



## A Systems Engineering Process Approach for AIoT-Based Export Supply Chain ESG Measurement

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### Abstract

The supply chain for export commodities is facing increasing demand driven by transparency and accountability regarding environmental, Social, and Governance (ESG) performance. However, ESG measurement in practice is still hampered by data distribution, reliance on manual reporting, and the absence of a framework for an engineering-structured system. Research: This aim is to design a system chain for ESG measurement of supply-export commodities and natural resources using a systematic Systems Engineering Process (SEP) approach. SEP is applied to transform raw data sourced from the chain sensor supply export into relevant ESG information for decision-making. Methodology study covering requirements analysis, system design, implementation, testing, deployment, and maintenance stages, to ensure integration between the operational needs and the technical solutions. Research results show that the SEP approach can provide a consistent, integrated framework that improves process traceability and supports the sustainability system in the long term. Approach. This expectation can serve as a base development system that is more reliable, adaptive, and applicable to the supply chain for export commodities.

**Keywords:** *Systems Engineering Process; ESG; Chain Supply Exports ; Commodities Nature ; AIoT ; Sustainability*

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### 1. Introduction

Chain supply of natural commodities. For activity export, one's own role is essential in the global economy. Still, it faces increasing pressure from big businesses to meet sustainability and environmental, social, and governance (ESG) standards. Stakeholders, including regulators, investors, and partners, trade internationally, demanding greater transparency and accountability to impact sustainability throughout the supply chain. In practice, measuring ESG performance in the supply chains of commodities remains limited due to complex business processes, distribution locations, production, and reliance on manual data that is not real-time. Conditions. This often leads to inaccurate, difficult-to-verify information and is less supportive of strategic decision-making.

Main problems are in ESG measurement across the supply chains of commodities, natural resources, and other resources. Yet, integrated operational data fields, with a system capable of analytics to serve information comprehensively and sustainably. Environmental and operational data, such as power source, emissions, production conditions, and compliance with social norms, are generally collected separately and in unstructured form. In addition, the organization does not yet have a clear engineering framework that can accommodate the needs of various stakeholders and ESG interests. The absence of an approach to systematize the existing sustainability dashboard results in a static, reactive, and less capable dashboard, giving an outlook that is predictive of ESG risks and performance throughout the supply chain export.

Several studies highlight the related implementation of ESG and smart supply chains. A study in Vietnam used the Neutrosophic Delphi–DEMATEL two-stage approach with a panel of 30 experts across sectors. For the map connection, causal relationships among ESG barriers were identified, with legal, institutional, and economic factors playing a primary role as driving forces, alongside other obstacles (Phan et al., 2025)[1]. In the Bangladesh context, the obstacles to the implementation of Smart Supply Chain Management (SSCM) are analyzed through a framework hybrid three-stage based on the Best–Worst Method (BWM) and Interpretive Structural Modeling (ISM), which shows that constraint economy and integrity system become dominant inhibitors of the sustainability chain supply (Diraz et al., 2026)[2]. Second studies confirm the importance of regulatory reform and support institutional foundations as the main drivers of sustainable development in developing countries.

Besides that, the study focused on adopting intelligent technology to increase sustainability and power competition in the industry. In manufacturing MSMEs' vehicle electricity in India, a development framework, Hybrid work based on Multi-Criteria Decision Making (MCDM), which integrates BWM, WINGS, and Quality Function Deployment (QFD), is used to identify key adoption of the Smart Circular Logistics System (SCLS), with results that IoT, RFID, and LoRaWAN become the determining main success [3]. While that, industry manufacturing congested energy analyzed through edge–cloud collaboration approach, with Kernel Principal Component Analysis (KPCA) for data filtration and TOPSIS based on Adversarial Interpretive Structural Model (AISM) for evaluation efficiency production, which is proven capable of lowering energy consumption and support taking decision ESG -based [4]. Second studies confirm the role of digital technology as a key enabler of efficiency and sustainability in the industry.

The issue of transparency and reliability of ESG data becomes an important issue in the study of a blockchain-based ESG reporting platform developed by a blockchain and IoT consortium with methodology design architecture system, four layers, simulation, experimental, as well as evaluation performance use fuzzy logic, which shows a significant impact on transparency and trust stakeholders interests [5]. In the cement sector, the effectiveness of blockchain in managing carbon emissions was evaluated through a mixed-methods approach, combining interviews with experts and surveys based on the Technology–Organization–Environment (TOE) and Diffusion of Innovation (DOI) frameworks, which identify prerequisite institutional and market incentives as key factors for success [6]. In the fisheries sector, a PRISMA-based Systematic Literature Review (SLR) of 19 studies empirically shows that blockchain consistently increases traceability and sustainability in the fish supply chain [7].

