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# Climate-centric data governance for timber traceability: A GRC framework for decarbonized and audit-ready supply chains

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## Abstract

This research article discusses how a Governance, Risk, and Compliance (GRC) solution to more effective timber-supply chain traceability, data governance, and climate-compliance can be created. The framework assists timber manufacturers in reducing the effects of greenhouse gas (GHG) emissions and gaining sustainability indicators across different phases of the timber supply chain, in line with the global climate objectives. The article suggests a systematic method of enhancing the level of emission reporting, risk management, and audit-readiness in the context that the business can adjust to new regulations and makes ready to face green-finance auditing. The framework underlines the significance of active risk management by data-based insight and mitigation measures of emissions in terms of actionable responses. It also emphasizes how SOPs and maturity models can facilitate the existence of sustainable practices. These are the future directions which state that more sophisticated data analytics and machine learning can be implemented to achieve more accurate emissions tracking and that the timber industry can be decarbonized further to move in a more sustainable future.

**Keywords:** Audit-Ready; Climate-Centric; Data; Governance; GRC; Decarbonized

## 1. Introduction

The concept of timber traceability is one that is important in the management of sustainability in the global supply chain especially as the environmental issues in relation to timber deforestation and depletion of resources continue to rise. Effective and precise tracing of timber goods is an opportunity to track and check their origin, which will eliminate the negative output on the environment related to illegal logging, carbon emissions, and uncontrolled and uncertified usage (Elias, 2024). With the trend of industries progressively considering that they may cut down their carbon footprints and conforming to mitigation objectives of climate change, it is critical that the global timber supply chains incorporate effective data governance (Elias, 2024). Through data governance, organizations are able to track, manage and report carbon impact of their operations to guarantee environmentally-approved standards and climate policies.

Presently, a huge deviation is present in climate-based data management models specific on timber supply chains (Koberg & Longoni, 2019). Although emissions tracking is turning out to be a common trend in most industries, timber

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supply chains may not have an organized method of measuring and reporting the total emissions in all their processes, starting with harvesting to delivery of the final products. Such a loophole complicates progress to sustainability in the field and does not give companies the required capacity to comply with climate regulations (Koberg and Longoni, 2019). The purpose of this article is to examine the creation of Governance, Risk, and Compliance (GRC) framework particularly targeting at the timber traceability. The framework will include the composite of climate-compliance markers and decarbonization plans so that it can help stain improved monitoring of emissions, increase transparency, and readiness to audit operations in timber supply chains.

*Objectives*

- To develop a sustainability controls matrix for emission-driven timber supply chains
- To design adaptive standard operating procedures (SOPs) for low-impact timber logging
- To establish a maturity model for transitioning to advanced climate stewardship in timber supply chains

## 2. Background and Literature Review

### 2.1. Timber Supply Chains and Sustainability

Timber industry is very important to the world economy as it supplies raw wood used in building construction, furniture, paper product, and other products. Nevertheless, a major effect of this sector has a lot to do with the environmental effects and this is predominantly through deforestation and forest degradation. The world puts uncomfortable stress on mitigating climate change, which contributes to an increase in the importance of timber supply chains becoming greener (Asamoah et al., 2020). Traceability of the whole supply chain is one of the key issues in a process of attaining sustainability in timber.

Traceability in timber is simply the capability to trace the timber item used in the forest to the end consumer. It assists in checking the legality of timber sourcing, its sustainability, and whether the manufacturing process complies with the rights of indigenous people and safeguards the biodiversity. Traceability is one of the issues although it is of utmost importance because the timber supply chain can be difficult to trace, with numerous intermediaries and processes being involved (Appelhanz et al., 2016). Also, in many cases, the effective monitoring of the environmental impact of timber is complicated by the fact that there are no standardized certification and reporting requirements.

Other hot issues of sustainability in the timber business include carbon footprint reduction. The effect of timber production and harvesting is the production and emission of carbon directly through land use change and deforestation but indirectly through the energy consumed in the supply chain (Mishra et al., 2022). Moving to a carbon-neutral timber sector is crucial to combating climate change since the sector needs large-scale investment in low-carbon technologies and sustainable forest management systems and enhanced data tracking systems to quantify and mitigate emissions throughout the supply chain.

