Even Electric Trains Use Coal: Fixed and Relative Costs, Hidden Factors and Income Inequality in HSR Projects with Reference to Vietnam’s North–South Express Railway

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Abstract: High-Speed Rail is often advertised as a sustainable alternative to air travel, and accordingly numerous initiatives for the construction of new HSR infrastructure are currently being pursued across Southeast Asia and the globe. However, beneath promises of “zero-emissions travel” frequently lie numerous hidden factors—how much steel is needed to build the railway? What energy sources are being used to generate the electricity which drives the train? Moreover, how many passengers are required for the train to be efficient relative to other forms of transport? This paper seeks to examine these questions to uncover what “hidden factors” may be present in HSR, using Vietnam’s proposed North–South Express Railway (NSER) as an example. This study calculates the CO₂ emissions likely to be produced by the NSER from the construction steel and the power consumed in operation using publicly available data on the technical standards of the railway and existing data on emissions per energy source, combining this data with market size analyses of the central provinces of the proposed line based on official population and income statistics across a range of scenarios to estimate what level of ridership will be required to outperform an equivalent-length air journey. The research finds that under current projections, the HSR may emit more CO₂ per end-to-end journey than a plane, that even in per-capita terms the emissions may be worse depending on the seat fill rate, and that the market size of Vietnam’s central provinces will present significant challenges in ensuring that the railway is efficient enough to outperform the plane in ridership terms. This demonstrates both the outstanding impacts of coal and other fossil fuel use in the energy mix and the potential link between environmental performance and regional inequality which constitute the hidden costs in HSR projects, and the exacerbated risks to the environment posed by inequality.

Keywords: high-speed rail systems; transport infrastructures; investment; equity; sustainability

1. Introduction

From Britain’s HS2 line to Japan’s Chuo Shinkansen maglev project, high-speed rail infrastructure is currently a hot topic among policymakers around the world, with Southeast Asian leaders among the forefront of this push. Vietnam’s proposed North–South Express Railway (NSER), initially proposed in the early 2000s and recently revived by the Vietnamese government [1], is no exception. High-speed rail projects are often pitched as sustainable and environmentally friendly modes of long-distance transport, but the realities can be much more complex (and often inconvenient) than the promises.

This project was initially based on three central hypotheses—each of these now forms one section of this article. These were:

- That the steel used in the railway’s construction would generate significant quantities of CO₂ which would take years to “pay off” next to air travel when accounting for the coal used in production;
- That the coal in Vietnam’s projected energy mix would make the theoretically all-electric NSER a major source of CO₂ emissions despite the lack of direct fossil fuel use;
That the per-capita CO\textsubscript{2} cost of taking the NSER may, depending on passenger usage and ridership, actually end up higher than taking an equivalent flight between Hanoi and Ho Chi Minh City due to the prevalence of coal in the energy mix.

These hypotheses stemmed from the author’s main research project on Vietnam, which is one of the world’s fastest-growing users of coal—having doubled the amount it imported between 2018 and 2019 [2], and continuing to invest in new coal power generation, which is expected to comprise more than half of Vietnam’s energy mix in output terms by 2030 [3] (pp. 4–37). Coal is used heavily in both the energy sector and also in the booming steel industry—Vietnam experienced the highest compound annual growth rate in steel consumption in the ASEAN-6 between 2000 and 2018, and in 2018 consumed 20 per cent of all the steel in this group [4]. Moreover, in steel production capacity Vietnam is already the second-highest among the ASEAN-6, and it is predicted by the South East Asia Iron and Steel Institute that it will eventually grow to have the highest production capacity in the region by some margin [4]. Given that steel is still being used widely, the author began to question the environmental credentials of such an enormous mega-project as the NSER—which would require huge amounts of steel for construction and then ultimately be running on electricity generated to a large degree by coal power stations. The JICA feasibility study is limited in answering how under these conditions the NSER project could be sustainable. To date, the academic literature provides limited analysis on the issue, with much of the analysis focused primarily on the economic perspective and with the environmental perspective still underdeveloped. This research seeks to carry out a supplementary analysis of the viability of the railway in relation to the “hidden factors” from the environmental perspective by finding answers to the following four research questions:

1. Will the fixed cost of the construction steel for the rails in terms of CO\textsubscript{2} emissions lead to a situation wherein the train cannot be competitive against air travel in the short term?
2. What will the impact of coal and natural gas in Vietnam’s national energy mix be on the fixed, end-to-end CO\textsubscript{2} emissions of the NSER?
3. What level of ridership will be required to make the NSER more efficient than air travel in terms of the relative costs in per capita emissions?
4. Are the socioeconomic and market conditions in Vietnam likely to meet the threshold projected in relation to question three?

These research questions seek to address existing gaps in the literature (as elucidated in the literature review section) to examine factors in HSR projects which are discussed less and to provide insight into the linkages between environmental performance in relative terms and regional inequality. The study provides a specific and unique analysis of the problems faced by Vietnam’s NSER specifically, but it also presents findings which can be more widely generalized and can better inform policy on HSR projects around the world—specifically on relative performance within a national power grid and in relation to regional inequality, particularly in developing countries where income levels have not always reached a level at which they can provide consistent disposable income for residents. Providing answers to these questions will allow for the creation of more informed policy on HSR systems based on market conditions in countries in which they are proposed—perhaps encouraging the creation of policy from a holistic perspective which incorporates a stronger analysis of secondary factors beyond direct carbon emissions in environmental performance.

The aim of this article is not to pronounce on whether the Vietnamese NSER will ultimately be environmentally beneficial or whether it will be fiscally viable. Indeed, there are compelling reasons to build the railway—for the purposes of enhancing national prestige, for the symbolic connection of two halves of a country which suffered deeply during the Cold War, for the purposes of economic stimulus and job creation, et cetera—regardless of the environmental and fiscal factors at play. For instance, there is evidence to suggest that HSR is popular among tourists and people wishing to visit nearby or intermediate cities [5,6], and it is likely that for cities along Vietnam’s coastline which have
a tourism focus such as Hue, the NSER would be extremely beneficial in that trips from Hanoi and Ho Chi Minh City would become “day-trippable” by reducing the projected travel time to only between two and three hours or less. Likewise, there is evidence to suggest that the availability of HSR infrastructure contributes to economic development in other fields, such as real estate [7]—in this sense, this paper does not seek to go against the HSR literature on potential long-term economic impacts. Rather, the aim of this article is to encourage conversation about “hidden factors” in construction and operation which can encourage the long-term sustainability of the project and minimize fixed and relative environmental costs, with a narrow focus on the consumption of coal, the generation of CO₂, and how this will compare to aviation under a range of scenarios. If the line is completed, it simply will generate a fixed amount of CO₂ per journey, and it is important to encourage the consideration of ways to make this as efficient as possible in engineering, operational and ridership terms.

This paper is structured as follows. It begins with a brief literature review, assessing some of the existing gaps in knowledge which this paper seeks to address. This is followed by a comprehensive outlay of the methodology and materials used in the paper, beginning with the baseline emissions for a comparable air journey between Hanoi and Ho Chi Minh City, and followed by the calculation methodology used to find the CO₂ emissions from the construction steel, the end-to-end journey by HSR on Vietnam’s national energy grid, and the seat fill rate necessary to ensure sustainability in relative terms. The results of these findings are each analyzed in turn, and are then discussed at length in relation to the social, economic and market conditions in Vietnam. Finally, policy implications are given for the findings to each of the research questions.

Literature Review

The NSER itself has thus far attracted little direct interest in the academic literature, and what little analysis of the NSER that exists largely focuses on the economics of the project. Kikuchi and Nakamura’s [8] paper employs an economic analysis which attempts to determine the potential profitability of the rail line under a range of potential scenarios, including the possibility of maintaining non-rail business ventures on the line and the possibility of adding cross-border sections to link to the NSER. This study is interesting particularly in relation to the third section of this article which will examine potential ridership rates; however, it is limited in that the comparative analysis it conducts is based on Shinkansen use in Japan. It does not consider regional issues in Vietnam, which is a significant limitation considering the difference in economic development and income levels between the two countries—this is an area which this study seeks to address by conducting a projected market analysis of the different provinces in the central portion of the line, supplementing the existing analysis in the paper with more data specific to the Vietnamese NSER. As the focus is on profitability, the analysis also excludes an examination of the environmental impact of the railway—a consideration which must ultimately be addressed considering that the JICA feasibility study [3] (pp. 11–12) considers reduced greenhouse gas emissions to be a direct benefit of the project, and considering the broader international context of decarbonization. Beyond this, the NSER is mentioned in passing in several papers relating to infrastructure development, such as Yoon and Doan’s [9] paper on Hai Phong Port, but there is little focus on the NSER project specifically in the wider literature—this is another gap which this study seeks to address, considering both the economic scale of the project and the national market and energy mix context which it will face.

There is somewhat more discussion in the literature of Vietnam’s wider infrastructure needs, but the linkages to environmental performance in existing studies are weak since they tend to focus on purely economic factors. For instance, Tran [10] discusses the impact of different infrastructure levels on FDI across the different regions of Vietnam, noting that FDI was unevenly distributed in part due to poorer infrastructure in rural areas of Vietnam. This is, perhaps, one of the issues which the Vietnamese government hopes
the new rail link will help to alleviate. However, while this is indicative of one of the
causes of regional inequality, it does not address a potential link to demand—rather, the
analysis is focused around the needs of investors rather than individuals, and it again
does not account for the issue of environmental sustainability—a relationship which this
study seeks to establish the extent of in the context of relative environmental performance.
Likewise, Nguyen et al. [11] discuss the success factors in public–private partnerships
for infrastructure in Vietnam—a category which the NSER will fit under—and conclude
that financial feasibility is an important factor in ultimate project success. However, it is
beyond the scope of their study to assess the factors which influence project success on an
individual level—they do not consider the income disparities or demographic differences
present in Vietnam or discuss in detail other factors which are likely to underpin financial
feasibility. This is again an issue that this study addresses—this study engages in a market
size analysis specific to the NSER which permits a discussion of the feasibility of the project
in terms of environmental performance, which, while not the main objective of the paper,
provides insight into economic market size in the central regions of Vietnam as well.