Digital twin and systems approach to quality also contribute to resilience in the supply chain. Development of a harmonized 7D model -based Digital Twin (DT) framework with IATF 16949 standard tested through a case study of a manufacturer of tractors, with a methodology design system, gradual, and utilization of IoT data for analytic predictive, which has proven to increase durability and quality of the automotive supply chain [8]. On the other hand, the review is conceptual about the integration of IoT and big data analytics in the chain supply green done through an editorial review of 19 scientific articles, which shows improved transparency, efficiency, logistics return, and performance environment in the context of Industry 4.0 [9].

The study also relates the digitalization chain supply to governance performance and access to financing. A study based on company panel data from China, using a two-factor fixed-effects model, shows that disclosure information in the supply chain increases access to credit, especially when moderated by centrality in the director network, serving as a governance indicator [10]. The relationship between digital commerce and corporate ESG performance is analyzed using two fixed-effects specifications and Two-Stage Least Squares (2SLS), which show that digital trade drives ESG through innovation, green initiatives, and internal governance improvements [11]. Both studies confirm that transparent digital-based functioning is a credible governance signal for financial markets.

The sector and macro levels: integrating digital technology with policy sustainability shows a significant impact. The implementation of blockchain-based Green Product Platforming (GPP) is analyzed using Partial Least Squares–Structural Equation Modeling (PLS-SEM), which is complemented by qualitative interviews, and it is found that stakeholder pressure strengthens the impact of GPP on declining emissions [12]. Studies on green innovation agriculture in Vietnam using Structural Equation Modeling (SEM) based on regional panel data show that international trade pushes the practice of intelligent agriculture when supported by domestic innovation policy [13]. In the agricultural sector, the integration of blockchain, Java-based smart contracts, and IoT has been tested through design architecture and development applications that enhance data security and investor confidence in small farmers [15].

Lastly, cross-country analysis and policy public expand understanding of the impact of smart supply chains on sustainability, energy, and infrastructure. Relationship between digital export, global supply chain, and green FinTech analyzed using Machine Learning–based Time Heterogeneous Factor Analysis (ML-THFA) and PQ-ARDL-ME on OECD panel data, which reveals the crucial role of green ICT infrastructure. In China, the impact of Smart Supply Chain on the transition to energy urban testing is examined using a Difference-in-Differences (DID)-based quasi-natural experiment, which shows a decline in coal dependence driven by innovative green technology [16].

Study this own innovation in the application of the Systems Engineering Process (SEP), comprehensive in design system ESG measurement on the chain supply export commodities, integrated nature with approach AIoT and machine learning, where research has previously generally focused on ESG indicators in general, partial, based on manual reporting, or only emphasizing analytical aspects without a structured system. Research gap. The existence of an ESG measurement model that is capable of integrating operational, chain sensor data supply, analytical processes, and sustainability systems to develop a systematic and sustainable system in one cycle. For the answer gap, said research offers a solution in the form of a design system chain, ESG measurement, supply, export commodities, natural-based computer, with SEP methodology, which includes requirements analysis, system design, implementation, testing, deployment, and maintenance stages, creating an integrated, adaptive, and reliable system. The goal of this study is to design and validate a framework for ESG measurement that can transform the raw data chain supply export into accurate and relevant ESG information, support decision-making, improve process traceability, and ensure long-term sustainability.

## 2. Research Methods

Study this adopted framework, the systematic Systems Engineering Process (SEP) work, for transforming raw data from the Chain sensor Supply Export into a decision Chain ESG Measurement Supply Export Commodity Nature. Methodology: This ensures that the system being built not only advances technically but is also relevant to operational ESG measurement on the floor. Supply Export Export Commodity Nature. Stages in Engineering Process Methodology System For Chain ESG Measurement Supply Export Export Commodity Nature. The following is Figure 1. Systems Engineering Process (SEP) for Chain ESG Measurement Supply Export.



**Fig 1:** Systems Engineering Process (SEP) for Chain ESG Measurement Supply Export

#### 1. Requirements Analysis

Requirements Analysis is a crucial stage in the Systems Engineering Process (SEP) methodology for ESG measurement of the supply chain for export commodities, aiming to formulate a clear, structured system. At this stage, this analysis for objective ESG measurement requires operational users, relevant ESG indicators, and an export process of a commodity nature, considering the use of raw data generated by agricultural sensors. In addition, data characteristics, the transformation of flow data into decision-making information, and the need for an integration system along the supply chain are comprehensively reviewed. The results of the Requirements Analysis stage serve as the basis for determining the need for a functional and non-functional system, ensuring the developed system can support ESG measurement in a general, accurate, and effective manner, in harmony with the operational context of the supply chain for export commodities.

