linear associations

By utilizing this range of regression analysis methods, we gained a comprehensive understanding of the linear and potentially non-linear relationships between the variables in the data. The outcomes of the regression analysis will serve as the foundation for forecasting future activity-driving factors; mainly fuel consumption. With these predictions, it is possible then to estimate GHGE projections.

6.3.1.3.4. Forecast Activity drivers

This section focuses on predicting future trends in fuel consumption, the main activity drivers in the transport sectors. By exploring the relationships between these dependent variables and other factors (independent variables) explored through regression analysis, it is possible to develop models to describe these relationships. These models will then be used to calculate future consumption estimates.

To ensure the accuracy of predictions, various techniques are employed to evaluate the models developed through regression analysis. These techniques include: (i) visualization of results; the fit between the model's predictions and the actual data is evaluated visually, (ii) R-squared (R^2); This statistical measure indicates the proportion of variance in the dependent variable explained by the model. A higher R^2 value suggests a better fit, (iii) sum of squared errors (SSE); this metric represents the total squared difference between the predicted and actual values. A lower SSE indicates a better fit. (iv) Root mean squared error (RMSE), this metric measures the average magnitude of the difference between predicted and actual values; a lower RMSE indicates better model performance. (v) P-values; in addition to the previous metrics, p-values from the statistical tests associated with the regression analysis are considered. A low p-value (typically below 0.05) indicates that the relationship between an independent variable and the dependent variable is statistically significant. This can help identify which independent variables are most important for explaining the variation in the dependent variable. By considering these evaluation techniques, we can refine and improve the models used for forecasting. Considering these statistical properties facilitates the selection of models that effectively capture the relationships between independent variables and consumption.

A critical factor influencing future fuel consumption is population growth. Population projections for 2025-2050 are obtained from the report "PALESTINE 2030: Demographic Transition in Palestine and What it Means for Development" (Prime Minister's Office & United Nations Population Fund, 2016). This report employs a combination of survey data (Palestinian Central Bureau of Statistics, 2021b), regression analysis, and expert assumptions. Fertility, particularly female education levels, is identified as the primary driver of population growth. The report explores three scenarios: a most likely scenario with declining fertility rates approaching replacement level, a high scenario with slower educational progress leading to higher fertility, and a constant scenario (for comparison) where fertility remains unchanged, the results are shown in **Table 6.2**. Mortality assumptions are consistent across all scenarios, with life expectancy projected to increase for both males and females. International migration's impact is considered minimal and assumed to be zero until 2025.

Table 6.2: Total population (thousands) of the State of Palestine, according to three scenarios, 2015-2050

Scenario	2025	2030	2035	2040	2045	2050
Medium	6,175	6,900	7,610	8,293	8,944	9,519
High	6,236	7,051	7,901	8,798	9,735	10,707
Constant	6,294	7,196	8,184	9,279	10,509	11,893

However, unlike population projections that rely on demographic trends, predicting GDP growth presents a significant challenge. Unlike conventional economies driven primarily by internal factors, Palestinian growth is heavily influenced by external forces and internal risks(Palestine Environment Quality Authority, 2016, 2020). While projections in Palestine's Initial NDC and the State of Palestine's Green Climate Fund (GCF) Country Programme (2020) offered some insights, specifically a 2.2% real GDP growth projection for 2018, the complex interplay of external factors like political instability and donor aid fluctuations, and internal risks such as limited productivity growth, makes predicting future growth a challenging task.

However, for this specific analysis, the focus will be on historical trends captured by regression analysis. By identifying these trends, they will be used as a base to predict future GDP values. While this approach offers valuable insights, it's important to acknowledge that it excludes the potential impact of political factors. Political instability and its associated uncertainties can significantly affect economic growth.

These population and GDP projections serve as a foundation for estimating future electricity and fuel consumption. Once reliable forecasts are established for future consumption (electricity, fuel), the next stage of analysis can be undertaken: estimating future emissions.

6.3.1.3.5. GHGE Projections

Building upon the previously established forecasts for population growth, GDP, and subsequent fuel consumption, this analysis delves into predicting future GHGEs. Emissions are calculated by multiplying an emission factor by the corresponding activity data. The activity data, in this analysis, refers to the projected fuel consumption derived from the previous analyses.

The projected fuel consumption, is multiplied by default emission factors established by the IPCC (IPCC, 2006). This calculation provides an estimate of future transport sector emissions.

This establishes an overall forecast for GHGEs projections under the baseline scenario, which assumes no major technological advancements or policy changes that would significantly alter emission factors.

6.3.1.4. Assessing the Impact of Emission Reduction Scenarios

This section outlines the methodology employed to estimate the impact of various policy interventions and technological advancements on future GHGEs in Palestine. A scenario analysis approach is implemented, utilizing a comprehensive Excel spreadsheet model to construct and model different future possibilities based on specific policy assumptions. These assumptions target two key aspects:

- Changes in activity data: some scenarios explore factors influencing activity levels, such as increased public transportation use. These changes are anticipated to result in decreased fuel consumption.
- Changes in technology and infrastructure: some scenarios explore the impact of advancements like a shift towards electric vehicles. These advancements have the potential to significantly reduce emissions associated with energy production and consumption.

The main function of the spreadsheet model is to calculate the projected reduction in GHGEs by 2040 compared to the baseline scenario for each scenario. This allows for a direct comparison of the effectiveness of different policy interventions in achieving emission reduction goals across the transportation sector. Below are some sector-specific considerations:

- Fuel Consumption Patterns: The model estimates changes in fuel consumption (e.g., gasoline, diesel) based on factors like biofuel use, public transport use, or vehicle fuel efficiency improvements. Specific characteristics of different fuel types are considered when calculating consumption changes.
- Vehicle Fleet Composition: The model considers how changes in the vehicle fleet, influenced by scrappage programs or a shift towards electric vehicles, might affect emissions. Emission factors specific to vehicle and fuel types are incorporated within the model to estimate the overall impact on emissions.

The results of the presented analysis are presented in the following section. These results provide valuable insights into the potential emission reduction achievable through various policy interventions and technological advancements in Palestine.

6.3.2. Results and Discussion

This section delves into the key findings of the analysis, exploring historical trends, regression analysis, forecasting future activity drivers, predicting greenhouse gas (GHG) emissions in Palestine's transport sector, and assessing the impact of various emission reduction scenarios.

6.3.2.1. Trend and Regression Analysis

6.3.2.1.1. GDP

Regression analysis was used to investigate the historical trend in GDP. Three models were evaluated: linear regression, quadratic regression, and Generalized Additive Model (GAM) with a smoothing term. The analysis aimed to balance model complexity with interpretability, considering adjusted R-squared, F-statistic, and Root Mean Squared Error (RMSE).

Linear regression provided a high adjusted R-squared (0.9301) and interpretability, but its RMSE (0.9848) indicated less accurate predictions compared to other models. The quadratic model captured some non-linearity (adjusted R-squared: 0.9298) but with a higher RMSE (0.9643) than the GAM. The GAM emerged as the best fit based on both adjusted R-squared (0.983) and a significantly lower RMSE (0.0203). GAM helps in capturing the underlying non-linearity and minimizing prediction errors are priority as in our case. **Figure 6.4** shows the actual data points (observed values) along with the fitted curves for different GDP regression models.

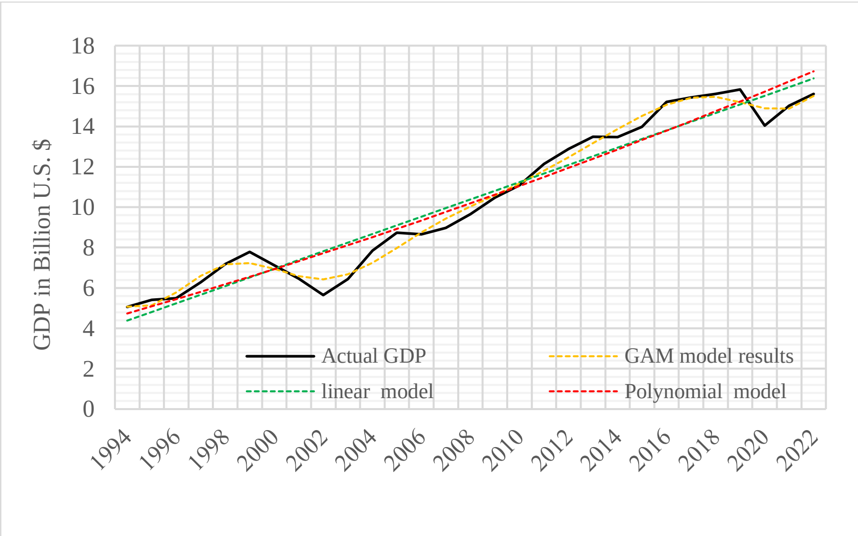


Figure 6.4: Different GDP regression models against actual data for the period 1994-2022.

6.3.2.1.2. Total Number of Vehicles:

The factors influencing the total number of vehicles were also investigated through regression analysis. Three models were evaluated: linear regression, quadratic regression, and GAM Model with a smoothing term.

Linear regression offered a good balance between interpretability and explanatory power (adjusted R-squared: 0.9643), with a moderate prediction error (RMSE: 0.0572). The quadratic model captured some non-linearity (adjusted R-squared: 0.993) but exhibited a significantly higher RMSE (5013), suggesting potential overfitting. The GAM emerged as the most accurate model based on both adjusted R-squared (0.996) and a significantly lower RMSE (0.0135). However, GAMs are susceptible to overfitting, requiring visualization of fitted terms for verification. For capturing the most accurate relationships and minimizing prediction errors, the GAM is preferred, with careful attention to overfitting. **Figure 6.5** shows the actual number of vehicles in Palestine along with the fitted curves for different regression models.

