Potential for Reducing Greenhouse Gas Emissions through Eco-Design of Elevators

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Abstract

As global urbanization accelerates, it is projected that 68% of the world's population will live in cities by 2050, leading to more high-rise buildings and a growing environmental impact from elevators. The IPCC Sixth Assessment Report emphasizes the need to reduce global greenhouse gas (GHG) emissions by 43% by 2030 and 60% by 2035. A circular economy strategy and GHG reduction for elevators is essential to meet these targets. Currently, most GHG emissions from elevators are generated during production and operation, with the industry primarily focusing on reducing operational emissions. However, eco-design and GHG reduction in production are necessary. This study examines the potential for reducing GHG emissions from elevators through the eco-design of materials, evaluated using life cycle assessment (LCA). As a representative example, a 9-person machine room-less elevator for apartment buildings was evaluated. The LCA results demonstrated that the primary source of emissions during the production stage is the steel components, including the car structure and the rail within the hoist way. To examine future emission trends, scenarios for the power emission intensities in 2030 and 2035 were initially set up. Based on these scenarios, emissions during the production stage of the elevator were projected when the steel materials used are blast furnace iron produced from iron ore as the raw material. Subsequently, emissions in 2030 and 2035 were evaluated for several scenarios in which steel materials are composed of a mixture of blast furnace iron, electric arc furnace (EAF) iron produced by electro-refining of iron scrap, and hydrogen direct reduction iron (H2-DRI) produced by direct reduction of iron ore with hydrogen. Furthermore, scenarios were established in which partial reuse of steel components was implemented in addition to the types of steel materials mentioned above, and emissions were evaluated accordingly. These studies indicate that while the utilization of EAF iron and H2-DRI is effective in achieving the 2030 reduction target, it falls short of achieving the 2035 target. However, the scenario of reusing steel components, in addition to the aforementioned factors, gives a reasonable prospect of meeting the 2035 target. The results indicate that combining the use of low-emission materials with the reuse of parts based on a circular economy is a fundamental strategy for eco-design in the production stage of elevators. Implementing this in conjunction with existing measures such as energy conservation will make a significant contribution to preventing global warming associated with urbanization.

Introduction and Motivation

The global acceleration of urban population growth has resulted in 55% of the world's population now residing in urban areas [1]. This trend is expected to continue, with projections indicating that 68% of the global population, approximately 6.7 billion people, will live in urban areas by 2050 [1,2]. High-rise buildings, which efficiently accommodate a large number of people and function within limited land space, provide an advantageous solution for optimizing urban land use. Consequently, the construction of high-rise buildings has increased alongside rapid urbanization to promote the densification and vertical utilization of land [3]. Elevators are indispensable for the operation of large-scale and high-rise buildings, and the number of elevators is projected to increase on par with the growth in high-rise construction [4]. As a result, the environmental implication caused by the operation and installation of elevators worldwide is also expected to rise. At the same time, mitigating catastrophic environmental changes caused by global warming requires limiting the average global temperature rise to 1.5°C [5]. According to the 2023 IPCC Sixth Assessment Report (IPCC AR6), this necessitates a global reduction in greenhouse gas (GHG) emissions by 43% by 2030 and 60% by 2035 compared to 2019 levels [6]. To decouple urban development from environmental impacts, circular economy strategies for elevators and corresponding reductions in GHG emissions are critical to achieving these targets.

According to the Environmental Product Declarations (EPDs) from major elevator manufacturers [7–12], GHG emissions from elevators primarily occur during the production and use stages of the elevator lifecycle (**Fig. 1**) [13], as illustrated in **Fig. 2**. While various prior studies on the environmental impacts of elevators have focused on reducing operational stage emissions through improved energy efficiency and operational efficiency [4,14–16], to the best of our knowledge, no prior research has examined the application of circular economy strategies in the production stage of elevators or their subsequent environmental impacts.

Therefore, this study evaluates the impact of the composition of steel materials, a primary component of elevators, on GHG emissions. Specifically, the effects of varying the proportions of blast furnace steel, electric arc furnace steel, and steel made of hydrogen direct reduction iron (H2-DRI) were analyzed. In addition to the composition of these materials, the study also examined the effects of reuse of the steel materials used in the elevator hoistway and car structure. Based on these calculations, the study discusses optimal material compositions for elevators that align with the GHG reduction targets in the IPCC AR6.