While there is little discussion of environmental factors in Vietnam’s transport infras-
tructure needs, there is considerably more criticism in the wider literature of the energy
sector in Vietnam—indeed, in recent years, Vietnam has been sharply criticized for its
investments in coal power generation and there is wide academic and political consensus
urging Vietnam to move to cleaner forms of energy. Dorband et al. [12] focus on the political
economy of coal use in Vietnam, concluding that vested interests drive its use—but they
also urge international financiers to move toward renewable energy investments. Likewise,
Tran [13], in predicting an increase in greenhouse gas emissions under a business-as-usual
scenario, notes the critical importance of increasing renewable energy in the energy mix.
This discourse, being related to this study, is an important one to consider in relation to
HSR—HSR, by its very nature, uses considerable amounts of energy, and so even if the
trainsets themselves do not directly emit CO\textsubscript{2}, they are straining an energy supply which
does. Considering the energy mix specific to Vietnam in assessing the environmental
performance of the NSER is of vital importance.

In assessing the CO\textsubscript{2} emissions and CO\textsubscript{2} savings made by HSR, comparable analyses
have been conducted in other national contexts. Of particular relevance from the recent
scholarship on the matter, considering that this study focuses on air travel as a baseline
comparison, is the paper by Avogadro et al. [14] which considers both travel time and costs
when substituting air travel with HSR in the European market and ultimately concludes
that emissions savings are likely if certain short to medium distance air routes which
can realistically be substituted for rail are discontinued, albeit with significant caveats for
regional accessibility and with varying impacts per EU member state. While ostensibly this
bodes well for the Vietnamese NSER, in reality the comparison cannot be made directly—
European energy mixes are extremely different to those seen in Vietnam, and in any case it
is unlikely that the Vietnamese government would stop flights outright between Hanoi and
Ho Chi Minh City considering both the fact that the government has an 86.16% share in the
Vietnam Airlines [15] and that the route is the sixth-busiest in the world [16]. Likewise, on
the costs side, as with the paper by Kikuchi and Nakamura [8], it is not realistic to translate
the cost variable to Vietnam where the base level of income is likely to be considerably
lower, even if some European countries actually perform worse on equality metrics such as
GINI (most notably Italy) [17].

Perhaps more comparable to Vietnam are China and Turkey, and both of these have
seen studies on the CO\textsubscript{2} performance of their respective HSRs. A study by Chang et al. [18]
examines “cradle-to-grave” emissions including the construction and operating costs of
the Beijing–Shijiazhuang HSR, and their study concludes that while the HSR is ultimately
preferable to air or road travel, the environmental performance can be improved by in-
creasing ridership. Their methodology for calculating construction costs goes beyond
what is possible in the scope of this study, incorporating materials other than steel and
accounting for energy costs in the construction process, but their findings are interesting
in that, prima facie, they confirm some of the hypotheses in this study. However, their chosen case study route is considerably shorter—only 281 km in distance compared to the 1541 km of the Vietnamese NSER [18,19]. As such, different considerations may be at play in relation to consumer behavior. The shorter distance, the journey time and the relative costs of the options available will be vastly different, and so a specific and tailored analysis of the NSER’s conditions is necessary. Perhaps more comparable is the Beijing to Shanghai HSR—a study of which, also cited by Chang et al. [18], was carried out by Yue et al. [20]. This study conducts a life-cycle assessment, including an examination of the role of the energy mix in the HSR’s performance and a recommendation that China move away from fossil fuel-based energy [20], but it is again placed in a very different social and economic context to the NSER, with considerably different conditions along the route considering China’s economic geography and the privileged position of the coastal areas relative to the inland areas. As such, this paper seeks to conduct an analysis which is specific to Vietnam—while the Chinese HSR is perhaps the closest, it is still not a perfect comparison, and a tailored, project-specific approach is necessary.

Outside of China, the most directly comparable HSR system is likely to be Turkey, on which an analysis of two HSR lines was conducted by Dalkic et al. [21]. It again seems to ostensibly support some of the hypotheses laid out in this paper, for instance in concluding that cost and travel time are likely to be barriers which reduce HSR use and that energy mix is a vital factor in estimating greenhouse gas emissions. However, this particular paper focuses largely on capturing road passengers rather than air passengers [21], and it is again specific to a single national context. If anything, this literature review has made clear the importance of conducting a specific, tailored analysis of HSR projects on a case-by-case basis, since the economic, social and demographic factors are vastly different in each proposed location and project. This paper therefore addresses this literature gap in relation to the Vietnamese NSER—a proposed line on which limited policy research has been conducted beyond the feasibility studies carried out by JICA, and enriches the literature on the relationship between energy mix, inequality, market size and environmental performance in relation to HSR more broadly.

2. Materials and Methods

This paper used the statistics and estimates contained within the October 2019 Japan International Cooperation Agency (JICA) Data Collection Survey on Vietnam’s proposed NSER [19] as the basis for most of the projections and modeled scenarios. The reason for this is that this is the most recent and most detailed proposal for the NSER, and that it contains detailed information on proposed technical standards on which estimates can be formulated. All estimates were based on the so-called “two-step scenario” laid out in the study, where the entire line would be expected to be open by 2040 [19]—this was selected over the alternative “five-step scenario” because the latter would only open fully in 2070, and predictions and projections for such a distance into the future would be impossible to make with any reasonable degree of rigor in the context of this study. Where appropriate, additional data provided by other ministries and agencies in Vietnam and elsewhere, such the Ministry of Natural Resources and Environment, which permitted further comparison of Shinkansen emissions factors or policy, and from various NGOs and industry bodies, including the International Energy Agency and the World Steel Association, were used. This study was broadly split into three areas; the amount of carbon produced to produce the rails, the absolute cost in carbon of each one-way journey along the entire length of the proposed line, and the “per capita” CO₂ costs under several projected passenger load scenarios. The numerous data points were synthesized to project the potential carbon emissions on the NSER—both in construction and in operation—in comparison to an air journey between Hanoi and Ho Chi Minh City, which formed a comparative baseline.

First, the emissions for the air journey were based on the data provided in the UK government’s greenhouse gas conversion factors for company reporting, using the figures specified for short-haul flights [22], with an assumption based on the principle of 184 passengers
(the capacity on a Vietnam Airlines Airbus A321 [23]) generating 19,416.6 kg of CO₂ per journey among them (105.525 kg/capita) on a flight between Hanoi and Ho Chi Minh City. This is naturally limited to some degree—there are numerous airlines and plane types serving this route with different specific passenger capacities and carbon emissions. This only covers the A321, and not every seat will be full on every flight. There were several reasons why it was selected over other plane types. First, of the 16 flights which Vietnam Airlines operates on a single day on this route, 6 are A321s, which is tied for the most-used plane type on this route with the Airbus A320 [24]. This was based on Monday 16 July 2021, a randomly selected date. As the route is so busy, there is unlikely to be significant variance between different working days over the course of a given year, although any date suffers from being selected during the period of reduced pandemic air passenger demand. Moreover, Vietnam Airlines does not permit access to historical flight schedules, so data could only be collected from a date in the future relative to the data collection period, which took place in July 2021. Second, both the A321 and the A320 have similar specifications, with only slight differences in fuel consumption and seat capacity [22]. Both planes are also marketed by Airbus as having “unbeatable fuel efficiency” and so they represent planes which are positioning themselves as being “environmentally friendly” by air transport standards [25,26]. Beyond this, the A321 was selected over the A320 because it is the aircraft which Vietnam Airlines chooses to more heavily market—it features prominently on the website, while the other plane type does not [23], and so it is likely the aircraft Vietnam Airlines would wish to be represented with on a domestic route. This route was also, in 2019, the sixth-busiest domestic air route in the world [16], so seat capacities would be likely to be high or full much of the time. This was favored over the ICAO emissions calculator because it permits specificity of plane type, where the ICAO calculator aggregates across all plane types used on the route making the figure less precise because it is not possible to calculate per-seat emissions without selecting a specific model of plane. To summarize, the emissions for the plane were based on an Airbus A321 and greenhouse gas conversion factors used by the UK government for company reporting, based on short-haul flights and assuming a full passenger load of 184 passengers.

The key data necessary for the calculation of the carbon cost of the steel production for the rails were the length of the proposed railway (1541 km), and the rail weight and type (60 kg per meter rails conforming to Japanese Industrial Standards), along with the carbon emissions per kilogram of steel produced. The former data are included within the JICA survey [19] (pp. 1–21), while the latter are based on the estimates provided by the World Steel Association, an industry body, which estimates that, averaged across the globe, 1.9 tonnes of carbon are produced per tonne of steel [27]. This is a rather crude estimate—no details on methodology are provided in the source, and the figure does not specifically target the Vietnamese steel industry or account for any specific pitfalls or inherent advantages within the Vietnamese steel industry. However, these figures would be beyond the scope of this article to collect to a higher degree of accuracy, and this figure provided a useful baseline from which to reasonably estimate the carbon emissions from the steel production needed for the railway. In terms of construction costs, additional CO₂ will be created in the production of concrete needed for slab sections of the track—however, it was not possible to calculate the CO₂ emissions from this with any degree of precision based on the available data. To summarize, this is a simple calculation of the CO₂ emitted, per the World Steel Association’s [27] estimate of 1.9 metric tonnes of CO₂ per tonne of steel calculated as the length of the entire railway and assuming that it is double-tracked (for four sets of rails) at 60 kg/m in weight.