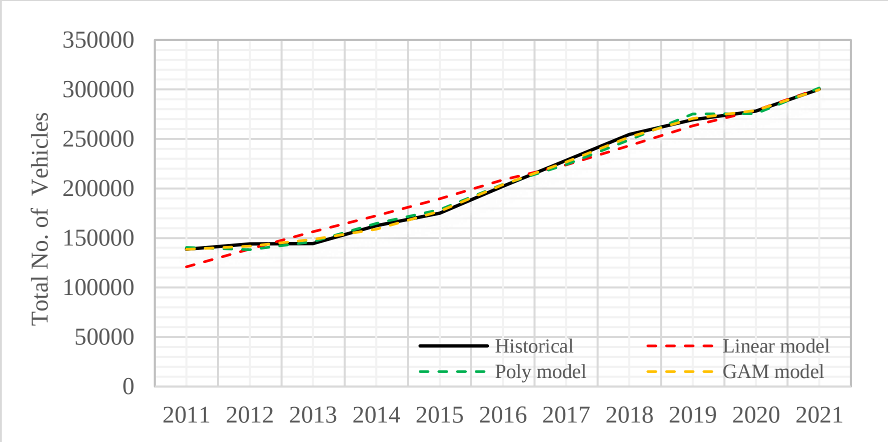


Figure 6.5: Different vehicle number regression models against actual data for the period 2010-2021. Historical represents the actual number of vehicles.

6.3.2.1.3. Transport Sector Fuel Consumption

Six models were evaluated to investigate how the number of vehicles and the price of fuel influence fuel consumption. These models include linear regressions, quadratic regressions, and GAMs with smoothing terms for both fuel types.

Linear regression models offered interpretable coefficients for both diesel and gasoline, with the gasoline model demonstrating a better fit (adjusted R-squared: 0.6176, RMSE: 1366.27) compared to diesel (adjusted R-squared: 0.4201, RMSE: 4101.43). Quadratic regressions captured potential non-linear relationships (adjusted R-squared: 0.599 - 0.7243). GAMs achieved the highest adjusted R-squared (0.843 - 0.889) and lowest RMSE (0.0939 - 0.0809), indicating the most accurate predictions.

It's important to note that while the linear model was chosen for interpretability, the visual representation of the relationship between the number of vehicles and fuel consumption might not appear perfectly linear in a plot as visualized in **Figure 6.6**. This is likely because the actual increase in the number of vehicles might not be perfectly uniform over time. This non-uniformity in the data can cause a seemingly non-linear pattern to emerge even though the underlying statistical relationship captured by the linear model is linear in nature.

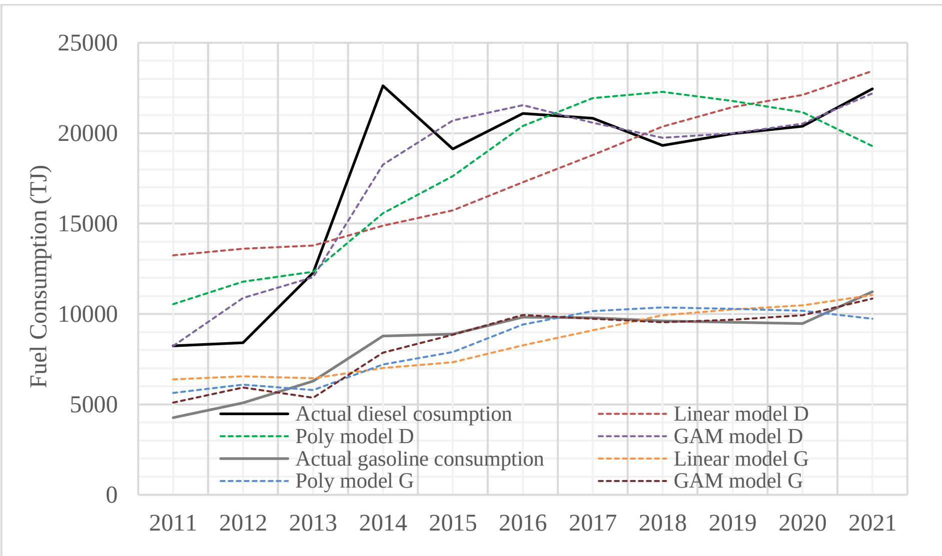


Figure 6.6: Different regression models for diesel and gasoline fuels consumption against actual data for the period 2010-2021.

6.3.2.1.4. Share of Diesel Vehicles

Regression analysis was used to explore how the share of diesel vehicles changes over time. Three different models were applied; linear models, polynomial model and GAM model.

Linear regression emerged as the most suitable choice based on several factors. It achieved the highest adjusted R-squared (adjusted R-squared: 0.9871, RMSE: 0.0039), indicating a strong explanatory power for the linear relationship for the change in the percentage of diesel vehicles over time. its simplicity reduces the risk of overfitting compared to the other models.

6.3.2.2. Forecast Activity Drivers

This section focuses on predicting the key activity drivers influencing GHGE within the transport sector in Palestine. The forecasting here is based on the results of the regression analysis in the previous section.

Among different regression models used, the GAM model was chosen for predicting GDP because of its ability to capture underlying non-linearity and minimize prediction errors.

The analysis identified population and GDP as the most significant factors affected total number of vehicles in Palestine. GAM (P, GDP) models proved to be the optimal model, balancing interpretability with explanatory power. Future predictions of total number of vehicles were based on this model. GAM models were also used for predicting diesel and gasoline fuel consumption in the transport sector. In terms of the share of diesel and gasoline vehicles, the Linear regression model was used. The results for the forecast are presented in **Table 6.3**.

Table 6.3: Forecasting of key activity drivers: GDP (in Billion U.S. $), population (in millions), the total number of vehicles, share of diesel vehicles (as a percentage), diesel and fuel gasoline consumption (in TJ (in GWh) for the forecasting period 2025-2050.

Year	GDP (Billion $)	Population (Millions)	No. of vehicles	% Diesel vehicles	Diesel consumption (TJ)	Gasoline consumption (TJ)
2025	18.8	6.17	486,545	0.57	40,168.8	21,547.3
2030	24.2	6.90	604,648	0.62	54,657.6	24,622.5
2035	29.3	7.61	721,084	0.67	70,797.3	25,733.6
2040	35.2	8.29	834,815	0.72	88,243.9	25,077.8
2045	40.7	8.94	942,879	0.77	106,688.1	22,522.2
2050	46.2	9.51	1,04,0981	0.82	125,482.5	18,079.0

6.3.2.3. Baseline Emission Projections

This section presents the results of GHGE projections which will be used later as a baseline or reference for emission reduction projections under different scenarios.

By combining forecasted future trends in total vehicle numbers and the percentage of diesel cars these forecasts with projected fuel consumption rates, estimates for future fuel consumption for each vehicle type were obtained. Applying emission factors specific to each fuel type resulted in projections for total vehicle emissions.The baseline emission projections for transportation consumption are presented in **Table 6.4**.

Table 6.4: Baseline projections of GHGE from electricity and fuel consumption in the household and transport sectors

Year	GHGE vehicles fleet (Mt CO_2 eq)
2025	4,585.1
2030	5,899.4
2035	7,196.0
2040	8,463.4
2045	9,668.5
2050	10,763.6

6.3.2.4. Assessing the Impact of Emission Reduction Scenarios

The baseline emission projections developed for the transportation sector provide a crucial foundation for evaluating the effectiveness of emission reduction scenarios in this area. The baseline projections represent the "BAU" scenario, outlining the projected emissions trajectory based on current trends. Emission reduction scenarios introduce hypothetical interventions aimed at reducing emissions. The specific results of these emission reduction scenarios are presented in this section. The target year in this analysis is 2040 in line with Palestine's NDC.

Under the BAU scenario, which represents a projection with no policy interventions, the number of vehicles, fuel consumption, and fleet composition are assumed to continue to grow along the historical trends. Based on the projections shown in **Table 6.3**, GHGE from the transportation sector is expected to be around 8,463 thousand tonnes of CO_2eq. While these results provide valuable insights under this scenario, it's crucial to acknowledge the limitations associated with the chosen calculation method and underlying assumptions. The limited availability of historical data on fuel consumption and emissions can significantly impact the accuracy of the BAU scenario projections. A small dataset provides less information about the overall direction and makes it harder to distinguish between true trends and random fluctuations or noise. Therefore, results from Scenario 1, should be interpreted with some caution.

Scenario 2, given the current low penetration rate of hybrid vehicles in Palestine, likely below 0.5% (Palestinian Ministry of Transport, 2020b, 2022b), this scenario incorporated a projected increase in hybrid vehicles (to 10% in 2040), requiring adjustments to gasoline and diesel vehicle shares to avoid double counting. The adjusted shares for gasoline and diesel vehicles in 2040 are 23.4% and 66.5%, respectively. This approach reflects the impact of increased hybrid adoption on the composition of the vehicle fleet. Utilizing data on fuel consumption rates (0.055 L/km) and emission factors for hybrid vehicles of 50 g CO_2/km (European Federation for Transport and Environment, 2022; GHG Protocol, 2017), the impact of increased hybrid adoption on fuel consumption could be directly estimated. This approach avoids relying on assumptions about the overall fuel consumption mix and provides a more accurate picture. As a result of integrating hybrid vehicles, the projected gasoline consumption in 2040 for this scenario is estimated to be 396,336 thousand litres. Diesel consumption is projected to be 2,307,463 thousand litres in 2040. Scenario 2 with hybrid vehicle integration projected total emissions of 7,964 thousand tonnes of CO_2eq by 2040.

