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Developing an Embodied Energy Database for Construction Materials in India

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Highlights

- Framework for developing an Embodied Energy Database.
- Using Pedigree matrix -data scoring method to reduce the uncertainties in the data.
- Integrating crowdsourcing for data collection to help the stakeholders.
- Optimizing environmental impacts and developing policy guidelines.

Abstract

Optimizing operational energy in buildings can increase the significance of embodied energy and associated carbon emissions. Promoting low embodied energy materials and construction processes is crucial for achieving low-carbon development while reducing operational energy. However, accessing reliable embodied energy data for construction materials in India poses a major challenge for conducting Life Cycle Assessments (LCA) to quantify the environmental impact. The proprietary nature of these datasets limits their availability in LCA studies, leading to uncertainties in building LCA results. Thus, this study aims to develop a construction material embodied energy database in India. A uniform data collection framework adapted for the building and construction sector and confidence level measurements for the embodied energy datasets will be used. This database will help reduce uncertainty in LCA studies and support informed decision-making.

Keywords: embodied energy, life cycle assessment, crowdsourcing database, construction materials

Introduction

According to the IEA report, 8% of the global energy-related and process-related CO_2 emissions result from using fossil fuels in the building, 19% from generating electricity, and 6% related to manufacturing building materials [1]. Buildings consume energy during all the lifecycle stages, including construction, use, maintenance, renovation, and demolition. The research conducted by CSIRO reveals that the typical household encompasses approximately 1,000 gigajoules (GJ) of energy embedded in the construction materials used to build it, which is equal to 15 years of normal operational energy use [2]. Embodied emissions encompass the significant environmental impact of various building life cycle stages. Additionally, all activities and processes throughout the supply chain that contribute to building construction also contribute to embodied emissions. These embodied emissions play a crucial role in understanding the overall carbon footprint of a building [3].

India's rapid urbanization and population growth have led to significant demand for residential spaces [4]. However, there is a concerted effort to construct buildings that are less intense on energy consumption and have reduced operational carbon emissions. As most of the residential buildings in India are either Naturally Ventilated or Mixed mode, the operational energy in the residential buildings is comparatively lesser. Additionally, the Government of India has also introduced codes like ENS – Eco Niwas Samhita, and initiatives like Pradhan Mantri Awas Yojana (PMAY) enhance the usage of sustainable materials and locally available materials, which helps to reduce embodied energy and emissions ultimately. There is a growing trend towards using sustainable and low-carbon materials to reduce embodied carbon in residential buildings. Materials like fly ash bricks, autoclaved aerated concrete (AAC) blocks, and bamboo composites are being promoted as alternatives to conventional high-carbon materials like red bricks and concrete. Apart from the material selection, the BEE has also introduced the standards and labelling problem through which the appliances are rated, and the energy savings potential of the appliances is informed [4]. Additionally, passive design strategies that optimize natural lighting and ventilation are being incorporated to reduce the energy demand of residential spaces [5] [6]. On the other hand, the commercial building sector is also undergoing a transition towards more energy-efficient practices and technologies. This includes adopting advanced building management systems, energy-efficient lighting, and HVAC (Heating, Ventilation, and Air Conditioning) systems, and integrating renewable energy sources. The Indian government, along with organizations like the Bureau of Energy Efficiency (BEE), has introduced energy efficiency codes and rating systems for buildings, such as the Energy Conservation Building Code (ECBC) and rating systems like the Indian Green Building Council (IGBC) certification. By implementing and adopting these measures, the operational energy consumption of commercial buildings can be significantly reduced [7] [8]. On the other hand, the operational versus embodied carbon ratio is changing due to efforts to reduce the embodied carbon in construction materials. This involves utilizing low-carbon or carbon-neutral materials, optimizing the design to reduce the required materials, and sourcing materials locally to reduce transportation emissions.

