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CASE STUDY OF DEFRAGMENTATION OF CITY SCALE'S GREENHOUSE GAS EMISSION IN MELAKA

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Abstract: The defragmentation of multiple sources of greenhouse gas emissions would allow for more effective climate action at the local level. The adoption of a Global Protocol for Community-Scale (GPC) framework will assist in determining the source of greenhouse gas emissions in Malacca based on inventory data. The online software tool (Harmonised Emissions Analysis Tool (HEAT+)) is used to translate data that can then be used to plan strategic initiatives at the local level. Malacca's per capita GHG emissions currently stands at 4.59 tonnes of CO_2 equivalent (tCO_2e). A GPC analysis revealed the industrial sector was the principal offender, who accounted for 39.6% (1,548.412 tCO_2e) of the emissions, this was followed by the transport and logistics sector, which accounted for 29.9% (1,160,333 tCO_2e), the commercial sector that accounted for 14.7% (574,844 tCO_2e) and individual residences which accounted for the balance 12.8% (499,655 tCO_2e). Scope 1 dominated GHG emissions by 72.1%, based on the electricity use data from buildings held by the Historical Malacca City Council and Hang Tuah Jaya City Council. The result indicates that the two government buildings need to lead sustainable infrastructure initiatives and reduce emissions by spearheading various energy efficiency programmes. These initiatives can then be followed by businesses and residences using decentralised energy strategies. Making climate change mitigation efforts a priority is recommended. This can be done by implementing a variety of low-carbon-based technologies supported by command and control frameworks and market-based policy interventions. The manufacturing and services sectors are the two most important economic sectors in Malacca, and both have the capacity to adopt more advanced greener and cleaner technologies. Nevertheless, active modes of transportation must be promoted as part of the adaptation strategy for clean, low-carbon modes of transportation.

Keywords: City, carbon, greenhouse gas, energy, building.
Abbreviations: Green-house gas, GHGs, tonnes of CO_2 equivalent, tCO_2e.

Introduction

The administration of cities across the globe have been chastised for their lacklustre efforts and lack of political will to tackle the impact in climate change. About 80% of the world's anthropogenic green-house gas (GHG) such as carbon dioxide are produced in cities worldwide (Satterthwaite, 2008; United Nations, 2009; Harris *et al.,* 2020). About 70% of GHG emissions come from infrastructure projects, fuel and electricity used in cities (Ramaswami *et al*., 2016).

Therefore, cities account for more than 71% of energy related GHGs (IEA, 2008; Harris *et al*., 2020). The construction sector's global impact to climate change accounts for 40% of the total global energy use and GHG emissions and 60% of the total global electricity use (Comstock *et al*., 2012; Levine *et al*., 2012). Private residences account for around 65% of the contributions to global climate change while commercial buildings account for 35% (Ürge-Vorsatz & Tirado Herrero, 2012). Between 80% and 90% of the energy used and GHG emissions take place during the operational period, whereas pre-production and demolition/deconstruction produces only between 10% and 20% of the energy and GHGs.

The three primary methods of reducing GHG emissions in buildings are:

i. Lowering the amount of energy used and embodied energy in structures,

ii. Embracing renewable energy by converting to low-carbon energy sources or

iii. Regulating non-CO_2 GHGs gas sources (Levine *et al*., 2012)

Most cities throughout the world are attempting to reduce GHG emissions, which necessitates action at the city, community local and national levels. The initiatives that are planned need to consider the components of urban growth, comprising industry, road networks, residential areas and other factors that have a substantial impact on GHGs emissions. Another important aspect that needs to be considered when dealing with or designing GHG mitigation initiatives is the spatial distribution of land users and the sizes of the population involved to wit, the population size and demographic. Policymakers and urban planners must determine acceptable levels of GHGs while planning for, developing and later, monitoring urban expansion to ensure that it is done in a sustainable manner. A compatible land use pattern that considers the impact on the local climate is critical for the balanced and sustainable growth of a nation.

The construction sector has been recognised by the Intergovernmental Panel on Climate Change (IPCC) as having the greatest mitigation potential (IPCC, 2007). Many projects and strategies to reduce energy use have been put forth, tested and used or adapted for use in the construction sector. Energy consumption in both new and existing buildings can be significantly reduced using currently available systems, designs, equipment, management software and other potential solutions (Levine *et al.,* 2007). Several cost-effective technologies and techniques for reducing GHG emissions in buildings must be pushed and adopted more broadly in order to obtain better GHG mitigation results. Among the methods used to reduce emissions in buildings include passive solar designs solar water heaters, better insulating materials, higher-efficiency lighting and appliances, improved ventilation and cooling systems that are extremely efficient, multiple glazing and highly reflective construction materials. Approximately 70% of the highest energy savings take place in newer buildings, as a result of designing and running buildings with the GHG systems integrated right from the start (Levine *et al*., 2012). These potential solutions are especially significant for government buildings, which have high energy usage levels.

The same phenomenon has been observed in Malaysia. The use of fossil fuels in the country, for the generation of electricity, use in transport, industry and in private homes contributes to the creation of carbon emissions.

The output of GHGs and other carbon emissions, account for 285.73 million tonnes of CO_2 in 2020, which is indicative of a 68.86% rise from 2000 (Sharliza *et al*., 2010). The electrical industry was a major source of carbon emissions in 2020, accounting for 43.40% of the total global emissions. The transport and logistics sector accounted for 30.34%, industrial sector (26.26%), followed by residences and other sectors (Sharliza *et al*., 2010).

Another important element leading to an increase in carbon emissions is urbanisation, which has increased from 25% in 1960 to 65% in 2005 (Siong, 2008). This was predicted to reach 70% by 2020. The rising percentage reflects the proportion of Malaysians living in cities, which accounts for more than 60% of the population in 2000 (Syafiee Shuid, 2004). On the other hand, more than three-quarters (77.6%) of the country's total population is predicted to be living in urban areas by 2030 (Siong, 2008). The increase in the population of cities has resulted in an increase in urban activity levels, which has worsened the environmental quality, the use of motorised transport, industrial and commercial activities and other human activities have contributed to an increase in carbon dioxide emissions, which has increased green-house gas levels (Ibrahim *et al*., 2012).