Key data necessary to calculate figures on the potential CO₂ emissions from the Shinkansen were combined from several datasets. The energy consumption data for the 10-car E5-series (31.7 kilowatt-hours per kilometer) is contained within the JICA survey ([19] Appendix pp. 14–15). This permitted a calculation of the energy consumption across an entire end-to-end journey, which could then be combined with data on Vietnam’s projected energy mix in 2030 (again found in the JICA survey) to determine how much of
the provided electricity was likely to come from fossil fuel-based sources. In this case coal and gas were used since other fossil fuels are not expected to form a significant portion of Vietnam’s future energy mix. In this case, by 2030, Vietnam’s projected energy mix in terms of actual power generated in billions of kilowatt-hours will include 53.2 per cent coal and 16.8 per cent gas, which will comprise the two largest sources in the energy mix [3] (pp. 4–37). The survey also provides the figures in terms of projected generation capacity, but it is more accurate to use the actual output since the capacity includes a high proportion of hydroelectric dams which fluctuate in performance over time. In essence, this calculation took the energy used across the entire journey, based on the estimate of a 10-car E5-series Shinkansen, and then divided the journey into “shares” based on the proportion of each fuel type in the energy mix as it is predicted to be in 2030.

For coal-based CO$_2$ emissions, the above figures were combined with data provided by Finenko and Thomson [28] who provide estimates of CO$_2$ emissions per megawatt-hour of generated electricity in Vietnam, comparing across a range of scenarios with different fuel mixes and technology types. For the purposes of this paper, the estimates used were based on the 2010 figure specified by Finenko and Thomson at 1056 kg of CO$_2$ per megawatt hour. This figure was used as the “worst case scenario” as it was the only confirmed and “real” figure in the data and is not a projection. This was supplemented by a “best-case scenario” estimate of approximately 730 kg of CO$_2$ per megawatt-hour if Vietnam switched entirely to the best current technology (ultra-supercritical plants) and fuel mix (bituminous coal) by 2030 [28]. A range of other potential scenarios apart from these two figures are projected in Finenko and Thomson’s paper [28], including a business-as-usual scenario and an expansion of subcritical plants using anthracite coal, both of which predict a small rise in CO$_2$ emissions by 2030 versus the 2010 figure. However, since there is only little difference between these high 2030 estimates and the “worst-case scenario” 2010 figure, it is more preferable to use the “real” 2010 figure where possible. The “best-case scenario” is useful because it is the most emphatic in demonstrating the savings in CO$_2$ emissions which can be gained by switching to better technologies—even if the scenario itself is improbable, it most clearly demonstrates the benefits of moving to cleaner technologies. In essence, this means that two estimates are provided, based on the figures provided in Finenko and Thomson’s [28] paper—one representing a continuation of the 2010 energy mix and one representing a hypothetical scenario in which all coal plants were upgraded to the cleanest possible coal technology. The calculation was again relatively simple—the megawatt-hours of electricity generated by coal as multiplied by the requisite CO$_2$ emissions per megawatt-hour to provide the overall level of CO$_2$ emissions.

Natural gas emissions per megawatt-hour are based on Vietnamese government data—in 2018, Vietnam generated 39,772,700.73 megawatt-hours of electricity from gas turbines, generating 17,272,563.05 t of CO$_2$ [29]. A simple division of the generated CO$_2$ by the megawatt-hours of electricity provided a workable figure which showed that the gas power in the energy mix is producing roughly 0.4342818751 t of CO$_2$ per megawatt-hour, which was rounded to two decimal places to provide the working figure of 430 kg of CO$_2$ per megawatt-hour used in the calculations made within this paper. These figures are based on official data, and the slight rounding down gives the train the “best chance” of outperforming the plane on CO$_2$ emissions. The methodology here is the same as for coal, except the coal figures were replaced with natural gas figures—the natural gas-based megawatt-hours of electricity were multiplied by the 430 kg of CO$_2$/megawatt-hour calculated above. An additional and hypothetical “gas-only” scenario is provided to demonstrate the CO$_2$ savings which could be achieved if coal were replaced with natural gas—the megawatt-hour share of coal was simply applied to natural gas instead.

With these figures, it was possible to calculate how much of the Shinkansen’s journey across Vietnam will theoretically come from each power source, and by extension how much CO$_2$ will be emitted per end-to-end journey on the NSER. If the E5-series uses 31.7 kilowatt-hours per kilometer, then this means that it will use approximately 48.88 megawatt-hours across the entire journey. It is then a simple matter of applying
the percentages of coal and natural gas in the energy mix to this figure to determine how many megawatt-hours come from each energy source, and then multiplying the number of megawatt-hours by the CO\(_2\) emission factors collected across the different data sources. This provides base estimates of the indirect CO\(_2\) emissions caused by the electricity consumed by the train across several scenarios—emissions which will be absolute and independent of seat occupancy. The results of these figures are represented in Table 1 in the results section.

**Table 1.** Energy consumption and CO\(_2\) emissions of 10 and 16-car E5-Series Shinkansen travelling from Hanoi to Ho Chi Minh City compared to the A321 under low and high coal emissions scenarios, including natural gas, expressed as a percentage of A321 emissions on the same journey.

| Scenario                  | Coal Emissions  | Coal + Natural Gas Emissions | % of A321 Emissions (19,416.6 kg) |
|---------------------------|-----------------|------------------------------|----------------------------------|
| High Emissions, 10-car    | 27,465.44 kg    | 30,997.18 kg                 | 159.64%                          |
| Low Emissions, 10-car     | 19,045.7 kg     | 22,577.44 kg                 | 116.28%                          |
| High Emissions, 16-car    | 43,866.24 kg    | 49,503.53 kg                 | 254.95%                          |
| Low Emissions, 16-car     | 30,324.2 kg     | 35,961.5 kg                  | 185.21%                          |

The final component of this paper focuses on per capita emissions on the plane versus the train. The plane was assumed to be at full capacity—in the case of the Vietnam Airlines A321, this is 184 seats [23], and considering that the route was the sixth-busiest air route in the world pre-pandemic [16], this is a fair assumption when working out per-capita emissions from the route. For the Shinkansen, a number of scenarios are projected, with seat occupancy rates projected at 10 per cent intervals. This is because average seat occupancy across the whole journey is difficult to predict accurately, with varying predictions based on journey time and using different calculation methodologies. This approach is similar to the one used in the Chang et al. [18] study, although their study divides the emissions of the entire life-cycle of the HSR across the passenger fill-rate rather than just the emissions of a single journey. The JICA survey predicts that the passenger demand will stay relatively consistent across all the sections of the railway, with a variance between 117,000 passengers per day in the least-used Nam Dinh-Ninh Binh section (three sections of the railway outside Hanoi and connecting two smaller cities) and 150,000 in the most-used section between Long Thanh and the Thu Thiem terminus station in Ho Chi Minh City by 2050 [19] (pp. 2–19). This averages a 70 per cent seat occupancy rate across all sections [3] (pp. 5–7). However, this is questionable—the prediction model used in the study is based on a JICA study from 2013 [19], and the modeling in the study is based on traffic demand data from between 2008 and 2010 [30]. However, the intravenous period has seen considerable shifts in Vietnam’s passenger transport market, which has seen extremely high passenger demand and which has seen the expansion of low-cost airlines in what is now a highly competitive space with three competing low-cost carriers (LCCs) [31]. This is only predicted to expand further with ten airport construction and expansion projects planned before 2030, including in the central regions of Vietnam such as a new airport in Quang Tri and a new terminal at Da Nang Airport [32]. To summarize, 10% interval seat fill-rates were projected, and then the CO\(_2\) emissions per one-way journey were divided between the passengers at these intervals to estimate per-capita CO\(_2\) emissions at each interval. Furthermore, the exact point at which the train became more efficient in per-capita terms was calculated by taking the total emissions of the train journey and dividing them by the per capita CO\(_2\) emissions from the plane journey, which provided the precise number of seats filled which would be needed to exceed the environmental performance of the plane. This was then converted into a percentage across both the high emissions and low emissions scenarios and on both the 10 and 16-car trains.

There is also the significant question of regional inequality—between the two economic centers of Hanoi and Ho Chi Minh City exist a number of significantly poorer regions. Another factor is that evidence from other countries, including Japan, suggests that demand for rail diminishes with distance [8]—and even with HSR the journey time between the
termini would be over five hours—more than double an equivalent flight. Vietnamese statistical data, sourced from Vietnam’s General Statistics Office, provincial government websites and state-owned regional and national newspapers [33–54] was combined with average income data from Open Development Mekong [33] and three estimates of provincial inequality in Vietnam are provided, with the first using a flat 7.076% compound annual growth calculation over the twelve years between 2018 (when the data was collected) and 2030, which is limited due to the different growth rates across the country. The second uses actual provincial gross regional domestic product (GRDP) growth rates from 2018, but since annual rates are prone to fluctuation (indeed, Ha Tinh’s data deliberately excludes the Formosa Ha Tinh Steel plant because the plant on its own accounts for more than half of the GRDP growth in that year and so it is unrepresentative) these figures are also likely to be flawed. The third set is a mean average of the two, and while still imperfect this allows the two sets to balance each other to some degree. However, it should be stressed that these figures are by no means definitive—since predicting future growth is difficult, and since the figures pre-date COVID-19 and do not adjust for the long term impact of it since reliable figures are unavailable which can account for it, this dataset is only intended to demonstrate the point that regional inequality is likely to persist. These combine with provincial population and population growth statistics [34] to create a rough estimate of market size based on the total personal income given per province—this is similar to Gross Regional Household Income, but is based on individual rather than household income. Figures are adjusted so that only those of legal working age (15+) are counted, with this being based on United Nations Department of Economic and Social Affairs population statistics [35]. Again, however, these figures are somewhat limited in that they do not account for the impact of COVID-19, with the final impacts of the pandemic ultimately impossible to predict. These predictions also do not account for overseas tourists, but as the most likely points of entry into Vietnam are the major international airports in Ho Chi Minh City and Hanoi, it is not expected that this would make a considerable difference considering that potential tourist HSR users would likely be boarding at or near the terminus stations and thereby only increasing their potential market size. The base data for the calculations in this section can be seen in Appendix A. To summarize, three estimates are provided of average incomes in 2030—one based on a compounded flat regional economic growth rate from the 2019 figures, one based on a compounded flat national growth rate, and one which uses the mean average of the two to adjust for potential outlying factors in regional growth figures. Regional growth rates are applied to existing population figures and compounded to provide an estimate of population size in 2030, and this is then adjusted to only account for the working age population. The estimated 2030 population size is then multiplied by the estimated average income per province to provide a market size estimate based on Gross Regional Personal Income, which is calculated in a similar manner to Gross Regional Household Income except that it is calculated on an individual and not a household level.