While demand-side measures, such as energy-efficient practices at the building and community scales, have been gaining momentum in improving energy efficiency in the built environment, there is also a pressing need to address supply-side measures for achieving substantial carbon reduction. Additionally, renewable energy continues to grow despite global uncertainties, which take a larger part of the operational energy of the building sector [9]. Building codes, energy regulations, and similar building rating systems primarily prioritize the reduction of energy consumption during building operation and the transition to low-carbon electricity sources, whether generated onsite or obtained from external sources. However, they have not made it a specific requirement to reduce embodied energy due to the inherent challenges of calculating it [10]. Focusing on less carbon-intensive production processes and materials is crucial. The supply-side measures emphasize the importance of considering the entire life cycle of buildings, from material extraction to manufacturing and transportation. Significant carbon emissions can be attributed throughout these stages to the production of building materials, such as cement, steel, and glass, and the energy consumed during manufacturing and transportation [11] [12]. The quantification of carbon emissions throughout the production of building materials and the energy-intensive manufacturing and transportation processes highlights their significant environmental impact. Hence, understanding the embodied energy of construction materials is crucial for assessing their overall carbon footprint and identifying opportunities for sustainable alternatives.

Thus, this study aims to develop a database of embodied energy of construction materials in India. This is achieved through a tool that serves three purposes:

- Generation of embodied energy database through crowdsourcing
- Quantification of the confidence level of the datasets
- Access point of the openly available database

The tool's scope includes a framework for collecting embodied energy data based on the "Fit-for-purpose" approach.

Context – Literature study

The embodied energy or carbon of a building considers the energy and carbon emissions associated with the extraction, processing, manufacturing, transportation, and assembly of building materials, as well as the energy used during construction and the disposal of waste materials. It also considers the potential for recycling or reusing materials and the environmental impact of demolition or removal. It refers to the total energy consumed throughout the life cycle phases of a building [13] [14].

Conducting a Life Cycle Assessment (LCA) study, which involves a systematic analysis of the environmental impacts of a product, process, or system throughout the entire life cycle of the building. The standard ISO/EN 15978 international standard is titled "Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method." It provides a standardized methodology for assessing and reporting the environmental performance of buildings throughout their life cycle. The standard focuses on calculating the environmental impacts associated with the construction, use, and end-of-life stages of buildings. It provides guidelines for evaluating various aspects such as energy consumption, greenhouse gas emissions, resource depletion, water consumption, and waste generation. ISO 15978 outlines a life cycle assessment (LCA) framework for analyzing the environmental impacts of buildings. This includes considering the extraction and processing of raw materials, manufacturing of building products, transportation, construction activities, operational energy consumption, maintenance and repair, and the eventual demolition or disposal of the building. It provides guidelines and requirements for conducting an LCA, including data collection, impact assessment, and reporting. This standard enables stakeholders in the building industry to evaluate and compare the environmental performance of different building designs and materials, facilitating more informed decision-making towards reducing embodied carbon and improving overall sustainability [15].

Furthermore, the principles and framework for conducting Life Cycle Assessment (LCA) the fundamental concepts, terminology, and structure for LCA studies established in the ISO 14040:2006 standards. This standard ensures consistency, transparency, and credibility in the assessment process by providing guidelines for goal definition, scope setting, inventory analysis, impact assessment, and interpretation of results [16]. The four components of LCA are described in the ISO /EN 14040 are as follows:

1. Goal and Scope Definition: Clearly define the purpose, boundaries, functional unit, and system limits of the LCA study to establish the scope and context.
2. Life Cycle Inventory (LCI): Compiling a comprehensive inventory of inputs (resources, energy, materials) and outputs (emissions, waste) associated with each life cycle stage to quantify the environmental inputs and outputs.
3. Life Cycle Impact Assessment (LCIA): Analyzing the inventory data to evaluate the potential environmental impacts of the assessed system in specific impact categories such as climate change, human health, ecosystem quality, and resource depletion.
4. Interpretation: Analyzing and summarizing the LCA results, including comparing impact categories, identifying hotspots, assessing uncertainties, and drawing conclusions to provide insights for decision-making and improvement opportunities [17].