### 2.2. Data Governance and Sustainability Frameworks

Data governance refers to the practice of regulating and controlling the gathering, storing and utilizing of information, so as to fulfill some depictions of quality, transparency and respectability. Data governance is a key element within the timber supply chains to guarantee that the right and dependable information is accessible to observe the emissions, sustainability and the executions of the climate policies (Alabi, 2023). Although there are many industries where data governance frameworks are common, their application to timber supply chains is rather immature.

Consistency of data and fullness throughout the supply chain cycle is one of the most remarkable issues of implementing data governance to timber. A climate-oriented data governance would be based on the idea of incorporating direct environmental indicators in the data management system, namely greenhouse gas emissions and carbon capture (Casandra et al., 2023). This would enable the businesses, the regulators and the other stakeholders to have a better understanding on the environmental performance of the timber industry.

The available data governance models in the field of supply chains, especially within the field of agriculture, mining, and energy, provide useful teachings. As an example, Global Reporting Initiative (GRI) and Carbon Disclosure Project (CDP) offer businesses models to report on environmental information (Duho, 2024). Correspondingly, the ISO 14001 is an environmental management system standard that can be adjusted to the timber supply chain. Such models emphasize that the concept of incorporating environmental, social, and governance (ESG) information into the supply chain management systems is exploitable and applicable to the timber industry.

### 2.3. GHG Emissions in Timber Supply Chains

The timber supply chains should be monitored and mitigate their release of greenhouse gases (GHGs) so as to achieve targets in the field of climatic control that are set by the international community e.g. the Paris Agreement. The GHG emissions by the timber industry are mainly because of deforestation and forest degradation, leading to the release of large carbon dioxide emissions to the atmosphere (Achard et al., 2014). Also, timber harvesting, transportation and processing also adds to the carbon footprint through consumption of energy.

Timber supply chains the common current approaches to tracking GHG emissions in timber supply chains use emission factors (the quantity of GHGs emitted by one unit of activity, e.g. ton of timber harvested). As an example, the REDD+ (Reducing Emissions through Deforestation and Forest Degradation) program offers the framework on which the deforestation and forest degradation can be tracked in third world countries (Achard et al., 2014). REDD+ will use carbon credits to provide incentives on forest conservation and sustainable land use, and can be sold on the international markets.

Alongside REDD+, initiatives such as sustainable development goals (SDGs) especially SDG 13 (Climate Action) focus on the necessity to cut down GHG emissions in all industries, and forestry should be among them. Carbon credits and climate-smart agriculture programs are generally incorporated into forest management programs and their carbon footprint accounting (Achard Fr Frederic et al, 2014). These attempts are, however, impeded by the unavailability of unified methodologies to trace and report emissions involving timber supply chains especially in cases where two or more parties are involved.

### 2.4. Previous Models and Case Studies

A number of case studies and models have been done to implement sustainability and GHG emissions data in timber supply chains. Another example is the Forest Stewardship Council (FSC), a company accrediting timber products based on the environmental, social, and economic performance (Leite et al., 2025). The FSC certification has a traceability aspect whereby the timber can be traced back to its origin till the end product is produced and also has a sustainable forest cover whereby the forestry practices are not harmful to the environment in terms of emissions, preserve of biodiversity.

An example of a study on the utilization of satellite imagery and technologies of remote sensing in monitoring the rate of deforestation as well as the amount of carbon released due to the production of timber is a case study performed in Brazil (Oliveira et al., 2024). Amazon Conservation Team (ACT) collaborates with local communities to track the deforestation in real-time and uses it to track the purchase of timber in a sustainable manner as well as reducing emissions by discouraging illegal logging activities.

The other important model is that of California in the Cap-and-Trade Program, which enables the trading of carbon credits by the businesses. Those companies in the timber industry can involve them by practicing sustainable forest management and the carbon credits will be allowed on activities like reforestation and forest conservation. This model motivates businesses to help in cutting down the emissions even as it gives an economic advantage by selling carbon credits.

