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A World without Railways: A Counterfactual Assessment of Avoided Transport Emissions and Path Dependence

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ABSTRACT

Counterfactual analysis has long been used in economic history to identify the contribution of transport infrastructure to growth, market access, and territorial integration, yet it has rarely been applied to the climate consequences of inherited transport systems. This paper examines how current transport-sector greenhouse gas emissions might differ in a counterfactual world without mechanized rail transport. It combines a structured qualitative counterfactual with a static modal-substitution estimate based on approximately 2.9088 trillion passenger-kilometres and 9.8131 trillion tonne-kilometres of global rail activity. Passenger emission factors are drawn from United Kingdom greenhouse-gas conversion data, and freight factors use well-to-wheel European estimates. Under central assumptions, transferring current rail activity to road, inland-waterway, and air substitutes would increase emissions by approximately 1.23 Gt CO₂e annually, within a sensitivity range of 1.07 to 1.55 Gt CO₂e. Freight substitution accounts for about 85% of the central estimate. The historical climate value of rail consists less of any emissions that may have been avoided in the 19th century (while also doubtlessly connected to lower levels of economic activity) and can largely be attributed to the high-capacity network that has developed over time and can be easily switched to electric and also climate-friendly operation with the power system. The qualitative analysis examines the relationships between the absence of rail networks and mobility, regional development, urban structures and technology choices. The quantitative analysis in turn addresses a more restricted question: How much additional greenhouse-gas emissions would there be from year to year if all existing rail transport were to be operated using appropriate replacement modes on a global scale.

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Introduction

The transport sector is one of the hardest to decarbonise since most of the activity in this sector generates direct emissions. Transport in 2019 released 8.7 Gt CO₂e, which equals 23% of all global energy-related CO₂ emissions and 15% of all human activity causing greenhouse-gas emissions. However, while many studies are now focusing on the huge mitigation potential of rail through modal shift, this potential will materialise in the long run. This paper focuses on the climate value already locked in existing rail infrastructure.

Historically, the introduction of railways has transformed patterns of mobility as well as settlement and economic geography. It has shaped cities and influenced how people perceive time and space [1]. A long-established network generates increasing returns and thus blocks off paths for subsequent development [2]. By drawing on this large body of work on the effects of railways for mobility and economic development, including the ‘social savings’ approach with its counterfactuals, as well as work on networks and market access, this paper sets out to estimate how transport-related greenhouse gas emissions might have looked like if there had been no development of mechanized guided land transport [3-7].

Instead, the “railway-free” scenario is used as an analytical benchmark against which the development of mobility, economic geography, the urban structure as well as the climate-mitigation options provided by rail transport can be measured. The same asset that was originally constructed to serve purposes completely different from climate change mitigation today can be a source of support for efforts to reduce emissions from transport while at the same time preventing lock-in of carbon-intensive transport solutions. The paper connects four lines of work on social savings, market access through transport networks, transport emissions and climate change lock-in in a counterfactual framework. Second, it estimates the greenhouse-gas emissions avoided through existing rail infrastructure and tests these estimates through sensitivity analysis. Third, it demonstrates how inherited rail networks can retain climate value through preservation, upgrading, and electrification, suggesting that network contraction itself should be understood as a climate-policy decision.

Literature Review

Counterfactual analysis evaluates the significance of infrastructure by comparing observed outcomes with a specified alternative. seminal railway study estimated the social savings of U.S. railroads by comparing them with canals and improved roads, placing agricultural-freight savings at 2.7% of GNP [8]. later estimated all-freight and passenger savings at 4.7% and 2.6%, respectively [9]. The approach generated debate over the specification of alternatives [3,2,5]. but remains useful when assumptions are

explicit and estimates are not equated with a technology’s total historical significance [6].