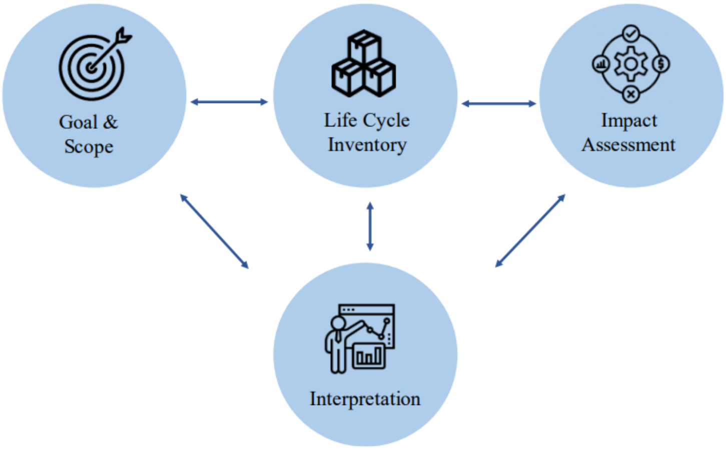

Figure 1: Life Cycle Assessment Phases

Furthermore, ISO 14044:2006 complements ISO 14040 by detailing the requirements and guidelines for conducting LCA studies. It provides a comprehensive methodology and technical guidance for each assessment stage. ISO 14044 specifies the data requirements, methods, and tools to collect and analyze life cycle inventory data, assess environmental impacts, and interpret the results. This standard promotes the use of reliable data, systematic analysis, and peer review to ensure the accuracy and validity of LCA studies. This standard helps to conduct robust LCA studies and make informed decisions to improve the environmental performance of their products and systems [17].

LCA can be easily calculated with the help of software, which can carry out detailed environmental assessments based on integrated databases. Numerous commercial tools are available in the market that facilitate the calculation of Life Cycle Assessment (LCA) as well as the estimation of both embodied and operational energy. These tools simplify the process and make it more accessible to users. Some tools include ATHENA, ACE, Boustead Model, EcoPro, EcoScan, EPS 2000, eToolLCD, GaBi, One Click LCA, Simapro, Umberto, etc. These tools allow using many databases and environmental impact assessment methods. Additionally, these tools follow ISO standards for assessments [18] [19] [20]. However, when it comes to commercial tools that incorporate LCA data for building assessment, there can be limitations regarding the reliability of data sources. Some tools are considered "black box" or "grey box" tools, meaning that the underlying data and calculations are not transparent, and it may be challenging to verify their accuracy or assess the reliability of the data used. For example: Ecoinvent, GaBi allows and supports black box modelling by offering data on the input and outputs of processes without detailed data [21] [22]. This lack of transparency and uncertainty in data sources can limit the widespread adoption of these tools, especially when developing national codes or regulations that rely on consistent and trustworthy data for assessing building performance [23].

In terms of research and development, there have been numerous papers focused on LCA methodologies and applications.

The methods include Life cycle costing, life cycle inventory, life cycle analysis and optimization [24] - [30]. However, a common and comprehensive method that is a universally accepted approach has yet to emerge. The field of LCA is still evolving, and researchers are continuously working on improving methodologies and addressing challenges, such as data reliability and standardization.

Additionally, it is worth noting that some countries are making attempts to incorporate embodied carbon. For example, the United Kingdom has introduced the "Redefining Carbon" initiative, which aims to establish a new framework for measuring and reporting embodied carbon in construction projects. The United States and the Netherlands have adopted a material-scale approach, which focuses on the performance of materials. Denmark has taken a more progressive approach than the building-scale method by establishing an embodied carbon budget of 12 kg CO_2 equivalent (CO_2-eq) per square meter per year for new buildings larger than 1000 square meters [31].

Regarding the building code, Marin County - United States, has successfully incorporated embodied carbon into its Marin Country code Chapter [32]. The Netherlands has introduced limits on embodied carbon in buildings through building regulations applicable to residential and non-residential buildings. France has introduced regulations "RE2020", which is relevant to the new buildings, that govern operational and embodied carbon. Countries like Finland are trying to develop legislation for low-carbon construction [33].