Although these case studies and frameworks present useful ideas, there is a demand to have more in-depth and standard data governance models that incorporate emission tracking, traceability, and climate-compliance into timber supply chains at a global level. In the absence of such structures, it is a hard challenge to achieve sustainability goals and to hold accountable stakeholders along the supply chain by regulators.

## 3. Methodology

In the research, the Supply Chain Greenhouse Gas Emission Factors was employed to determine the greenhouse gas (GHG) emissions of different processes in the timber supply chain (Hayat, 2024). This dataset has the emission factors of various industries in detail, thus offering the information on the carbon impact of timber production. The NAICS codes, emission factors (with and without margins), and unit measurements of calculating the carbon footprint of both products and services are key variables in the dataset (Hayat, 2024). The dataset also covers margins which cover indirect supply chain emissions giving a complete insight to the whole emissions.

Google Colab was used as the preferred platform in the analysis of data. A cloud-based platform, Google Colab is used to code in Python that is best suited to work with big data and execute complex calculations (Vallejo et al., 2022). It is easy

to use, supports libraries like pandas to manipulate data, and is able to execute code without any constraints on the local resources; that made it an effective tool to use in this research.

The analysis also encompassed filtration of the appropriate industries; computing of the emission factors, as well as formulating a Sustainability Controls Matrix to monitor the emission along the timber supply chain (Adhikari and Ozarska, 2018). This was aimed at defining high-carbon phases and considering ways of enhancing the data governance, traceability and decarbonization of the work on timber industry.

## 4. Findings and Discussion

### 4.1. Framework Design: The Sustainability Controls Matrix

The Sustainability Controls Matrix of timber supply chains is created in this section, using the Supply Chain Greenhouse Gas Emission Factors dataset. This data can be valuable as a bondage of all the timber production phases by offering the major emission factors of different agricultural and farming activities. The matrix is structured in such a way that it traces and quantifies the amount of greenhouse gas emissions (GHG) in the supply chain so that businesses and stakeholders can evaluate their effect on the environment and make prudent conclusions regarding sustainability.

**Table 1** Supply Chain Emission Factors for Various Farming Activities

| 2017 NAICS Title | Supply Chain Emission Factors with Margins (kg CO2e) | Emissions per Unit (kg CO2e) |
|---|---|---|
| Soybean Farming | 0.532 | 0.532 |
| Oilseed (except Soybean) Farming | 0.532 | 0.532 |
| Dry Pea and Bean Farming | 0.848 | 0.848 |
| Wheat Farming | 0.848 | 0.848 |
| Corn Farming | 0.848 | 0.848 |
| Rice Farming | 0.848 | 0.848 |
| Oilseed and Grain Combination Farming | 0.848 | 0.848 |
| All Other Grain Farming | 0.848 | 0.848 |
| Potato Farming | 0.631 | 0.631 |
| Other Vegetable (except Potato) and Melon Farming | 0.631 | 0.631 |
| Strawberry Farming | 0.488 | 0.488 |
| Berry (except Strawberry) Farming | 0.488 | 0.488 |
| Tree Nut Farming | 0.488 | 0.488 |
| Fruit and Tree Nut Combination Farming | 0.488 | 0.488 |
| Other Noncitrus Fruit Farming | 0.488 | 0.488 |
| Tobacco Farming | 0.740 | 0.740 |
| Cotton Farming | 0.740 | 0.740 |
| Sugarcane Farming | 0.740 | 0.740 |
| Hay Farming | 0.740 | 0.740 |
| Sugar Beet Farming | 0.740 | 0.740 |
| Peanut Farming | 0.740 | 0.740 |
| All Other Miscellaneous Crop Farming | 0.740 | 0.740 |

| | | |
|---|---|---|
| Beef Cattle Ranching and Farming | 2.893 | 2.893 |
| Dual-Purpose Cattle Ranching and Farming | 2.893 | 2.893 |
| Hog and Pig Farming | 1.128 | 1.128 |
| Sheep Farming | 1.128 | 1.128 |
| Goat Farming | 1.128 | 1.128 |
| Finfish Farming and Fish Hatcheries | 1.128 | 1.128 |
| Shellfish Farming | 1.128 | 1.128 |

Note: The emission factors represent the amount of CO2 equivalent emissions (kg CO2e) per unit of value produced in each activity.

