SG Laws and Regulations

1. Building Control Act

- **Regulation Overview**: This act sets the minimum standards for building safety, structural integrity, and environmental sustainability. It covers the requirements for building design and construction to ensure safety and quality.
- **Relevance to the Project**: The sustainability aspect of this act is crucial for understanding how building design influences energy consumption and GHG emissions. Buildings that comply with the act are likely to have better energy efficiency and lower emissions. Our GHG calculator can leverage this information to assess whether buildings meet minimum efficiency standards, allowing users to identify improvement areas based on compliance with these regulations.

2. Energy Conservation Act

- **Regulation Overview**: This act mandates large energy consumers (those using more than 54 TJ of energy annually) to submit energy consumption reports and conduct regular energy audits. This encourages organizations to implement energy-saving measures.
- **Relevance to the Project**: The energy reports and audit requirements provide valuable data for our GHG calculator. By integrating this energy consumption data, this tool can accurately assess the actual energy usage and associated GHG emissions of buildings. Users can track energy consumption patterns and identify opportunities for reducing waste and emissions.

3. Green Mark Scheme

- **Regulation Overview**: This is a voluntary rating system that promotes sustainable design and performance in buildings through energy efficiency, water conservation, and environmental protection. Buildings can receive different ratings (e.g., Platinum, Gold) based on their sustainability features.
- **Relevance to the Project**: The Green Mark certification can serve as a benchmark for the GHG calculator. The energy efficiency and emission levels of buildings with different Green Mark ratings can vary significantly. Our calculator can incorporate these ratings to help users understand how different efficiency levels affect GHG emissions. Additionally, companies can use the GHG tool to evaluate their performance relative to Green Mark standards and identify potential improvements.

4. Carbon Pricing Act

- **Regulation Overview**: This act imposes a carbon tax on facilities that emit more than 25,000 tonnes of GHGs annually, incentivizing reductions in carbon emissions and the adoption of cleaner technologies.
- **Relevance to the Project**: The carbon pricing information can be integrated into the GHG calculator to help businesses calculate the potential costs of their carbon emissions. If users' buildings exceed the carbon tax threshold, the calculator can estimate the associated tax burden, providing financial insights for operational decisions. Understanding the carbon pricing framework can also help users assess the return on investment for emission reduction strategies, as lowering GHG emissions not only reduces tax liabilities but can also lead to long-term cost savings.

5. Environmental Protection and Management Act (EPMA)

- **Regulation Overview**: This act focuses on controlling environmental pollution, particularly in terms of energy consumption standards and air emissions.
- **Relevance to the Project**: The standards and requirements of EPMA directly influence the design of the GHG calculator. As companies comply with EPMA regulations, they must ensure that their emissions meet legal requirements. This provides a framework for our GHG calculator to generate compliance reports, ensuring that users adhere to local emission regulations. By analyzing compliance with EPMA, the calculator can identify opportunities for further reducing direct emissions.

Summary table

Regulation Name	Effective Date	Main Requirements	Applicable Parties	Remarks	Relevance
Building Control Act	1 Dec 2010	Mandatory submission of Green Mark certification for new buildings. Minimum environmental sustainability standards required.	Building developers, owners, construction companies	Helps identify GHG emissions factors linked to building design	Ensures that the GHG tool accounts for different sustainability tiers.
Energy Conservation Act (ECA)	22 Apr 2013	Large energy users must submit energy consumption reports and conduct energy audits	Companies consuming more than 54TJ of energy annually	Energy audit results provide input data for the GHG calculator.	Ensures accurate energy consumption data integration.

		regularly.			
Green Mark Scheme	2005	Assessment of energy efficiency, water efficiency, and environmental protection standards for buildings.	Property developers, building owners	Aligns with international standards for carbon footprint measurement	GHG tool should integrate Green Mark energy efficiency data.
Carbon Pricing Act	1 Jan 2019	Mandatory reporting and payment of carbon tax for facilities emitting more than 25,000 tonnes of GHG annually.	Facilities exceeding GHG emissions threshold	Determines reporting thresholds and penalties for carbon emissions.	Important for understanding emission factors and cost-saving measures.
Environmental Protection and Management Act (EPMA)	1 Jul 2021	Specifies air emissions standards and control limits on energy consumption and environmental pollutants for industries.	Manufacturing , heavy industries	Ensures compliance with emission standards for corporate operations	Can be used to calculate Scope 1 and Scope 2 emissions.