While the scenario directly proposes a 10% hybrid share, limitations remain in other aspects. The actual fuel efficiency of hybrid vehicles in real-world conditions differs from laboratory test results which can lead to underestimation or overestimation of GHGE (European Federation for Transport and Environment, 2022; GHG Protocol, 2017).

Scenario 3 explored the effect of promoting multimodal transportation. Shifting towards a multimodal transportation system, encouraging walking, cycling, and public transport use, decreases the reliance on private vehicles, particularly for short trips within urban areas. However, the effectiveness of this scenario depends on multiple factors including but not limited to the types of infrastructure improvements implemented (e.g., increased frequency, expanded coverage), their accessibility for various demographics, and weather dependence (particularly in the case of cycling and walking). A 15% reduction in gasoline and diesel VKT due to a modal shift had led to a reduced consumption of fossil fuel. The predicted amounts of consumed diesel and gasoline in 2040 are 2,094,065 and 359,921 thousand litres, respectively. Under Scenario 3, the predicted vehicular emissions by 2040 are expected to be 7,194 thousand tonnes of CO_2eq by 2040.

While Scenario 3 presents a promising approach towards emission reduction, limitations need to be considered. One of the main assumptions made in this scenario is that the reduction in fuel consumption is equal to the reduction in VKT. It's important to acknowledge that a 15% reduction in VKT doesn't directly translate to a 15% decrease in fuel consumption. The impact of VKT reduction on fuel consumption depends on several factors including: (i) the distribution of trip lengths; e.g. shorter trips, often, tend to be less fuel efficient due to cold starts and stop-and-go traffic, (ii) the fuel efficiency of alternative modes, (iii) traffic congestion; a 15% VKT reduction can lead to less traffic congestion, which can improve fuel efficiency for remaining vehicles.

Scenario 4**,** is focusing on biofuel adoption. Here to establish a more refined scenario the change in efficiency due to the use of B20 is accounted for. Under this scenario, gasoline vehicle emissions are projected to remain consistent with the BAU scenario due to the B20 biodiesel adoption being exclusive to diesel vehicles. Concerning diesel vehicles, 30% of the diesel vehicles were assumed to run on B20. Emissions from these vehicles are estimated using a B20 blend emission factor of 2.14 kg CO_2/litre, adapted from the GHG Protocol. (GHG Protocol, 2017). Based on this analysis, the predicted emissions of the vehicle fleet in 2040 are estimated to be 8,050 thousand tonnes of CO_2eq.

It is important to point out that, the calculations here have not accounted for indirect emissions associated with biofuel production, such as land-use change, fertilizer use, and transportation. These can significantly impact the overall carbon footprint of biofuel (European Environmental Agency, 2023).

Scenario 5; targeted policy focus on high-emission vehicles. This scenario depends on a scrappage program aimed to remove 30% of vehicles aged 15 years or older by 2040. The program automatically adjusts to the ageing fleet, capturing progressively older vehicles over time. This program is built upon the fact that about 30% of the fleet in Palestine during the years 2019-2022 aged 15 years or older, potentially containing higher-emission vehicles (Palestinian Ministry of Transport, 2022b). According to this, the scrappage program is expected to remove about 54,622 and 20,511 old diesel and gasoline vehicles, respectively. Scenario 5 predicted the emissions of the vehicle fleet to be 8,086 thousand tonnes of CO_2eq.

Several limitations should be considered when calculating the effectiveness of the scrappage program in Scenario 5. One is that newer vehicles are expected to be significantly more fuel-efficient than those scrapped. Additionally, in reality, the number of vehicles scrapped (scrapping rate) can be significantly influenced by the condition of the vehicle, scrap metal prices, and other factors. Another limitation is the difficulty in accurately predicting the emission intensity of both scrapped and new vehicles because real-world emissions can vary depending on driving habits, maintenance, and fuel quality.

6.3.2.5. Projected Reductions in Emissions

To further illustrate the findings, the projected emissions from the five scenarios alongside historical emissions are presented in **Figure 6.7**. Comparing the effectiveness of different future reduction scenarios requires consistent ground rules. Using the same baseline assumptions for the volume and composition of the vehicle fleet in the target year (2040) ensures a clear isolation of each policy's impact and facilitates a more accurate comparison of their potential to reduce emissions. Here, all scenarios are benchmarked against the BAU scenario for comparison.

The results show that increasing the adaption of hybrid vehicles to 10% of the total vehicle fleet by 2040 will reduce the BAU emissions by 6.0%. Compared to the baseline, the reduction in VKT due to the multimodal transportation system in Scenario 3 would lead to a significant reduction in greenhouse gas emissions of 15.0%. On the other hand, introducing the B20 biodiesel blend mandate to 30% of the diesel vehicles in Scenario 4 will decrease the BAU emissions by 5.0%. In Scenario 5, the removal of 30% of old diesel and gasoline vehicles aged 15 years or older will cut carbon emissions by 4.6%.

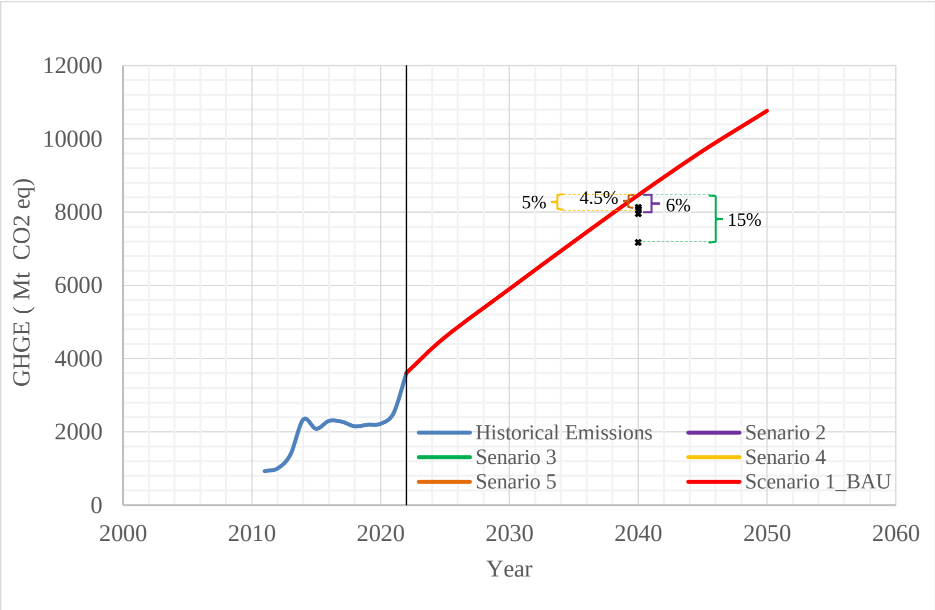


Figure 6.7: Historical GHGE from the transport sector in Palestine (2011-2021) alongside baseline emission forecast (2022-2050) and emission projections under different reduction scenarios in 2040.

6.3.3. Policy Recommendations

The preceding sections outlined various emission reduction scenarios for the transportation sector. However, successful implementation hinges on acknowledging the unique challenges faced by Palestine due to the Israeli occupation.

The fragmentation of the West Bank and the presence of Israeli-controlled checkpoints impede Palestinian movement (Aburas & Shahrour, 2021). This discourages public transportation use and fuels preference for private vehicles, hindering efforts to promote modal shift (increased reliance on public transport, walking, and cycling) as envisioned in scenarios focusing on transportation sector transformation. Restrictions on imports limit access to clean transportation technologies like electric vehicles and essential components for hybrid vehicles. Additionally, control over fuel imports creates uncertainties around fuel availability and cost, impacting the feasibility of scenarios heavily reliant on specific fuel types, such as biofuel production (Scenario 4) in the transportation sector.

these limitations highlight the increased cost and complexity of implementing various emission reduction strategies under the current political context. Despite the challenges, opportunities exist for mitigation efforts by focusing on achievable measures within Palestinian control.

Promoting fuel-efficient driving practices and encouraging alternative modes of travel like walking and cycling remain feasible options, regardless of import restrictions. This aligns with aspects of Scenario 3. Focusing on the adaptation of hybrid electric vehicles, particularly for high-mileage fleets like taxis, offers significant emission reduction potential within the current limitations on clean technology imports. This approach aligns with aspects of Scenario 2 for the transportation sector. Implementing a vehicle scrappage program can incentivize the retirement of older, less fuel-efficient vehicles from circulation. This approach in line with Scenario 5 can be particularly effective when combined with financial incentives for the purchase of newer, cleaner vehicles (consider limitations due to import restrictions).

Table 6.5 present specific policy recommendations for each emission reduction scenario, along with their associated pros and cons, considering the realities of the Palestinian context.