Industrialisation also contributes to a rise in the country's carbon emissions. Malaysia is no exception, the transformation from an agricultural economy to an industrial economy over the last several decades has increased carbon emissions by 221% (+221%).

Globally, the use of energy by the industrial and logistics sectors has increased (Al-Jazeera, 2007; Watkins, 2007). Malaysia's carbon emissions stood at 194 million tonnes in 2011, a 290.7% increase from 1990 (IEA, 2008).

A long-term energy alternative planning system (LEAP) report indicates that if no mitigation measures are implemented, carbon dioxide (CO_2) emissions in Malaysia would have exceeded 285.73 million tonnes (68.86%) or 259,209,884 tCO_2e by 2020 (Safaai *et al*., 2011).

At the 2009 United Nations Climate Change Conference in Copenhagen (COP-15), Malaysia agreed to reduce its GHG emissions by 40% (from 1990 levels) by 2020 (DOE, 2010). Efforts to rein in urban population growth must be balanced against our way of life, which must be maintained by modifying the carbon emissions mitigation plan accordingly. As a result, by encouraging a greener economy, we can encourage lower-carbon developments. The Malaysia Sustainable Consumption Report, published by the Economic Planning Unit, identified eight major categories of the green economy that can promote low-carbon developments and lower GHG emissions (Adam & Siwar, 2012). The eight categories are renewable energy, green construction, clean transportation, water management, waste management, sustainable land management, sustainable economy, and industrial and service sector management.

It should be noted that no legislation limiting GHGs emissions in vital industries or sectors such as transportation, energy and oil exploration has been adopted at the time of this report (Zaid *et al*., 2015).

Cities can implement a variety of efficient solutions to combat climate change through initiatives that use specific assessment tools to identify the sources of GHG emissions and assign the responsibility for additional reduction actions to the correct party, agency or individual. Despite being blamed for being the primary source of GHG emissions due to their high carbon intensity, several cities have made deliberate efforts to minimise GHG emissions by introducing new low-carbon modes of transport (Mills, 2007; Banister, 2011), zero-carbon buildings (Kylili & Fokaides, 2015) and a low-carbon city lifestyles that are even more environmentally friendly than sub-urban or rural living (Dodman, 2009, Zen *et al*., 2021).

Green technology is largely addressing and managing the challenges related to handling the GHGs and climate changes in many regions of the world. This has also occurred in Malaysia. Stakeholders have undertaken a number of green projects, for example, the Energy, Green Technology and Water Ministry has published a Green Technology Master Plan (2017-2030) and a Low Carbon Society Blueprint for Iskandar Malaysia to be completed by 2025.

Climate change and green technologies have been included in several development plans, whether it is the National Physical Plan, State Structure Plan, District Local Plan or Special Area Plan level. However, carbon emissions calculations that link to local action has yet to materialise. The purpose of this study is to examine GHG emissions at the local level in Malacca. This was accomplished by defragmenting GHG emissions and identifying the sources of the emissions using a GPC assessment framework. The results of the study will contribute to the development of strategic initiatives and action plans at the local level.

Literature Review

The Global Protocol for Community-Scale Greenhouse Gas Emissions or GPC for short, intends to create internationally acceptable GHG accounting and reporting standards to harmonise emissions measurement and reporting methods for cities of all sizes, with widespread local adoption (Fong *et al.,* 2015).

Launched in 1998, GPC is a multi-stakeholder partnership includes government, businesses, non-governmental organisations (NGOs) and others. The GPC is the brainchild of the World Resources Institute (WRI), a United States-based environmental NGOs, the Sustainability for Local Government (ICLEI) and the C40 Cities Climate Leadership Group (C40) and is supported by the World Bank.

Later, the GPC was codified as an international standard reporting for sub-national governments all over the world and it was widely accepted by many nations.

City Scale of GHGs Inventory

The GPC framework and assessment, which is being carried out as a city-based strategy, considers the entire range of activities that contribute to global GHGs emissions. The GPC established three methods or means of determining organisational boundaries for GHG emissions, which mapped the activities linked to cities (WBCSD, 2004). In GPC measurement, sector analysis allows for the identification of the principal sources of emissions. For example, in the New York State Climate Smart Communities Programme, the use of GPC assists local governments in reducing GHG emissions while saving taxpayer dollars, improving the efficiency of building operations and infrastructural facilities, and advancing collective goals for health and safety, economic viability, alternative energy and wellbeing (Osofsky, 2015). The programme involves various related government agencies in the city such as the transport, health, public services and energy development authority. Finally, the programme matured into a state-local partnership that can be replicated elsewhere with minimal changes.

The purpose of a local government's GHG inventory is to get a better understanding of the sources of emissions. It can also be used to oversee and monitor the operations of sources like manufacturing and transportation. Local governments can improve their ability to control energy consumption by establishing baselines and identifying possibilities to minimise energy use and GHGs emissions. In this scenario, local governments set a good example by increasing transparency and cutting costs.

The steps that could be taken are as follows: To begin with, improving a local government's ability to regulate energy consumption allows it to identify the largest energy consumers and GHG emissions sources (e.g., by building, sector or department), allowing it to direct energy efficient technologies to the regions with the greatest opportunity. Secondly, local governments should immediately use the measures indicated above in order to inspire local businesses and communities to do the same. Thirdly, increasing accountability by publicly disclosing and explaining inventory data promotes transparency and accountability of local governments to their taxpayers in order to run efficiently and effectively use resources. And finally, financial savings from efficient energy consumption and strict inventory control will go a long way towards ensuring a healthier environment.