Benchmarks

Through researching the above laws and regulations, we found out that:

The **Building Control Act(BCA)** did not specify any detailed benchmarks for greenhouse gas (GHG) emissions specific to office buildings. It serves as a broad framework for regulating building safety, structural integrity, and energy efficiency, with a focus on compliance with safety and environmental standards. However, it lacks explicit guidelines or emission factors tailored for GHG calculations in office settings. As such, for a more precise validation of emissions, benchmarks from internationally recognized protocols like those from the IPCC or regional schemes such as the Green Mark certification system are more appropriate.

The **Environmental Protection and Management Act (EPMA)** primarily establishes broad regulations for pollution control in Singapore, but it doesn't specify detailed benchmarks for greenhouse gas (GHG) emissions specific to office buildings. Instead, the Act outlines general requirements and restrictions for pollution and emissions, with additional detailed guidelines and standards typically established by agencies like the National Environment Agency (NEA) or the Building and Construction Authority (BCA).

The **Energy Conservation Act** outlines requirements for corporations in Singapore to report their energy use and greenhouse gas (GHG) emissions if they meet certain thresholds. While it doesn't provide specific emission limits per unit of gross floor area (GFA) for buildings, it does require companies that meet defined energy use thresholds to:

1. **Register** with the Director-General if their energy consumption exceeds set levels.
2. **Report** their energy consumption and GHG emissions periodically, as prescribed, based on standards established by the National Environment Agency

The **ISO 14064** standard provides frameworks for quantifying and reporting greenhouse gas emissions. Under this standard, benchmarks for building emissions are categorized by Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy), and Scope 3 (other indirect emissions from activities like transportation and waste management). The **WRI's Greenhouse Gas Protocol** also serves as a globally accepted framework for tracking and reporting GHG emissions, offering specific methodologies for calculating emissions across various sectors and scopes. Both ISO 14064 and the Greenhouse Gas Protocol are essential references for establishing internationally recognized benchmarks.

However, we did not use ISO 14064 and the WRI's protocol as benchmarks for this project because these frameworks, while comprehensive, are more general and apply to a wide range of industries and sectors. They do not provide the level of specificity required for office building GHG emissions in the context of Singapore's unique environmental and regulatory landscape.

Green Mark Scheme

- The **Green Mark 2021 scheme** now prioritizes energy efficiency as a critical criterion. Certification levels under this scheme are mainly based on achieving specified energy-efficiency targets. For example, Super Low Energy (SLE) Buildings must demonstrate energy consumption reduction of over 60% compared to standard buildings. For new developments, 80% of the building's gross floor area (GFA) is expected to achieve these SLE standards by 2030.
- Buildings certified under this scheme must also adhere to performance-based recertification, which considers energy consumption and carbon emissions over the building's operational lifecycle. These improvements are aimed at helping Singapore meet its target to green 80% of buildings by 2030.

In our collected dataset, we identified the Green Mark award granted to each building. Given the accessibility of the data and the convenience of validating against a locally relevant standard, we have chosen the Green Mark certification scheme as our primary benchmark for validation.

Validation System

Benchmarking Based on Green Mark Certification

- The **Green Mark award level** (e.g., Platinum) implies that certain energy efficiency and sustainability standards were met when the award was given. For instance, a **Platinum** level certification typically requires a high standard of energy performance.
- Buildings with a **Platinum Green Mark** might be expected to show lower GHG intensity (e.g., emissions per square meter of GFA) than buildings without such awards. We could use this expectation as a criterion for cross-validation.

Validation Rules

These thresholds are based on the Green Mark certification standards and BCA's requirements for energy efficiency and environmental standards.