While these issues are considered in the discussion section, these various complicating factors make projecting the passenger demand with any degree of accuracy impossible, and so it is better to use an approach which captures numerous potential scenarios using average seat fill rate. While it is true that the train will allow passenger embarkation and disembarkation along the route, the fact remains that the trains will be doing end-to-end journeys just as the planes will. This makes assessments of both the end-to-end journey emissions and the per-capita emissions based on average occupancy rate important. Since an E5-series Shinkansen with ten cars has 740 seats [3] (pp. 4–87) the per-capita seat emissions can be calculated using the aforementioned total energy used across the journey and then dividing it by different seat fill rates at 10 per cent intervals based on the total seat numbers. The JICA feasibility study [3] also discusses the possibility of moving to a 16-car model after 2040 with a predicted increase in passenger demand, with this model having 1220 seats. The energy consumption of this model is not disclosed, but a crude estimate is provided based on the figure from the 10-car model and multiplying it by 1.6. This provides a working estimate of 78.08 megawatt-hours per one-way journey, but this
is limited since it does not account for any specific factors such as aerodynamic drag or different carriage weights, such as first-class or dining cars. As such, the figures for the 10-car layout should be considered more accurate.

**Limitations of This Study**

The data used in this study were naturally limited by several factors. First is data availability—it is not possible within the context of this study to provide a full life-cycle analysis on the level of the studies by Chang et al. and Yue et al. [18,20] because most of the data available to do so are not available or have not yet been assessed in rigorous detail by the project planners, with specific route details still to be finalized. Much of the data are also commercially sensitive—several parts of the publicly-accessible version of the JICA study are redacted and finding specific data on Shinkansen train sets is difficult. This is the reason for the limited estimate given for the 16-car E5-series Shinkansen (which does not yet exist even in Japan)—with only the figures for the 10-car model available, the only way to provide a workable estimate was with a crude calculation which assumed that being 1.6 times larger would equal 1.6 times the energy consumption. It does not, and cannot, compensate for issues such as additional aerodynamic drag, and of course it is not possible to tell in advance how many carriages will be assigned as different types, whether they be luggage storage, first or business-class accommodation, or dining cars. Because of this, none of the figures provided should be taken as in any way definitive—they are realistic estimates based on the data available, but they are designed to model the points made in the study and should not be considered technical samples which are completely accurate.

The second factor is the simple fact that the NSER only exists on paper, and this means that several factors must be estimated or assumed. On energy mix, for example, it is possible that Vietnam will change policy significantly by 2030 and that coal power will have significantly reduced—indeed, it promised to cease constructing new coal plants and transition completely from coal in the 2030s at COP26 [55] but it remains to be seen whether this will be fully implemented. It is, of course, also possible that the opposite could happen. The use of the feasibility study as a base, while being the best source of data available on the NSER project, is itself demonstrative of this—the original 2008 passenger demand data, for instance, predates the expansion of LCCs in Vietnam and so the data collected are of questionable value now. The same may be true of this study in the future—any use or citation of this study should ensure that the points being made are still relevant at the time they are used, because while the estimated scenarios are all as realistic as possible, they are also purely hypothetical in nature.

The third factor—which makes the limitation outlined above even more prescient—is that fact that this study was conducted during the COVID-19 pandemic. This will have significant ramifications for regional economic growth in Vietnam which are not accounted for, since the author felt that the pandemic recovery timescale would not be possible to predict and would bias the economic growth estimates provided. This means that, in all likelihood, the actual growth in regional incomes will be somewhat lower than the estimates provided in this study. Again, they should by no means be taken as definitive because of this. Similarly, the flight data provided were taken during the height of the pandemic, at a time of reduced air passenger demand—but since Vietnam Airlines does not provide historical flight schedules this was the only option open for this study.

Finally, the comparison with the plane is significantly caveated by the fact that it only covers one type of aircraft on a single airline with a single configuration. The route operates with numerous aircraft types—some larger and some smaller than the A321—and each of these vary in both CO₂ emissions and in passenger load (and therefore per-capita CO₂ emissions). The A321 was deemed the best option for this study—being a modern aircraft which is likely to still be in use and which has relatively good emissions performance among planes and therefore a high benchmark for the NSER to compete against since it is likely that emissions from new aircraft types will continue to decline. However, the NSER’s performance may vary in relative terms to other types of aircraft depending on their size,
emissions, and passenger load, and so this limitation should be considered by readers of this study.

3. Results

This section is split into three components, each of these being based on the hypotheses laid out in the introduction. The first part concerns the CO\(_2\) involved in the production of the steel, the second part discusses the CO\(_2\) emissions of each end-to-end journey along the NSER in relation to the energy mix, and the third part discusses per-capita CO\(_2\) emissions under a range of scenarios.

3.1. Steel CO\(_2\)

Contrary to the hypothesis, the steel used in construction will only form a minor part of the carbon footprint from the railway. In absolute terms, it was calculated using the above methodology that the railway steel—assuming that it is all virgin and not recycled steel—will generate 702,696 metric tonnes (t) of CO\(_2\) in production with an indeterminable amount also used in shipping. This assumes that the entire line is double-tracked (for four sets of rails) under the JIS-60 kg rails specified in the JICA study [3,19], and it only considers the tracks themselves. This constitutes a reasonable “worst case scenario” when testing the hypothesis and simplifies the calculation necessary since there is no indication of which sections of the line would, in reality, be double or single-tracked. If 19,416.6 kg (19.41 t) of CO\(_2\) are indeed emitted per flight, this would mean that the railway steel was “equivalent” to around 36,202 flights. Vietnam Airlines alone operates some 40 flights per day on this route [24], which means that in effect, the steel is equivalent to around 905 days of operations by only Vietnam Airlines—in practice, considering the presence of other airlines and larger plane types also in operation, the steel CO\(_2\) would be the equivalent of far fewer “operational days” of equivalent flights. Nonetheless, this is still a large, fixed cost, and means to reduce it will be considered in the discussion section.

That being said, considering the results of the studies on the Chinese HSR system by Chang et al. and Yue et al. [18,20], it is clear that rail steel is only a small component of the overall CO\(_2\) emissions cost of construction. While the data necessary to conduct a thorough life-cycle assessment of the Vietnamese NSER were beyond the reach or scope of this study, the results of the above studies clearly demonstrate the need for such an assessment to take place.

3.2. Per-Journey CO\(_2\) Emissions on Vietnam's Inefficient Power Grid

The Shinkansen is, of course, fully electrified. However, the original hypothesis of this article was that due to the coal and gas-heavy nature of Vietnam’s power grid, an electrified train running on it would not deliver significant environmental savings and would, in fact, generate significant amounts of CO\(_2\). This was confirmed by the findings. Table 1 shows the energy costs of the journey using a 10-car E5-series Shinkansen traveling at the projected speed of 320 kph (again, per the JICA study) analysis [3] (pp. 4–87). Per the JICA Study which itself is using figures based on Vietnam’s 7th National Power Development Plan, by 2030 it is predicted that 53.2% of electrical output will be from coal, followed by natural gas at 16.8%, and fossil fuel-free sources (hydropower, renewables and nuclear) will only comprise 29.8% of the energy mix. A further 1.2% will be imported, but since this amount is small and its own makeup cannot be calculated precisely, it is excluded from the analysis [3] (pp. 4–37). It is calculated that even in the best-case scenario, using the smaller train and if all the coal power in Vietnam were to be generated by ultra-supercritical plants per the projections laid out by Finenko and Thomson [28], then the CO\(_2\) emissions performance of an end-to-end trip on the Shinkansen would still be worse than an equivalent A321 flight by 16.28%. In the baseline high emissions scenario, the performance of each end-to-end journey would be 59.64% worse in terms of CO\(_2\) generation on the 10-car train and 154.95% worse on the 16-car train. In the “best case” low-emissions scenario with the best and most efficient form of coal technology available on the 10-car
train, the emissions from coal alone are almost a perfect match for the entirety of the plane journey as expressed in Figure 1, and this is before adding the extra CO\textsubscript{2} from the natural gas in the energy mix. This “hidden factor” in coal usage is a significant finding which calls into question the environmental credentials of the NSER in terms of the absolute and fixed costs of running the railway. Of course, the train has far more seats than a plane and therefore the potential of being more efficient on a per-capita basis—this is discussed in Section 3.3. It is also worth noting that on the 16-car train (expressed in Figure 2), even in an extremely unlikely hypothetical scenario of replacing all coal in the energy mix with gas power, the one-way train journey would still emit more CO\textsubscript{2} than the plane in terms of fixed costs—of all the scenarios calculated in this paper, only the 10-car train in the gas-only scenario exceeds the performance of the A321 in terms of fixed costs per one-way journey.