#### 2. System Design

System Design is a stage in the Systems Engineering Process (SEP) that focuses on translating the results of the system Requirements Analysis into the system's design architecture and components, for example, ESG measurement, supply, and commodities. At this stage, the designed system is comprehensive, covering architecture, agricultural sensor data acquisition, mechanism data integration and processing, and channel raw data transformation to support ESG information in decision-making. The design also considers operational aspects, such as interoperability between subsystems, reliability, data security, and scalability, to support the dynamic export chain. Thus, the System Design stage ensures that developed solutions not only fulfil the technical specifications but are also implementable effectively in the operational context of ESG measurements.

#### 3. Implementation

The Implementation Stage in the Systems Engineering Process (SEP) framework focuses on realizing the design system chain, ESG measurement, and the supply and export of commodities to deliver solutions that can be executed in practice. At this stage, the architecture and specifications of the system are set and implemented through the development of hardware and software devices, including agricultural sensor integration, system data communication, and ESG data processing and analysis. The implementation process also includes configuring the data flow from the source field to the system that supports decision-making so that raw data can be processed into meaningful ESG information. During the implementation stage, the system is designed not only to function technically but also to be ready for operational support of ESG measurement in the supply chain of export commodities.

#### 4. Testing

Testing stage in the Systems Engineering Process (SEP) methodology aims to ensure that the system chain ESG measurement supply export commodities natural has functioning in accordance with needs and established designs. At this stage, testing has been conducted comprehensively on the performance system, covering data acquisition from agricultural sensors, the reliability of data integration and processing processes, and the accuracy of the output ESG information to support decision-making. Testing also includes functional and non-functional aspects, such as stability systems, data security, and response systems to varying field operational conditions. During the Testing stage, potential errors and discrepancies can be identified and corrected, ensuring the system is ready to be used optimally for ESG measurement of supply export commodities.

#### 5. Deployment

The deployment Stage in the Systems Engineering Process (SEP) framework is the process of implementing the system chain, ESG measurement, supply, export commodities, and natural resources into the environment and into actual operations. At this stage, the system, which has undergone development and testing, has been implemented in the chain supply export so that stakeholders can use it in accordance with the planned functions. Deployment activities include an adjustment system with a condition operational field, integration with the existing system, and ensuring data flow from agricultural sensors so the module makes decisions consistently. With

the implementation stage of this system, ESG measurement is not only technically ready but also capable of operating effectively to support the operational chain for the supply and export of commodities.

6. Maintenance

The maintenance Stage in the Systems Engineering Process (SEP) framework focuses on sustainability and reliability. system chain ESG measurement supply export commodities natural after system operated. At this stage, this is done by periodically monitoring the performance system, addressing disturbances or declines in performance, and updating component systems to adapt to operational changes, ESG indicators, and the condition of the export supply chain. In addition, maintenance includes managing data quality across the sensor supply chain, strengthening security systems, and improving analytics functions for fixed ESG measurements, resulting in accurate, relevant ESG measurements. At this stage, the system can continue to adapt and provide ongoing support for ESG decision-making in the supply chains of export commodities.

### 3. Results and Discussions

#### 3.1. Chain ESG Measurement Supply Export

Chain ESG Measurement Process Supply Export Commodity Natural is a series of activities structured with a purpose: to evaluate Environmental, Social, and Governance (ESG) performance comprehensively throughout the channel, from production to export commodities. This process started with data collection from various points in the supply chain, including cultivation, processing, storage, transportation, distribution, and exports, some of which were sourced from sensors, systems, operational information, and supporting data. Raw data is then integrated and processed to produce relevant ESG indicators , including environmental aspects (e.g., use of source power, emissions , and impacts on ecology ), social elements (welfare, power, work, safety, and engagement with society ), and governance aspects (compliance, regulation, transparency, and practice management ). Furthermore, the results were measured, analyzed, and validated to ensure accuracy and consistency before being presented in a report or dashboard to support decision-making. Through this process, ESG measurements not only serve as a tool for evaluating sustainability but also as a basis for strategic planning to increase power's competitiveness, compliance, and the sustainability of the supply chain for exporting commodities. The following is Figure 2. Chain ESG Measurement Process Supply Export.