Current State of the Technology Industry Uses

Elevator manufacturers publish EPDs based on LCA to evaluate the environmental impact of elevators across their entire lifecycle, promoting the environmental performance of their products. As mentioned earlier, these EPDs indicate that GHG emissions from elevators primarily occur during the production and operation stages. Most of the prior studies on the environmental impact of elevators have focused on reducing operational carbon through improvements in energy efficiency and operational efficiency [4,14–

16]. However, few studies have specifically addressed emissions during the production stage of elevators. Among the literature most relevant to the current study, the work by Tomatis et al. focused on elevator drive machines, exploring the potential for reducing environmental impact through refurbishment [17]. The emphasis on operational energy consumption as a key environmental performance indicator can be attributed to its direct reflection on building operational costs and GHG emissions during use, which are compelling factors for customers. Conversely, emissions during the production stage are rarely considered, likely because they do not directly align with customers' immediate concerns in the current market context. However, as the World Green Building Council emphasizes in its report Bringing Embodied Carbon Upfront, reducing emissions across the entire lifecycle of buildings and construction is critical [18]. This includes addressing not only operational carbon but also embodied carbon especially during the production stage. Therefore, this study investigates the potential for reducing GHG emissions during the production stage of elevators.

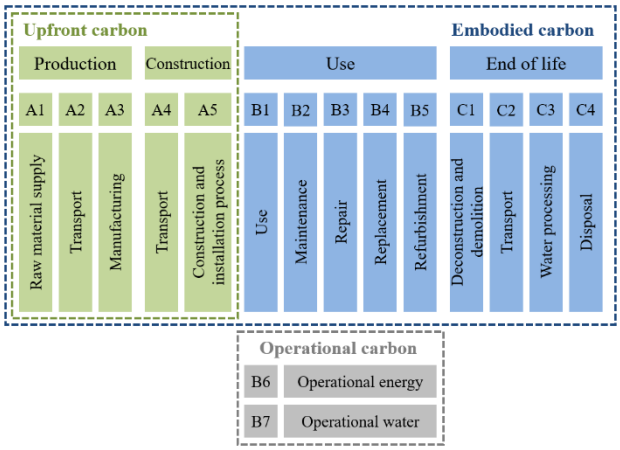

Figure 1 *Lifecycle stages of an elevator [13].*

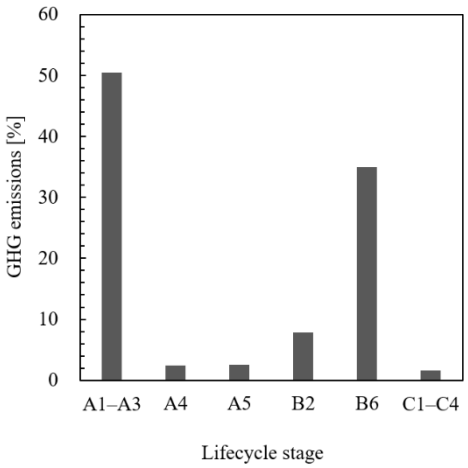

Figure 2 *GHG emissions from each lifecycle stage of an elevator (average values from EPDs) [7–12].*

Technology Approach

Methodology to evaluate environmental impact

The LCA was conducted in accordance with ISO 14040/44 [19,20]. The objective of this analysis is to identify the changes in GHG emissions resulting from differences in the material composition of elevators and the implementation of reuse strategies. Data on the materials required for manufacturing were obtained from the Bill of Materials (BOM) and production data of an actual elevator with the specifications detailed in **Table 1**. The inventory data were obtained from LCI database IDEA Ver.3.3, developed by Japan's National Institute of Advanced Industrial Science and Technology (AIST) [21]. This study focused exclusively on evaluating GHG emissions during the production stage.

Table 1 Specifications of the target elevator.

Elevator type	Hitachi Machine Room-Less type (UA)
Building type	5 floor residential building
Rated load	600 kg (9 persons)
Rated speed	60 m/min
Traveling height	12 m
Internal dimension of the elevator	1.1 m × 1.5 m × 2.3 m
Installation location	Japan