1. Platinum

- **Energy Efficiency**: The building should achieve an **Envelope Thermal Transfer Value (ETTV) ≤ 40 W/m²** for air-conditioned spaces and **≥30% energy savings** compared to a reference model.
- **GHG Intensity (tCO_2e per m^2)**: For Platinum, consider a **GHG Intensity ≤ 0.1 tCO_2e/m^2**, which reflects the high standard expected of Platinum-rated buildings in terms of emissions per square meter of GFA.
- **Water Efficiency**: Systems should use highly efficient fixtures, ideally with ≥80% of water fittings rated at the highest efficiency under the Water Efficiency Labeling Scheme (WELS).

2. GoldPLUS

- **Energy Efficiency**: An **ETTV of 42 W/m² or lower** is required, along with a **minimum of 25% energy savings**.
- **GHG Intensity**: Aim for **GHG Intensity ≤ 0.12 tCO_2e/m^2**. GoldPLUS-certified buildings are still highly efficient but do not reach the same stringent criteria as Platinum.
- **Water Efficiency**: At least 70% of water fittings should be of high efficiency (using WELS ratings).

3. Gold

- **Energy Efficiency**: Achieve a **Green Mark Score between 75 to <85**. No specific ETTV is enforced, but the building should show a **minimum of 15-20% energy savings** over the baseline.
- **GHG Intensity**: Set a threshold of around **0.15 tCO_2e/m^2**.
- **Water Efficiency**: Systems should include efficient water fittings, with at least 60% of fittings having high-efficiency ratings.

4. Certified

- **Energy Efficiency**: These buildings meet the basic Green Mark standards, with a **Green Mark Score of 50 to <75**. Basic energy efficiency measures are in place, although specific ETTV values are not stipulated.
- **GHG Intensity**: For buildings that only meet the Certified standard, we can use **GHG Intensity thresholds of up to 0.2 tCO_2e/m^2**.
- **Water Efficiency**: These buildings should meet minimum water efficiency, with around 50% of fittings rated under the WELS system.

Summary Table:

Green Mark Level	Energy Efficiency (ETTV or % savings)	GHG Intensity (tCO_2e/m^2)	Water Efficiency (WELS Rating)
Platinum	ETTV ≤ 40 W/m², ≥30% savings	≤ 0.1	80% high-efficiency fittings
GoldPLUS	ETTV ≤ 42 W/m², ≥25% savings	≤ 0.12	70% high-efficiency fittings
Gold	15-20% savings over baseline	≤ 0.15	60% high-efficiency fittings
Certified	Basic compliance, 10% savings	≤ 0.2	50% high-efficiency fittings

Assumptions and Reasoning for each threshold:

1. Platinum Level: GHG Intensity ≤ 0.1 tCO_2e/m^2

- **High Performance**: The Platinum certification is the highest Green Mark level, reserved for buildings that demonstrate exceptional energy performance and sustainability. To achieve this level, buildings often must incorporate advanced energy-saving technologies and sustainable practices that significantly reduce GHG emissions.
- **Reference to Energy Efficiency**: Platinum buildings are required to achieve substantial energy savings (30% or more). In a typical office building, achieving this level of energy efficiency would likely correlate with a very low GHG Intensity per square meter. Based on industry reports and similar high-performance buildings globally, achieving a GHG Intensity of around **0.1 tCO_2e/m^2** is feasible for well-optimized, energy-efficient buildings.
- **Benchmark Comparison**: In contexts where buildings meet rigorous energy standards, such as LEED or BREEAM, emissions intensity of **≤ 0.1 tCO_2e/m^2** is a realistic target. This assumption allows for a benchmark that reflects the high sustainability expectations of Platinum-certified Green Mark buildings.