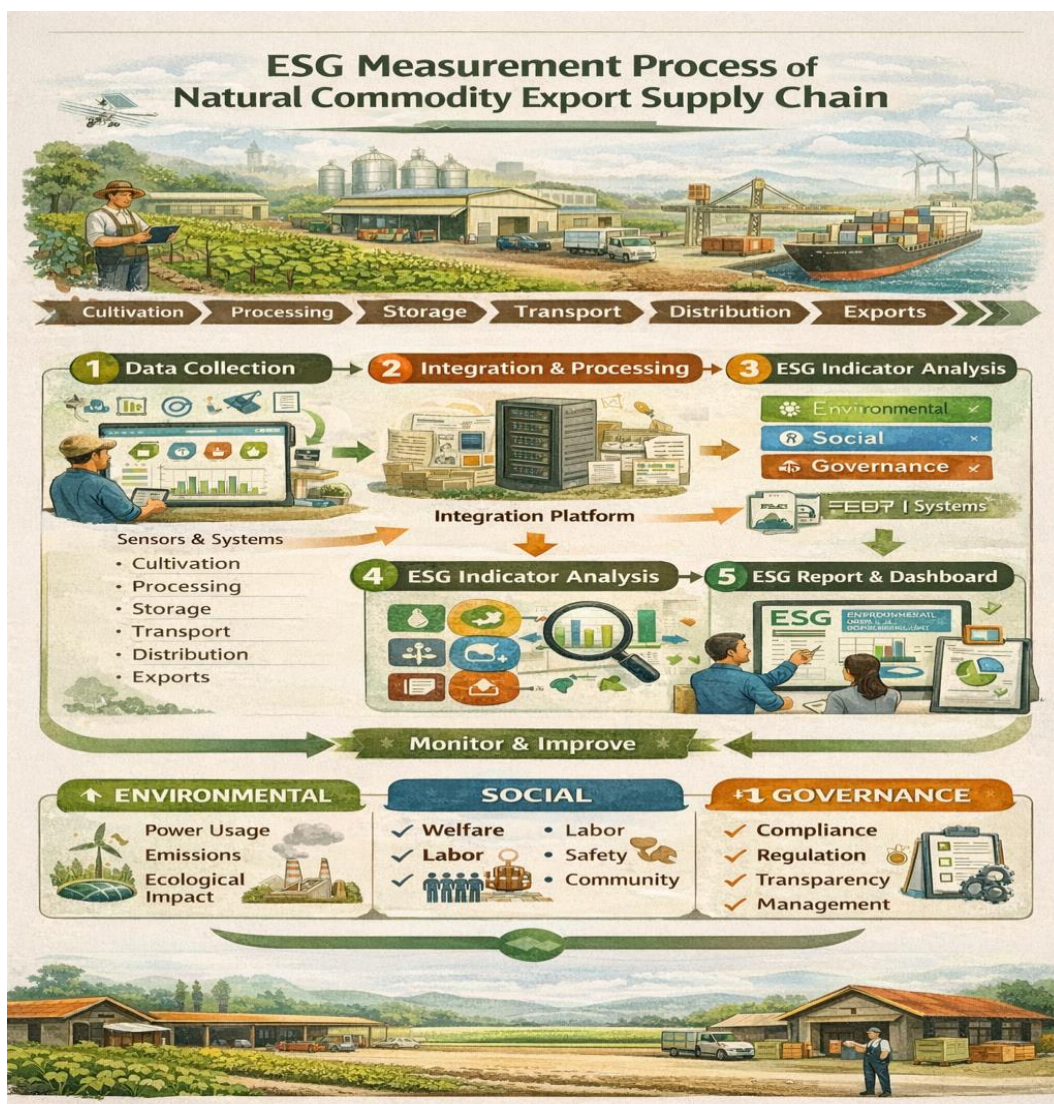


Fig 2: Chain ESG Measurement Process Supply Export

Based on the Chain ESG Measurement Process, Supply Export Commodity Natural, the required tool utilizes a system-based computer. This medium can help officers part export in determining evaluation Chain ESG Measurement Supply Export Commodity Natural with the System Engineering Process (SEP) methodology, which requires a comprehensive design. The System Engineering Process (SEP) is an approach to the systematic development, operation, and maintenance of a complex system. The System Engineering Process (SEP) is a methodology that focuses on in-depth analysis, modeling, and testing throughout the development cycle to ensure the system meets user needs and functions optimally. The System Engineering Process (SEP) is well-suited to projects that require coordination among elements and ensure that the system meets the technical and operational needs. The methodology involves several stages focused on understanding, designing, testing, and maintaining the system.

## 1. Requirements Analysis

The Requirements Analysis stage is the foundation of the System Engineering Process (SEP), which aims to identify, analyze, and document all system needs comprehensively. In the context of ESG measurement, supply, export, commodities, nature, and stage, this focuses on understanding stakeholders' needs, interests, and characteristics of the sustainable export process and operations.

### 1. Identification Stakeholders Interests (Stakeholder Identification)

The system is designed must consider need various parties involved include :

- a. Officer part export as users main system
- b. Management company exporter as taker decision strategic
- c. Regulators and institutions certification related ESG standards
- d. Chain partners supply (farmers, suppliers, logistics, and distributors)
- e. ESG internal and external auditors

Identification This aim For ensure system capable accommodate interest technical, operational , and regulatory in a way simultaneous .