Table 6.5: Recommended policy measures for each emission reduction scenario for the transport sector, along with their associated pros and cons

Scenario/ Strategy	Recommended Policy Measures	Pros & cons
Scenario 1: Business-As-Usual (BAU) Baseline	No immediate policy changes or investments	**Pros:** • Requires no immediate policy changes or investments, potentially appealing in a resource-constrained environment. • Clear Benchmark: The BAU scenario provides a clear reference point for assessing the effectiveness of proposed emission reduction strategies. **Cons:** • Does not address the issue of rising emissions, leading to potential health and environmental issues. • Missed opportunities for economic benefits from a cleaner transport sector, such as job creation in renewable energy or sustainable transportation infrastructure.
Scenario 2: Increased Hybrid Electric Vehicle Adoption (Target: 10% penetration by 2040)	• Government Incentives: Implementing tax breaks, subsidies, or low-interest loans for hybrid vehicle purchases can incentivize consumers. • Market Availability and Affordability: Collaborating with automakers to increase the supply and affordability of hybrid options in Palestine. • Raise Awareness and Encourage Adoption: Public awareness campaigns promoting hybrid vehicles • Focus on high-mileage fleet segments (taxis, delivery).	**Pros:** • Improved fuel efficiency (due to regenerative braking and electric motor assistance) leads to reduced fuel costs for consumers in the long run due to reduced consumption. • They require lower maintenance than conventional cars. **Cons:** • Requires government incentives to overcome the higher upfront cost of hybrid electric vehicles. • Market development for hybrid options is crucial, considering the limited presence of major automakers in Palestine. • Maintenance Needs: The introduction of hybrid electric vehicles might necessitate: ○ Training mechanics for hybrid electric vehicle maintenance

		○ Additional investment in specialized service infrastructure
Scenario 3: Multimodal Transportation (Target: 15% reduction in VKT by 2040)	• Improved Public Transportation Systems: Invest in expanding, modernizing, and increasing the frequency and reliability of public transportation. • Investment in Cycling and Walking Infrastructure. • Non-motorized Transport Promotion: Encouraging walking, and cycling, and providing subsidies for Public Transit and Active Transportation. • Congestion Pricing: Introduce congestion charges for entering congested areas during peak hours.	**Pros:** • Promotes a shift towards more sustainable transportation modes, potentially reducing traffic congestion in urban areas. • Economic Benefits: Investing in public transportation and cycling infrastructure can create jobs in construction, maintenance, and operation. • More affordable transportation options for citizens. **Cons:** • Public transport infrastructure development requires significant investment, which may be challenging in the current political and economic climate. • Shifting behaviour towards non-motorized or public transport options may take time, especially considering the limited reach of public transport networks in rural areas. • Effectiveness depends on urban planning and infrastructure development
Scenario 4: Biofuel Adoption (Target: 30% of diesel vehicles run on B20 by 2040)	• Biodiesel Blending Mandates: Introduce a national or regional mandate requiring a minimum percentage of biodiesel to be blended with conventional diesel fuel. • Tax Breaks and Subsidies: Offer tax breaks or subsidies for consumers who purchase B20-compatible vehicles or for fuel retailers selling B20. • Infrastructure Investment: Invest in upgrading fuelling infrastructure at gas stations to accommodate	**Pros:** • Biofuels offer a lower carbon footprint compared to traditional gasoline or diesel. • Energy Security: Increased reliance on domestic biofuel production can reduce dependence on imported fossil fuels, enhancing energy security and potentially reducing vulnerability to price fluctuations. **Cons:**

	B20 and other biofuels, and Investment in domestic biofuel production facilities (considering feasibility) • Public Awareness Campaigns: Invest in public education campaigns to raise awareness about the benefits of B20 biodiesel, such as reduced emissions and improved air quality.	• Biofuel production can have environmental concerns related to land use and potential indirect emissions, requiring a focus on sustainable feedstock sources. • The effectiveness of biofuels depends on the specific type and production process, necessitating careful selection and monitoring. • The availability and sustainability of biofuel feedstock need careful consideration, ensuring production doesn't compete with food security or lead to deforestation.
Scenario 5: Targeted Policy Focus on High-Emission Vehicles (Target: Removal of 30% of old diesel and gasoline vehicles aged 15 years or older)	• Scrappage Program: A well-designed scrappage program can incentivize vehicle owners to retire older, high-polluting vehicles. This program could offer: ○ *Cash-for-clunkers incentives:* Financial rewards for scrapping old vehicles and purchasing newer, cleaner models. ○ *Trade-in programs:* Partnerships with dealerships to offer discounts on newer, lower-emission vehicles when trading in older models. • Ban on the import of used, high-emission vehicles • Development of a proper dismantling and recycling infrastructure for scrapped vehicles.	**Pros:** • Rapid emission reductions by removing the most polluting vehicles, particularly older models with limited emissions control technology. • Promotes fleet modernization, potentially stimulating the automotive sector and creating jobs in related industries. **Cons:** • Requires significant funding for a well-designed scrappage program, potentially straining government resources. • May disproportionately impact low-income residents who rely on older, more affordable vehicles. • Replacement vehicles need to be demonstrably cleaner to avoid a rebound effect, where increased vehicle use offsets the emission reductions from scrapping older models. • Careful program design is needed to ensure the accessibility and affordability of newer, cleaner vehicles for low-income residents.

6.4. Part 2: Household Sector

Mirroring the approach taken for the transportation sector in Part 1, this part focus on the analysis of the household sector. Here, we'll detail the specific methods used and present the resulting data, providing a clear picture of the household sector in Palestine.

6.4.1. Methodology

Building on the general methodology, this part delves into the application of this for predicting GHGEs from electricity consumption within the household sector.

Similar to the transportation sector, scenario development for the household sector relies heavily on a meticulous review of existing plans and strategies related to household energy consumption (Abu-Madi & Rayyan, 2013; Ersoy et al., 2022; Euro-Mediterranean Partnership Unit, 2019; Ibrik, 2020; Jafar et al., 2023a; Juaidi et al., 2022; Palestine Environment Quality Authority, 2016, 2021; Palestinian Energy and Natural Resources Authority, 2011, 2014, 2016, 2020, 2023b, 2023a; Palestinian Investment and Promotion Agency, 2017, 2020; Qureitem et al., 2020; World Bank Groupe, 2017).

Our review of relevant plans and strategies, particularly those developed by PERA between 2011 and 2023, reveals a strong focus on: (i) maintaining a reliable energy supply, and ensuring sufficient energy to meet domestic demand with international quality standards, (ii) improving service quality and efficiency by enhancing the performance of energy service providers, (iii) promoting energy efficiency, through implementing measures to reduce overall energy consumption, and (iv) developing renewable energy sources, by encouraging the use of solar, wind, and other renewable sources for electricity generation. Focusing on the building sector; key plans and initiatives include (i) building design enhancements; improved insulation, window shading, optimized airflow, and white roofs all contribute to reduced energy demand for heating and cooling, (ii) integration of solar power through rooftop photovoltaic (PV) systems allow on-site clean electricity generation, reducing reliance on the grid, (iii) lighting upgrades by transitioning to energy-efficient lighting solutions like LED bulbs delivers substantial energy savings across all building types, and (iv) national grid modernization; upgrading the electricity grid infrastructure is crucial for maximizing the integration of renewable energy sources. This not only improves overall efficiency but also allows for increased reliance on clean energy by minimizing energy losses during transmission.

Building upon the established methodology outlined for the transportation sector, this section will replicate the same sequence of steps for the household sector. A framework will be developed for emission reduction scenarios, followed by data collection and analysis to evaluate their environmental effectiveness. Similar considerations regarding data needs and analytical tools will apply.

6.4.1.1. Scenario Development and Policy Assumptions

Similar to the transportation sector, scenario development for the household sector will rely heavily on an extensive review of relevant plans and strategies.

Based on the Palestinian context and the plans of the energy sector (e.g. reduce reliance on imported electricity, increase the capacity of electricity generation, and increase the share of renewable energy in the total energy mix) (Palestinian Energy and Natural Resources Authority, 2023b), four scenarios are developed to explore potential pathways for emission reduction in Palestinian households.

Scenario 1; Business-As-Usual (BAU). This scenario assumes no significant changes in current trends. Consumption behaviour, appliance efficiency, and grid losses remain at their present levels. This scenario requires no policy interventions and service as a benchmark of comparison of the effectiveness of other scenarios to reduce GHGE. This analysis utilizes Scenario 1, as a critical benchmark for comparison. Establishing a baseline is essential for evaluating the effectiveness of various emission reduction strategies explored in subsequent scenarios. It allows the quantification of the potential environmental benefits of these strategies relative to a well-defined starting point that reflects current trends (assuming no significant changes in policy or technology).

A similar approach was used in Palestine's NDC and World Bank report for securing energy in Palestine (Palestine Environment Quality Authority, 2016, 2021; World Bank Groupe, 2017).

Scenario 2; Moderate reduction of 10% by 2040. This scenario focuses on reducing emissions by 10% compared to the BAU scenario. This scenario achieves this target through two independent strategies: (i) direct reduction of household electricity consumption by 5% (mainly through changes in behaviour), and (ii) appliance efficiency improvement leading to a reduction in emissions by 5%. This scenario applied the first approach in the PENRA plan to make the Palestinian energy sector sustainable through energy efficiency and consumption rationalization. The original plan set a goal of achieving an energy savings of 384 GWh (which constitutes 5% of the total energy consumed) by 2020, but unfortunately, this goal was not met. (Palestinian Energy and Natural Resources Authority, 2016).