2. GoldPLUS Level: GHG Intensity ≤ 0.12 tCO_2e/m^2

- **Moderately High Efficiency**: The GoldPLUS level represents a high standard but is slightly less stringent than Platinum. Buildings at this level are expected to achieve at least 25% energy savings. As a result, they may have a slightly higher GHG Intensity compared to Platinum but still fall within a low emissions range.
- **Assumption Based on Savings**: Given the reduced energy savings requirement, a reasonable increase in the threshold (up to **0.12 tCO_2e/m^2**) reflects this slightly lower efficiency target. This benchmark aligns with moderate energy-saving improvements that are still considerable but not as aggressive as Platinum requirements.

3. Gold Level: GHG Intensity ≤ 0.15 tCO_2e/m^2

- **Balanced Efficiency**: Gold-certified buildings are expected to have 15-20% energy savings. This level is a middle ground, reflecting a solid commitment to energy reduction without necessarily achieving high-end performance.
- **Slightly Higher Intensity**: A target of **0.15 tCO_2e/m^2** is reasonable for buildings achieving modest energy efficiency measures and is comparable to intermediate benchmarks used by other green building certifications. This assumption provides a manageable threshold for buildings that make energy-saving upgrades but don't incorporate more advanced technologies as seen in Platinum and GoldPLUS.

4. Certified Level: GHG Intensity ≤ 0.2 tCO_2e/m^2

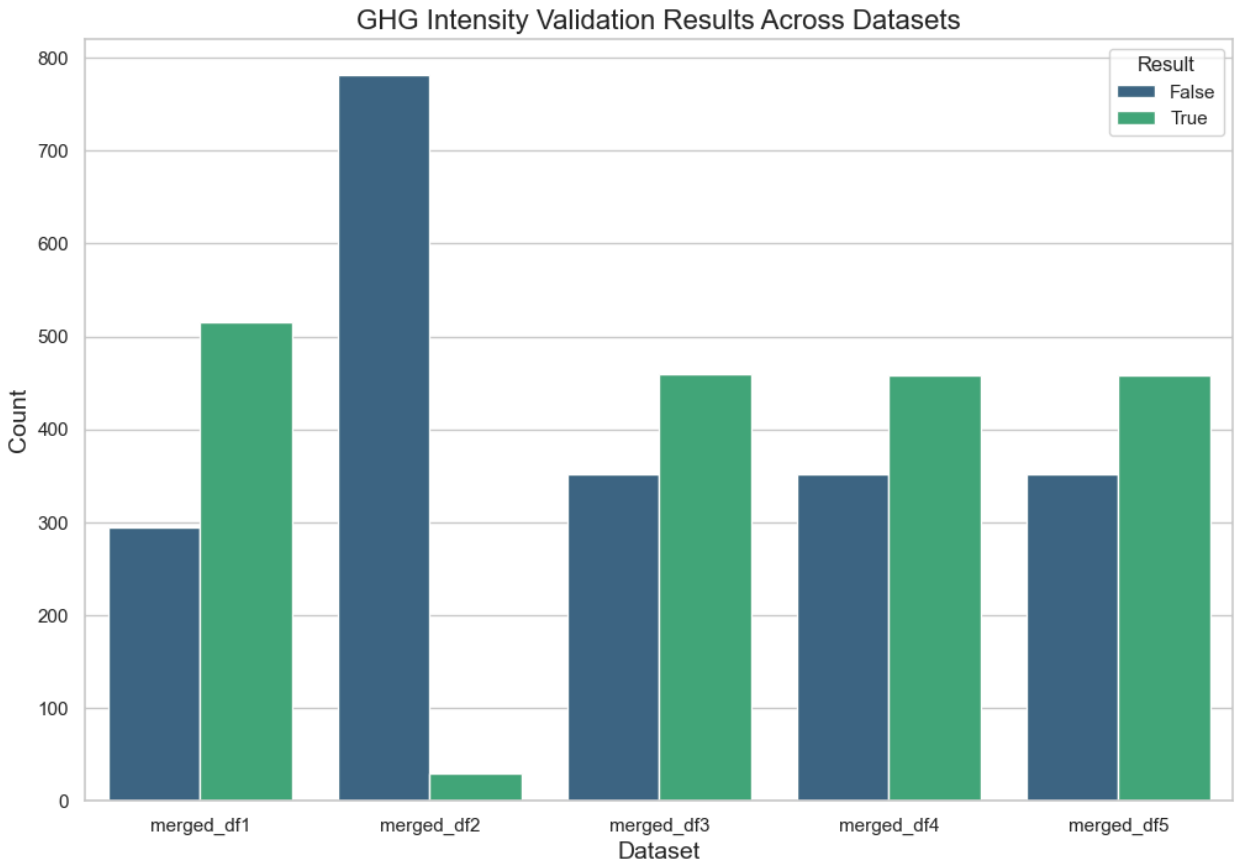
- **Basic Efficiency**: Certified buildings meet minimum standards for energy efficiency and environmental sustainability, focusing on compliance rather than aggressive savings.