The dataset has emission factors at margins of the various agricultural sectors; the units are normally in kilograms of CO2 equivalent per unit of value (kg CO2e). The following emission factors are carbon footprints that are attributed to every activity in farming. The table below shows the corresponding emissions of the various types of agricultural activities applicable to timber production processes which can be applied to timber production by relating the farming activity to the related stages of the timber production supply chain including harvesting, transportation and processing activities.

The evidence points to the existence of a lot of variances in relations to the industries in emissions. Beef Cattle Ranching and Farming is the example with the greatest factor of emissions of 2.893 kg CO2e per unit. This value is very high because cattle farming is a high-impacting type of farming, as it entails the change of land use, the production of feeds, and the release of methane. Conversely, Soybean Farming and other types of crops farming such as Oilseed Farming and Wheat Farming are less carbon-intensive, with the factor of emission of methane and less resource use, which is the main reason.

Tobacco Farming and Cotton Farming have an emission factor of 0.740 kg CO2e per unit, which is a moderate contribution of carbon because of aspects such as consumption of water, disturbance of soil, as well as processing. Farming activities such as Strawberry Farming and Berry Farming have relatively lower emission factors and are usually of the order 0.488 kg CO2e/unit. This implies that the carbon footprint of the production processes of fruit and nuts is lower than more resource-intensive processes such as livestock production.

Such factors of emission can be used in the timber supply chain, especially during harvesting and transportation, to estimate its total carbon footprint. Using these factors of emission on timber-related operations, it is possible to measure and manage the carbon impact of the supply chain more efficiently. This discussion shows the possibility of decarbonization initiatives which could be applied in different points of timber production and in this case, it is better to concentrate on the issue of minimizing the emissions produced by the high-impact activities.

### 4.2. Adaptive SOP Templates for Low-Impact Logging Practices

This section entails development of the Standard Operating Procedures (SOPs) of low-impact logging practices with consideration of the greenhouse gas (GHG) emission factors in relation to different timber production stages. The information is useful in explaining the carbon footprint at strategic areas of the timber supply platform which include logging, transportation and processing. This is aimed at developing a range of adaptive SOP templates which cover these GHG emission factors and specify particular measures to decrease emissions and make sure of sustainability.

**Table 2** GHG Emission Factors and Emission Reduction Strategies for Timber Supply Chain Stages

| Stage | GHG Emission Factor (kg CO2e/Unit) | Unit | Emission Reduction Strategy |
|---|---|---|---|
| Logging | 0.912414 | per 2022 USD | Use Renewable Energy |
| Transportation | 0.912414 | per 2022 USD | Optimize Delivery Routes |
| Processing | 0.912414 | per 2022 USD | Reduce Energy Consumption |

Note: The emission factor represents the amount of CO2 equivalent emissions (kg CO2e) per unit of value produced in each stage.

The GHG emission rates of the individual steps of timber production are under the category of kg CO2e per unit (per 2022 USD). The figure of emission per unit process of all the stages- logging, transportation and processing- is 0.912414

kg CO2e. This means that an average unit of timber manufactured at these stages has this quantity of carbon dioxide equivalent emissions.

In the case of logging which entails extraction of timber in the forest, the GHG emission factor is the cost of the environment in the activities which involve it like the use of machines, move to the processing plants and other aspects of the operations. The emission reduction strategy that should be used in this phase to minimize the emission is using renewable energy to power the logging activities. The fossil fuel is replaced by renewable energy sources, which decreases the emissions significantly.

In the case of transportation, the same number of emissions is considered and this implies that the transportation of the timber, once the logging has been done, has the same effect on the environment as the logging does. This is the role of cutting on the emission by the optimization of delivery routes. This plan involves the design of more productive transport routes, fuel efficiency, and general emissions during the transportation. Fleet management systems and route optimization software could become useful accomplice toward the achievement of this goal.

The emissions at the processing phase are once more, 0.912414 kg CO2e per unit which also indicates that the processing of timber is an energy consuming process that involves milling, drying, and shaping, among others. The processing emission reduction scheme entails the minimization of energy usage. This can be achieved through the next efforts: making machinery energy efficient, placement of efficient machinery in operation areas and use of renewable energy in processing plants. Those measures will assist in decreasing the carbon footprint of the processing step. These strategies can be incorporated into the SOPs by timber producers as a way of minimizing the effects of the production on the environment, but still operate efficiently.