Scenario 3; Ambitious reduction of 16% by 2040. This scenario explores a more ambitious pathway with significant reductions in both energy consumption and emissions. Similar to scenario 2; the target reduction is achievable through consumption reduction (8%) and appliance efficiency improvement (8%). Since the emission reduction target is directly set in Scenario 2 and Scenario 3, the exact percentage of appliance efficiency improvement (for the largest electricity consumers in a household) required to achieve the target is investigated.

Scenario 4; Solar energy integration (400 MW by 2030). This scenario explores the potential emission reduction impact of integrating solar energy into the national grid for cleaner electricity generation. This scenario is aligned with the Palestinian government's target of achieving 400 MW of electricity generation from solar energy projects by 2030 (Khaldi & El Musa, 2022; Palestinian Energy and Natural Resources Authority, 2023b). The 400 MW target could be achieved through a combination of various-sized solar power plants and roof-top units.

Table 6.6 summarizes the four potential emission reduction scenarios for Palestine's transport sector, outlining their key targets and assumptions.

Table 6.6: Emission Reduction Scenarios for Palestine's Household Sector (2030 and 2040)

Scenario/ Strategy	Policy Goal /Target	Assumptions
Scenario 1: Business-As-Usual (BAU) Baseline	This scenario assumes a continuation of current trends in emissions growth.	• Electricity consumption continues to grow along the historical trends. • The emission Factor of Imported electricity equals 470 tons CO_2eq/GWh
Scenario 2: Moderate reduction; Consumption Reduction and Appliance Efficiency Improvement	10% reduction in GHGE by 2040 compared to the BAU scenario; 5% through consumption reduction and 5% by appliance efficiency improvement	• Households have the same baseline consumption and implement the same efficiency improvements • Appliance electricity consumption is estimated for a typical house

Scenario 3: Ambitious reduction; Consumption Reduction and Appliance Efficiency Improvement	16% reduction in GHGE by 2040 compared to the BAU scenario; 8% through consumption reduction and 8% by appliance efficiency improvement	The same assumptions as in Scenario 2.
Scenario 4: Solar Energy Integration	400 MW of electricity generation from solar energy projects by 2030	• Palestine has total sunshine hours of 3000 hours per year • Average capacity factor = 18.5%

6.4.1.2. Data Acquisition and Preparation

The specific data required for analysis depends heavily on the chosen emission reduction scenarios for the household sector. Data collection focuses on the following elements:

Activity data; historical electricity consumption data in the household sector is obtained from national energy balance tables published by PCBS and PENRA (Palestinian Central Bureau of Statistics, 2022a) and households' energy survey carried out by the PCBS from 2001 to 2015 (Palestinian Central Bureau of Statistics, 2023a). The survey involves; the annual consumption of electricity and other fuels of the household's sector, households' average consumption of energy by type of energy and energy use (cooking, lightning, space cooling and heating, etc), and the percentage of households that use these energy types. Regarding households' appliance electric consumption; data on the average consumption of electricity by the type of appliance (lightning, fridge, TV, air conditioner, electric heater, washing machine, …etc.) in a typical household is collected from a survey published by the World Bank on "Securing Energy for Development in West Bank and Gaza" (World Bank Groupe, 2017).

Emission factors, these factors were estimated earlier in Chapter 3 for both electricity production and consumption in Palestine (2011-2021). The emission factors take into account the energy mix used to generate electricity including imported electricity. The emission intensity for imported electricity is obtained from the importing country (Electricity Authority, 2023). Emission factors for different fuel types in the electricity mix (gasoline, diesel, biofuels) were obtained from IPCC guidelines and GHG Protocol (GHG Protocol, 2017; IPCC, 2006).

Similar to the transport sector, additional statistical data encompasses demographics (e.g. population, age group, education), economic indicators (GDP, GDP/capita, electricity and fuel prices), and health statistics (fertility rate, mortality rate, and death rate) is employed for prediction analysis.

6.4.1.3. GHGE Projection Analysis

6.4.1.3.1. Historical Emission

Historical emissions in the household sectors are calculated to establish a baseline for GHGE projection as previously explained in Part 1 of this chapter. This baseline serves as a crucial starting point for projecting future emissions under different scenarios.

The estimation process is based on activity and emission factors, electricity consumption in the household sector, and the number of households representing the activity data in this case. The details of these calculations are presented in Chapter 3.

6.4.1.3.2. Trend Analysis

Similar to the transportation sector, the household sector analysis utilizes the same software and tools for trend analysis.

Preliminary trend investigation using the TheilSen function within R (4.3.2) software revealed scattered data on electricity consumption with a weak statistically significant upward trend as seen in **Figure 6.8**.

Consequently, emission projections cannot solely rely on this approach. Trends in activity data are also explored using this technique. The analysis showed that electricity consumption in the household sector showed a strong increasing trend during the study period, and these trends were statistically highly significant ($p < 0.001$)

Due to the limitations of this approach, emission projections will shift focus towards predicting electricity consumption adopting the same approach in the transport sector. By applying regression models, to investigate the relationship between electricity consumption and other dependant factors like GDP and population.

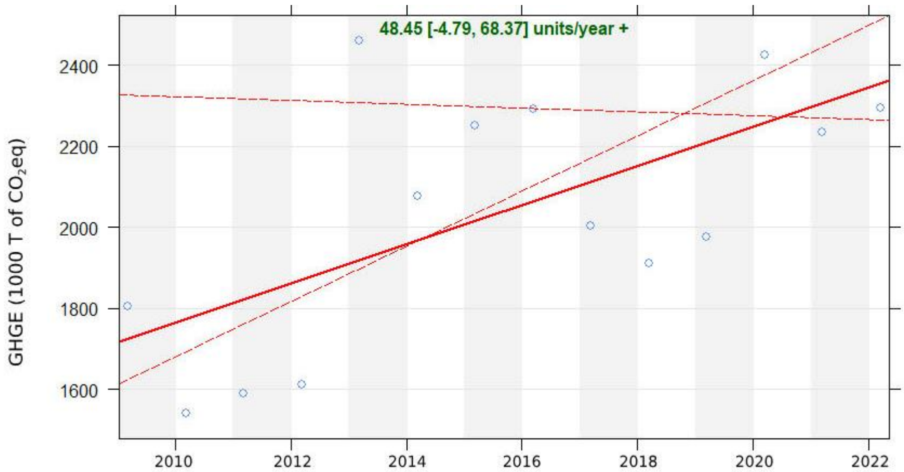


Figure 6.8: Trends in GHGE from electricity consumption in the household sectors in Palestine during the period (2009-2022)

6.4.1.3.3. Regression Analysis

Building upon the established regression methodology outlined in the transportation sector in Part 1, this section will focus on the unique considerations and adaptations required for analyzing household electricity consumption data. We will delve into the specific variables chosen and the rationale behind their selection for modelling household energy use.

6.4.1.3.4. Forecast Activity drivers

This section focuses on predicting future trends in household electricity consumption. As electricity consumption is a key driver of household sector emissions, understanding its relationship with other factors is crucial. Through regression analysis, it is possible to explore these relationships between electricity consumption (the dependent variable) and various independent variables affecting household energy use. These independent variables may include factors like population growth, GDP, appliance ownership rates, and energy prices. By building models that describe these relationships, we can then use them to estimate future electricity consumption patterns within the household sector.

As a foundation for predicting future electricity consumption, we will utilize the population and GDP projections established earlier in Part 1. This ensures consistency and avoids redundancy in our forecasting efforts. Additionally, we will build upon the forecasting process explained in Part 1, tailoring it specifically to the household sector and its unique activity drivers.

6.4.1.3.5. GHGE Projections

Building upon the previously established forecasts for population growth, GDP, and subsequent electricity consumption, this analysis focuses on GHGEs projections. Forecasted electricity consumption, derived from population and GDP projections, serves as the basis for analysis. A baseline emission factor for electricity consumption in the year 2022 is used. This assumption reflects a scenario with no significant changes in technology or policies affecting the electricity grid's emission profile. The forecasted electricity consumption is then multiplied by this constant emission factor to estimate household sector emissions. This establishes an overall forecast for GHGEs projections under the baseline scenario, which assumes no major technological advancements or future possibilities based on specific policy assumptions (changes in activity data, technology and/or infrastructure). Below are some sector-specific considerations:

- Appliance Efficiency: The model focuses on maximizing the impact of appliance efficiency improvements while maintaining baseline consumption for other appliances. This iterative process utilizes data on the electricity consumption of different appliances in a typical Palestinian house (World Bank Group, 2017). The model adjusts the efficiency improvement for each appliance (focusing on high-impact appliances) without changing the baseline consumption for other appliances. Then the overall impact on electricity consumption is calculated, and the process is repeated until the targeted reduction is reached.
- Solar Energy Potential: The model estimates the potential reduction in emissions achieved by offsetting traditional electricity generation with cleaner solar power. This is based on assumptions about installed capacity (defined in **Table 6.6**) and avoided emissions from solar energy integration.

The subsequent section delves into the insightful results of this model. These findings shed light on the potential for emission reduction achievable through various policy interventions and technological advancements within the Palestinian household sector.

6.4.2. Results and Discussion

6.4.2.1. Assessing the Impact of Emission Reduction Scenarios

The same scenario analysis approach adapted in the transport section in Part 1 is also implemented here. This approach is mainly based on a comprehensive Excel spreadsheet model to construct and simulate different Trend and Regression Analysis

This study investigated the factors influencing electricity consumption through regression analysis. Various models were investigated, focusing on their adjusted R-squared values to assess the explained variance. The analysis revealed a trade-off between interpretability and capturing potential non-linear relationships.