### 2. Analysis Need Functional (Functional Requirements)

Need functional system covers ability system For :

- a. Collecting and managing ESG data from all over chain supply export commodities natural
- b. Do measurement and assessment ESG (Environmental, Social, and Governance ) indicators structured
- c. Integrating data from various source (manual or digital/IoT)
- d. Provide feature ESG assessment, weighting, and scoring automatic
- e. Serve results ESG measurement in form easy reports and dashboards understood
- f. Support the retrieval process decision by the officer export and management
- g. Analysis Non - Functional Requirements

Besides function main, system must fulfil non- functional requirements following :

- a. Reliability : System capable operate in a way stable and consistent
- b. Security : ESG data protection , including access based authorization
- c. Performance: Data processing and visualization processes are carried out in real-time or near real-time
- d. Convenience Usability : Interface friendly users for officer export
- e. Scalability : System can developed along increasing data volume and complexity chain supply
- f. Compliance Regulation (Compliance): System in harmony with national and international ESG standards
- g. Analysis Data Requirements

Stage This identify the types and characteristics of data required include :

- a. Environmental data ( emissions carbon, use energy, waste, and water)
- b. Social data ( safety work, welfare power work, involvement public )
- c. Governance data ( compliance law , transparency , internal policies )
- d. Operational data chain supply export ( production, transportation, logistics, and distribution )
- e. Data must be own attribute validity, accuracy, consistency, and traceability.

### 5. Analysis Need Operational (Operational Requirements)

Need operational system includes :

- a. Support to channel export process work commodities natural
- b. Ability system For used in environment dynamic operations
- c. Integration with system information that has been There is
- d. Support maintenance and updates system in a way sustainable

## 6. Specifications Need System (System Requirements Specification – SRS)

All over the results of the Requirements Analysis then summarized in System Requirements Specification (SRS) document which becomes reference main stages in the next SEP stages , namely System Design, Implementation, Verification, and Maintenance.

## 2. System Design

Stage System Design is a phase in the System Engineering Process (SEP) that aims to translate the system need identified at the Requirements Analysis stage into a design for a technically and architecturally structured system. At this stage, this defines how the system will be built, integrated, and operated to support the ESG measurement process for the supply chain, export commodities, and natural resources.

### 1. Design Architecture System ( *System Architecture Design* )

Architecture system designed use modular approach to ensure flexibility and scalability. System consists of on a number of component main, namely :

- a. Layer Data Acquisition Layer : Collecting ESG data from various source chain supply, good either manually or automatic.
- b. Layer Data Processing (Processing Layer): Do normalization, validation, and processing of ESG data.
- c. Layer ESG Analytics (ESG Analytics Layer): Count ESG scores and indices based on indicators and weights that have been set.
- d. Layer Presentation Layer: Serve results ESG measurement in dashboard forms, graphs, and reports.
- e. Layer Management System (System Management Layer): Manage users, security, and configuration system.
- f. Approach This ensure integration between subsystem at a time make it easier future development.

### 2. Functional Design Planning

Functional design define function main every module system, including :

- a. Chain ESG data input and integration module supply
- b. Assessment module Environmental, Social, and Governance indicators
- c. Weighting and calculation module ESG score
- d. Visualization and reporting module ESG performance
- e. Management module users and rights access

Every function designed For support need operational officer export in do ESG assessment in general consistent and standardized.

### 3. Data *Design* Planning

Data design includes design data structure and data flow in systems, including :

- a. Database schema for storing ESG data, chain data supply, and metadata
- b. Relation between data entities that represent actors and chain processes supply
- c. Mechanism storage historical data for audit and reporting needs
- d. *Data flow* design that ensures traceability of ESG *data* from source until results evaluation

### 4. Design Interface User *Interface* Design

Interface users designed with principle *user- centered design* For make it easier officer part exports , including :

- a. Simple and structured data input display
- b. ESG dashboard that displays scores, trends, and indicators performance main
- c. Reporting features that can customized with need users
- d. Intuitive and easy navigation understood
- e. This design aim For increase effectiveness use system in environment operational daily.

### 5. Design Security and Control Access ( *Security Design* )

System designed with mechanism security that includes :

- a. Authentication and authorization based roles ( *role-based access control* )
- b. ESG sensitive data encryption
- c. Recording activity user ( *logging* ) for audit requirements
- d. Protection to access No legitimate and lost data
- e. Security become aspect crucial considering that ESG data has mark strategic and regulatory.