One of the most significant barriers to tackling local climate change is a lack of expert and human resource capacity to carry out or follow through on the GHG reduction initiatives at the local level. This is part of the bigger agenda to combat climate change which has become the main task of the local authorities. As an ICLEI member, the Local Authorities Network for Sustainability provides a learning platform and network for local personnel.

Local governments can learn about frameworks for cities adopting policies and possibilities from networks and they can also offer opportunities for local climate change leaders to communicate and engage with one another (Osofsky, 2012). An innovative empirical investigation of multilevel climate network participation across six geographically diverse United States metro locations: Atlanta, Chicago, Denver, New York, San Francisco and the Twin Cities.

Estimating GHG emissions per capita enables the identification of emission sources as well as the economic activity connected with them in specific areas. Majority of Amman, Jordan's 3.25 tCO_2e per capita emissions come from the use of fossil fuels for power and in-city ground transportation (Hoornweg *et al.,* 2011). Due to the city's reliance on fossil fuels for electricity generation in comparison to a similarly sized impoverished rural population, for instance, Shanghai's per capita GHG emissions at 12.6 tCO_2e are much greater than the country's national emissions levels at 3.4 tCO_2e. In this situation, a locally based low-carbon-based technology solution must be adapted to serve the national goal of reducing carbon emissions. Most other Organisation for Economic Co-operation and Development (OECD) countries have city-per-capita GHG emissions that are far lower than their national inventories (Hoornweg *et al*., 2011). Malaysia's per capita GHG emissions in 2010 were higher than the global average and higher than neighbouring nations such as Singapore (2.7 tCO_2e), China (6.2 tCO_2e) and Indonesia (1.8 tCO_2e) (World Bank, 2016). The National Green Technology Policy, a five-year development plan and a structural plan, all support this figure, which must be translated at the municipal/city level for climate action.

GHG inventory and measurement are linked to risk management. The collection of baseline data for GHG inventories aids in the monitoring of emissions in order to identify dangers and potential reduction possibilities (Almihoub, 2013; Bastioanoni *et al*., 2014). This is related to the identification of expenses following effective reductions, the development of GHG objectives and progress assessment and reporting. GHG inventories encourage public disclosure and participation in voluntary GHG programmes, as well as optional stakeholder disclosure of GHG emissions and progress toward goals. It sets a reporting mechanism for governments and NGOs, including greenhouse gas registries and includes provisions for eco-labelling and certification. Participation in volunteer carbon reporting projects boosts participation in government reporting programmes (Zen & Mohamad, 2021), recognised for taking proactive action and sharing information to enable the collection of baseline data. However, many governments have struggled to develop an effective national regulatory response (Peel 2011; Peel *et al*., 2012).

To create a favourable environment for the climate change programmes, baseline data and the collection thereof must be linked with a voluntary objective for GHG emissions, which must be supported by legislative authorities. For example, in accordance with the European Union, Directive 2009/28/EC that encourages the of use of energy from renewable sources, the United Kingdom has committed to obtaining 15% of its energy from renewable sources by 2020. It was an almost seven-fold increase over the previous year's share of just 2.25%. In the United Kingdom, the Localism Act 2011, the Flood and Water Management Act 2010 and the Climate Change Act 2008 were enacted to allow for the voluntary reporting of GHG emissions (Dixon & Wilson, 2013).

The regulatory approach should increase the assessment of GHGs emissions for climate action at the local level. For example, the Climate Change Act of 2008 established a legislated goal of reducing carbon dioxide emissions by at least 80% below 1990 levels by 2050 (Parry *et al*., 2008). The legislation requires the preparation of carbon budgets, techniques for reducing GHGs across government sectors and policy direction based on the sectors. The Localism Measure 2011 in the UK is another act that encourages the local government to adopt a carbon neutral stance.

As a result, the regional planning layer is abolished and a new 'obligation to cooperate' with respect to land planning for sustainable development is put in place. This project enables Local Enterprise Partnerships (LEPs) to have a role in informing development plans at the local and neighbourhood levels (Parry *et al.,* 2008). The legislation is critical in legitimising the execution of climate change programmes, which necessitates greater commitment at the municipal level. As a result of adopting a broad-scale systems approach to urban development and sustainability assessment, new opportunities for communities are created and more research on urban integrated assessment facilities is conducted (Hall *et al*., 2010).

Background of Malacca Economic Outlook

In keeping with the modernisation of the industrial sector and overall economy in the state, the services and manufacturing sectors dominate Malacca's State's economic development, accounting for up to 86% of the total share (World Bank, 2019). With its wealth of tourism items that draw visitors from across Malaysia and the world, the tourism sector has become the key driver of Malacca's economy. Many other connected services such as lodging, business and finance, benefit from the rise of the tourism sector's value chains. Malacca's Gross Domestic Product (GDP) in 2013 was RM22,646 million and the GDP per capita was RM34,109, which translates to a GDP growth rate of 3.2% (Malacca Basic Data, 2013).

As a city with a strong industry-driven economy, the industry sector employed 29% of Malacca's workforce in 2011 and accounted for 45% of the city's GDP.

Between 2011 and 2020, the city's population was predicted to increase to more than 120,000 people (World Bank, 2019). Aside from that, the number of tourists visiting the historic city of Malacca increased to 14.3 million in 2013 (Malacca Basic Data, 2013). The environmental impact of the expansion in the tourism sector is tied to a large fleet of tourist buses that is still expanding and which add to the GHG emissions in the State. Furthermore, the number of private vehicles and motorcycles owned has increased to 1.4 cars and 1.9 motorcycles per household, respectively.

During the eight-year period from 2004 to 2011, there was a huge growth in vehicle ownership, with automobile ownership increasing by 58% and motorbike ownership increasing by 4.3%. Besides the domination of services industry which account 45% from the per capita income in 2013, it followed by manufacturing sector 41.4% (Table 1). The domination of the two sectors reflects in GDP sector for 2012 and 2011 consecutively.