Linear models incorporating population (P) and GDP provided a good baseline (0.9335 adjusted R-squared) with interpretable variable effects. Including electricity Tariff yielded a slight improvement (0.9489 adjusted R-squared) but with a less significant Tariff contribution (see **Table 6.7**).

While the polynomial model achieved a high adjusted R-squared (0.9293), careful examination of individual term p-values is necessary to avoid overfitting. The exponential model (0.9171 adjusted R-squared) showed a lower explanatory power compared to top contenders. The logarithmic model with P and GDP (0.9333 adjusted R-squared) offered a similar performance to the baseline linear model. The influence of GDP in some models was less clear (p-values close to 0.05).

Table 6.7: Comparison of regression models for household electricity consumption in Palestine. Note: The Significance codes: '***' p-value < 0.001, meaning the variable is highly statistically significant, '**' 0.001≤ p-value <0.01, indicating a strong level of significance. '*' p-value < 0.05 is a commonly used threshold for statistical significance. ' ' p-value ≥ 0.05, meaning the variable is not statistically significant

Model Name	R-squared (Adjusted)	Significant Variables (p-value < 0.05)	RMSE
Linear (P, GDP)	0.9335	P (***), GDP ()*	214.89
Linear (P, GDP, Tariff)	0.9489	P (***), GDP ()*, Tariff ()	202.58
Polynomial (P, GDP, Tariff)	0.9293	Investigate p-values of individual terms (might be overfitting).	238.28
Exponential (P, GDP)	0.9171	P (***), GDP ()	262.19
Logarithmic (P, GDP)	0.9333	P (***), GDP ( )*	231.44
GAM_1 (P, GDP, Tariff)	0.948	P (***), smooth term of P (***)	0.045
GAM_2 (P, GDP)	0.952	P (***), smooth term of P (***)	0.050
GAM_3 (P, bs="ps") + s(GDP, bs="ps") + Tariff	0.963	P (***), smooth term of P (***) less significant variable: GDP (p-value = 0.076) - inclusion might be debatable depending on the desired level of significance.	0.037
GAM_4 (P, bs="ps") + s(Tariff, bs="ps") + GDP	0.965	P (***), smooth term of P (***) Non-significant variables: Tariff (p-value = 0.321) and GDP (p-value = 0.280)	0.03

GAMs 3 and 4 emerged as strong contenders with the highest adjusted R-squared values (0.963 and 0.965). This indicates that GAMs effectively explained a larger proportion of the variance in electricity consumption compared to other models. Notably, GAMs have the capability to capture potentially non-linear relationships between variables. In this case, they effectively captured the non-linear relationship between population density and electricity consumption, likely due to factors like economies of scale in infrastructure and changing consumption patterns with population growth. Tariff's effect appeared less significant in these top GAM models.

The best model among the four GAMs for electricity consumption is likely the second model (GAM_2 (P, GDP)) with an adjusted R-squared of 0.952. \ This model focuses on interpretability and only includes a smooth term for Population (P) and GDP. It balances complexity and explanatory power by maintaining a high adjusted R-squared value (0.952) indicating strong explanatory power, while being simpler than the fourth model which includes non-significant variables (Tariff and GDP). **Figure 6.9** shows the actual electricity consumption along with the fitted curves for different regression models.

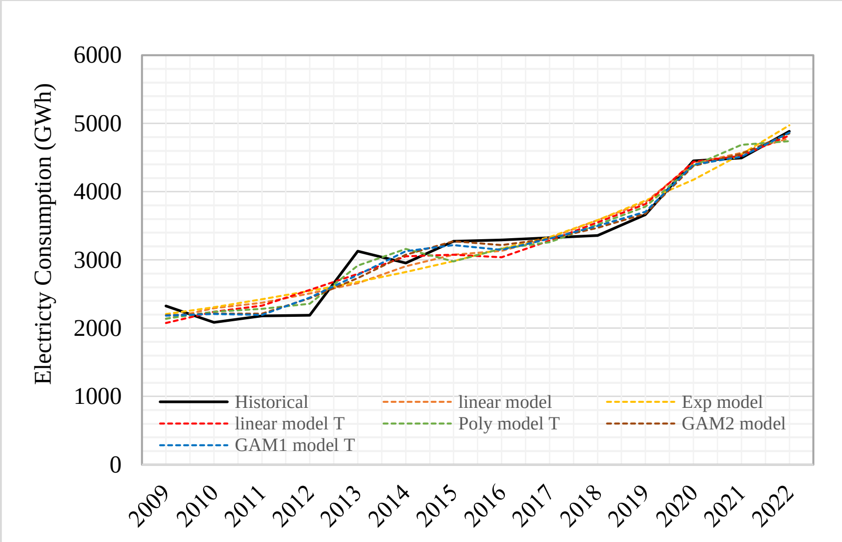


Figure 6.9: Different electricity consumption regression models against actual data for the period 2009-2022. Note: Historical represents the actual consumption, while T stands for regression models containing the Tariff factor besides GDP and population

6.4.2.2. Forecast Activity Drivers

This section focuses on predicting the key activity drivers influencing GHGE within the household sectors in Palestine. The forecasting here is based on the results of the regression analysis in the previous section.

The analysis identified population and GDP as the most significant factors for household electricity consumption. GAM_2 (P, GDP) model proved to be the optimal model, balancing interpretability with explanatory power. Future predictions of household electricity consumption were based on this model. The results for the forecast are presented in **Table 6.8**.

Table 6.8: Predicted electricity consumption in the household sector (in GWh) in Palestine, for the forecasting period 2025-2050, with its key drivers: population (millions) and GDP (in Billion U.S. $).

Year	GDP (Billion $)	Population (Millions)	Electricity Consumption (GWh)
2025	18.8	6.175	7,690.2
2030	24.2	6.90	9,116.5
2035	29.3	7.61	10,483.5
2040	35.2	8.29	11,773.7
2045	40.7	8.94	12,936.4
2050	46.2	9.51	13,898.1

6.4.2.3. Baseline Emission Projections

This section presents the results of GHGE projections which will be used later as a baseline or reference for emission reduction projections under different scenarios.

Future household electricity demand is based on projected population and GDP growth. Multiplying the projected electricity consumption with the emission factor for electricity generation in the study region yielded estimates for future emissions from household electricity use. The baseline emission projections household electricity consumption are presented in **Table 6.9**.

Table 6.9: Baseline projections of GHGE from electricity consumption in the household sector

Year	GHGE household electricity consumption (Mt CO_2 eq)
2025	3,614.4
2030	4,284.7
2035	4,927.2
2040	5,533.6
2045	6,080.1
2050	6,532.1

6.4.2.4. Assessing the Impact of Emission Reduction Scenarios

The baseline emission projections developed for the household electricity consumption sectors provide a reference to assess the effectiveness of reduction scenarios in this sector. The baseline projections represent the "BAU" scenario, reflecting GHGE projections under current situation. Emission reduction scenarios introduce policies or interventions that aim to reduce GHGE. The specific results of these emission reduction scenarios are presented in this section. As mentioned in Pari 1, the target year in this analysis is 2040 in line with Palestine's NDC.

Under the baseline scenario, and utilizing the projections shown in **Table 6.8**, GHGE from electricity consumption in the household sector is expected to be around 5,533 thousand tonnes of CO_2eq in 2040. While the BAU Scenario provides a helpful baseline for comparison, it has limitations. It assumes current trends will not change, neglecting potential disruptions from unforeseen events, changes in occupant behaviours, appliance ownership patterns, technological advancements, or policy shifts. This lack of consideration for uncertainty limits the scenario's ability to reflect the full range of possibilities for the future. However, these limitations don't negate its usefulness as a starting point.

In Scenarios 2 and 3, unlike other scenarios, the reduction targets (10% and 16%, respectively) are set, and according to these targets, the required interventions were estimated. The main assumptions in these scenarios are that the target reduction would be achieved using two independent interventions each would achieve 50% of the target; (i) consumption reduction through consumer behavioural change, and (ii) appliance efficiency improvement. The spreadsheet projected total emissions of 4,980 thousand tonnes of CO_2eq in 2040 under Scenario 2, and 4,648 thousand tonnes of CO_2eq under Scenario 3.

In terms of appliance efficiency improvement, the analysis revealed that the appliances with the highest contribution to overall consumption are water heating (26.2% of total household electricity consumption), electric room heating (18.6%), Air conditioners (12.8%), followed by fridge and lightning (11.6% for each). To achieve the target reduction by efficiency improvement (5% in Scenario 2 and 8% in Scenario 3), the efficiency of high-impact appliances needs to be improved by the percentages specified in **Table 6.10** below. Trends in emission projections alongside historical emissions are visualized in **Figure 6.10**.