- **Higher Allowable Intensity**: Since Certified is the most accessible Green Mark level, the **0.2 tCO_2e/m^2** threshold allows for a higher level of GHG emissions per square meter. This threshold is based on the assumption that these buildings adhere to fundamental energy-saving requirements without implementing extensive efficiency measures.

As our data are mainly obtained through imputation rather than actual measurements, this would impact the accuracy of our validation results. To address this, we refined our validation system by using slightly relaxed thresholds for validation, acknowledging the increased uncertainty. In this project,we decided to allow a small buffer (10%) above the standard threshold for imputed data, acknowledging that it may not be as precise as real-world measurements.

Consistency Check & Validation Result

As we have 5 dataframes through different data imputation method, we applied green mark level award validation on each dataframes. As the green mark award is the actual measurement from the real-world data, this process helps us determine which one best matches the expected results for GHG Intensity based on the Green Mark certification.



As shown from the graph, **merged_df1** has the highest validation match rate: 36.60%, which is likely the **most reliable** in terms of how well the imputed data aligns with the Green Mark standards. This approach ensures that we choose the DataFrame that most closely reflects expected building performance based on the given Green Mark level and minimizes discrepancies in validation results.

Sensitivity Analysis

Sensitivity analysis is about varying the inputs within the realistic range.

Sensitivity analysis might seem redundant when we already know our key features are **Energy, Waste, Water, and Transportation**. However, sensitivity analysis serves a distinct purpose in refining our understanding and application of these key factors. Here's how it adds value, even when the key features are known, and how our team can use it to draw more general conclusions without needing to analyze each building individually.

The Purpose of Sensitivity Analysis can be summarized as follows:

- ➔ **Quantifying Influence**: Sensitivity analysis helps us **quantify the impact** of each feature on the target variable (GHG_Total). This means we can understand, on average, how much a 10% change in Energy, for instance, influences GHG_Total across all buildings, compared to a 10% change in Waste or Water.
- ➔ **Relative Importance**: Even though we know the four features, sensitivity analysis allows us to **compare the relative importance of each feature** within the context of emissions. This can help us determine whether Energy consistently has the largest influence across buildings or if its impact varies significantly depending on the building type.

1. Align Sensitivity Analysis with Each Scope

Activity	Likely Scope	Description
Energy	Scope 2	Indirect emissions from purchased electricity for building operations.
Water	Scope 3	Emissions from water use and treatment, often classified as indirect.
Waste	Scope 3	Emissions from waste disposal, recycling, or treatment processes.
Transportation	Scope 1 or 3	Scope 1 if company-owned;

		Scope 3 if from employee commuting or outsourced transport.

- **Scope 1**: Typically covers direct emissions from sources like **fuel combustion** in company-owned vehicles or heating systems.
    - We could adjust the fuel consumption levels in our sensitivity analysis and observe how Scope 1 emissions vary.
- **Scope 2**: Encompasses indirect emissions from **purchased electricity** or other energy sources.
    - Since **Energy** (electricity or heat consumption) directly impacts Scope 2, changes in energy usage should correlate with changes in Scope 2 emissions. As part of our analysis, we can adjust the energy use by different percentages (e.g., ±10%) and track the corresponding Scope 2 emissions to see how sensitive our total GHG emissions are to energy usage.
- **Scope 3**: Considers other indirect emissions, such as those from **water treatment**, **waste disposal**, and **employee commuting**.
    - We can adjust water and waste data in our sensitivity analysis to evaluate their impact on Scope 3. For example, increasing or decreasing waste generation by a percentage allows us to observe how Scope 3 emissions change accordingly.