However, details on the sources of emissions could not be captured especially with regard to the penetration of green technologies that reduce the GHGs. Hence, a profiling analysis to understand the sources of emissions needs to be conducted to reflect and capture the economic development and the mechanism to reduce its emission. Further, profiling GHGs emissions using the GPC method can provide a more advanced understanding of the various

Table 1: Gross Domestic Product by sector, Malacca from 2011 to 2013

Sector	2011		2012		2013	
	RM (Million)	Share (%)	RM (Million)	Share (%)	RM (Million)	Share (%)
Agriculture	1,905	9.3	1,997	9.1	2,095	9.0
Mining	8	0.0	10	0.0	11	0.0
Manufacturing	8,527	41.6	9,030	41.1	9,680	41.4
Construction	579	2.8	906	4.1	1,000	4.3
Services	9,455	46.2	9,995	45.5	10,555	45.2
Import duties	8	0.0	15	0.1	16	0.1
Per Capita Income (RM)	31,093		33,550		35,283	

Source: Malacca Basic Data 2013

activities associated with it based on sector and scope. This has the potential to prioritise climate mitigation and adaptation actions based on scientific policy interventions and evidence.

Materials and Methods

The research in this paper was conducted in the following sequence: The GPC method for Malacca, the scoping and sector analysis of GPC, the geographical boundary of the study, the basic GHG emission inventory, the identification of data sources and the collection of the same. The research thresholds were identified based on the annual inventory data related to GHGs emissions from various government and private entities in Malacca-based industries as explained in the GPC framework used for the assessment.

The research looked at the 2013 GHG inventory data generated for Malacca: GHG SEIR, 2013 (2016). The data collection and drafting of the inventory was carried out in accordance with the established principles and criteria set out by the GPC, which may be used by local governments to quantify GHG emissions from the entire community and sectors (WBCSD, 2004). The assessment system considers the geographical borders of cities and regions.

Global Protocol for Community-Scale Greenhouse Gas Emissions (GPC) for Malacca

The GPC method is explained in detail in the next three sections which cover: The scoping and sector analysis of GPC, the basic GHGs emission inventory, the geographical boundary and data identification and collection.

The Scoping and Sector Analysis of GPC

The scope includes both direct and indirect operating boundaries for GHG emissions. Under the GPC, three scopes are defined (Figure 1). The first part of the scope is concerned with all the direct GHGs generated by the combustion of in-boundary fossil fuels (WBCSD, 2004). This includes emissions from the combustion of petrol, diesel, natural gas or fuel oil, as well as

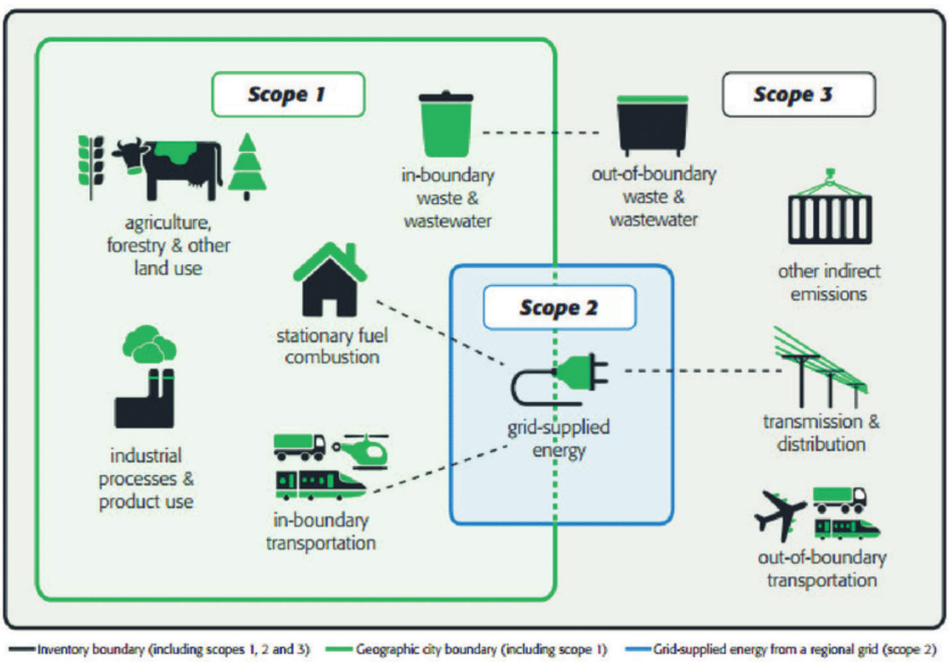

Figure 1: An overview of the scopes of GHGs emissions
(Protocol 2011)

emissions from non-energy industrial operations and waste; the second section addresses indirect GHGs emissions from imported power. Examples include emissions from upstream and downstream, transportation services not regulated by the reporting entity, outsourced activities, recycling and waste management, and so on; meanwhile, the third scope includes all other indirect GHGs emissions linked to the supply chain life cycle of materials and energy carriers used within the boundary that are produced outside the boundary (WBCSD, 2004).

Sector analysis was utilised to define the GHGs inventory in order to classify distinct emission sources (WBCSD, 2004). Identification of sectors with high levels of emissions helps cities to use the best direct solutions to mitigate GHGs emissions for a strong internal adaptive resilience capacity. The four major sorts of sectors have already been highlighted.

Basic GHGs Emission Inventory

GHG emissions were created by unfavourable elements released into the atmosphere as a consequence of human activities. As a result, communities must compile baseline data for GPC based on source emissions to plan for future mitigation activities. Approximately, 99% of GHG emission inventories contained carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (N_2O) gases that contribute to global GHG emissions.

The data is presented in terms of total carbon dioxide equivalent (CO_2e) emissions, which is calculated using the GHG 100-year Global Warming Potentials (GWPs) for CO_2. The GWP of each measured gas is taken into account in order to calculate the CO_2e over a 100-year period.