Subsequent research broadened the analysis from transport costs to network-wide economic and spatial effects. Demonstrated the importance of railways for U.S. market access, while studies of colonial India linked rail expansion to lower trade costs, reduced price gaps, higher real incomes, and greater resilience to local shocks [7,10-12]. These findings reinforce the importance of considering railways as networks rather than simply as transport services as you can read below. This perspective also relates

to path dependence and carbon lock-in. Increasing returns can create self-reinforcing technological trajectories, while transport technologies, infrastructure, institutions, and land-use patterns can reinforce carbon-intensive development [2]. Conversely, existing rail networks may preserve low-carbon pathways because long-lived infrastructure - alignments, stations, bridges, tunnels, and signalling - can accommodate successive technologies and benefit from electrification and electricity-sector decarbonization.

A summary of the data from the specialized literature regarding the requirement for this study is presented in the following table.

Table 1: Literature Informing the Inherited Climate Infrastructure Framework

Literature strand	Key references	Relevance to this study
Counterfactual analysis and social saving	Fogel (1964, 1979); Fishlow (1965); David (1969); Crafts (2004); Leunig (2010)	Establishes the counterfactual method and sensitivity to substitute-system assumptions.
Market access and network effects	Burgess & Donaldson (2010, 2017); Donaldson & Hornbeck (2016); Donaldson (2018)	Shows that rail networks generate wider economic and spatial effects beyond transport costs.
Path dependence and carbon lock-in	Arthur (1989); Unruh (2000)	Explains how infrastructure can reinforce high - or low-carbon development pathways.
Transport emissions and modal efficiency	IEA (2019); Doll et al. (2020); IPCC (2022); Ritchie (2023)	Provides evidence for rail’s comparatively low emissions and the importance of substitution assumptions.
Research gap	This study	Conceptualizes existing rail networks as inherited climate infrastructure.

Rail’s operational efficiency supports this interpretation. Globally, rail represents approximately 2% of transport energy use but less than 1% of transport CO2 emissions, while the identifies energy-efficient modes and public transport as important mitigation measures [13,14]. Nevertheless, emissions depend on occupancy, electricity mix, vehicle technology, distance, and the mode displaced. Demonstrates these variations for passenger transport, while estimate European freight emissions at approximately 18 gCO2e per tonne-kilometre for rail compared with 137 gCO2e for heavy road freight [15,16].

Although there are studies in the literature, existing railway networks have rarely been examined explicitly as inherited climate infrastructure. This study addresses that gap by connecting counterfactual analysis, network effects, carbon lock-in, and modal emissions to evaluate how preserving, upgrading, and electrifying existing rail infrastructure can retain low-carbon transport options.

Methodology

The research design combines qualitative counterfactual reasoning with a quantitative static substitution estimate. The counterfactual assumes the absence of mechanized guided land transport from the outset. It is stronger than a delayed-development scenario and therefore less historically plausible, but analytically clearer. Three epistemic commitments follow. Documented historical claims are distinguished from conditional inferences; unobservable assumptions are stated rather than hidden; and quantitative estimates are confined to current activity, for which mode volumes and emission factors exist. The scenario shows the mechanisms but does not claim to describe a probable alternate world.

Global activity is taken from the International Union of Railways: approximately 2.9088 trillion passenger-kilometres and 9.8131 trillion tonne-kilometres, based on national returns centred on 2022–2023 [17]. Passenger factors derive from the United Kingdom greenhouse-gas conversion factors for 2022 as compiled by Ritchie [15]. Freight factors derive from the well-to-wheel

European estimates prepared by Doll et al. [16]. Industry claims are used only for contextual comparison and do not determine the calculations.

Avoided emissions are calculated as $\Delta E = (EF_{sub} - EF_{rail}) \times A$, where A is passenger-kilometres or tonne-kilometres, EF_{rail} is the relevant rail factor, and EF_{sub} is the activity-weighted factor of substitute modes. Passenger and freight activity are calculated separately because plausible substitutes differ. Passenger rail is redistributed among cars, coaches, and, in the high case, limited aviation. Freight is transferred principally to heavy road vehicles, with inland waterways absorbing a residual share in the low and central cases.