In India, the Energy Conservation Building Code (ECBC) is undergoing a restructuring process to introduce a new chapter called the Building Materials in the Energy Conservation Building Sustainable Codes Standards (ECBSC). This new chapter will focus on addressing building materials' embodied energy and carbon. Including embodied carbon considerations will be applicable to structural and envelope systems, excluding building finishes and electrical, mechanical, plumbing, and non-structural elements. The additions to the code will consider factors such as seismic zones and the availability of floor space index or floor area ratio. The embodied energy or carbon will be reported in kilograms of carbon dioxide equivalent per square meter ($KgCO_2e/m^2$). The benchmark for embodied carbon will be calculated using a CSV file and is subject to annual revisions, making it a dynamic benchmark that can change over time. Overall, restructuring the code in India aims to incorporate embodied carbon considerations into the regulatory framework, providing guidelines and benchmarks for reducing carbon emissions associated with building materials in buildings' structural and envelope systems.

Similar Crowdsourcing Databases:

Crowdsourced data collection offers a cost-effective method for researchers to delegate straightforward tasks or surveys, enabling them to gather data in real time. This approach allows for a significantly larger and more geographically diverse set of observations than traditional data collection methods, keeping costs relatively low. The crowdsourcing database is popular and used in many fields. Some of the popular crowdsourcing databases are listed as follows:

Table 1: Crowdsourcing Databases - Examples

Crowdsourcing Database	Description	Usage Examples
Autodesk Revit Families	A category within Autodesk Revit where manufacturers, designers, and architects can upload their BIM files for users to download and incorporate into their own BIM projects [34].	Architectural design, building modelling, component sourcing
ASHRAE DB II	A specialized database for collecting and compiling Thermal Comfort data worldwide, ensuring proper attribution and referencing. Data is structured for consistency and easy analysis. Rigorous validation checks maintain data integrity [35].	Research, analysis, and exploration of thermal comfort conditions
3D Warehouse-Sketchup	A cloud-based platform within Autodesk SketchUp where users can share their 3D models. Professional companies, including furniture manufacturers, can upload their products for designers to incorporate into their projects [36]	Architectural visualization, product design, collaboration
Open Street Map	A collaborative mapping project that relies on crowdsourcing for data collection, validation, and maintenance. User-contributed data is reviewed and verified through peer review, cross-referencing, and automated technologies [37].	Mapping, navigation, geographic information systems
Google Maps	Google Maps allows users to contribute crowd source data, which is validated through a structured process. Users can submit updates, corrections, reviews, and additional information to improve the accuracy and completeness of map data [38].	Navigation, local business information, real-time traffic updates
Wikipedia	Wikipedia is a collective platform for sharing structured knowledge. Quality control is maintained through community engagement, moderated discussions, and secondary processes such as arbitration committees [39].	General knowledge, research, reference

Methods

The proposed methodology for developing the embodied energy database of building materials involves the creation of a user-friendly tool. This tool allows users to input their data related to the embodied energy of various building materials. Once the data is collected, it undergoes analysis and verification to ensure its accuracy and reliability. The verified fit datasets are then saved into the database for further utilization.

The database's final dashboard will provide users with valuable information regarding the embodied carbon of different building materials. Users can access this dashboard, which will present the data comprehensively and easily understandable. The dashboard will visually represent the embodied energy database, enabling users to explore and analyze the embodied carbon of specific building materials.