This means that the warming effect of each GHG's impact on the atmosphere with a focus on CO_2. Table 2 explains the GWP values based on the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.

It is not possible to conduct a direct physical measurement of GHGs that are emitted to determine the emission levels of GHGs from various activities carried out in a region.

The most popular method for estimating GHG emissions is to use the emission factor concept outlined in Equation 1 (IPCC, 2006) and relevant activity data to estimate the emissions levels.

$$\text{GHGs A} = \text{EF A} \times \text{D A} \quad (1)$$

where:
GHGs A = GHGs emissions resulting from activity A
EF A = emission factor for activity A
D A = data for activity A

The emission factor for a specific activity is calculated by calculating the amount of energy utilised and the direct emissions of GHGs because of the activity. It is represented in this equation by data for activity A or any activity that emits carbon as defined in the sectoral assessment laid out in the GPC framework (WBCSD, 2004). The four major sectors are as follows:

i. Stationary units (residential buildings e.g., electricity, commercial/institutional buildings and facilities e.g., electricity, manufacturing industry and construction, agriculture, forestry and fishing activities).

Table 2: Global Warming Potential (GWP) values for GHGs

Name	Formula	GWP Values for 100 Years (CO_2e)
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265

Source: IPCC Third Assessment Report (2001)

ii. Mobile units (on-road/ground transportation, railway, aviation (Landing and Take Off).

iii. Waste (solid waste disposal, biological treatment of waste).

iv. Agriculture, forestry and livestock. The various sorts of data for each sector such as electricity per kWh, travel distance per km, and so on will be estimated based on their emission factor. As a result, each source of emissions sector serves as a parameter in the study.

Emission variables might vary depending on the place you live as well as the technology you utilise. The emission factor per kWh of electricity used, for example, may differ between countries or regions due to variances in energy mix, fuel characteristics and power generation efficiency (IPCC, 2006). The emission factor per kilometre travelled varies depending on the fuel conditions, engine characteristics of the vehicle, the driver, driving conditions and traffic patterns. For an effective estimate of the GHG inventory, it is necessary to use the emission factor most suited to the area. This research paper used the Malaysian emission factor, which was included in the HEAT+ software, for this exercise. Several key components from the Malacca GHG inventory (2013, 2016) were highlighted during the process.

Geographical Boundary of the Study

The determination of geographical boundary for the collection of data to be used to calculate the GHG emission data it is crucial to comply with GPC assessment framework. This is related with the source of emissions and the level of economic activity and the authority of the body that is responsible for the mitigation action.

Malacca, a renowned tourist destination is located on Peninsular Malaysia's southwest coast, near to the Straits of Malacca. Its northern boundary is shared with Negeri Sembilan and its southern border is shared with Johor (Figure 2).

Malacca's Historical City Council, the Hang Tuah Jaya Municipal Council, the Alor Gajah Municipal Council and the Jasin District Council were chosen for this study (Figure 1). As of 2014, the recorded population in the area under review was 862,500 people with 25% of the population under the age of 15 and 7% over the age of 60. This demonstrates that the productive age group accounts for 68% of Malacca's population. The state's population has increased dramatically, from 830,900 people in 2011 to 952,500 people in 2020 with the annual growth rate of 1.5%. Malacca's ethnic structure is consisting of Malay (66%), Chinese and Peranakan (25.9%), Indians and Chitty (6.2%) and the Kristang and Dutch Eurasian minorities (Malacca Basic Data 2016).

Malacca is divided into three primary districts, each with its own jurisdiction and has a total area of 1,663.1 sq. km (Table 3). Much of this area, 82% of the total is used for agricultural activity which is predominantly conducted in Alor Gajah (673.8 sq. km) and Jasin (689.2 sq. km). Table 3 shows the area and population numbers for four different local authorities.

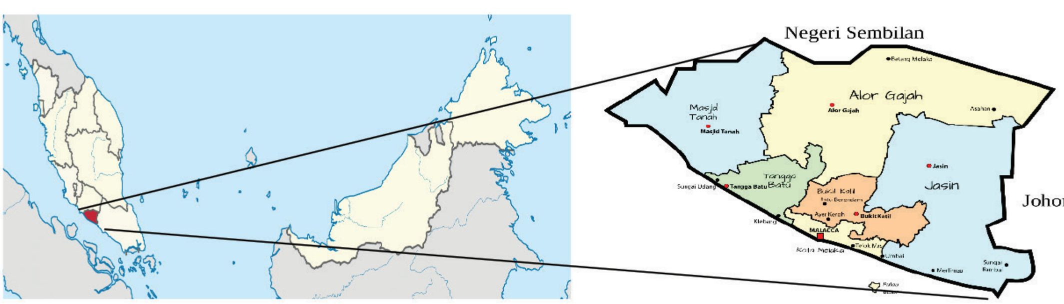

Figure 2: Location of local government in Malacca
Source: Malacca Basic Data (2016)

Table 3: Administrative division of Malacca State

District	Area (sq. km)	Population (2013)	Local Government
Central Malacca	300.1	522,200	1. Malacca Historical City Council 2. Hang Tuah Jaya Municipal Council
Alor Gajah	673.8	192,200	3. Alor Gajah Municipal Council
Jasin District	689.2	138,800	4. Jasin District Council
Total	**1,663.1**	**852,400**	

Source: Malacca Basic Data 2013

Central Malacca has the highest urban density, with a population of 522,200 people in an area covering 300.1 sq. km, accounting for only 18% of the entire administrative area.

The population of Central Malacca accounts 61% of the total population of the state. This includes the historic Malacca centre, the newly planned district of Hang Tuah Jaya (Malacca's administrative centre), which was established in 2010. The agriculturally dominant areas of Alor Gajah and Jasin, which account for 82% of the total area, have a slightly lower population of about 331,000 people in 2013 or 39% compared with Central Malacca. This statistic reveals that Central Malacca has a high population density, which accounts for the concentration of economic activity in that area.