Three scenarios test sensitivity. The low case assumes car occupancy of 1.8, comparatively favourable collective alternatives, 60% of displaced freight moving by road, and a higher rail baseline. The central case assumes occupancy of 1.5, 75% of displaced passenger activity moving by car, 80% of freight moving by road, and a rail baseline of 38 gCO2e per unit. The high case assumes single-occupancy cars, 90% passenger displacement to cars, 5% to air, full freight displacement to road, and a national-rail baseline of 35.5 gCO2e per passenger-kilometre. These scenarios represent a structured range rather than probabilities.

The model is static. It holds activity, relative prices, and technology constant and therefore measures the emissions service provided by rail at current volumes. It is not a forecast of a railway-free economy. Higher transport costs would suppress some demand, while earlier motorization and different urban form might increase other activity. A complete dynamic counterfactual would require an integrated assessment of economic growth, technological innovation, land use, and demographic change that exceeds the available evidence.

Regional values are allocations rather than independent estimates. The central passenger and freight totals are distributed according

to reported regional activity shares, which means that the same substitution mix and factors are applied across diverse systems. This simplifies comparison but cannot represent differences in grid carbon intensity, diesel traction, car occupancy, waterway availability, or freight commodity mix. Regional results are therefore interpreted as indicative orders of magnitude.

The study also performs an internal plausibility check by comparing the central result with the IEA estimate that road replacement of rail services would add approximately 1.2 Gt CO₂-equivalent annually on a well-to-wheel basis [13]. Agreement does not prove correctness, because both exercises share broad modal assumptions, but it reduces concern that the result is an artifact of one factor set.

Railways and Historical Path Dependence

The nineteenth-century railway transformed inland transport by reducing costs and increasing capacity, enabling bulk commodities to reach industrial and national markets at unprecedented scales [18,19]. Its impact was geographically uneven: coastal and riverine regions had viable alternatives, while continental and landlocked territories depended more heavily on rail.

Without railways, inland transport would have relied on animal traction, canals, and roads, all constrained by capacity, geography, or energy requirements. A railway-free trajectory would therefore likely have produced lower nineteenth-century mobility and greater subsequent dependence on road transport and petroleum, particularly where alternative networks were limited [7]. Evidence from India further shows that rail access improved market integration and resilience to food-supply shocks [10-12].

Railway networks also produced distinct spatial legacies. European systems developed largely as interconnected networks, whereas many colonial railways, particularly in Africa, functioned as port–hinterland corridors serving resource extraction [8]. Despite these differences, railways created durable transport corridors and shaped urban development around stations, labour markets, and suburban growth.

These historical effects have contemporary climate implications. Rail-oriented corridors retain opportunities for electrification, service expansion, and transit-oriented development, whereas dispersed road-based systems reinforce automobile dependence and carbon lock-in. Existing corridors, rights-of-way, stations, and engineering systems can therefore be understood as inherited climate infrastructure: long-lived assets whose preservation retains lower-carbon transport options beyond their original purpose.

Results: Quantifying Avoided Emissions

Passenger and freight comparisons reveal different substitution dynamics. United Kingdom-based factors compiled by Ritchie place national rail at 35.5 gCO₂e per passenger-kilometre [15]. Single-occupancy petrol cars are approximately 170.5 gCO₂e per passenger-kilometre, while the value falls to 85.2 with two occupants. Coaches, at approximately 27.3, can perform better than national rail when well occupied. These comparisons show why occupancy must be modelled explicitly and why it would be misleading to assign all displaced passenger activity to single-occupancy cars.

Freight shows a wider and more stable modal difference. Estimate approximately 18 gCO₂e per tonne-kilometre for rail,

137 for heavy goods vehicles, 49 for inland waterways, 12 for maritime shipping, and 834 for air cargo under European well-to-wheel conditions [16]. The ratio between rail and road freight is approximately 1:7.6 in these data. The result reflects rolling resistance, train capacity, operating patterns, and a substantially electrified European network. It should not be confused with industry claims about fuel efficiency in diesel systems.