The establishment of SOP templates on these emission factors offers an orderly manner of low impact logging practices. Through the implementation of renewable energy, route planning and energy minimization among other approaches, producers of timber can make their activities linked with aspects of sustainability. The practices are in aid of a reduction of carbon footprint of the timber industry and mutually benefit the overall world in an attempt to curb greenhouse gas emissions and are in line with climate-smart forest management and sustainability requirements.

***Maturity Model for Mitigation: Transitioning to Advanced Climate Stewardship***

The Maturity Model of Mitigation is created to help organizations in their steps of a climate stewardship so that there can be a systematic way to overcome the entry-level legal compliance and improve to more mature climate stewardship. The model will evaluate and facilitate the development of timber supply chains toward the targets of lower emissions and sustainability, and provide a path of continuous improvement.

**Table 3** Maturity Model for Mitigation: Stages of Transitioning to Advanced Climate Stewardship

| Stage | GHG Reduction Target (%) | Emission Factor Benchmark | Preparation for Future Regulations |
|---|---|---|---|
| Basic Legal Compliance | 5 | 0.912414 | Basic Compliance |
| Intermediate Climate Stewardship | 15 | 0.5 | Adaptation to Future Regulations |
| Advanced Climate Stewardship | 30 | 0.1 | Leadership in Green Finance |

Note: The table outlines the stages, GHG reduction targets, emission factor benchmarks, and strategies for preparing for future regulations in timber supply chains.

The table contains a three-stage maturity model of organizations that belong to timber supply chain aimed at measuring their level of performance in addressing greenhouse gas (GHG) emissions. The first stages are Basic Legal Compliance where organizations look after the minimum legal requirements of environmental management. Currently, the GHG reduction target is formulated at 5 percent and this is the level of reduction of emissions that should be achieved when there is a compliance with the regulations. Emission factor benchmark has been placed at 0.912414 kg CO2e per unit, which means the normal carbon footprint of producing a timber at this stage.

Intermediate Climate Stewardship which is more proactive. The target reduction has been fixed at 15 percent by organizations at this stage and wants to have a substantial reduction in emissions. The benchmark emission factor is

decreased to 0.5 and this indicates more effort is concentration on reducing the emissions. At this step, the organizations start planning in advance of more stringent environmental rules and start investing in greener practices that are beyond mere compliance.

Advanced Climate Stewardship is the ultimate action towards climate. The organizations in this stage work towards being a leader in sustainability by having a GHG reduction target of 30 percent and emission factor benchmark of 0.1. They are concerned with green finance, carbon credits and renewable energy uptake and are at the forefront to a decarbonized future. This systematic framework enables organizations to measure their achievements and find measures to maintain cutting down their carbon footprint on the planet.

The Maturity Model of Mitigation is a clear route towards advanced climate stewardship by the organizations in the timber supply chain. Having specific objectives applied to GHG reduction and continuous changes of the emission standards enables companies to track their development and implement the required modifications in the functioning process. It also highlights the need to prepare against changes in regulations in the future and become a leader in green finance, so it is a necessary instrument of organizations that are concerned with environmental sustainability and climate action.

### 4.3. Integrating the Framework with Supply Chain Risk Management

#### *4.3.1. The Role of GRC in Sustainability*

Governance, Risk, and Compliance (GRC) models are very important in assisting business firms to deal with different risks, including climate change- and greenhouse gas (GHG)-related risks in its supply chain. The frameworks allow a methodological approach to governance since they guarantee that the sustainability activities relate to organizational pursuits, risk management through the identification, and reduction of environmental risks, and compliance through legal and regulatory needs. Due to the increased effect of climate change on global supply chains, the risk posed by environmental regulations coupled with changes in the market and reputation management is increasing among businesses.