Material eco-design of elevator

The average material composition ratios listed in the EPDs of various companies [7–12] are shown in **Fig. 3**. Among the materials used in elevators, steel materials such as galvanized steel sheets, stainless steel sheets, and cast-iron account for 61% to 93% of the total mass, contributing significantly to the emissions from elevator materials. Therefore, implementing eco-design for steel materials is crucial to improving sustainability in the production stage. Steel materials can be broadly categorized into Blast Furnace steel (BF steel), which is produced by reducing iron ore with coke in a blast furnace, and Electric Arc Furnace steel (EAF steel), which is made by melting steel scrap in an electric furnace. BF steel is considered virgin material, while EAF steel is recycled material. According to statistics from the World Steel Association, the proportion of EAF steel varies by region: 45% in the EU, 68% in the United States, 26% in Japan, and 10% in China, with a global average of 29% [22]. In BF steel production, coke is used to reduce iron ore during the manufacturing process, resulting in significant carbon dioxide emissions and a high emission intensity. In contrast, EAF steel, which uses steel scrap as a raw material, has lower GHG emissions. Moreover, emissions from EAF steel can be further reduced by utilizing low-emission energy sources such as renewable energy. However, the availability of steel scrap is limited, making it impossible to replace all global steel usage with EAF steel. As a future method for producing virgin steel materials, hydrogen direct reduction (H2-DRI) is a promising alternative. In this method, hydrogen is used to reduce iron ore to produce direct reduced iron (DRI), which is then refined in an electric furnace to produce various steel materials.

In this study, we analyzed changes in GHG emissions during the production stage in relation to variations in the steel composition of elevators and then examined material eco-design strategies. The replacement of BF steel with EAF steel was assumed to be at most 80%, while the replacement of the remaining BF steel with H2-DRI steel was assumed to range from 0% to the entirety of the remaining quantity.

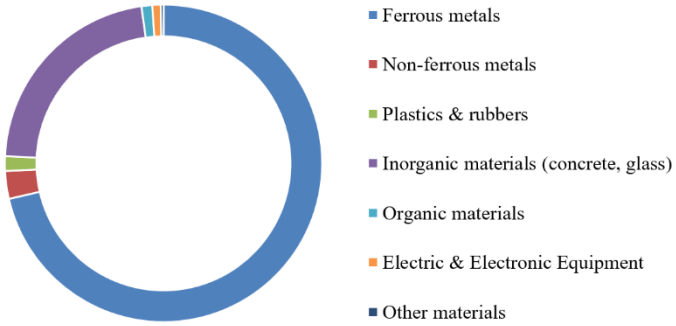

Figure 3 *Material mass in elevators (average values from EPDs) [7-12].*

Scenario set-up

To assess whether material eco-design can achieve the GHG emission reduction targets in IPCC AR6 for 2030 and 2035, it is necessary to establish scenarios for the trends in electricity emission intensities and emission intensities of various materials, including steel.

The scenario for electricity emission intensities is shown in **Table 2**. The 2019 value is based on actual data [23], the 2030 value aligns with the target set by Japan's Ministry of Economy, Trade and Industry [24], and the 2035 value was estimated by the author as a quadratic interpolation based on the 2019 and 2030 values and the 2050 Net Zero target.

Table 2 Settings of GHG intensities of electric generation in Japan.

Year	GHG intensity of electric generation [kg-CO2eq/kWh]
2019	0.47 [23]
2030	0.25 [24]
2035	0.15

Approximately 70% of the GHG emissions from BF steel production are generated during the ironmaking process in the blast furnace [25]. Since these emissions are unavoidable as long as coke-based reduction reactions are utilized, the emissions from the blast furnace process were assumed to remain constant in this study. The emission intensity during the production of BF steel and EAF steel was recalculated using the electricity emission intensities described above, as based on IDEA process data. Similarly, the emission intensities for other materials used in elevators, such as glass, were recalculated using the same approach. For the emission intensity of H2-DRI steel, it was assumed that the hydrogen used in the production of H2-DRI is generated through electrolysis and that the emissions during the production of H2-DRI are linearly dependent on the electricity emission intensities. The emission intensity of H2-DRI was first estimated by linear interpolation of literature values [26]. Then, as H2-DRI is refined in electric arc furnaces to produce H2-DRI crude steel, the emissions for H2-DRI crude steel were calculated by substituting the primary raw material (steel scrap) in the EAF process data with H2-DRI. In

the modeling of steel component reuse, it was assumed that the existing hoistway and car structure would be directly repurposed without modification, and thus the emissions associated with the reused components were considered to be zero. In summary, this study examined three countermeasures for reducing GHG emissions: replacing BF steel with EAF steel, replacing BF steel with H_2-DRI steel, and reusing steel components. **Table 3** presents the relative GHG emissions of each countermeasure compared to BF crude steel in 2009.

The baseline for evaluating material eco-design was set as 100% BF steel based on the 2019 electricity emission intensity.