Table 2 summarizes the passenger factors used to structure substitution assumptions. The factors are not universal. They reflect UK grid conditions and observed load factors, while car values originate per vehicle-kilometre and must be divided by occupancy. Nevertheless, they provide a consistent accounting basis and make sensitivity to occupancy visible.

Table 2: Greenhouse-Gas Emission Factors by Passenger Transport Mode

Mode	gCO ₂ e per passenger-km	Ratio to national rail
National rail	35.5	1.0
Eurostar	4.5	0.1
Light rail / tram	28.6	0.8
Underground / metro	27.8	0.8
Coach	27.3	0.8
Bus, average	96.5	2.7
Electric car	47.1	1.3
Petrol car, single occupancy	170.5	4.8
Petrol car, two occupants	85.2	2.4
Motorcycle	113.6	3.2
Long-haul flight	147.9	4.2
Short-haul flight	151.0	4.3
Domestic flight	245.9	6.9

Note: Values are derived from UK greenhouse-gas conversion factors for 2022 as compiled by Ritchie (2023). Aviation values include non-CO₂ warming effects. Car values depend on occupancy; ratios are computed against national rail.

Applying the activity totals and substitution assumptions produces a low estimate of 1,065 Mt CO₂e, a central estimate of 1,233 Mt CO₂e, and a high estimate of 1,546 Mt CO₂e annually. The central result is close to the IEA's published estimate of 1.2 Gt CO₂e. This convergence is reassuring because the calculation uses an independently assembled combination of activity data and modal factors.

The decomposition is more important than the total alone. In the central scenario, passenger substitution contributes approximately 173 Mt CO₂e, while freight contributes approximately 1,060 Mt CO₂e (see Table 3). Freight therefore represents about 85% of the combined result. Across the scenario range, passenger effects vary from 112 to 379 Mt CO₂e, reflecting strong sensitivity to car occupancy and substitute-mode shares. Freight varies less, from 953 to 1,168 Mt CO₂e, because road haulage remains the principal plausible substitute and its advantage relative to rail is consistently negative.

Table 3: Annual Greenhouse-Gas Emissions Avoided Under Three Substitution Scenarios

Scenario	Passenger (Mt CO2e)	Freight (Mt CO2e)	Total (Mt CO2e)
S1 Low	112	953	1,065
S2 Central	173	1,060	1,233
S3 High	379	1,168	1,546
IEA (2019) comparison	—	—	1,200

Note: Estimates apply after Ritchie and Doll et al. factors to UIC activity totals [15,16]. The calculation is static and holds activity, prices, and technology constant. Totals may differ slightly because of rounding. Data is processed by the author.

The central total is equivalent to approximately 14% of the 8.7 Gt CO₂ -equivalent of direct transport emissions reported for 2019 by the IPCC [14]. This comparison should not be read as a share of current emissions literally eliminated by rail, because the estimate uses well-to-wheel factors and fixed current activity. It indicates order of magnitude: inherited rail infrastructure supplies a mitigation service comparable in scale to a major sector-wide policy program.

Regional concentration qualifies the global result. Asia-Pacific and the Middle East account for most rail passenger activity, while freight is concentrated in China, the United States, Russia, and Europe. Allocating the central passenger and freight components by reported activity gives approximately 546 Mt CO₂e to Asia-Pacific and the Middle East, 352 Mt to Europe including Russia, 312 Mt to the Americas, and 16 Mt to Africa as you can see in table 4. These are not region-specific estimates, but they show that the historical inheritance is unevenly distributed.

Electrification deepens this inequality. India reported electrification of 99.2% of its broad-gauge network, China 82%, Japan 64%, the European Union 57.6%, and Russia 52%, whereas most sub-Saharan networks remain unelectrified [8,20,21]. A route-kilometre in a diesel freight system is not equivalent to an electrified corridor, even though both preserve rights-of-way and can potentially be upgraded. The environmental value of inheritance therefore combines network extent, traffic density, connectivity, and *electrifiability* (author's concept for *feasibility of electrification*).