Table 6.10: Recommended appliance efficiency improvements under Scenarios 2 and 3

Appliances	Improved efficiency under Scenario 2	Improved efficiency under Scenario 3
Air conditioner	3%	6%
Electric room heating	7%	10%
Water heating	4%	8%
washing M/C	-	2%
Fridge	5%	12%
lightning	15%	15%

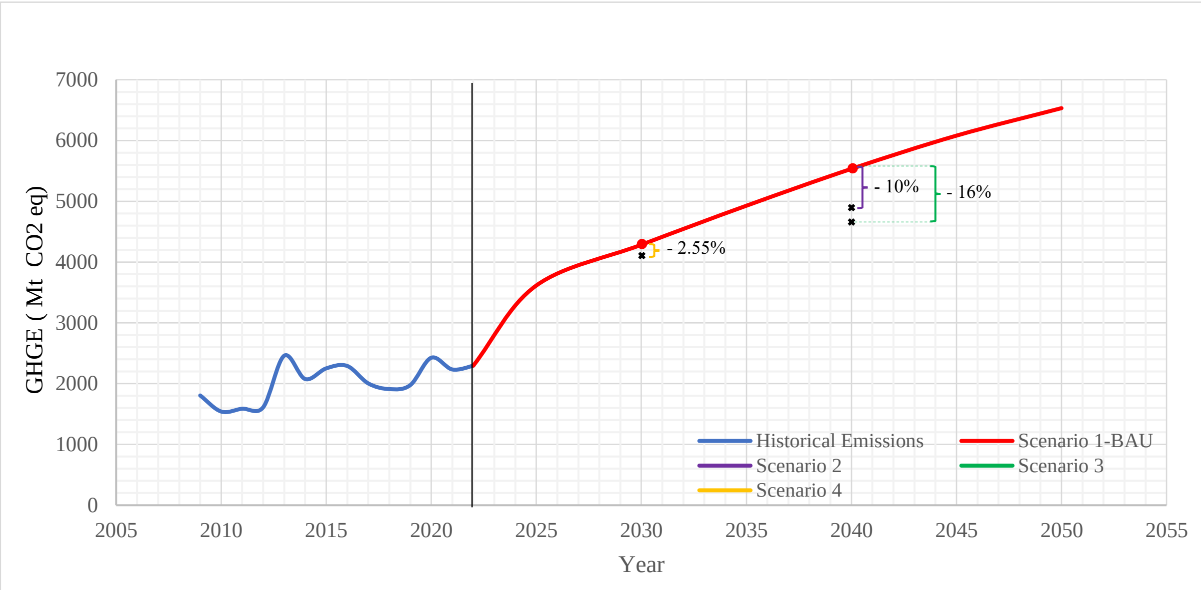


Figure 6.10: Historical GHGE from electricity consumption by the household sector in Palestine (2009-2022) alongside baseline emission forecast (2023-2050) and emission projections under different reduction scenarios in 2030 and 2040

It is important to acknowledge the limitations of these two scenarios. One limitation is that all households are assumed to have the same baseline consumption and implement the same efficiency improvements. In reality, households have significant variations in electricity consumption due to many factors like size, occupancy, appliance types, climate, and usage patterns. These variations would lead to a range of reduction percentages across different households, even with the same efficiency improvements. Thus, the percentage of reduction due to efficiency improvement is for a specific house, not the entire household's sector under real-world conditions. Moreover, the scenarios estimated the effects of both interventions (consumption reduction and efficiency improvement) independently, while, there might be interactions between them, leading to a different combined reduction.

Scenario 4, promotes a large-scale solar integration with a capacity target of 400 MW to reduce reliance on conventional grid electricity. To estimate the potential electricity production from solar energy two key factors were considered. A total sunshine of 3000 hours per year in Palestine (Juaidi et al., 2022), and an average capacity factor for PV installations in Palestine of 18.5%; reflects the percentage of time the solar panels are expected to operate at their maximum capacity throughout the year (Ibrik, 2020). Based on these assumptions, the estimated annual electricity generation is 232.49 GWh. Taking into account the emissions avoided by solar production, the total emissions expected under Scenario 4 in 2030 are 4,175 thousand tonnes of CO_2eq. However, this is still an estimation using average values. The actual electricity generation varies depending on many factors including; weather conditions, maintenance practices, specific capacity factors, and transmission and distribution losses.

6.4.2.5. Projected Reductions in Emissions

The projected emissions from the four scenarios alongside historical emissions are presented in **Figure 6.10**. Similar to the transport sector, here the BAU Scenario is also used as a reference point or benchmark for comparison with other scenarios.

For Scenario 2 and 3, the scenarios are built to achieve a targeted reduction in household baseline emissions of 10 % and 16%, respectively, by 2040. This is achieved through the integration of two interventions, efficiency improvement, and consumption reduction. Implementing only one intervention was estimated to yield a 5% reduction in Scenario 2 and 8% in Scenario 3. On the other hand, the integration of solar energy in Scenario 4 would reduce the emissions by 2.55% from the baseline emissions in 2030.

6.4.3. Policy Recommendations

The previous sections explored various emission reduction pathways for the Palestinian household electricity consumption sector. However, translating these scenarios into reality necessitates acknowledging the distinct challenges posed by the Israeli occupation.

Israeli control over essential resources and infrastructure development significantly hinders the Palestinian Authority's ability to comprehensively improve the energy sector. Building new power plants, deploying large-scale solar projects, and upgrading the electricity grid to minimize energy losses become considerably more complex without international support and Israeli approval, both of which can be extremely difficult to secure. This substantially restricts the immediate applicability of scenarios heavily reliant on large-scale infrastructure advancements, such as Scenario 3 (Smart Grid Advancement) within the household sector.

Despite these challenges, hope remains, it is possible to create a path towards a more sustainable energy future for Palestinian households. Public awareness campaigns and conditional financial incentives for energy-efficient appliances and practices remain highly applicable (as outlined in Scenarios 2 and 3). This strategy can significantly reduce household electricity consumption without requiring major infrastructure changes. Additionally, collaboration with international partners and NGOs can facilitate small-scale rooftop solar initiatives, especially for large public buildings. This approach, aligned with aspects of Scenario 4, promotes energy security and reduces reliance on imported electricity. Some initiatives already exist, demonstrating the potential for further expansion through strategic partnerships.

Table 6.11 present specific policy recommendations for each emission reduction scenario, along with their associated pros and cons, considering the realities of the Palestinian context.

Table 6.11: Recommended policy measures for each emission reduction scenario for the household sector, along with their associated pros and cons

Scenario/ Strategy	Recommended Policy Measures	Pros & cons

Scenario 1: Business-As-Usual (BAU) Baseline	No immediate policy changes or investments	**Pros:** • Requires no immediate policy changes or investments, potentially appealing in a resource-constrained environment. • Clear Benchmark: The BAU scenario provides a clear reference point for assessing the effectiveness of proposed emission reduction strategies. **Cons:** • Does not address the issue of rising emissions, leading to potential health and environmental issues. • High electricity costs due to dependence on imports • High grid losses (21%) increase the cost and wasting energy
Scenario 2: Moderate reduction; Consumption Reduction and Appliance Efficiency Improvement (Target: 10% reduction by 2040)	• Public awareness campaigns for energy-saving behaviour. • Incentives for upgrading to energy-efficient appliances. • Stringent regulations or mandatory efficiency standards for appliances.	**Pros:** • Potential for cost savings on energy bills. • Reduced environmental impact. • Improved energy security. **Cons:** • Behavior change can be challenging. • Upfront costs associated with appliance upgrades. • Regulations might face resistance. • May not address the issue of high grid losses
Scenario 3: Ambitious reduction; Consumption Reduction and Appliance Efficiency Improvement (Target: 16% reduction by 2040)	• Public awareness campaigns for energy-saving behaviour. • Incentives for upgrading to energy-efficient appliances. • Stringent regulations or mandatory efficiency standards for appliances.	**Pros:** • Deeper emission reductions compared to Scenario 2. • Potential for long-term cost savings. • Improved energy security and reduced demand for imported electricity **Cons:**

	• Investment in smart grids and home automation technologies.	• Behavior change can be challenging. • Upfront costs associated with appliance upgrades. • Regulations might face resistance. • Implementation costs for smart grid technologies.
Scenario 4: Solar Energy Integration (Target: 400MW by 2030)	• Installation of solar panels on rooftops or centralized farms. • International Partnerships: Seek partnerships with international organizations or private investors to explore financing models for regional solar projects.	**Pros:** • Reduced reliance on fossil fuels. • Increased energy independence and security • Cleaner energy source with lower emissions. **Cons:** • High upfront costs for solar panel installation. • The intermittency of solar energy requires storage solutions. • Geographical limitations (sunshine hours). • Requires overcoming potential challenges in obtaining approval for large-scale projects • May face technical challenges in integrating solar power into the existing grid

6.5. Conclusion

This chapter explored potential pathways for reducing GHGEs from the household and transportation sectors in Palestine. The methodology of this research is based on a multi-pronged approach, combining scenario analysis with regression modelling to identify key factors (e.g. GDP, population) influencing emissions activity drivers (e.g., number of cars, electricity and fuel consumption). This approach allowed for forecasting future trends in these drivers and projecting GHGEs under various mitigation scenarios.

Different emission reduction scenarios were developed targeting the transport and household sectors in Palestine, highlighting the potential impact of various mitigation strategies on future emissions. Regression models identified key factors influencing energy consumption and activity drivers.

Emission projections analysis revealed an expected non-linear increasing trend in future emissions from both sectors under baseline or BAU status. Baseline emissions for the target year 2040 were expected to reach 5,533 thousand tonnes of CO_2eq from electricity consumption at households and 8,463 thousand tonnes of CO_2eq from the transport sector.

This chapter explored four potential scenarios for reducing GHGE from the household sector in Palestine. Scenario 3, which prioritized consumption reduction and appliance efficiency improvements, emerged as the most effective strategy, achieving a significant 16% reduction in GHGEs. The analysis highlights the challenges associated with each scenario under the current political context. While full implementation of some scenarios might be challenging (like Scenario 4 focusing on electricity generation from solar energy), opportunities remain. Analysis showed that implementing a combination of strategies as in the case of Scenario 2 and 3 is the most effective approach to reduce emissions. Integrating solar energy holds promise for increasing energy security and decreasing reliance on imported electricity.