**Figure 1.** Train emissions from indirect fossil fuel consumption on the Hanoi-Ho Chi Minh City route by single journey using a 10-car train versus the A321 under high and low coal emissions scenarios, expressed in kilograms of CO\textsubscript{2}. Includes a hypothetical gas-only scenario.

**Figure 2.** Train emissions from indirect fossil fuel consumption on the Hanoi–Ho Chi Minh City route by single journey using a 16-car train versus the A321 under high and low coal emissions scenarios, expressed in kilograms of CO\textsubscript{2}. Includes a hypothetical gas-only scenario.
This is consistent with the results seen in the existing academic literature on the subject, most of which consider energy mix to be a vital part of assessing the performance of HSR infrastructure. The results seen here match closely the results in Yue et al. [20] wherein the coal in the Chinese energy mix is determined to be the single most significant contributor to the overall environmental impact of the railway, albeit with the caveat that coal use is slightly higher in the Chinese energy mix than in the Vietnamese one [56]. They are also in accord with the conclusions of Dalkic et al. [21] who note that in their study of the Turkish HSR that 65% of the country’s electricity is supplied by fossil fuel-based power plants, including coal and natural gas, and that switching to alternative energy sources could create significant savings in greenhouse gas emissions on the HSR. The results differ somewhat than the findings of Avogadro et al. [14], who conclude that emissions savings are likely if HSR replaces air travel—but if anything, this only proves the point on energy mix being important—across the EU, only 12.6% of energy is provided by solid fossil fuels such as coal, and while petroleum and natural gas use is still present [57], these fuel sources are not as emissions-intensive as coal. Moreover, in the countries with the greatest prevalence of HSR infrastructure such as France, Germany, Italy and Spain, coal use has declined significantly and forms only a small part of these countries’ respective energy mixes [58–61]. Of these, Germany has the highest coal use, but even Germany only had 19.6% of its energy met by coal in 2019 and 15.53% in 2020 [57,59], both far below the projected figure for Vietnam in the JICA study of 53.2%, per Table 2. This in itself is a strong demonstration of the impact of energy mix on environmental performance.

### Table 2. Predicted 2030 Per Capita Income (USD) (based on a 7.08% flat national growth rate, per-region growth rate, and mean of the two).

| Station Name      | 2030 p/c Income (Flat National Growth Rate) | 2030 p/c Income (Regional Growth Rate) | 2030 p/c Income (Mean Calculation) |
|-------------------|---------------------------------------------|----------------------------------------|-----------------------------------|
| Ngoc Hoi (Hanoi) | 13,751.43705                               | 14,211.43241                          | 13,981.43473                     |
| Phu Ly            | 8195.43853                                  | 13,350.56538                          | 10,773.00196                     |
| Nam Dinh          | 7684.359355                                 | 8614.106253                           | 8149.238804                      |
| Ninh Binh         | 8579.31578                                  | 10,943.3519                           | 9761.43383                       |
| Thanh Hoa         | 6846.189505                                 | 14,628.52528                          | 10,737.35739                     |
| Vinh              | 5774.058965                                 | 6970.83958                            | 6372.449274                      |
| Ha Tinh           | 6460.047973                                 | 8008.02964                            | 7234.05179                       |
| Vung Ang          | 6462.937294                                 | 8008.02964                            | 7235.483429                      |
| Dong Ho           | 6055.720378                                 | 6024.57548                            | 6040.14791                       |
| Dong Ha           | 5774.058965                                 | 5802.59372                           | 5788.32734                       |
| Hue               | 7005.191915                                 | 7063.50852                            | 7034.35022                       |
| Da Nang           | 12,506.67532                                | 13,650.89727                          | 13,078.7863                      |
| Tam Ky            | 6598.600037                                 | 7405.19579                            | 7001.897908                      |
| Quang Ngai        | 6584.971259                                 | 8079.13184                            | 7674.05155                       |
| Phu My            | 6868.904135                                 | 7059.10683                            | 6964.005486                      |
| Dieu Tri (Qui Nhon)| 6868.904135                               | 7059.10683                            | 6964.005486                      |
| Tuy Hoa           | 6444.140552                                 | 7312.53799                            | 6878.338976                      |
| Nha Trang         | 7847.904691                                 | 8101.36287                            | 7974.633784                      |
| Thap Cham         | 5976.219173                                 | 8485.23792                            | 7230.728562                      |
| Tuy Phong         | 7822.918598                                 | 8749.98239                            | 8286.450453                      |
| Phan Thiet        | 7822.918598                                 | 8749.98239                            | 8286.450453                      |
| Long Thanh        | 12,036.48248                                | 13,492.80509                          | 12,764.64379                     |
| Thu Thiem (HCMC)  | 14,030.827                                 | 16,081.22324                          | 15,056.02512                     |

Stations in provinces which are predicted to have less than half of Ho Chi Minh City’s Per Capita Income are marked in blue, clearly demonstrating the geography of the inequality along the middle portions of the line.

### 3.3. Per-Capita CO$_2$ Emissions on the E5-Series versus the A321

At full capacity, with every seat filled, the 10-car E5-series’ CO$_2$ emissions performance would be 41.89 kg/capita in the high-emissions scenario and 30.51 kg/capita in the low-emissions scenario. The 16-car E5-series performs marginally better on a per-capita
basis, with 40.58 kg/capita in the high-emissions scenario and 29.48 kg/capita in the low-emissions scenario. Either case is, ostensibly, very favorable for the train—in both cases it far surpasses the performance of the 184-seat A321 which would generate 105.525 kg/capita on the same journey. However, the main variable—passenger numbers—severely impacts this calculation. Taking the JICA estimate of 70% occupancy across all sections [3 p. 5–6], on the 10-car train the per-capita CO₂ emissions would be 59.84 kg in the high-emissions scenario and 43.58 kg in the low-emissions scenario, while on the 16-car train they would be 57.96 kg in the high-emissions scenario and 42.1 kg in the low-emissions scenario. In all cases, this is still better than the performance of the A321, but as the seat fill-rate declines, so does the per-capita environmental performance. Figures 3 and 4 show the per-capita performance of the E5-series 10 and 16-car trains compared to the A321 at different passenger capacity intervals—they provide a stark demonstration of the impact of seat occupancy, with the cut-off point being at 39.7% (approximately 294 seats) in the 10-car high-emissions scenario and 28.91% (approximately 214 seats) in the 10-car low-emissions scenario. In the 16-car train, the cut-off points are 38.45% (469 seats) and 27.93% (341 seats) in the high and low emissions scenarios, respectively.

Figure 3. Per-capita CO₂ emissions in the high and low emissions scenarios on the 10-car E5-series Shinkansen in Vietnam at 10% Intervals (10-car Train)

This also provides further demonstration of the impact of the fuel mix—by moving to ultra-supercritical coal technology, the train, regardless of size, becomes significantly more efficient in per-capita terms—the 10-car train is able to take 80 fewer passengers and the 16-car train is able to take 128 fewer passengers before reaching their respective cut-off points compared to the A321. These represent efficiency boosts on a per-capita basis of 10.81% (10-car) and 10.49% (16-car), respectively, and are indicative of the hidden factors relating to both passenger load and energy type.

This is again consistent with the findings in the existing literature. Dalkic et al.’s [21] study, in one scenario estimate of passenger demand for the train, predicts a variance in emissions reduction against road use from trains between Ankara and Istanbul of between 112.2 kt of CO₂ and 151.8 kt of CO₂, and this is based on a 30% variance in passenger numbers with the higher figure representing 95% occupancies and the lower number representing 70% occupancies. While in their study in either case emissions reductions are achieved, it is clear that the seat fill rate has a significant impact on relative performance. While this is based on modal capture—i.e., travelers using the HSR over other modes of transport such as cars—it nonetheless appears to be in accordance with this study that there is a strong link between relative performance and seat fill rate. This also further
confirms the Yue et al. [20] and Chang et al. [18] studies. The Yue et al. study [20] notes that with low market penetration (since again the analysis for the HSR includes modal capture) emissions will increase since in essence, the train will still be running without capturing passengers from other modes of transport, and that with low occupancy, emissions from numerous greenhouse gases might increase by 8–15%. The Chang et al. study [18] likewise considers passenger occupancy rate, and calculates that greenhouse gas emission intensity would be more than three times worse on a train with 30% occupancy (130 g CO₂/km traveled) than one with 100% occupancy (40 g CO₂/km traveled). These results are entirely consistent with the findings for the NSER and underscore the importance of passenger occupancy in relation to relative performance.

![Figure 4. Per-capita CO₂ emissions in the high and low emissions scenarios on the 16-car E5-series Shinkansen in Vietnam at 10% Intervals (16-car Train)](image)

### 3.4. Regional Inequality and Potential Market Size in Vietnam

The regional income inequality in Vietnam is evidently significant—the (albeit limited) modelling in Table 2 demonstrates that of the 23 proposed stations along the line, at least 10 and potentially up to 13 stations will be in provinces (marked in blue)—all in the middle portions of the line—with less than half the per capita incomes of those living in Ho Chi Minh City even by 2030. This is exacerbated by the significantly smaller populations of the intermediate areas—no province in Vietnam reaches even half the populations of Hanoi (8,093,900) or Ho Chi Minh City (9,038,600), with the closest three (Thanh Hoa, Nghe An and Dong Nai) all being in the 3,000,000 range [34]. Dong Nai also directly borders Ho Chi Minh City and its largest city in administrative terms (Bien Hoa) is part of the Ho Chi Minh City conurbation. These combined factors create a situation wherein the potential market size of the middle provinces is much smaller than the GRDP, population size or personal income figures alone would suggest—a significant “hidden factor”.