Table 3 Countermeasures for GHG reduction in the elevator production stage.

	Relative emission intensity to BF steel in 2019 [%]	
	2030	2035
BF steel	95	94
Replacement of BF steel to EAF steel	18	15
Replacement of BF steel to H2-DRI steel	73	52
Reuse of steel components	0	0

Discussion

Baseline scenario (BF steel 100%)

Figure 4 illustrates the trend in emissions during the production stage of elevators in 2030 and 2035 under the baseline scenario of 100% BF steel. The baseline emissions for 100% BF steel in 2019 are 13.5 tons-CO2eq. The target for 2030 is to reduce emissions to 7.7 tons-CO2eq or less, and for 2035, to 5.4 tons-CO2eq or less. As the trends in **Fig. 4** show, maintaining a 100% BF steel scenario would not meet the reduction targets.

Mix scenarios (BF/EAF/H2-DRI) for 2030

First, we examined a scenario in which BF steel was gradually replaced with EAF steel, and the emissions during the production stage of elevators in 2030 were evaluated. **Figure 5** shows the results of the mixed scenarios of BF steel and EAF steel. The findings indicated that increasing the proportion of EAF steel reduces emissions during the production stage, and achieving the 2030 reduction target is estimated to be feasible with an EAF steel proportion of 70% or more.

Mix scenarios (BF/EAF/H2-DRI) and reuse scenario for 2035

Using scenarios in which BF steel was replaced with EAF steel and H2-DRI steel, we evaluated the GHG emissions during the production stage of elevators in 2035. The results are shown in **Fig. 6**. Although emissions decreased with the replacement of BF steel by EAF steel and H2-DRI steel, the 2035 target is

expected to remain unmet.

To address this, we examined an additional scenario that aimed to achieve further emission reductions through the reuse of steel materials. Reusable steel components include rail steel in the elevator hoistway and structural parts of the car. Assuming that up to 50% of the steel used in the elevator hoistway and car could be reused, we calculated emissions under the reuse scenario. The results are shown in **Fig. 7**.

Under scenarios where the proportion of EAF steel is 70%, either with a reuse rate of 50% or with a reuse rate of 25% combined with an increase in the proportion of H2-DRI steel to 30%, it is projected that the 60% GHG reduction target for 2035 can be achieved. Similarly, when the proportion of EAF steel is 80%, either with a reuse rate of 50% or with a reuse rate of 25% and an increase in the proportion of H2-DRI steel to at least 10%, the 2035 target is also expected to be met. These findings demonstrate that combining the utilization of H2-DRI steel and EAF steel with the partial reuse of steel components in elevator hoistway and car structures is an effective strategy for achieving the 2035 target.

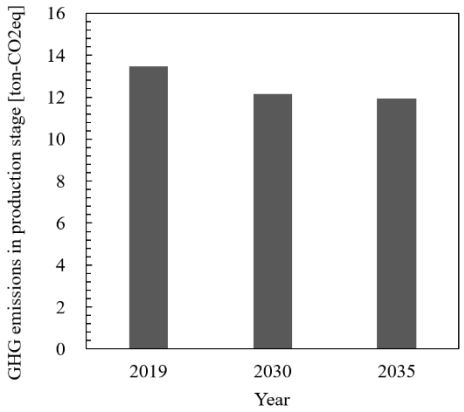

Figure 4 *Trends of GHG emissions of the elevator in production stage in case of BF steel 100%.*

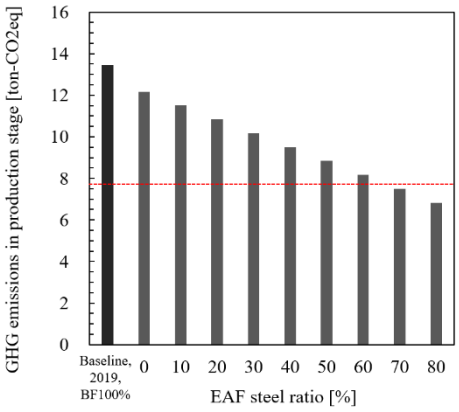

Figure 5 *GHG emissions in elevator production stage with steel material transition from BF steel to EAF steel in 2030.*