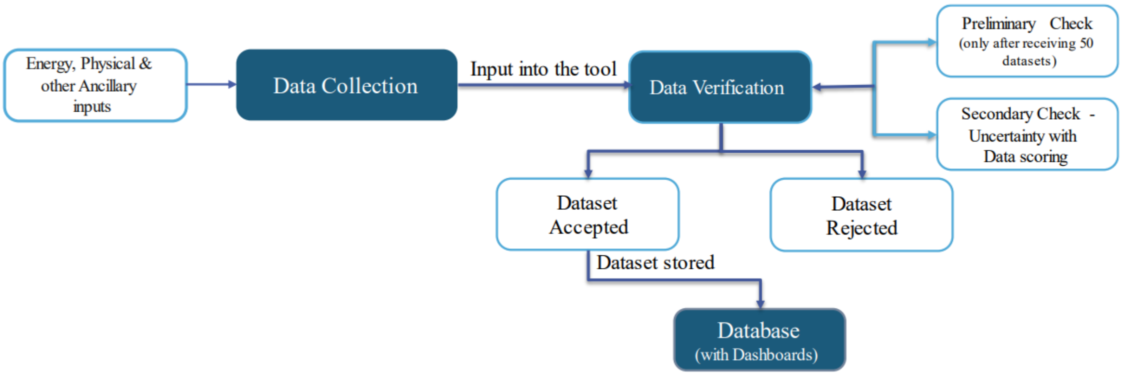

Figure 2: Process flow of the Embodied Energy Database Too

Data collection: Collecting embodied energy data is indeed a complex task due to the lack of consensus on the specific details, units, metrics, and data format. To set up an embodied energy database, the initial crucial step is to formulate a comprehensive data collection format capable of storing and validating the collected information. We propose creating a standardized database format designed to collect material carbon emissions during the A1 to A4 life cycle processes – Cradle to Gate. These processes, including raw material extraction, procurement, manufacturing, and transportation, form the foundation of the overall life cycle assessment. By focusing on these core processes, the proposed format can effectively capture the essential data needed for assessing building materials' embodied energy and carbon emissions. This standardized format will establish a consistent framework for data collection, enabling efficient storage, validation, and analysis of the gathered information, laying the groundwork for developing a robust and reliable embodied energy database. The following points were considered while finalizing the data collection format:

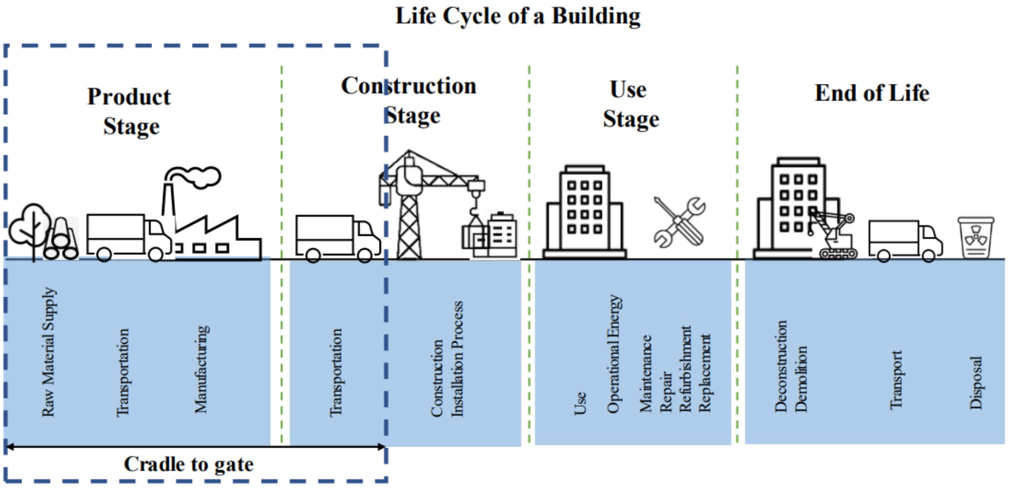

Figure 3: The life cycle of a building

1. ***Data Collection*** – The data being collected includes both embodied energy and carbon emissions. The units used are MJ (megajoules) for embodied energy and kg CO_2 or kg CO_2eq (carbon dioxide equivalent) for carbon emissions.
2. ***Life cycle process*** – The proposed granularity of the life cycle process data collection is at the individual process level. The database aims to collect data for each specific activity within a life cycle process. For example, if Process A1 includes activities such as "Raw material extraction" and "Raw material procurement," contributors would be encouraged to enter data for each activity separately to achieve the highest level of granularity.