Table 3 building on the results of Table 2, combines the estimated population figures for 2030 (based on 2018 population growth rates [34] compounded over 12 years across the 71.7% of the population which is considered working age [35]) with the mean estimate from Table 2 to produce an estimate of the total personal income earned by the entire population of each province. The table clearly demonstrates the spiraling impacts of income inequality when combined with population size on the potential market size of a given product or service. Essentially, this is the gross sum of personal incomes, and it represents the hypothetical “pot of money” available for people in any given province to spend on the goods and services which they need, although in practice the figure will be less due to
necessities such as household bill payments and taxation. Nonetheless, in assessing market size via total income rather than by GDRP, we gain a more accurate image of the potential market size since the figures only account for the money available to potential customers and exclude parts of the GRDP calculation with no bearing on market size. The results are quite stark—by this metric of market size, Hanoi and Ho Chi Minh City are by far the largest potential markets—at USD 105.72 bn and USD 128.29 bn, respectively—and no other province along the route reaches even half of these, with seventeen stations (marked in orange) having less than one tenth of the market size of even the smaller terminus of Hanoi. Only four stations are in provinces which are above one-tenth of the market size, and one of these, Long Thanh, is in a province which directly borders Ho Chi Minh City. When placed in the context of the wider HSR environmental performance literature and the general unanimity around the need for occupancy rates to be high, these issues represent significant barriers to achieving a high seat fill rate which will prevent the NSER from achieving its potential in environmental and sustainability terms, since the markets in the middle portion of the line will have fewer people each with less money to spend.

Table 3. Predicted 2030 GRPI (Gross Regional Personal Income) in USD by Station along the NSER.

| Station Name               | Gross Regional Personal Income  |
|----------------------------|---------------------------------|
| Ngoc Hoi (Hanoi)           | 105,722,897,998.09              |
| Phu Ly                     | 7,332,107,844.73                |
| Nam Dinh                   | 10,134,386,492.23               |
| Ninh Binh                  | 7,727,528,117.25                |
| Thanh Hoa                  | 30,774,039,565.59               |
| Vinh                       | 17,973,606,125.79               |
| Ha Tinh                    | 7,096,833,626.19                |
| Vung Ang                   | 7,098,254,408.70                |
| Dong Hoi                   | 4,176,949,776.90                |
| Dong Ha                    | 2,858,274,568.96                |
| Hue                        | 5,828,031,589.81                |
| Da Nang                    | 12,809,029,855.96               |
| Tam Ky                     | 7,981,683,489.12                |
| Quang Ngai                 | 6,860,554,564.12                |
| Phu My                     | 7,428,870,958.48                |
| Dieu Tri (Qui Nhon)        | 7,428,870,958.48                |
| Tue Hoa                    | 4,395,097,792.77                |
| Nha Trang                  | 7,637,009,889.50                |
| Thap Cham                  | 3,292,035,151.51                |
| Tuy Phong                  | 7,829,018,480.83                |
| Phan Thiet                 | 7,829,018,480.83                |
| Long Thanh                 | 34,763,100,564.15               |
| Thu Thiem (HCMC)           | 127,286,030,619.32              |

Stations in provinces predicted to have a GRPI of less than one tenth of Hanoi’s are marked in orange, again clearly demonstrating the geography of the inequality along the middle portions of the line.

4. Discussion

This section will focus on three topics—reducing the fixed costs of the steel needed for construction, the energy mix in Vietnam, and finally means by which seat occupancy rates can be maximized. The results outlined in the previous section raise numerous interesting questions about the long-term environmental and commercial sustainability of the NSER project, the issues of equity and equality in Vietnam, and the means by which these issues can be mitigated.

4.1. Construction Steel

Steel is an unavoidable fixed cost, and there is only so much that can be done to avoid the use of coking coal in the production process. Vietnam itself is currently a major producer of steel—the largest producer of the ASEAN-6 countries (Indonesia, Malaysia, the Philippines, Singapore and Thailand in addition to Vietnam itself) by a significant
margin, having produced some 14.5 m MT of steel in 2018 and with a rapid upward growth trajectory [4]. Of the two countries most likely to provide the steel, while Vietnam has a relatively high amount of scrap-derived, recycled steel from electric arc furnace and interstitial free processes (in 2019, they were 32% and 10% of production, respectively), and while the country is a growing importer of scrap steel for the purpose of recycling [62], the proportion of this has also declined in recent years as more traditional blast furnace mills have been created. With rising electricity prices recycled steel was expected to become less competitive over time [63], but this has not yet come to pass with the largest supplier Vietnam Electricity’s (EVN) tariffs remaining constant since 2019 both in terms of retail and wholesale prices [64–67]. Nonetheless, with the growth of blast furnace steel relative to other forms of production, a further decline in the relative amount of recycled steel can be expected. It is also worth briefly considering other potential sources of steel for the railway. Japan, as the proposed financier of the NSER, is actually even worse than Vietnam in this regard—only 24.5% of steel is produced in electric furnaces (with the rest produced in basic oxygen furnaces), which makes Japan rank as the second-worst performer among the major steel producers after only China (the largest single exporter of steel products to Vietnam) where only 10.4% of steel is produced in electric furnaces [62,68]. Regardless, blast furnace steel is by some margin the most likely source for the railway despite being the most environmentally damaging—mitigation of this to the greatest degree possible by sourcing Electric Arc Furnace (EAF) and interstitial free steel should be considered as a policy priority in planning. This is true of all HSR projects—steel production is one of the leading sources of carbon emissions, with the World Steel Association [69] estimating that between 7 and 9% of all CO₂ emissions globally are due to steel production. This also ties into the later point about energy mix—even EAF and interstitial free steel cannot be said to be carbon-neutral when the energy needed to power the processes behind them is still ultimately coming to a large degree from coal plants, and so moves to increase EAF steel and reduce coal in the overall energy mix would be mutually-reinforcing initiatives in any country which decided to adopt such policies.

While the hypothesis when tested did indeed show that a lower amount of carbon than initially expected would be generated, the fact is that the railway steel alone would generate some 702,696t of CO₂ based on the crude estimate in this paper—still constituting a “hidden factor” in coal-generated CO₂ which should not be ignored. The incorporation of as much recycled steel as possible into the project should be considered as a means to promote its sustainability. The JICA Study [19] (pp. 1–36) also mentions the possibilities of having lower-demand sections of the line single-tracked or, on the opposite end, dual-gauged (to allow for the passage of regular-speed freight trains)—further feasibility studies may also consider these proposals in more detail so that when the project commences construction in earnest, further steel is not added unnecessarily, impacting on and perhaps bringing down the fixed costs necessary for the railway to commence operation.

Even though the steel used for the tracks will emit less CO₂ than hypothesised, a more thorough analysis of the construction costs of the railway and the trains operating on it in environmental terms would be beneficial as future research, which, if possible, should be a full life-cycle analysis. This is beyond the scope of this particular project, but a thorough analysis of this, in line with the work on the Chinese HSRs completed by Chang et al. and Yue et al. [18,20] would be of great benefit in assessing the overall environmental impact of the NSER. Considering the data volumes needed to do justice to such an enormous project in the Vietnamese context, this should ideally involve an open, transparent and collaborative process of research between relevant actors in Vietnam, JICA, and the private sector (including academia) to pool resources and expertise—the incorporation of all relevant stakeholders to pool resources and expertise is especially important considering that capacity, or lack thereof, in the general environmental impact assessment system is considered a weakness in Vietnam [70]. In development aid terms, this could also be addressed via capacity building and technical assistance programmes—JICA has carried out capacity building projects dealing with EIA issues and environmental management in
several countries such as Mauritius, Cambodia and even, historically, Vietnam itself [71–73], in addition to projects carried out by NGOs and International Organisations in Vietnam [73]. Addressing this weakness not just in Vietnam but more generally will allow for more informed decisions to be made on major infrastructure projects from an environmental perspective and may in the long-term lead to carbon emission reduction though the promulgation of best environmental practices in the construction and operation of HSR infrastructure. While the issues discussed in this section are not equity issues in a direct sense, the findings do have equity-related impacts. The contribution to climate change is, of course, the main issue, but as the succeeding sections will discuss, relative performance will hinge on income equality across different regions.

4.2. Power Consumption and Vietnam’s National Grid

The projection that even if Vietnam switched entirely to the best and cleanest available coal power generation technology that the train, regardless of size, would still emit more CO$_2$ than the A321 per one-way journey between Hanoi and Ho Chi Minh City underscores the unsustainable and environmentally destructive nature of coal as a power source and this paper agrees with the wide consensus in the literature in calling for Vietnam to phase out coal in its energy mix to the greatest degree possible. The projection that in the more realistic “high emissions” scenario the train will actually emit 59.64% more CO$_2$ than an equivalent flight, even on the less power-consuming 10-car train, on the same route is of particular concern, and the fact that the 16-car train more than doubles the per-journey CO$_2$ emissions of the plane (and even reaches almost double in the low-emissions scenario) further underscores this issue. These findings drive home the immediate and unequivocal need for a reduction in coal in Vietnam’s energy mix, with even a shift to natural gas—while still emitting CO$_2$—producing significantly cleaner results. Indeed, if Vietnam were to hypothetically replace the entirety of the coal in the energy mix with natural gas, then the 10-car train would comfortably exceed the plane’s per-journey environmental performance in terms of the fixed costs, generating only 14,714.6 kg of CO$_2$ or 75.78% of the plane’s emissions. The 16-car train’s performance would also significantly improve, generating 23,503.8 kg of CO$_2$ or 21.05% more than the plane, but less than half of what it would emit in the high-emissions scenario with coal. In any scenario, the coal used to create the electricity to drive the train constitutes a considerable “hidden factor”, in line with the results seen by Yue et al. and Chang et al. [18,20], and in line with the criticism of Vietnam’s energy mix seen across the literature. This study is a good example of the impact that energy mix has—significant savings can be achieved via industrial upgrading, whether to “better” coal technology or by replacement with natural gas or, ideally, renewable energy sources. Again, this should be considered a policy priority for the NSER to achieve its potential in environmental terms—if savings along the lines of those seen in Avogadro et al.’s study [14] against the emissions of air travel are to be achieved, there is simply no alternative to excising coal and fossil fuels from the energy mix, and so phasing them out should take priority not just in Vietnam, but wherever possible globally.