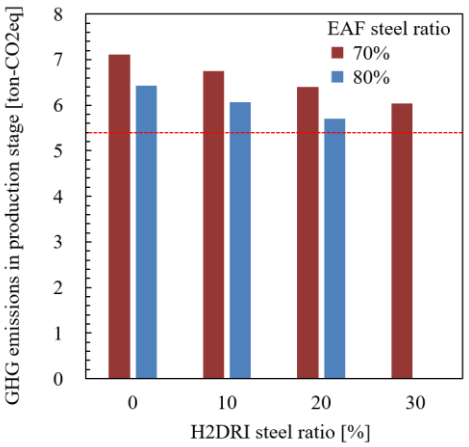

Figure 6 *GHG emissions in elevator production stage with steel material transition from BF steel to EAF and H2-DRI steel in 2035.*

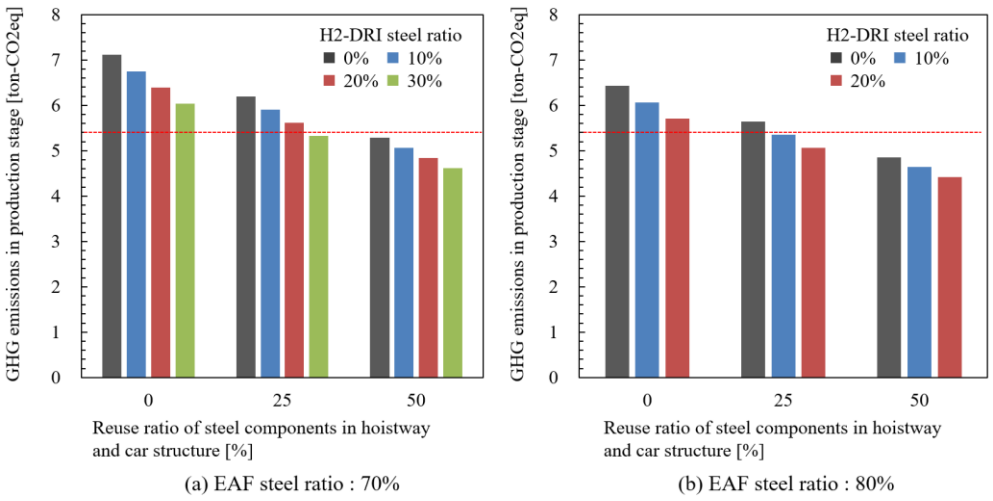

Figure 7 *GHG emissions in elevator production stage with steel material transition and reuse integration in 2035. (a) EAF steel ratio: 70%, (b) EAF steel ratio: 80%.*

Conclusions & Recommendations

This study highlights the potential to enhance the sustainability of elevators by reducing production-stage emissions, which account for approximately half of their lifecycle emissions. These reductions can be achieved through the use of low-emission steel materials, guided by circular economy strategies, and the circular reuse of reusable components.

The LCA estimation results indicated that the emissions from the production stage of the elevator in 2019, when steel materials were composed entirely of BF steel, amounted to 13.5 ton-CO2eq. This value was used as the baseline for evaluating reduction potentials.

For 2030, the analysis indicated that the 43% emissions reduction target could be met by replacing more than 70% of high-emission BF steel with EAF steel. However, for 2035, it was projected that improvement measures to replace BF steel with EAF steel and H2-DRI steel alone would result in emissions of at best 5.7 tons-CO2eq, falling short of the 60% reduction target. By incorporating the partial reuse of the steel materials in elevator hoistway and car structures, we identified potential pathways to achieve the 60% reduction target under several configurations. Examples of viable configurations include Reuse:BF:EAF = 50:30:70 or Reuse:BF:H2-DRI:EAF = 25:10:10:80.

Historically, efforts to improve elevator sustainability have primarily focused on reducing operational-stage emissions through energy-saving technologies, with limited attention given to production-stage emissions. Even so, the construction industry increasingly acknowledges the importance of addressing upfront carbon, including emissions from production.

To promote the use of low-emission materials in the future, it is imperative to focus on expanding the recycling system for steel scrap utilized in EAF steel, thereby ensuring a stable supply chain. Parallelly, the development of production processes for the large-scale and cost-effective manufacturing of H2-DRI steel

must be prioritized. Regarding component reuse, key challenges such as evaluating remaining service life and ensuring the reliability of residual components should be addressed through the development of reliable lifespan prediction and inspection technologies, supported by advanced material evaluation. With these measures, the utilization of low-emission materials and the reuse of components can be practical and effective strategies for reducing emissions during the production stage of elevators. By combining these upfront carbon reduction measures with improvements in operational carbon through energy-saving technologies, notable contributions can be made toward achieving sustainable urbanization.

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