3. ***Data source*** – The data sources can be primary and secondary. Preliminary data may be obtained directly from material suppliers, scientific publications, or material-specific Environmental Product Declarations (EPDs). Secondary data is information gathered from existing databases or literature that compiles relevant life cycle assessment data.
4. ***Age of data*** – The age of the data can vary. Contributors may enter the age of the data directly, or it can be categorized into time slabs, such as 1-2 years old, to indicate its recency.
5. ***The geographical region of data*** – The region from which the data was collected should be specified. For example, contributors would be prompted to provide information on the location of material extraction for Process A1 or the manufacturing location for Process A3. This helps to account for regional variations and specific environmental conditions that may influence the life cycle assessment.
6. ***Who would be able to enter the data*** – Contributors can range from PhD scholars to material manufacturers. The database aims to be inclusive and welcomes data contributions from a wide range of stakeholders who possess relevant knowledge and information regarding the life cycle processes of materials.
7. ***Level of technical rigour of the database***– The database will be maintained with a high level of technical rigour. While data can be collected from various sources, it will undergo rigorous validation checks to ensure its fitness and reliability. The validation checks will be applied at the individual process level, meaning that data for each specific process will be evaluated separately. For instance, if a contributor provides data for Processes A1, A2, and A3, the validation checks will assess the confidence intervals for each process. This means that data for A1 and A2 might fall within a 95% confidence range, while data for A3 may fall within an 80% confidence interval. All data will be integrated into the database but will be differentiated based on their associated confidence intervals, indicating their reliability.

We propose the establishment of a centralized database that will be interconnected with multiple data collection files. Each contributor will receive separate data collection files tailored to their specific contributions. The data collection file will be structured into four sheets corresponding to the A1, A2, A3, and A4 life cycle processes. The following data is proposed to be collected for each life cycle process:

- **For the A1 life cycle process:** In the case of the A1 life cycle process, contributors are encouraged to provide data at the most detailed level possible, if available. They can enter specific information related to the activities involved or provide comprehensive data for the embodied energy or carbon of the process. Background information is crucial for establishing the context of the data, while some details are specific to embodied energy or carbon. It also requires the contributors to indicate the source of the data, which can be either primary data from the contributor or data obtained from material manufacturers, scientific literature, reports, and other sources. Data sources indicate the data type, specifying whether the data was directly measured by the contributor, calculated indirectly, or derived using conversion factors. For example, indirect calculations or conversions can be used to estimate the data if certain information is unavailable, such as the total weight of coal used. This approach ensures an accurate and comprehensive collection of embodied energy and carbon data for the A1 life cycle process by emphasizing granularity and providing relevant context.
- **A2/A4 life cycle process:** In the case of the A2 and A4 life cycle processes, contributors will be requested to provide information regarding transport-related carbon emissions or embodied energy. The data collection format for these processes will be similar. Contributors will have the opportunity to enter details related to transport for as many vehicles involved in the process as necessary. Detail 10 in the format will indicate the vehicle category, distinguishing between Light Duty Vehicle (LDV), Medium Duty Vehicle (MDV), or High Duty Vehicle (HDV). This information will enable comprehensive data collection and analysis for transport-related aspects of both the A2 and A4 life cycle processes.
- **A3 life cycle process:** In this stage, contributors will provide data on the embodied energy or carbon emissions resulting from the manufacturing process. The data collection will capture information about all the raw materials utilized in the manufacturing process and the specific method or technology employed.

We propose to have the data collection of each stage with four levels of detail; the above-mentioned information is further broken down into four levels according to its availability.

Table 2: Lifecycle stages process breakdown into four levels of details

	Raw Material Acquisition	**Transport**	**Manufacturing**	**Transport**
LOD 1	Manufacturer, Raw materials, Quantity	Vehicle used, Distance from the mine to the manufacturing site	Manufacturing process, Quantity of the raw materials	Vehicle used, Distance from the mine to the manufacturing site
LOD 2	Equipment type, Fuel type of the equipment	Number of vehicles, Vehicle type, Fuel type of the Vehicle	Equipment used, Energy used (Fuel and electricity)	Number of vehicles, Vehicle type, Fuel type of the Vehicle
LOD 3	Manufacturer and model of the equipment, Embodied energy	Manufacturer and Number of vehicles, Number of trips, Embodied energy	Manufacturer and model of the equipment embodied energy	Manufacturer and Number of vehicles, Number of trips, Embodied energy
LOD 4	Waste	Waste	Waste, Material Production Quantity	Waste

We propose implementing an online data collection method for this database. The data collection template will be available for download, allowing contributors to access and complete it. Once the contributors have filled out the template with the relevant data, they can share it with the designated database manager(s) via email. The database manager(s) will then review and validate the data for its quality and accuracy. This process ensures that the collected data undergoes a rigorous quality control check, enhancing the reliability and credibility of the information stored in the database. By providing an accessible and straightforward method for data submission, we aim to encourage widespread participation and collaboration from various stakeholders, ultimately enriching the database with comprehensive and diverse life cycle process data. The data validation process is explained in detail in the further sections. Note that in case of data scarcity, we may propose the users use syntenic data for their calculation.