Again, it is worth emphasizing that this will be a fixed cost. Even if every train were running full and therefore at maximum per-capita efficiency, the project would still benefit from a greener energy mix to reduce the environmental costs of running it. The failure to account for the fixed costs of the project is a significant limitation in the existing feasibility study—especially considering the projected carbon emissions resulting from Vietnam’s energy mix. The results confirmed and indeed exceeded the original hypothesis that the train would have a “hidden factor” in that it would generate significant amounts of CO$_2$ due to coal use and to a lesser degree due to natural gas use. It is true that Vietnam is—albeit slowly—moving away from coal and is planning to increase the use of renewable energy in its power grid [74], but a key goal of development assistance to the country (and indeed more widely), including by Japan as the main external advocate of the project, should be to assist in making this transition as quickly and affordably as possible if the NSER project is to be environmentally sustainable in the long term. Indeed, Japan has
been heavily criticized in recent years for continuing coal financing, both academically with one study finding that more than 80% of Japanese energy capacity projects were fossil fuel based and fewer than 10% were based on renewable energy sources [75], and by environmental NGOs and civil society groups [76]. It is encouraging that the Suga administration did pledge to end overseas coal financing in 2021 [77], and Japan’s aid programs can be a major contributor to energy transition financing in Southeast Asia and Vietnam—a policy which will ultimately have significant benefits for the NSER’s environmental performance as well as for climate change mitigation more broadly. While this far from a unique policy suggestion, considering that across the globe more than 80% of energy production is still fossil fuel-based and that roughly one third of this comes from coal [78], financing transitions either completely away from fossil fuels where possible or at the very least towards cleaner sources such as natural gas is an urgent and critical requirement in development assistance policy going forward, regardless of which countries are the recipients and which are the donors.

This is a hidden factor and an equity issue with very real consequences for Vietnam if left unaddressed—the country is among the most vulnerable to climate change, facing numerous challenges such as coastal flooding and increasing incidences of extreme weather among others [79]. Mitigation of these consequences could be achieved by reducing carbon emissions to the greatest degree possible—the hidden factors of which should be considered by all “green” technologies which rely on national power grids with coal including HSR projects. This also again underscores the importance of conducting a thorough and comprehensive life-cycle impact assessment in line with those carried out by Yue et al. and Chang et al. [18,20]—there are likely to be carbon impacts left unaddressed within the limited scope of this study, but these must be accounted for if the NSER project is to achieve its full environmental potential in line with the suggestions laid out in Section 4.1 on both conducting a thorough environmental analysis using overseas expertise where necessary and also for capacity building projects from donor countries to improve the quality of future environmental impact assessments. This is true of not just the Japan–Vietnam relationship and the NSER, but more broadly to mitigate the impacts of climate change when assessing the potential pitfalls of major infrastructure projects.

4.3. Passenger Load, Per-Seat Emissions and Income Inequality

The results of this study, while confirming the efficiency advantages of the train in per-seat terms, also confirm the need to fill those seats for the performance of the train to be favorable to the plane in relative emissions terms. While having slightly fewer than 40% of the seats occupied at any given time is ostensibly not a particularly high threshold compared to the JICA estimate of an average 70% load rate, there are several reasons to doubt this figure which are insufficiently addressed in the feasibility study or by the political actors involved.

The first issue—and perhaps the most important “hidden factor” in the NSER project is Vietnam’s entrenched inequalities, which see Hanoi and Ho Chi Minh City as having by some margin the most economic activity and the highest incomes—180 of Vietnam’s 335 industrial zones are in these two regions, and in extreme cases incomes are double those of Vietnam’s rural provinces [34]. While growth can, of course, be expected to continue in rural Vietnam, it is questionable whether the middle portions of the line will reach this 70 per cent threshold. Indeed, Kikuchi and Nakamura’s study predicts that the majority of passenger traffic will be on the Hanoi–Vinh and Ho Chi Minh City–Nha Trang sections [8], which are at the peripheries of the proposed line with a large stretch in the middle portion ending up underused. This appears to be largely supported by the gathered data—the market size in the middle provinces along the line, per Tables 2 and 3, is simply much smaller, and so it can be expected that ridership rates will be considerably smaller. In this sense, the inequality in Vietnam is likely to have a direct negative impact on the relative environmental performance of the NSER. While it is impossible to predict consumer behavior or future trends with perfect accuracy, the simple fact of the matter
is that most of the stations on the railway line will be in provinces with fewer people who each have less money than the larger, wealthier populations of Hanoi and Ho Chi Minh City. This is, of course, true to some degree in many HSR projects or operating lines, but Vietnam is a standout case. While Vietnam does not have an especially high GINI score—indeed, of the 34 countries listed by the International Union of Railways as having operational, under construction or approved HSR projects [80], 11 are in countries with higher GINI scores (although the World Bank GINI Index excludes Saudi Arabia [17]. However, of these 11, only one—Morocco—also has a lower Human Development Index score (India is tied with Vietnam on GINI score but also has a lower HDI score) and only two, Morocco and India, have lower GNI per capita scores [81]. This places Vietnam’s HSR in a difficult position—Vietnam not only has pervasive inequality, but it also has a relatively low level of baseline personal income, and these factors in conjunction are a relatively unique phenomenon when assessing the viability of a major HSR project. This severely calls into question the JICA assumption that the passenger load rate will stay constant through the entire length of the line—Vietnam’s regional inequality will be high among HSR-possessing countries, and the gaps in both population and income combined with the low average across the country mean that the market may be limited for the stations in the middle portions of the line—an equity issue with consequences for the project’s sustainability.

Another potential complication is Vietnam’s growing LCC market—round-trip plane tickets between Hanoi and Ho Chi Minh City can fall as low as USD 78 at certain points in the year, making flying potentially cheaper than even a one-way HSR journey, and even in peak travel seasons such as Tet the price difference between the HSR and air does not reach the same level of difference as in Japan, with journeys available from around USD 241 USD which are still faster than the NSER [82]. While the Vietnamese government has indicated that NSER tickets will cost USD 50–90 per one-way journey targeting an average of half the cost of a plane journey [1], this target does not seem to account for the LCC market and so it may create an over-estimate of passenger demand. For end-to-end Hanoi-Ho Chi Minh City journeys specifically, Kikuchi and Nakamura [8] predict a less than 10 per cent market share for the railway based on data from the European and Japanese HSR markets. Indeed data provided by JR ostensibly confirms the estimates in the study; with journeys between Tokyo and Hakata, a journey slightly shorter in terms of distance at 1174.9 km and with a similar travel time to the projected NSER at roughly five hours having a 10 per cent market share compared to the 90 per cent market share of airlines [83,84]. The study does not account for the potential impact of ticket prices, but for the sake of comparison, a one-way Tokyo-Hakata journey costs approximately USD 213 (23,390 Japanese yen at an exchange rate of 1 yen = USD 0.00909634 (exchange rate on 9 July 2021)), while Japan’s highly-developed low-cost carrier (LCC) airline market (via Google Flights data) means that a plane journey averages between USD 100 and 135 for a return journey, making a return journey by plane approximately ⅓ of the price of the Shinkansen even when booked only one day in advance [84,85]. This calculation is somewhat limited—the relative costs of taking a journey in a developed country are quite different to those in a developing country, and the study itself largely focuses on journey length rather than costs. The issue here is the expected growth in the LCC and wider aviation market—and this will not only apply to end-to-end journeys but also for journeys to the intermediate stations on the route. The aviation market in Vietnam is already highly competitive and the competition is only growing [31]—these market factors do not bode well for the relative price competitiveness of the train and by extension the number of travelers who will choose to use it, especially considering the Japanese experience, the smaller potential market size, and the reduced personal incomes available in the middle sections of the line.

In the present literature, the Avogadro et al. [14] study presents an interesting point of comparison. In the European context, they consider the potential emissions savings in relation to HSR as an alternative for flying, and as noted they ultimately conclude that significant emissions savings can be achieved where HSR alternatives are available while
noting the impacts on regional accessibility where flying is removed as an option and the uneven impacts per member state, noting the need for policymakers to balance between environmental and passenger needs [14]. While the first issue is arguably not applicable to the NSER—indeed, the NSER is likely to boost connectivity to Vietnam’s central provinces—the cost issue will arguably be much more acute. Within western Europe, countries with HSR have a considerably higher baseline income level—for instance, Italy, which has a slightly higher GINI than Vietnam [17] also has an average personal income of EUR 30,804 in its poorest NUTS 1 statistical gathering region of Sud (Southern Italy, or ITF in the Eurostat database) [86]. This is, of course, considerably higher than anywhere in Vietnam but especially Vietnam’s middle provinces. Because of this, cost is considerably more likely to be a factor in passenger choice, and if the LCC market continues to be cheaper and faster for most journeys then the seat fill-rate required to achieve better results than the plane will be difficult to reach. As noted in the results section, the literature was unanimous in noting the need reach as high a seat fill rate as possible to ensure the maximum potential of the NSER is reached in environmental terms. Indeed, more widely with the growth of LCCs worldwide, it will be an increasing problem for HSR to capture passenger share, especially in markets with low base levels of income where cost will be a more significant factor.

