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Circular economy implementation in railway systems beyond net zero

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Introduction

Built environments with special attention to the railway sector faces significant challenges in successfully implementing circular economy towards the transition to net zero. These challenges stem from (i) the lack of pragmatic solutions and bottom-up technologies; (ii) non-inclusive, undiversified policies and fundings; (iii) inadequate cooperation among fragmented stakeholders; and (iv) poor inter-relationships among academic, industrial and public sectors. Circular economy transition towards net zero is the global challenge, and we must strike to resolve the climate issue altogether through both domestic and international cooperation. The paper thus highlights the essential need for harmonized actions together with tactical and pragmatic strategies to overcome technical challenges and barriers of circular economy implementation.

By nature, the railway is a system of complex functional systems, integrating multiple essential functions containing many subsystems within each of the functional systems. Holistically, the railway system mainly consists of railway infrastructure system, railway electrification and power system, rolling stock and traction system, railway signaling system, railway communications system, and other passenger-related systems (e.g., ticketing, frontline operations, and so on). Circular economy perspectives have been predominantly driven by top-down policies stemming from policy and decision makers (Kaewunruen et al., 2016; Rungskunroch et al., 2021). Therefore, with the complex systemic issue in mind, it is very clear that top-down policies cannot be effective since the blanket policies cannot fit every complex system. This is due to the fact that each system will require different circular economy approaches to consume less resources and energy while simultaneously be more carbon efficient, and to reduce industry wastes (Kaewunruen et al., 2014; Kaewunruen et al., 2015). It is thus very important to design out the wastes from the very beginning, rather than relying solely on waste recycling or reusing at the end of the chain (Kaewunruen and Lee, 2017; Serrano et al., 2017; Silva and Kaewunruen, 2017; Kaewunruen et al., 2019). In addition, the circular economy implementation needs to span across all scales from materials viewpoints to products and components, to subsystems of assets, infrastructures, or building, and to the operating rail system.

Recent studies (Liu et al., 2021) also revealed that transportation and transit systems are an essential backbone for sustainable supply chain and logistics globally. By shifting freight transport from road to railway systems, over 25% of carbon emissions derived from the whole transport sector can be reduced. But it is unwise to simply rely on the

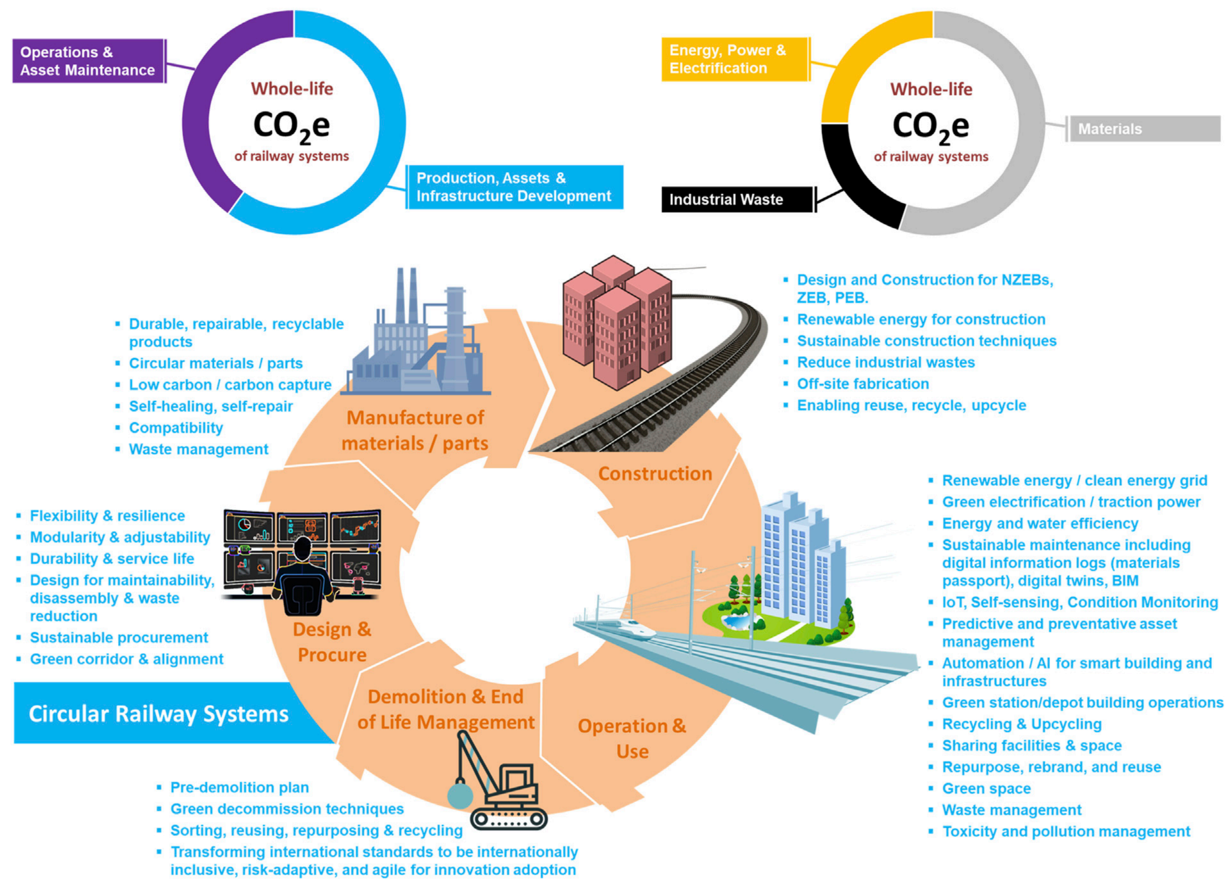

FIGURE 1
Circular economy strategies and tools for integrated railway systems.