### 6. System Integration Design

Stage This establish integration strategy with system others, including :

- a. System information exports that have been There is
- b. System management chain supply
- c. External ESG reporting platform or regulator

- d. Integration is designed use interface services ( *API* ) for ensure reliable interoperability and data exchange.
7. System Design Specification ( *SDS* )  
All over results design summarized in document **System Design Specification (SDS)** which is reference at the stage implementation, testing, and maintenance system in cycle *System Engineering Process* .

### 3. Implementation

Stage Implementation in the Systems Engineering Process (SEP) is the phase of realizing the system design defined at the System Design stage. At this stage, all component system chain ESG measurement supply export commodities natural realized in a form system based on a computer that can be operated by officers part export in a real and integrated way.

#### 1. Implementation Architecture System

Implementation done with build system in accordance architecture that has been designed, which includes :

- a. Implementation layer data acquisition for receive ESG data input from chain supply export
- b. Layer development data processing for validation, normalization, and data storage
- c. Implementation layer ESG analytics for calculation ESG indicators and scores
- d. Implementation layer presentation For display results analysis in dashboard and report forms
- e. modular approach is applied so that each subsystem can developed and tested in a way separated.

#### 2. Functional Module Development

At the stage This done coding and configuration modules functional main, including :

- a. management module (data input, editing, and validation )
- b. Assessment module Environmental, Social, and Governance indicators
- c. Weighting and calculation module ESG scores in general automatic
- d. Reporting and visualization module ESG performance
- e. Management module users and rights access

Every module developed based on specification design and needs user .

#### 3. Database Implementation

Database implementation is done For support ESG data storage and management, including:

- a. Making appropriate database schema data design
- b. Implementation relation between table representing the chain process supply
- c. Historical data storage For audit and evaluation needs sustainable
- d. Mechanism backup and data recovery
- e. Database designed For ensure consistency, integrity, and traceability of ESG data.

#### 4. Implementation Interface Users

Interface users implemented in accordance principle *user- centered design* with objective make it easier officer part exports , which include :

- a. Structured and easy ESG data input form used
- b. Interactive dashboard For display ESG scores and indicators
- c. Reporting features that can customized with need users
- d. Navigation intuitive and responsive system
- e. Implementation This aim increase efficiency and accuracy of the ESG assessment process.

#### 5. Implementation Security System

Security system implemented For protect data and access users, including :

- a. Implementation authentication and authorization based roles ( *role-based access control* )
- b. Data security through encryption and management credentials
- c. Recording activity user ( *audit trail* ) for needs supervision
- d. Protection to error use and access No legitimate
- e. Aspect security become an integral part of implementation system ESG- based.

#### 6. Implementation of System Integration

At the stage This done implementation integration system with system external, including :

- a. Integration with system information exports that have been There is
- b. Integration with system chain supply and logistics
- c. Provision interface services ( *Application Programming Interface – API* ) for data exchange
- d. This integration ensure system ESG measurements can operate in a way integrated in digital export ecosystem commodities nature.

#### 7. System Configuration and Deployment

Stage end implementation includes :

- Configuration system in accordance need operational organization
- Installation and *deployment* systems in the environment operational
- Testing beginning For ensure system walk in accordance design
- Preparation documentation technical and guidance users
- Deployment is done in a way gradually For minimize risk disturbance operational.

#### 4. Testing

Stage Testing in the Systems Engineering Process (SEP) aims to ensure that the system chain ESG measurement supply export commodities nature is implemented and functioning in accordance with user needs, and that it fulfills the technical and operational specifications set. Stage: This is a verification and validation process for the overall component system before it entirely operates.

##### 1. Unit Testing

Unit testing is performed For verify function of each module system in a way separate, including :

- a. ESG data input and validation module
- b. Data processing and storage module
- c. Calculation module ESG indicators and scores
- d. Visualization and reporting module
- e. Management module users and security
- f. Testing This aim ensure every module walk in accordance specifications and free from error functional.

##### 2. Integration Testing

After module tested individually , done testing integration For ensure interaction between module walk with good, among others:

- a. Integration between module data acquisition and database
- b. Module integration ESG analytics with module visualization
- c. System integration with system information export and chain supply external
- d. Testing This aim detect error interface and data flow between subsystem.

##### 3. Testing System ( *System Testing* )

Testing system done to overall system as One unity, including :

- a. Testing channel ESG measurement workflow from beginning until end
- b. Testing performance system in processing ESG data
- c. Testing security systems, including authentication and authorization users
- d. Testing reliability system in condition burden different work
- e. Stage This ensure system fulfil specification design and needs operational.

##### 4. Testing Functional *Testing*

Testing functional done For ensure all over function system walk in accordance need users, including :

- a. Ability system do evaluation ESG indicators in general accurate
- b. Accuracy calculation ESG scores and indices
- c. Conformity of report output and dashboard with ESG standards
- d. Convenience officer export in use system
- e. Testing This focus on suitability between function systems and needs real user.