2. Incorporate Emission Factors Based on Activity and Scope

- Use **specific emission factors** for each activity under its corresponding scope. This ensures that any adjustment in the activity level (e.g., ±10% for energy, water, or waste) translates into a GHG emission change that is accurately reflected in its respective scope.

3. Recalculate Total GHG Emissions Based on Adjusted Scopes

- After adjusting the values in each scope, we **sum Scope 1, 2, and 3 emissions** to obtain an updated Total GHG Emission for each scenario.
- This approach will allow us to see how different scenarios in energy, waste, and water adjustments affect the total emissions.

Result

		Mean Sensitivity
Feature	Factor	
Energy	0.9	-5.13E+00

Waste	0.9	-4.64E+00
Water	0.9	-4.64E+00
Transportation	0.9	-2.34E-01
Energy	1	-4.53E-16
Waste	1	-4.53E-16
Water	1	-4.53E-16
Transportation	1	-4.53E-16
Energy	1.1	5.13E+00
Waste	1.1	4.64E+00
Water	1.1	4.64E+00
Transportation	1.1	2.34E-01

Interpreting the Sensitivity Results by Scope

The sensitivity values indicate the percentage change in GHG_Total emissions when each feature (Energy, Waste, Water, and Transportation) is adjusted by ±10%:

- **Negative Values** (e.g., factor 0.9): A negative sensitivity value (e.g., -5.125945 for Energy at factor 0.9) shows a decrease in total emissions as that feature is reduced by 10%. Conversely, a positive sensitivity value (e.g., 5.125945 at factor 1.1) means that increasing the feature by 10% leads to an increase in emissions by that percentage.

Linking Each Feature to Its Scope

- **Energy (Scope 2)**:
    - **Sensitivity**: The results show the largest positive and negative values for Energy, with around -5.13% and +5.13% changes in total emissions for factors 0.9 and 1.1, respectively.
    - **Scope Impact**: This high sensitivity indicates that **Scope 2 emissions**, which include emissions from purchased electricity, are the most significant contributors to total GHG emissions for our dataset. Thus, changes in energy consumption have the greatest direct impact on GHG_Total.
    - **Insight**: Any efficiency improvements in energy usage (e.g., HVAC upgrades, lighting, or energy management) would directly lead to meaningful reductions in total GHG emissions.
- **Waste and Water (Scope 3)**:

    - **Sensitivity**: Waste and Water show similar sensitivity values, with approximately -4.64% and +4.64% for factors 0.9 and 1.1.
    - **Scope Impact**: Both Waste and Water are contributors to **Scope 3 emissions**, which include indirect emissions associated with waste disposal and water use (such as emissions from treatment and transportation).
    - **Insight**: Changes in Waste and Water have a moderate influence on total emissions. This indicates that efforts to manage these areas, such as **waste reduction programs** and **water-saving measures**, will have a beneficial but slightly lower impact on emissions compared to energy. These are still important, however, in achieving comprehensive GHG reduction goals.
- **Transportation (Scope 1 or 3)**:
    - **Sensitivity**: Transportation shows the smallest sensitivity, with values like -0.23% and +0.23%, indicating that changes in transportation activities have minimal direct influence on GHG_Total.
    - **Scope Impact**: If Transportation relates to company-owned vehicles, this would fall under **Scope 1**. Otherwise, if it involves third-party services or commuting, it contributes to **Scope 3**.
    - **Insight**: Although transportation is crucial in some industries, for this specific dataset, it has a relatively minor impact on total emissions compared to other features. This means that while optimizing transportation may contribute to sustainability goals, **its direct impact on GHG_Total is limited**.