railway transport alone to be sustainable. In fact, freight logistic operations are based on 1) distribution services and 2) infrastructures. The distribution services or transport will demand energy, power, moving assets (trucks, wagon, containers), and fuel, which enable the movement from Point A to Point B. The supporting infrastructures such as roads, railways, airports, pipelines/tunnels, ports will consume materials from construction and regular maintenance activities. It is clear that significant amount of carbon equivalence and energy consumption are necessary to enable safe and reliable logistics and supply chain. On this ground, it is inevitable that cost-, carbon- and energy efficiency must take place across all modes of transport and mobility. However, current practices are limited in focus, scale and scope. The current focus merely prioritises the cleaner and more-efficient energy generation or traction power for the logistics operations. However, substantial carbon emissions ranging from 50% to 85% of the whole transportation systems are stemming from large and widespread infrastructure construction and asset management throughout the whole lifecycle. The predominant source of the carbon emissions in the transport system comes from materials and waste. Therefore, there is a necessity to catalyze effective circular economy transition strategies and funding realignments across all stages of life cycle.

In recent years, railway sector has gained popularity for a greener transportation choice, and attracted significant global investments for railway infrastructure development. According to McKinsey report (McKinsey, 2023), global railway projects are currently worth over 1.4 trillion U.S. dollar at various design, planning and execution phases of light-rail and metro rail networks. Asia is the leader of the investment pack. However, not much has been explicitly and evidently allocated to improve innovations towards circular economy and sustainability. This is probably because a railway system is very complex and highly fragmented: some functional systems and subsystems are vividly obvious, but many are not (Turner and Welford, 2023). Everyone is competing with every other to cut costs or make profits, rather than to save the planet. For instance, certain railway development projects do not consider sustainability aspects and may consider sustainability as a burden (International Railway Journal, 2023). Some projects lack details of life cycle costs and thorough justifications of added whole-life values (BBC, 2023; Burrier et al., 2023; The Telegraph, 2023). In contrast, ISO standard [ISO 14040 series (International Standards Organisation, 2006)] for environmental management and life cycle assessment of has been enacted for over 20 years; and indeed ISO 55000 series (International Standards Organisation, 2014; Kaewunruen et al., 2020; Borjigin et al., 2022) have been developed to enrich United

Nation's sustainable development goals and climate actions. Although the adoption of these standards can be optional to most countries, the implementation of the standards to railway and transportation projects will address some of the missing links towards circular economy transition. The insightful information will help to identify new facets that are lacking support and fundings, and will help to facilitate the realignment of strategy, priority, resources, and sponsorships.

On this ground, this paper aims to address strategies and insights into circular economy implementation for railway systems, and to highlight the essential need to overcome industry challenges and barriers through 1) harmonized actions and 2) tactical and pragmatic solutions to circular economy implementation beyond net zero.

Circular economy

The circular economy is an industrial endeavor to enable restorative economy by intention at every stage of whole lifecycle. It aims to 1) totally use clean and renewable energy; 2) minimise, trace, and eliminate toxicity and hazardous materials; and 3) remove waste through careful design, construction and maintenance. There are many potential benefits with the circular economy transition to net zero, including cost savings (in materials, waste management, energy use), material price stability (via materials recycling), improved security of supply, employment creation, as well as reduced environmental burdens and climate impacts. To achieve net zero, circular economy thinking vitally demands early adoption and implementation across all phases of life cycle.

Despite the fact the railway is the least contributor towards carbon emissions compared to other modes of transport (Kaewunruen et al., 2016), its total amount of whole-life carbon footprints has dominated the transport sector and its potentially large amount of carbon emission have not been completely neutralised (Lai et al., 2023). Thus, it is vital to establish cleaner and greener routes for railway services that are fully interconnected with other modes of green transport (i.e., local electrified vehicle services and other active transport). As aforementioned, shifting as many freights as possible to railways will dramatically cut down the carbon emissions in transportation. In addition, sustainable development of the supporting infrastructures (e.g., bridges, tunnels, tracks, yards, electrification, track circuits), assets (e.g., trains, rolling stocks, traction systems, locomotives/wagons, signaling systems, communications systems), and associated built environments (e.g., railway stations, commercial mixed-use buildings, depots) cannot be ignored. The enabling infrastructures, assets and built environments need many more innovations and circular economy implementation across scales in order to get on a fast track to net zero. Figure 1 illustrates and demonstrates circular economy strategies, tactics and tools that will enable railway systems to be beyond net zero. For instance, IoT (internet of things) and digital twins of rail infrastructure systems have been proven to drive the carbon emission reduction while improving resilience over the life cycle (Kaewunruen et al., 2023; Sresakoolchai and Kaewunruen, 2023). The key solutions to overcome the challenge and barriers are that 1) the government needs to be impartial and work collaboratively with both academia and industry to develop and implement many more innovations beyond net zero; 2) fundings should be strategically reallocated to green solutions that timely and rightfully tackle the climate and carbon issues; 3) all stakeholders need to be objective and adopt inclusive, unbiased system-thinking approach to work together beyond net zero.

Remarks

Fragmentation of railway industry causes unorganized, unproportional and non-inclusive circular economy implementation actions. Reaching neutrality and beyond net zero emissions will require a transformation of thought, industry practices, focus, international standards, and strategy to drive innovative cradle-to-grave life-cycle sustainable solutions for the complex railway system as a whole. Last but not least, societies and the public need to influentially stress the significance of circularity to every railway stakeholder, supply chain actor, government and policymaker.

Author contributions

Concept: SK, YG, GJ, and AM Investigation: SK, YG, GJ, and AM Methodology: SK and YG Data visualisation: SK, All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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