Data Verification:

The data checking and verification will consist of two phases: the Primary Check and the Secondary Check.

1. Primary Check: This phase occurs after the tool submits the data. The dataset is compared with similar datasets that have been previously accepted. The dataset is deemed unfit and excluded from further analysis if any major errors or discrepancies are identified. The Primary Check phase commences once sufficient datasets, such as 50, have been gathered to enable effective comparisons. The distribution range will be fixed with the obtained dataset, and if the new dataset doesn't fit into the distribution range, it will be rejected.
2. Secondary Check: This is a mandatory phase. During this phase, the selected datasets undergo scoring based on the pedigree matrix method outlined in ISO 14044. The scoring considers regionality, time relevance, and units used. The uncertainty of the dataset about the identified scoring parameters is also assessed. The Secondary Check helps evaluate the quality and reliability of the datasets, considering their alignment with specific criteria and the level of uncertainty associated with the provided data.

By following these two comprehensive checking phases, the database ensures that only reliable and high-quality datasets are included for further analysis and utilization. The primary check eliminates major erroneous data, while the secondary check evaluates datasets based on predefined scoring parameters and uncertainty assessments, providing a robust framework for data validation.

Data Scoring

The scoring system can consider various factors, such as data source reliability, data age, geographical coverage, completeness, and consistency. Each criterion can be assigned a score based on its importance and relevance to the analysis. For this study, we have used the Weideman and Wesnaes (1996) proposed framework for scoring based on five parameters:

The parameters for scoring are as follows:

Data source: The data source refers to the origin or provider of the information used for scoring. It is crucial to consider the data source's reliability, credibility, and validity. High-quality data sources, such as reputable research institutions, government agencies, or well-established organizations, are generally preferred as they are more likely to provide accurate and trustworthy information.

Age of the data: The age of the data indicates how recently the information was collected or updated. More recent data is generally preferred because it reflects the current state of affairs and is likely to be more relevant. However, the importance of the data's recency may vary depending on the specific context.

Geographical coverage: Geographical coverage refers to the extent to which the data represents different geographic areas. Depending on the application, it may be necessary to have data that covers a specific region, country, or even the entire globe. The geographical coverage should align with the scope of the analysis or decision-making process.

Lifecycle stages: The lifecycle stages parameter considers the different phases or locations of the assessed phenomenon. The inclusion of data from different lifecycle stages provides a more comprehensive understanding of the phenomenon and allows for better decision-making across the entire lifecycle.

Units/Indicators: This parameter refers to the measurement units or indicators used to quantify and assess the phenomenon of interest. The choice of appropriate units or indicators depends on the specific context and the scoring goals. It is important to use indicators that are meaningful, valid, and aligned with the objectives of the analysis. The units or indicators should capture the relevant aspects of the phenomenon and enable meaningful comparisons and evaluations.

The obtained datasets are scored with the help of the pedigree matrix provided above, and with the data quality score obtained, the dataset's quality will be assessed. The pedigree matrix is carried out to determine the data uncertainty.

The overall uncertainty will be calculated once the Data Quality Indicators (DQI) are scored. The general uncertainty is computed by calculating the coefficient of variation, which is obtained by taking the square root of the sum of the squares of the individual coefficients. The formula for calculating the overall uncertainty is given below:

$$\text{Uncertainty (Co-efficient of the Variation)} = \sigma / \mu$$

The Uncertainty value is calculated for the individual process in the system. It is said that a low score on the data quality indicator often leads to higher uncertainty and changes in the mean value. The uncertainty value helps to decide on the data quality and its acceptance into the database.