The risks caused by climate change can be properly addressed by businesses before they take place by employing the concept of sustainability within the GRC construct. This implies determining the possible threats of the environment, including changing carbon levies, varying regulations or disruptions of extreme weather patterns. These risks can be mitigated with the help of GRC frameworks which provide companies with the means of implementing mitigation strategies to manage them, as well as promote transparency and accountability in operations. Moreover, it has been observed that through incorporation of sustainability metrics, e.g. the data on GHG emissions, into the GRC system, the organizations in question guarantee that they are always monitoring their effect on the environment, making it easier to control and decrease the emissions throughout the supply chain.

#### *4.3.2. Data and Risk Mitigation*

The framework proposed focuses on the application of data governance to alleviate environmental risks, that is, through emissions data and other metrics of the environment. This will enable businesses to recognize the risks that may arise due to climatic conditions at the onset and therefore strategies developable to cope with them are established with ease. As an illustration, incorporating the GHG emission factors into the process of the supply chain management process allows receiving the understanding of those stages of the process that generate a high level of emission and focus on activities aimed at minimizing the carbon footprint. This evidence-based strategy helps the organizations to evaluate the state of their initiatives in terms of the adherence to changing environmental requirements and an existing gap in sustainability initiatives.

Early detection of risks is essential to make future proactive actions, i.e. switching to renewable energy sources, streamlining transportation paths, or finding sustainable raw materials. The data can also enable the companies to gauge the success in the current mitigation strategies they are employing, and they are therefore on their way to achieving climate targets. Using climate risk assessments as part and parcel of the GRC framework will allow businesses to align their sustainability initiatives with the larger mitigation of climate change strategies, such as the ones contained in the Paris Agreement. This minimizes regulatory penalties, reputational losses, and supply chain disruption as a consequence of climatic incidences.

*4.3.3. Audit-Readiness and Compliance*

The crucial attribute of the offered framework is that it will enable supply chains to become audit-ready, so that businesses will be able to show that they are complying with sustainability requirements and green-finance audits. As concerns over transparency and accountability in the corporate sustainability practices continue to increase, regulatory agencies, and financial institutions are increasingly emphasizing on climate-related disclosures and environmental performance.

The audit-readiness of the framework will make this process easier allowing the businesses to have well-rounded and precise information on the environmental impact, and complete documentation of GHG emissions and the measures the businesses put in place to limit the emissions. The data may be utilized to prove that it is in accordance with the national laws and principles, as well as those that govern the global reporting initiatives that include the Global Reporting Initiative (GRI) or the Carbon Disclosure Project (CDP). Being audit-ready helps businesses to be more responsive to green-finance audits and acquire sustainable investments. Such audits determine the compatibility of the activities of a company with green finance standards and investments that are climate-smart.

Furthermore, when companies take the audit ready strategy, they ensure not only that they meet regulatory compliance, but would also improve their reputation to consumers, investors and other stakeholders. The companies can also get green investments, improved financial access, and brand loyalty by showing that they require sustainable practices. The inclusion of data-driven metrics in the GRC model places businesses in a vantage position to cash in on the financial benefits that are attached to sustainability and climate friendliness, hence further supporting the significance of the framework towards business success in the long term and reduction of risk.

Combining a holistic GRC strategy and supply chain risk management can assist businesses to take care of any environmental risks, conforming with the regulations and being audit ready. The framework gives firms the power of monitoring and cutting their greenhouse gas emissions, protects against climate change related shocks, and portrays that they are achieving sustainability standards in an increasingly regulated global market.

## 5. Conclusion

The Governance, Risk and Compliance (GRC) framework that was proposed is a systematic way of enhancing the data governance systems, traceability and climate compliance in timber supply chains. The framework also allows the businesses to monitor and minimize the emission of gasses, and this makes them compliant with the climate objectives set internationally since it incorporates both the emission factors and sustainability indicators. The main findings mark how an effective data governance may contribute to the increase of sustainable practices and audit-readiness of timber producers.

Stakeholders should be recommended to implement this GRC framework to ensure a better traceability and regulatory compliance, use more sustainable practices with policy incentives, and promote industry-wide standards on carbon emissions and traceability of supply chains. The future prospects of this structure are in the possibility to combine highly developed data analytics and machine learning solutions that may considerably provide the accuracy of tracking emissions, sustainability initiatives, and decarbonization in the timber industry.

## Compliance with ethical standards

*Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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