Data Identification and Collection

Emissions from stationary units (residential, commercial/institutional facilities, industrial, agricultural), mobile transportation, trash, industrial processes and product consumption, as well as agriculture, forestry and land-use were considered when calculating the GHG emission levels in the GPC (Table 4). The energy consumption and GHG emissions from the water supply, wastewater treatment and street lighting facilities were also included in the community-wide energy and emissions data.

The community-level inventory contains emissions within the state, which includes the four local governments covering the supply-side and demand-side energy sectors, based on secondary data acquired from various government agencies and commercial entities in the state.

The base year was chosen based on data availability for all source of emissions for each sector that was both compatible and representative. Due to data limitations, the calculation of GHG emissions was not conducted for each local authority. The data from all sources of emissions was collected from government agencies representing the state (Table 4). The types of data collected are described in Table 5.

Data was collected for 2013, to better understand the changes in the levels of energy use and GHGs emissions across industries in the city. Finally, the baseline year, 2013, was utilised as the baseline for the state's GHGs inventory. The data was then examined using ICLEI's online software programme, Harmonised Emissions Analysis Tool (HEAT+) (Local Government for Sustainability).

Data Analysis by HEAT+

After the data collected, the various sources of emission sectors data were aided by the ICLEI online software tool, which used the Harmonised Emissions Analysis Tool (HEAT+). The software contains the IPCC's most recent technical findings and guidelines and it accounts for the GHGs emissions reports in accordance with the Global Protocol for Community-Scale for GHG Emissions.

The HEAT+ tools are intended to assist regional and local governments in estimating and

Table 4: GPC's sectoral based and sources of emission data

Sector	Sub-sector	Sources	Data Carbon Emission (tCO_2e)
Stationary energy	Residential buildings	Grid electricity	Tenaga Nasional Berhad (TNB), Suruhanjaya Tenaga (ST)
		Kerosene	Petron, PETRONAS, Shell
		LPG	Gas Malaysia Berhad
	Commercial and institutional buildings and facilities	Grid electricity	Tenaga Nasional Berhad (TNB), Suruhanjaya Tenaga (ST)
		Street lighting (Grid electricity)	Tenaga Nasional Berhad (TNB)
		Kerosene	Petron, PETRONAS, Shell
		LPG	NGC Energy, Gas Malaysia Berhad
	Manufacturing industries and construction	Grid electricity	Tenaga Nasional Berhad (TNB), Suruhanjaya Tenaga (ST)
		PNG	Gas Malaysia Berhad
		Petrol	BH Petrol, Chevron
		Diesel	Petron, PETRONAS, Shell
		Furnace oil	Petron, PETRONAS, Shell
	Energy industries supplied to the grid	Diesel	Petron, PETRONAS, Shell
		Natural gas	Gas Malaysia Berhad
	Agriculture, forestry and fishing activities	Grid electricity	Tenaga Nasional Berhad (TNB), Suruhanjaya Tenaga (ST)
Mobile transportation	On-road transportation	Petrol	Panorama Melaka Sdn Bhd, Lembaga Lebuhraya Malaysia (LLM)
		Diesel	Mara Liner Sdn Bhd
		CNG/NGV	Gas Malaysia Berhad
	Railway transportation	Grid electricity	Tenaga Nasional Berhad (TNB), Suruhanjaya Tenaga (ST)
		Diesel	Keretapi Tanah Melayu Berhad (KTMB)
	Civil aviation	Landing and Take Off (LTO)	Malaysia Airlines Holdings Berhad (MAHB), Lembaga Penerbangan Awam Malaysia (CAAM)
Waste	Solid waste disposal		SW Corp
	Biological treatment of solid waste		Indah Water Konsortium (IWK), Syarikat Air Melaka Berhad (SAMB)
AFOLU	Livestock emission		Jabatan Perkhidmatan Veterinar Negeri Melaka (DVS), PLAN Malaysia, Jabatan Pertanian Negeri Melaka, Jabatan Perhutanan Negeri Melaka

Table 5: Type of data represent parameter for sectoral GPC framework of assessment for Malacca in 2013

Sector	Type of Data Collected	Unit of Measurement (SI)
Stationary Units		
Residential buildings e.g., electricity	Electricity consumption	kWh/year
Commercial/institutional buildings and facilities e.g., electricity	Electricity consumption	kWh/year
Manufacturing industry and construction	Electricity consumption	kWh/year
Agriculture, forestry and fishing activities	Area	Hectare
Mobile Units		
On-road/ground transportation	Fuel consumption (petrol, diesel)	Litre/year
Railway	Rail transportation fuel consumption (freight and passenger)	kL
Aviation	(Number of Landing and Take Off) Typical aircraft	
Waste		
Solid waste disposal	Amount of waste collected	Tonnage
Biological treatment of waste		
Agriculture, Forestry and Land Use (AFOLU)		
Livestock	Per capita cattle emission Methane emissions from enteric fermentation* CH_4 emissions from manure management	

Note: *Methane emissions from Enteric Fermentation – Enteric fermentation is a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal. Enteric fermentation produces methane as a by-product, with ruminant animals (e.g., cattle, sheep) being the primary source but nonruminant animals (e.g., pigs, horses) also emitting CH_4

totalling emissions of the six key GHG pollutants to generate a comprehensive emissions inventory.

Results and Discussion

Malacca Per Capita GHGs Emission

As per the HEAT+ analysis, Malacca's per capita GHGs emissions are 4.89 tonnes CO_2 equivalent (tCO_2e). In 2013, it had a population of 852,400 people and total GHGs emissions of 4,172,333.10 tCO_2e (Table 6).

The figure was higher than the global average per capita GHGs emissions of 4.6 tCO_2e but lower than Malaysia's average per capita GHGs emissions of 7.7 tCO_2e in 2010. However, the tourism sector contributes the most to GHGs emissions. It is possible that the result will be skewed as a result of the influx of tourists. As a result, careful data interpretation is required, considering the activity that becomes the source of emissions.