Table 3: Scoring of data sources based on data quality indicators (adapted from Weidema & Wesnæs, 1996) [40]

	1	2	3	4	5
Data Source	Life Cycle Database or Manufacturer or EPD	Peer-Reviewed Journal Paper	Government Report or Conference Paper	All other sources	-
Age of the data	<3 years	<6 years	<10 years	<15 years	Unknown or more than 15 years
Geographical Coverage	City/State	India	South Asia	Asia	World
Units/Indicator	$KgCO_2e$	$kgCO_2$	kWh or MJ	-	-
Lifecycle stages covered	A1-A4	A1-A3	A1, A2, A4/A3	A1, A2	Anyone lifecycle stage

Uncertainty information can guide further data collection efforts, improve data quality, or prioritize uncertainties for future research. Clearly communicate the uncertainties associated with the LCA results to stakeholders and decision-makers, sensitivity plots, probability distributions, confidence intervals, or other appropriate means. Transparently conveying the uncertainties enables stakeholders to make informed decisions, understand the limitations of the assessment, and identify areas where further data collection or research may be needed.

To ensure the accuracy and relevancy of the dataset, users and manufacturers need to update the data on a yearly or biyearly basis regularly. This periodic updating process helps maintain the dataset's dynamic capability by incorporating any changes or advancements in the embodied energy or carbon data over time. By encouraging users and manufacturers to provide updated information regularly, the dataset can effectively reflect the latest industry standards and practices, providing users with reliable and up-to-date information for their analysis and decision-making processes.

Discussion

The proposed framework for data collection of embodied energy will introduce uniformity and comparability of LCA data pertaining to stages cradle to the gate of the building life cycle. Further, the adopted methodology for database generation can ensure continuous availability of the most recent and relevant embodied energy data.

Each dataset's confidence level measure can help reduce uncertainty in LCA studies that refer to or use the database during the process. At the same time, crowdsourcing of data will ensure that the database is rich in terms of geographical specificity. Hence, it could be used to understand geographical trends in the energy impacts of construction materials during the lifecycle stages cradled to the gate across different parts of India. The database can also be extended to include embodied carbon emissions of these materials. The study focuses on developing a continuously updating embodied carbon database specific to Indian construction materials. This is achieved with the help of a uniform data collection framework adapted for India's building and construction sector. The database also measures and provides the confidence levels of various embodied energy data sets, which is crucial to reducing the uncertainty in LCA studies.

The study aims to create a crowdsourcing database for the embodied energy of the building materials of India. The embodied energy database benefits the Indian built environment in many ways. Some of the benefits are listed as follows:

Understanding environmental impact: By having a comprehensive embodied energy building database, we can better understand the environmental impact of different building materials, construction methods, and design choices. This knowledge enables us to make informed decisions to minimize energy consumption and reduce carbon emissions.

Comparative analysis: An embodied energy buildings database will compare different building materials, products, and construction techniques. With access to such a database, architects, engineers, and builders can evaluate various options' energy efficiency and environmental performance. This will facilitate informed decision-making during the design and construction phases, helping select materials and methods with lower embodied energy and reduced environmental impact.

Performance optimization: The embodied energy buildings database will serve as a resource for optimizing the energy performance of buildings. By analyzing the embodied energy data, designers and developers can identify areas where improvements can be made. This includes exploring alternative materials, assessing the energy efficiency of different building components, and optimizing the construction processes to minimize energy consumption.

Policy development and regulation: A comprehensive embodied energy building database will provide a foundation for developing energy policies, regulations, and certifications related to sustainable construction practices. Governments and regulatory bodies can use this data to set standards, incentivize low-energy and low-carbon construction practices, and promote environmentally friendly building materials.

Research and innovation: An embodied energy building database will facilitate research and development efforts focused on reducing energy consumption and environmental impact in the building sector. Researchers can use the data to analyze trends, identify opportunities for improvement, and develop innovative solutions. This knowledge-sharing platform will encourage collaboration among stakeholders, foster innovation, and accelerate the adoption of sustainable practices in the construction industry.

In summary, an embodied energy buildings database will provide a valuable resource for understanding, analyzing, and optimizing buildings' energy performance and environmental impact. It will enable informed decision-making, support policy development, foster research and innovation, and promote the transition towards more sustainable built environments.

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