Table 4: Regional Allocation of Central Avoided-Emissions Estimate

Region	Passenger share	Freight share	Allocated Mt CO2e
Asia-Pacific and Middle East	77.8%	38.8%	546
Europe, including Russia	15.1%	≈30.7%	352
Americas	1.1%	29.2%	312
Africa	1.7%	1.2%	16
World	100%	100%	1,233

Note: Central passenger and freight components are allocated in proportion to UIC regional activity. Values indicate relative order of magnitude and are not independent regional estimates. Data are processed by the author.

The annual estimate should not be projected backward through history. A railway-free nineteenth century would have lower activity and delayed industrialization in some regions, potentially reducing early emissions. At the same time, the twentieth century would rely more heavily on road transport and might adopt motorization earlier. The cumulative balance is ambiguous. The determinate result concerns the present capital stock: a world without historical rail development would arrive at the climate-policy era without a mature, guided network.

The scenario range should be interpreted as a sensitivity envelope around a fixed-activity question rather than as a confidence interval. Each scenario changes several assumptions simultaneously to test whether the main conclusion survives plausible variation in passenger occupancy, substitute-mode allocation, and rail baselines. It does. Even the low case remains above one gigatonne of additional annual emissions, and freight remains the dominant component. The robustness of this ordering matters more than the precise central value because the policy argument depends on the scale and composition of the service supplied by rail, not on a claim that 1.233 Gt is a uniquely correct estimate.

Passenger results are the least stable because occupancy transforms vehicle-level factors into passenger-level factors. A petrol car

with two occupants has approximately half the per-passenger emissions of the same car with one occupant, while a well-used coach can compare favourably with national rail under the UK factors. The passenger estimate must therefore be read as a system-level substitution effect, not as a universal ranking of individual journeys. Route length, train load, traction source, car technology, and the availability of coach travel all affect the result. This is why the high scenario assigns only a small share to aviation and why the central case avoids assuming universal single-occupancy driving.

Freight results depend principally on the share assigned to road and the baseline intensity of rail. Inland waterways provide a lower-emission substitute where geography and port infrastructure permit, but they cannot serve every origin and destination. Maritime shipping can be highly efficient for suitable coastal flows, yet it is not a general substitute for inland rail. Air cargo is excluded from the principal freight mix because assigning bulk rail commodities to aviation would be physically and economically unrealistic. The selected scenarios therefore concentrate on road and water, the modes capable of absorbing meaningful tonne-kilometre volumes.

The comparison with the IEA estimate provides triangulation rather than validation. Both results express a counterfactual in

which rail services are replaced while activity is held broadly constant, so conceptual overlap is unavoidable. Nevertheless, the independent use of UIC activity totals and published passenger and freight factors produce a central value close to the IEA's 1.2 Gt estimate. This reduces the likelihood that the result is driven by a transcription error or an implausible single parameter. It does not resolve the deeper uncertainty associated with demand adjustment or regional heterogeneity.

Accounting boundaries also require care. The passenger and freight inputs are described as well-to-wheel or conversion-factor estimates, not complete cradle-to-grave life-cycle assessments of every infrastructure component. The calculation does not add embodied emissions for railway construction, vehicle manufacture, road expansion, airport infrastructure, or maintenance. Including those elements could change comparisons, especially for new construction, but the present paper evaluates the service delivered by an already existing network. For that purpose, operational and energy-chain factors are aligned with the question more closely than a greenfield infrastructure comparison would be.

Avoided emissions should not be conflated with additional reductions that can automatically be claimed by rail policy. The difference between the current rail service and a set of potential alternative modes is estimated in this study, as a 'baseline' service, i.e. it does not form the basis of a forecast of the potential for a particular project to deliver savings. Instead, new projects would require a corridor-specific analysis of induced demand, occupancy, emissions from new construction, of electricity supply, and of the modes that will be displaced by the new service. The total of such estimates would provide strategic insights, however: that not removing existing rail capacity or failing to maintain it risks transferring activity to a more emitting transport system and locks out future options.