Table 6: GHGs emission by sector in Malacca State for 2013

Sector	GHGs Emissions (tCO_2e)	Share (%)
Stationary Units	2,661,583.33	63.79
Residential buildings e.g., electricity	499,654.88	11.98
Commercial/institutional buildings and facilities e.g., electricity	574,844.16	13.78
Manufacturing industry and construction	1,548,411.50	37.11
Agriculture, forestry and fishing activities	38,672.79	0.93
Mobile Units	1,165,108.94	27.92
On-road/ground transportation	1,160,333.48	27.81
Railway	4,411.96	0.11
Aviation (Landing and Take Off)	363.49	0.01
Waste	268,829.37	6.44
Solid waste disposal	268,828.81	6.44
Biological treatment of waste	0.56	0.00
Agriculture, Forestry and Land Use (AFOLU)	76,811.46	1.84
Livestock	76,811.46	1.84
Total	**4,172,333.10**	**100**

Supply Side Energy, GHG Emissions and Scope Analysis

The supply-side analysis covers a variety of energy mix sources. The supply-side energy classification refers to the types of primary and secondary energy that are supplied to the demand-side sectors for use such as liquid, solid and gaseous fuels, electricity and renewables. Table 7 summarises the energy types consumed in Malacca in 2013 and the resulting GHG emissions. Scopes 1 or (‘territorial’) emissions reports emissions occurring within the geographic boundary of a city, indicating a large contribution from electricity in the state’s residential and business infrastructure. The Scope 1 of emissions includes source of energy (both stationary and in-boundary transport), waste and wastewater, and AFOLU.

In Malacca, indirect electricity accounts for the major share of energy sources, accounting for an estimated 34% of the energy mix. Whereas petrol and diesel account for 53% of the energy mix, they are mostly used in the industrial sector and to meet energy demand for road transportation. Indirect electricity uses account for almost two-thirds of the state’s GHGs emissions. This is followed by petrol and diesel, which account for 18% and 15% of state GHGs emissions, respectively. As a result, natural gas stands, which meet a significant portion of energy demand in the industrial sector. Because natural gas is a cleaner fuel, its percentage of GHGs emissions in relation to its share of the energy mix is substantially lower than that of diesel and petrol.

Emissions and Demand Side Energy

Within a geographical area, this refers to the energy used by the final consumer or sectors such as residential, commercial/institutional, industrial, agricultural, and transportation. On-the-road transportation accounts for 43% of Malacca’s energy consumption (Table 7). This is followed by energy consumption by industries, which accounts for 33.3% of total energy consumption.

Table 7: Energy mix, GHGs emission and scope analysis in Malacca in 2013

Fuel/Energy Source	**Energy Use by Source Category (GigaJoule)**		**GHGs Emission by Source Category (tCO_2e)**	
	Stationary Units[1]	**Mobile Units[2]**	**Stationary Units**	**Mobile Units**
Diesel	1,174,641	6,462,741	91,421	480,369
Petrol	27,773	9,842,406	2,162	684,331
Natural gas	3,642,977	388	204,935	46
Furnace oil	59,379	-	4,621	-
LPG	371,816	-	23,520	-
Kerosene	13,270	-	960	-
Indirect electricity	11,339,100	-	2,333,965	-
Total			**2,661,584**	**1,164,746**
Scope Analysis			**Scope 1**	**Scope 3**

Note: [1]Refers to energy use and GHGs emissions resulting from stationary fuel combustion and consumption of grid electricity in stationary units such as buildings, facilities, boilers, furnaces, burners, turbines, heaters, incinerators etc. [2]Refers to energy use and GHGs emissions resulting from fuel combustion and consumption of grid electricity in mobile transit or transportation modes such as road, rail, water and aviation (Modify from ICLEI 2016. HEAT+ analysis)

The usage of energy in the households and commercial sectors, which amounts to 8.0% and 8.7%, respectively is especially significant. As a result, one of the most prevalent tactics used by cities to attain a carbon neutral stance or mitigate GHGs is a fuel switching energy policy (Kennedy *et al*., 2012).

Sector and Scope Wise Analysis

A sector-by-sector analysis of GHGs emissions showed that industry contributed 37.11% (1,548.412 tCO_2e) of total GHGs emissions in Malacca in 2013 (Table 8). It is supported by an increase in the number of factories from 432, 398, 405 and 435 in 2010, 2011, 2012 and 2013. (Malacca Basic Data 2013). It is followed by in-boundary transportation (29.9%) (1,160,333 tCO_2e), business (14.7%) (574,844 tCO_2e), domestic (12.8%) (499,655 tCO_2e), agriculture (2.8%) (108,069 tCO_2e) and trash (0.4%) (15,643 tCO_2e) (Table 8).

This increase in carbon emissions must be accompanied by a variety of strategic policy instruments based on low-carbon energy technologies and systems, as well as a regulatory approach (IPCC, 2007). To avoid or reduce the "carbon lock-in effect" caused by inefficiencies in the sectors and ageing infrastructure and the prolonged operation of obsolete technologies, it is necessary to mainstream the installation of new technologies, especially clean and green technology. Current systems are very energy-reliant and results in widespread "carbon lock-ins" (Brown *et al.*, 2007).

Within the boundaries of Malacca, approximately 72.1% of GHGs emissions are categorised as scope 1 or production-based emissions (Table 9). Only roughly 0.51% of GHGs emissions outside the boundary are classed as scope 3 or consumption-based emissions. Scope 3 emissions come from trash, aircraft and maritime transport and are embodied in the city's fuel, food, building materials and water. The results suggest that the highest concentrations of carbon emissions are localised in Malacca and its cities.