##### 5. Performance Testing

Testing performance aim For evaluate ability system in handle burden operational, including:

- a. Response time system in processing and displaying ESG data
- b. Ability system manage data in amount big
- c. Stability system in condition use simultaneous
- d. Test results This used For optimize performance system before implemented in a way full.

##### 6. Testing Security ( *Security Testing* )

Testing security done For ensure data and system protection, including :

- a. Testing mechanism authentication and authorization
- b. Testing vulnerability to access No legitimate
- c. Validation ESG data protection that is sensitive
- d. Stage This important For guard integrity and confidentiality of ESG data.

##### 7. Testing Reception User *Acceptance Testing* ( UAT )

Testing reception users done with involving officer part export as users end, including :

- a. Evaluation convenience use system

- b. Compliance system with channel Work operational
- c. Identification need repair or adjustment
- d. UAT ensures system Ready used and accepted by users in environment operational real .

#### 8. Documentation and Evaluation of Test Results

All over results testing documented in a way systematic in report testing, which includes :

- a. Findings errors and discrepancies system
- b. Corrective actions and testing repeat
- c. Recommendation readiness system For stage operations and maintenance
- d. Documentation This become base taking decision For continue to stage *Operation and Maintenance in System Engineering Process*.

### 5. Deployment

Stage Deployment in the Systems Engineering Process (SEP) is a phase of implementation in an operational environment, following stage testing. This aims to ensure the system chain for ESG measurement, supply, export, and commodities can be used effectively by officers, both for export and integrated with ongoing business processes.

#### 1. Preparation Environment Operational

Stage initial deployment begins with prepare environment operational system, which includes :

- a. Preparation infrastructure device hardware and devices soft
- b. Server, database, and network configuration
- c. Adjustment system with policy technology information organization
- d. Verification readiness system support and integration external
- e. Preparation This aim ensure system can walk stable and safe in environment operational.

#### 2. Installation and Configuration System

Installation system done in accordance with specification technical that has been determined, including :

- a. Installation application system ESG measurement
- b. System parameter configuration in accordance need export organization and process
- c. Arrangement right access and roles users
- d. Configuration module integration with other systems
- e. Stage This ensure system Ready used in accordance need operational.

#### 3. Data Migration and Initialization

If there is ESG data or chain data supply Previously, a data migration process was carried out , which included :

- a. Historical data transfer to in system new
- b. Validation and verification accuracy of the resulting data migration
- c. Initialize initial data For needs operational system
- d. Data migration is performed with guard integrity and consistency information.

#### 4. Trial Operational ( *Pilot Deployment* )

Before implemented in a way full, trial run operational through *pilot deployment*, including:

- a. Implementation systems on a scale limited or work unit certain
- b. Evaluation performance system in condition operational real
- c. Identification constraint technical and operational
- d. Improvement system based on results evaluation
- e. Stage This aim minimize risk failure in implementation scale full.

#### 5. Training and Socialization Users

Training done For ensure officer part export capable operate system optimally, including :

- a. Training use systems and features main
- b. Giving guide operational and documentation users
- c. Socialization procedure Work new based system ESG measurement
- d. Training This increase level adoption and effectiveness use system.

#### 6. Implementation Full Deployment

After system stated stable and feasible, done implementation full, which includes :

- a. Implementation systems across all work units related
- b. Transfer of the ESG assessment process from manual method to system based computer
- c. Initial monitoring use system in a way intensive
- d. Stage This mark system official used in the operational process ESG measurements.

### Initial Monitoring and Evaluation

At the stage At the end of deployment, monitoring and evaluation are carried out beginning, including :

- a. Monitoring performance and stability system
- b. Collection bait come back from users
- c. Identification need adjustment or repair beginning
- d. this monitoring become input important For stage *Operation and Maintenance* in cycle *System Engineering Process*.

## 6. Maintenance

Stage Maintenance in the Systems Engineering Process (SEP) is a phase of maintenance and improvement of the system after it is implemented and used in an operational stage. The aim of the guard performance, reliability, and sustainability system chain ESG measurement supply export commodities nature to remain in accordance with user needs, development regulations, and dynamic environmental operations.

### 1. Maintenance Corrective *Maintenance*

Maintenance corrective done For repair error or disturbances that arise during use system, including :

- a. Repair error function or *bug* in the module system
- b. Handling failure system or decline performance
- c. Correct error processing or ESG data display
- d. Adjustment system consequence error configuration or integration
- e. Maintenance This aim ensure system still walk in accordance expected function.