Discussion: Railways as Inherited Climate Infrastructure

Assessing the mitigation potential of rail requires a view beyond the current use of the transport mode and considers the option value of existing physical infrastructure. Historical rail corridors form a stock of 'inherited climate infrastructure' which in the form of long-lasting structures can be used for the upgrading of rail traffic to electrification and capacity expansion as well as for environmentally friendly mobility.

Established corridors offer several advantages such as existing alignment, land and major civil works. This climate-friendly transport option can be used to support future low-carbon transport and development that is compact and station-centred. It can also help to avoid the land requirements and high greenhouse gas emissions associated with new greenfield transport infrastructure. Abandoned corridors in particular are often made up of fragmented rights-of-way that are difficult and expensive to re-assemble.

The historical network structures should also be analysed critically. Colonial railway lines often were part of structures that reinforced an extractive economy and unequal spatial development rather than promoting balanced connectivity. Assessing and considers the topology, accessibility and territorial impact of past and current structures is essential for a climate-oriented infrastructure appraisal.

Thus, in considering new rail investment, the notion of 'inherited climate change infrastructure' must not be confused with an opposition to new rail lines. Historically established climate change / transport infrastructure can be best and most quickly

influenced by adapting, upgrading and using existing climate change / transport infrastructure, retaining options for future use and holding them for as long as possible for adaptation to future requirements and to other uses.

Policy Implications

The result of the study could have has several policy implications. Proposals to close, dismantle, or permanently repurpose rail corridors should include a comprehensive carbon appraisal covering current operations, plausible alternative transport modes, embodied emissions from maintenance or renewal, and the corridor's long-term option value. Climate considerations should inform rather than determine decisions, but excluding the future mitigation capacity of existing infrastructure would result in incomplete valuation.

However, for low volume lines the greatest climate value may derive from a strategy of preservation with the line electrified or powered by an alternative low carbon option. The ability of rail to connect high-capacity surface transport to an increasingly decarbonised electricity supply must be acknowledged and brought into surface transport and energy strategies. The greater share of the central estimate of avoided emissions lies in the freight market and hence freight policy must look at the whole logistics chain and not at individual rail lines in isolation.

Finally, infrastructure strategies should take into account regional differences about inherited rail infrastructure. Preservation and modernization are likely to be most beneficial in regions with dense rail networks already in place, whereas other regions may require new rail infrastructure to offer alternatives for environmentally sound freight transport. Long-term network effects, regional integration, and distributional impacts should all be considered when assessing alternatives to individual rail corridors rather than relying on rigid traffic-volume thresholds.

The above does not mean to preserve every railway or to construct new rail tracks in every single corridor. Assets on rail track must be evaluated against the background of a whole transport system as well as of land use and energy systems. The closure of a railway line is irreversible. It is important to consider the value of potential future transport options that would be destroyed by a line closure. When carrying out a carbon appraisal of a line, the emissions, constraints and climate change impacts of the alternative(s) that could use the same corridor(s) in the future should also be considered in addition to current use of the line.

Limitations and Future Research

A fully dynamic "railway-free world" model of inherited climate infrastructure would require detailed, annually updated information about prices, settlement patterns, incomes, demands, technologies and land uses. This study does not attempt to create such an alternative historical simulation of the world. Instead, it outlines and estimates the annual emissions from current railway activity in a number of different counterfactual scenarios of modal substitution. The set of emission factors applied in this study are regionally approximated using a combination of information about passenger and freight transport on railways in the UK and European countries and indicating average emissions for different modes in different countries. The activity data, for a variety of years centred on 2022–3, are of somewhat varying quality and detail. Consequently, the results presented here should be viewed as rough indicative estimates rather than precise quantitative findings.