About 27.5% of GHGs emissions co-share under scopes 1, 2 and 3, indicating a large contribution from electricity in the state's

Table 8: Energy use by sector in Malacca in 2013

Sector	GHGs Emission (tCO_2e)	Share (%)
A. Stationary Units	2,755,5218.43	72.07
Residential buildings	612,270.76	16.04
Commercial/institutional facilities	688,804.61	17.85
Manufacturing industry and construction	1,548,411.50	37.25
Agriculture, forestry and fishing activities	38,672.79	0.93
B. Mobile Units	1,165,108.94	27.93
On-road transportation	1,160,333.48	27.81
Railway	4,411.96	0.11
Aviation (Landing and Take Off)	363.49	0.01
Total A + B	**3,826,692.26**	**100**

Table 9: GHGs emission by sector in Malacca State for 2013

Sector	GHGs Emissions (tCO_2e)	Share (%)
A. Stationary Units	2,661,583.33	63.79
Residential buildings e.g., electricity	499,654.88	11.98
Commercial/institutional buildings and facilities e.g., electricity	574,844.16	13.78
Manufacturing industry and construction	1,548,411.50	37.11
Agriculture, forestry and fishing activities	38,672.79	0.93
B. Mobile Units	1,165,108.94	27.93
On-road/ground transportation	1,160,333.48	27.82
Railway	4,411.96	0.11
Aviation (Landing and Take Off)	363.49	0.01
C. Waste	268,829.37	6.44
Solid waste disposal	268,828.81	6.44
Biological treatment of waste	0.56	0.00
D. Agriculture, Forestry and Land Use (AFOLU)	76,811.46	1.84
Livestock	76,811.46	1.84
Total A+B+C+D	**4,172,333.10**	**100**

residential and business infrastructure. In Table 8, scope 2 (consumption-based emission) is defined as emissions released outside the city's geographical boundaries, the Central Malacca, that enable energy, including electricity and district heat, to be consumed by the infrastructure in Central Malacca.

In general, energy indirect emissions are caused by grid electricity used in municipal buildings and street lighting. Malacca's local governments utilised 97,140 gigajoules of energy in 2013, contributing to a total GHG output of 17,013 tCO_2e. GHG emissions from electricity consumption and emissions from buildings owned by the state's local governments in 2013 indicated that Historical Malacca City Council accounts for 60% or 2,332 tCO_2e and Hang Tuah Jaya Municipal Council, which accounts for 27% or 1,059.6 tCO_2e. The two-city council are in Central Malacca, which has the largest urban population density (61%) yet only accounts for 18% of the overall administrative area. The remaining 82% of the overall land is still primarily agricultural land with lower population densities and is overseen by two local governments: Alor Gajah and Jasin (Figure 1, Figure 2 and Table 1).

Despite, the GDP economic data and size of the area reflect high concentration of economic activity in the manufacturing and service sectors in the urban area, Central Malacca. The result from GPC method details the outsourcing of high intensity of GHGs emissions from the government buildings and infrastructure. This justifies the need for low-carbon infrastructure (Kennedy *et al*., 2014).

The energy indirect emissions from grid electricity contributed by local government buildings and street lighting reveal that approximately 60% or 2,332 tCO_2e resulting from electricity consumption and GHGs emissions from buildings owned by the Malacca City Council and approximately 27% or 1,059.6 tCO_2e from the Hang Tuah Jaya Municipal Council. Additionally, street lighting consumes the most energy in the state, accounting for more than 43% of total electricity usage, followed by water supply and wastewater treatment. The Malacca City Council has historically had the largest GHGs emissions, contributing 4,298.1 tCO_2e for street lighting, followed by Hang Tuah Jaya Municipal Council with 3,129 tCO_2e, Alor Gajah Municipal Council with 2,163.7 tCO_2e and Jasin City Council with 1,867.3 tCO_2e. This is where the advantages of being part of a multilayer network at the local, state, regional, national and international levels come into play to promote local action (Zen *et al*., 2019). Malacca as an ICLEI member has begun the process of compiling its GHGs inventory.

Conclusion

To protect renewable and low-carbon energy supplies by adopting decentralised energy policies, a large percentage of the energy mix must be in mix mode development. Furthermore, the proposed new development must consider the utilisation of renewable and low-carbon energy infrastructure. The environment must be given significant weight by combining the social and economic benefits of renewable and low-carbon energy initiatives. Recognising the importance of small scale power projects in contributing to the local region, as well as contributing to the secure supply of power and the reduction of GHGs is very important. Local planning authorities should charge developers with providing well-designed buildings within a high-quality locally sourced materials that are well adapted to the local environment, resulting in a low carbon footprint in a dynamic climate. Priority should be given to proposed developments that consider zero-carbon or energy-efficient building standards.

Grid electricity from two local government buildings, the Malacca City Council and Hang Tuah Jaya City Council, and street lighting dominate electricity use from indirect energy emissions. As a result, local governments must upgrade to low-carbon infrastructures and implement energy-efficiency programmes. The two are in Central Malacca, which has the largest urban density yet only accounts for 18% of the overall administrative area.

Demand must be generated for bio-energy fuels, which have been shown to result in net carbon emissions reductions due to manufacturing methods, transportation requirements, and/or the loss of carbon sinks. As a result, support for sustainable waste management is required as well as the provision of proper spaces for recycling and composting. Manufacturing and services are the two leading economic sectors in Malacca, with the manufacturing sector maintaining a consistent economic share, while the service industry (medical and cultural tourism related) continues to grow at a rapid pace. As a city in a relatively tiny state, the impact of the manufacturing sector on the GHG emissions is high. As a result, a large portion of the manufacturing sector is well-suited to embracing greener and cleaner technologies in line with the green economy agenda and its eight areas of concern.

A rise in the proportion of trips done in the local region by sustainable modes, particularly active travel modes, is essential under clean transportation. It is vital to have safe and enticing walking and cycling options, including secure cycle parking and, if needed, showers and changing facilities. Managing the availability of car parks, including the supply of electric vehicle charging infrastructure, must be enticing enough encourage people to actively seek to lower greenhouse gas emissions.

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