### 2. Maintenance Adaptive *Maintenance*

Maintenance adaptive done For adapt system with change environment external, including:

- a. Change regulations or national and international ESG standards
- b. Business process adjustment export and chain supply
- c. Integration with technology or system new
- d. Change need organization or stakeholders interest
- e. Stage This ensure system still relevant and compatible with development environment operational.

### 3. Maintenance Preventive ( *Preventive Maintenance* )

Maintenance preventive done For prevent occurrence disturbance future systems, including:

- a. Inspection routine performance systems and infrastructure
- b. Updates device software and systems security
- c. Database optimization and management storage
- d. Usage monitoring system and capacity source Power
- e. Approach preventive aim guard stability and reliability system in term long .

### 4. Maintenance Perfective ( *Perfective Maintenance* )

Maintenance perfective focused on improving quality and capability systems, including :

- a. Improvement features and interface users
- b. Improvement accuracy and efficiency ESG calculations
- c. Addition module analytic or reporting advanced
- d. Optimization experience users based on bait come back
- e. Stage This aim increase mark use system for users and organizations.

### 5. Monitoring and Evaluation of System Performance

Monitoring and evaluation done in a way sustainable For evaluate effectiveness system, including :

- a. Monitoring performance technical and operational system
- b. Evaluation level utilization system by officers export
- c. Analysis consistency and quality results ESG measurement
- d. Identification opportunity development more carry on
- e. Evaluation results become base planning improvement future systems .

### 6. Management Documentation and Technical Support

Stage This includes :

- a. Updates documentation technical and guidance users
- b. Provision support technical *support* for users
- c. Recording change system and history maintenance
- d. Management related knowledge ( *knowledge management* ) system
- e. Management good documentation ensure sustainability operational system .

### 7. Planning Development Sustainable

As part end from stage *Maintenance*, carried out planning development sustainable, including:

- a. Identification need development system furthermore
- b. Preparation of development roadmap system
- c. Adjustment system with sustainability strategy organization
- d. Planning This ensure system ESG measurements can Keep going develop and support objective sustainability term long.

### 3.2. Architecture System AIoT Evaluation Risk Credit

Architecture AIoT Chain ESG Measurement Supply Export Commodity Natural designed as a system layered that integrates sensors, edge computing, cloud computing, as well as artificial intelligence for support in making decisions ESG-based. On the First (sensing) layer, various sensors are placed along the chain supply export, from cultivation and facilities processing to warehouse storage and transportation to ports for export. This sensor collects environmental data, such as temperature, humidity, energy consumption, emissions, and relevant operational and social data, with ESG indicators.

Data from the sensor is then processed on the edge layer using a device-embedded system (e.g., a microcontroller) running firmware to initiate data acquisition and network communication. At this stage, pre-processing is basic, including filtering, denoising, data normalization, and time- or location-based segmentation, so that the raw data is ready to be sent to the system center efficiently and reliably.

Next, the data is sent to the IoT cloud server via API and secure communication protocols. Integration and processing processes are carried out continuously. In the data processing layer, data from various point chain suppliers is combined and further processed through pre-processing, feature extraction, and grouping by Environmental, Social, and Governance dimensions. Layers: This serves as a bridge between field data and AI-based analytical models.

In the AI and analytics layer, the intelligence model, artificial intelligence, and machine learning are applied to analyze ESG patterns, trends, and risks. Models such as machine learning-based tree decision or deep learning are used to evaluate the level of compliance, the impact on sustainability, and potential ESG risks in supply chain exports—analysis results. Then, it is classified or mapped to category-specific ESG performance as a base evaluation and decision-making.

The final layer is the application and decision support layer, which provides ESG measurement results through an interactive, innovative dashboard and report forms. This dashboard offers real-time and periodic visualizations of ESG performance, making it useful for management, regulators, and stakeholders interested in other areas. For supporting strategic decisions, improving compliance, and repairing the sustainable supply chain of export commodities. The following is Figure 3. Architecture AIoT Chain ESG Measurement Supply Export.



Fig 3: Architecture AIoT Chain ESG Measurement Supply Export

## 4. Conclusion

This study concludes that the Systems Engineering Process (SEP) approach provides a framework for systematic, structured, and consistent work in the design of ESG measurement systems for the supply chain of export commodities. The implementation of SEP enables the development process to be carried out in a sequential and integrated way, from the formulation of needs and stakeholders' interests, through the translation of needs into a design system, to the realization, testing, implementation, and maintenance of the system in a sustainable way. By approaching this, every stage's development is connected to and traceable, which reduces the risk mismatch between operational needs and the technically built solutions. Research results confirm that SEP plays an essential role in ensuring that system ESG measurement is not only designed technically but also in tune with the operational context of the supply chain export, adaptive to changing needs, and capable of supporting ESG decisions in a general, sustainable, and systemic way.

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