The scenarios developed in this paper are intentionally extreme to illustrate the maximum impact of historical development choices on today's greenhouse gas emissions. Guided land transport systems may not have disappeared entirely, and canals, coastal shipping and other transport modes could have grown to take up some of the demand that has gone onto the railways. Future work could therefore develop scenarios around delayed or partial development of the railway, earlier road motorisation, alternative scenarios for change and the associated uncertainty distributions. Additionally, use of more detailed national level emission factors, mode-specific activity data and commodity-level substitution matrices would aid in increasing the accuracy of the scenarios.

Inheritance effects on urban form are not examined in this paper. To study such long-term effects, one could carry out a set of longitudinal urban studies on different historic cities with varying degrees and times of rail provision. Alternatively, a set of quasi-experiments could be designed to test effects of successive openings and closings of railway lines and stations, as well as their preservation. Furthermore, it would be useful to develop indicators of inherited climate change infrastructure, such as the continuity of routes and connections, the potential for electrification, capacity, and the accessibility of stations. These would allow an appraisal of different options for the use of the existing stock of physical and other infrastructure, to identify those with the greatest option value for future low-carbon use and to compare the cost of preserving and reopening existing assets with that of new construction.

The application of the framework to other types of infrastructure (e.g. ports, power networks, water supply, district heating, public buildings) can provide more general insights on the extent to which inherited climate change 'lock-in' can be reduced by that same infrastructure or whether it is even increased. The unique characteristic of long-lived fixed infrastructure such as railways is that it can continue to have value for future generations even when currently of little use (i.e. it can preserve options for decarbonising transport in the future).

Conclusions

This paper used a railway-free counterfactual scenarios to reveal the climate value embedded in existing transport infrastructure. The central scenario indicates that replacing present global rail activity with plausible road, coach, waterway, and air substitutes would add approximately 1.23 Gt CO₂-equivalent annually, within a range of 1.07 to 1.55 Gt. The close agreement with the IEA's 1.2 Gt estimate supports the order of magnitude, while the scenario range makes the dependence on occupancy and modal assumptions explicit [22].

The most consequential empirical result is freight dominance. Approximately 1,060 Mt of the central 1,233 Mt total derives from freight, or roughly 85%. This reverses the emphasis of many public debates, which focus on passenger rail. Freight rail has a bigger toll on climate because tonne-kilometre activity is substantial and the emissions difference between rail and heavy road haulage is wide.

The main conclusion, however, is conceptual. Rail's historical climate significance does not rest on the proposition that steam rail reduced emissions during industrialization. The cumulative balance is uncertain because rail facilitated economic activity while a railway-free world would have been less mobile and, in some periods, less productive. The determinate effect is the composition of the inherited capital stock. Earlier generations created a guided network that can be electrified and paired with a decarbonizing electricity system.

Railways should therefore be understood as inherited climate infrastructure. Their environmental value includes not only present operations but the mitigation options they preserve. A corridor may support future service intensification, freight transfer, electrification, or station-oriented redevelopment. Losing the corridor can remove these possibilities on timescales relevant to climate policy, while reconstruction may require decades of planning and investment [23]. The policy implication is to protect and differentiate between existing and new infrastructure: preserve, maintain and electrify where economic appraisals justify; give freight more attention in climate change policy; and in decisions about closure, assess carbon emissions as well as option value. In regions without existing rail infrastructure, new construction may be necessary and should be supported by international climate change and development finance. Preservation of assets where they already exist and creation of new assets in their absence are not mutually exclusive but complementary strategies.

A world without railways would not have been a world without carbon. It might have emitted less during parts of the nineteenth century because activity was lower, then more during the motorized twentieth century because the electrifiable alternative was absent. Its most important difference would be contemporary: society would confront the same decarbonization imperative with one fewer mature, high-capacity land-transport technology. The counterfactual makes that inheritance visible and underlines a broader principle. Infrastructure choices made now will define the mitigation options available to generations that face problems not yet fully understood [24].

Declarations

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Author Contributions: Liviu-Gabriel Baicu: conceptualization, methodology, investigation, analysis, writing, and manuscript preparation.

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