Five scenarios were explored for emission reduction from the transport sector. Analysis revealed that Scenario 3; focusing on multimodal shift achieved the highest reduction in emissions (15%), but the effectiveness of this scenario is subjected to infrastructure development and political situation. The full implementation of this scenario and others like Scenario 2 which adapts hybrid vehicles and Scenario 4 promoting biofuel may face significant challenges. However, this doesn't negate the existence of achievable opportunities for emission reduction. Through a combination of CO_2 reduction measures, Palestine can achieve significant progress in achieving a more sustainable and cleaner transportation sector. focusing on the adoption of hybrid electric vehicles for high-mileage vehicles like taxis combined with promoting walking and cycling, and scrapping old high-polluting vehicles can reduce GHGE from the transport sector significantly.

6.6. Implications and Future Research

These findings offer valuable guidance for Palestinian policymakers in developing data-driven policies that promote energy efficiency, cleaner transportation options, and a shift towards renewable energy sources in both sectors.

While this research provides a robust foundation, further exploration can enhance future mitigation strategies. Future research is recommended to study the exact impact of combining different strategies using transportation modelling software, conduct detailed field studies to obtain more reliable data on household energy consumption behaviour in Palestine and carry out cost-effectiveness analysis and financial assessment for each emission reduction scenario. These advancements will ensure Palestinian policymakers have the most reliable information to navigate towards a cleaner transportation future.

General Conclusion and Perspectives

Climate change, driven by rising GHGEs, stands as one of the most pressing challenges facing the planet. Understanding the sources and distribution of these emissions is crucial for developing effective mitigation strategies. However, this task becomes particularly complex in conflict zones and regions with limited data availability where ongoing political instability and disruption often hinder comprehensive data collection efforts

To bridge the critical gap in understanding carbon footprints in developing countries, especially conflict zones, this research focuses on developing a novel carbon accounting methodology based on a hybrid approach that goes beyond national reports. This will ultimately allow for a more in-depth understanding of GHGEs across multiple scales and consequently, the development of more effective and targeted mitigation strategies. The research framework consists of four main phases; national GHGE inventory, sector-specific analysis, spatial analysis, and scenario-based emissions reduction pathways.

Palestinian National scale analysis based on the IPCC guidelines revealed how the occupation influenced the Palestinian GHGEs, particularly the energy sector. The arbitrary procedures of occupation have constrained the ability of Palestinians to develop the energy sector, which in turn has limited the capacity of electricity generation and consequently affected GHGEs in the country, making emissions from the energy industries extremely minimal (only 11% of total emissions) and very low compared to other countries worldwide, for instance, the energy industry accounts for 50% of total emissions within the energy sector in Jordan. The analysis has emphasized the significance of imported energy (electricity and heat) on carbon emissions in areas which are characterized as energy-dependent such as the case of Palestine. Including the imported electricity in the estimation of the GHGEs doubled the total emissions of the energy sector. The effect of including imported electricity was primarily noticeable in changing the lead among the emission-contributing sources from the transport sector to the household sector. Initially, emissions from households constituted 25% of the total, whereas those from the transport sector comprised 56%. However, after factoring in emissions from imported electricity, the proportion attributed to households rose to 44%, while that of the transport sector decreased to 30%, highlighting the substantial influence of imported electricity on emissions distribution among sectors. Furthermore, banning the Palestinians from importing the necessary equipment, machines, and dual-use materials has a significant impact on limiting the ability of the Palestinian economy to improve and expand, which in turn reduces the CO_2 emissions from the industry/commerce and public service sectors (about 4% and 3% of the total GHGEs, respectively). In neighbouring countries with a similar situation but without any restrictions, such as Lebanon, the shares of these sectors account for more than 20% and 10%, respectively.

Zooming in from the national perspective, the sector-specific analysis provided a detailed breakdown of emissions from the transport sector using a novel hybrid method. The transport sector was selected due to its significant contribution to greenhouse gas emissions within the country. Additionally, Previous studies lacked a detailed breakdown of emissions from this sector, necessitating a thorough analysis to enhance understanding. This analysis highlighted the importance of combining bottom-up and top-down approaches to obtain detailed sectoral emissions in areas where data is limited. The assessment of the vehicle fleet in Palestine showed that private vehicles were the main contributor to GHGEs in the transport sector. The heightened emissions from private cars are primarily attributed to factors associated with occupation, compounded by restrictions on infrastructure development within the transportation sector. These constraints limit the availability of alternative transportation modes like trains, metro systems, and planes and hinder the necessary infrastructure development for supporting electric and plug-in vehicles. Specifically, the absence of adequate charging stations further diminishes the viability of electric and hybrid vehicles within the country. Furthermore, fragmentation of the West

Bank and the presence of Israeli-controlled checkpoints impede Palestinian movement. This discourages public transportation use and fuels preference for private vehicles.

This research presented a novel approach for spatial analysis of GHGEs in conflict areas with application to the electricity sector in Palestine. This method is based on a vector mapping approach, where data was disaggregated to the level of built-up area (mapping unit). The flexibility of the developed method allows for the aggregation of results across different scales. This scalability provides policymakers with a powerful tool for understanding the spatial distribution of emissions and developing targeted mitigation strategies. This analysis revealed the pronounced impact of occupation on the spatial distribution of emissions. Areas under restricted control of the occupation exhibited lower emissions than other regions. However, this does not imply a green effect but rather reflects the impact of occupation restrictions on various aspects such as displacement of residents, restrictions on building permits, and discriminatory practices. These constraints have led to the forced displacement of residents from these regions to areas A and B, which have fewer restrictions. Additionally, the limitations imposed in these areas have hindered economic and commercial development. This serves as clear evidence of how occupation influences the spatial patterns of emission distribution within the occupied country. Moreover, mapping emissions facilitates the pinpointing of emissions hot-spot areas and reveals interesting results on the interaction between population density, energy consumption and GHGEs. A deeper analysis revealed that emissions per capita showed a huge spatial variation in the study area.

Building on the findings of previous analysis in this research, a multi-pronged approach was developed to explore potential pathways for reducing GHGEs in Palestine. Combining scenario analysis with regression modelling has enabled the identification of key factors (e.g. GDP, population) influencing emissions activity drivers, forecasting future trends in these drivers and projecting GHGEs under various mitigation scenarios. This analysis targeted the country's main contributors to GHGEs: the household and transport sectors. Different emission reduction scenarios were explored taking into account the geopolitical context of the area.

In light of the results outlined above, the occupation control over essential resources and infrastructure development significantly hinders the Palestinian Authority's ability to achieve its emission reduction targets. This substantially restricts the applicability of emission reduction strategies heavily reliant on large-scale infrastructure advancements, such as building new power plants, electricity grid advancement and large-scale renewable energy projects. Furthermore, hindering efforts to promote a modal shift as envisioned in actions and plans focusing on transportation sector transformation. Restrictions on imports limit access to clean transportation technologies like electric vehicles. Additionally, control over fuel imports creates uncertainties around fuel availability and cost, impacting the feasibility of strategies heavily reliant on specific fuel types, such as biofuel.

These limitations highlight the increased cost and complexity of implementing various emission reduction strategies under the current political context. Despite the challenges, hope remains, and opportunities exist for mitigation efforts by focusing on achievable measures within Palestinian control. Public awareness campaigns and conditional financial incentives for energy-efficient appliances and practices remain highly applicable. This strategy can significantly reduce household electricity consumption without requiring major infrastructure changes. Collaboration with international partners and NGOs can also facilitate small-scale rooftop solar initiatives, especially for large public buildings. This approach promotes energy security and reduces reliance on imported electricity. Some initiatives already exist, demonstrating the potential for further expansion through strategic partnerships. Promoting fuel-efficient driving practices and encouraging alternative modes of travel like walking and cycling remain feasible options, regardless of import restrictions. Focusing on the adaptation of hybrid electric vehicles, particularly for high-mileage fleets like taxis, offers significant emission reduction potential within the current limitations on clean technology imports.

Implementing a vehicle scrappage program can incentivize the retirement of older, less fuel-efficient vehicles from circulation.

In summary, this research presented a novel hybrid for multiscale carbon accounting in conflict areas, with application to Palestine. It provides a more in-depth understanding of GHGE sources, distribution and patterns in these areas. Through the discussion of the analysis results, the research shed light on the impacts of occupation on emissions in a country, including the amount and types of emissions from different sources and their spatial distribution. Additionally, it showed how occupation limits the country's ability to adopt effective measures to reduce emissions. These findings facilitate the development of targeted policies and strategies to reduce emissions in conflict areas and support progress towards achieving climate targets.

Future research is recommended to focus on (i) impact assessment of occupation policies on emissions: conduct assessments to understand how occupation policies influence GHGEs in conflict-affected regions. (ii) Regulation compliance and enforcement: assess the compliance and enforcement mechanisms of new regulations aimed at reducing emissions in occupied territories, considering the effectiveness of local authorities in enforcing these regulations under occupation.(iii) International institutions' role in emission reduction: evaluate the role of international institutions in supporting emission reduction efforts in conflict areas under occupation, examining the impact of interventions such as funding for renewable energy projects or capacity-building initiatives.

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