The factors outlined above cast significant doubt on the ability of the train to attract a 70% passenger load rate across all sections of the line—indeed, if, per Kikuchi and Nakamura’s [8] prediction, fewer than 10% of all one-way, full-length journeys end up being made by train, the economic cores and largest markets of the line are at the termini in Hanoi and Ho Chi Minh City, and low-cost flights are becoming increasingly prevalent across the country, then whether even a 40% load rate can be averaged is questionable. This is perhaps due to the JICA study’s estimate being based on data which pre-date the spread of low-cost flights in Vietnam. This has the effect of dramatically increasing the relative costs of running the NSER. With the fixed costs remaining the same, the per-capita emissions rise as the numbers of passengers decrease—and Vietnam’s energy mix means that the threshold for per-capita efficiency over an equivalent plane journey may be relatively high. Even without the comparison to the plane, the NSER project would have considerably more environmental viability if coal were to be reduced in the energy mix. Future research which focuses on how Vietnam can incentivize rail travel over air travel, and research on market demand between different sections of the line conducted in more detail so that operators could make informed decisions about service provision and train size, would be of benefit here. As things stand, the project’s environmental benefits remain questionable with the various factors which will curb passenger demand and by extension relative environmental performance. This is very clear evidence of how inequality and inequity can impact relative environmental performance which act in conjunction with the high fixed costs of running the line on a largely coal-driven power grid, and these factors should be considered when planning HSR infrastructure more widely. While Vietnam has a particularly high level of inequality among HSR-possessing countries, and it has a particularly competitive LCC market, these factors are likely to be applicable in any kind of HSR planning, and so should be taken into account in policymaking more broadly.

This leads to several policy implications. In the immediate term, a problem specific to the NSER is the lack of an up-to-date, forward-looking and comprehensive demand and market analysis, and this should be carried out with the inequality issue in mind. The market size analysis carried out in this paper is based solely on statistics rather than qualitative data, and will naturally be limited because the figures utilized pre-date the pandemic—a future analysis should consider both the LCC market and potential pandemic-induced changes to the general business environment (for instance, the potential for reduced business demand with the prevalence of online meetings), which would present a much more accurate view of passenger demand along the NSER route. Consideration of these factors should be included in analysis of future HSR projects more broadly—policymakers often consider HSR to be an alternative to air travel and a more sustainable mode of transport, as stated in the Avogadro et al. and Chang et al. studies [14,18] but if
the minimum threshold of seat fill rate cannot be achieved, then all the HSR does is create an additional energy and environmental burden by ‘running empty’ while plane demand continues unabated.

Second, to combat low passenger demand in off-peak times and areas, consideration should be given to the introduction of data-driven floating fares and airline-style ticketing (instead of fixed-price ticketing), which is also recommended by the Chang et al. study [18]. This may allow for the subsidization of lower-demand sections and travel times and encourage the use of trains in off-peak hours and regions with less demand to enable higher fill rates across the line more generally. Several studies confirm the efficacy of this method—a study by Jiang et al. [87] modeled a 13.48% revenue increase as a result of a floating fare mechanism on the Beijing–Shanghai HSR, and another study by Qin et al. [88] predicted a 7.98% (peak time) to 10.41% (off-peak) revenue increase and a sustained increase in the passenger load rate in off-peak times. A floating fare system would therefore boost both the environmental and the economic prospects of the railway by more accurately reflecting passenger demand. This demand data will also benefit operational planning, and based on it consideration should be given to operating shorter trainsets, reducing service numbers, and only running on certain sections of the line where demand is lower to minimize the energy needed to operate the line.

Third, when planning operational mechanisms for the HSR such as ticket sales and interior and station design, significant attention should be given to ease of use and passenger comfort in order to increase the market share captured from the wealthier, larger markets in Ho Chi Minh City and Hanoi. There is a general view in the literature that HSR is more comfortable and generally has higher service quality than air travel, with some studies citing convenience as an additional advantage depending on the context [5,89–92] and this is backed by several passenger surveys in both Europe and Asia with the study by Pagliara et al. [5] of the Spanish HSR having found that comfort was considered the most important factor by 8.5% of respondents, the second most important by 23.1% of respondents, and the third most important by 32.2% of respondents. Additionally, convenience-related factors such as speed and accessibility to other cities ranked highly in their study [5], and they make the interesting point in a different paper focusing specifically on the Madrid–Barcelona HSR that HSR offers an additional advantage of more easily facilitating en-route work among business travelers due to more availability of seat space, internet access, and the ability to use a cellphone [90]. The study by Zhen et al. [92] likewise considers the possibility of mobile working as a potential means to give HSR a competitive edge against air travel. Accordingly, the design of the Vietnamese HSR should lean into these perceived advantages as laid out by Pagliara et al. and Zhen et al. [90,92]—the travel time issue would be significantly mitigated among business travelers if the travel time itself could be used efficiently, for instance with free internet access and with adequate availability of power sockets for laptops and cellphones. These are factors on which air travel—and especially services offered by LCCs—will not be able to compete effectively, and so it is likely that by offering a significantly differentiated business model focusing on passenger convenience and service that passenger numbers would increase, both in the leisure and business markets. This would allow for the transformation of a transaction cost into a potential unique selling point, and if this could be used as a means to increase ridership then it would have the beneficial effect on the per capita CO₂ emissions of the NSER.

This is linked to the broader issue of sludge and transaction costs. Since convenience appears to be such an important factor in HSR success, per the Pagliara et al., Zhen et al. and Jeng and Su, studies [89,90,92], consideration should be given to reduce the impacts of sludging (such as inconvenient form-filling requirements, hidden fees and inconvenient refund conditions as defined in Shahab and Lades’ study [93]) on the HSR to the greatest degree possible. Numerous studies again confirm the value of ease of use in booking systems (especially e-tourism systems) and this is again an area where HSR has significant potential to outperform aviation. For instance, a study by Jeng [94] finds that perceived ease of use is the single highest influence on whether or not users choose e-tourism
services, while a study by Li et al. [95] finds that complementarity with other sales channels, another convenience-based factor, is important in influencing choices in the economy hotels sector in China. These studies effectively demonstrate the power of reducing transaction costs and sludge—customers gravitate to easy-to-use options. The basic design of all operational systems related to the NSER being as frictionless as possible—for instance with a modern, secure and well-designed smartphone app and website, automatic refund systems (especially in a more financially-sensitive market such as Vietnam) in the event of delays, easy and secure logins for repeat users, and so on to foster a reputation of convenience and ease-of-use for the NSER is likely to increase ridership and capture market share by differentiating the HSR as the “convenient option” over air travel—this may go some way toward mitigating the ostensible speed advantage of the plane. Further consideration on this topic of how to reduce the transaction costs on the railway would be a useful area for future research, but more broadly, de-sludging and reducing transaction costs for HSR users is likely to increase ridership and bring down the per-capita CO$_2$ emissions of HSR systems—especially if people can be tempted away from aviation in the process. This is perhaps another opportunity for development assistance donor countries to introduce capacity building and technical cooperation programs to assist in website and application design as well as customer service provision.

5. Conclusions and Policy Recommendations

The environmental performance of HSR is contingent on both fixed and relative costs. The fixed costs of the NSER—the construction steel and the emissions per journey—have a direct bearing on the relative costs, with significant thresholds needing to be met in terms of passenger load for the project to be environmentally sustainable because of the continuing prevalence of coal in Vietnam’s energy mix.

While the fixed cost of the steel was not projected to be as high as expected in the hypothesis, there are still three key policy recommendations relating to construction costs in CO$_2$ emissions. The first is to make as much use of EAF and interstitial free steel where possible—these are much less carbon-intensive than traditional blast furnace steel, and sourcing from these processes will greatly reduce the carbon footprint of the railway. Second, there is a pressing need for a full life-cycle environmental impact assessment on the NSER, in line with the analyses carried out by Chang et al. and Yue et al. [18,20] on the Chinese HSR systems. Such an assessment, backed by expertise from development assistance donor countries such as Japan as well as relevant private sector partners, would allow for significantly more informed policy through the planning and construction stages and would be likely to identify means to reduce carbon footprint where possible. The third suggestion is for development assistance donor countries to provide capacity building programs and technical cooperation to boost environmental impact assessment capabilities in recipient countries—again, this will permit the formulation of policy based on more informative and comprehensive data.

Significant hidden costs emerge from the contribution of coal to the overall energy mix—even if the trains are modern, efficient electric trains, which they will be if E5-series Shinkansen are ultimately used, they will still be indirectly powered by coal from thermal power plants in the Vietnamese context, and this issue must be mitigated to the greatest degree possible if the chances are to be maximized of the train being environmentally beneficial. This leads to two primary policy recommendations. The first is that Vietnam must urgently reduce fossil fuel use, and especially coal use, in its energy mix, and the second is that development assistance donor countries must urgently support this transition with effective financing and technology transfer programs. The fact that in most circumstances the train would emit more CO$_2$ via indirect energy use than an A321 aircraft is of great concern, and this severely calls into question the environmental benefits of the NSER. This again also underscores the importance of a full life-cycle environmental impact assessment which takes these issues into account in order to allow for informed policy decisions to be made.
On the issue of ridership rates, this paper has severely called into question the possibility of achieving either the 70% JICA-predicted average passenger load rate or the roughly 40% passenger load rate required to exceed the A321 in per capita CO\textsubscript{2} emissions. The fact that when considering both incomes and population size the market size most of the stations in the middle portions of the line will be less than one tenth of the size of Hanoi and Ho Chi Minh City is of grave concern, and this combined with the prevalence of low-cost airlines and potential fares and travel time mean that this passenger load rate will be difficult to achieve. As noted above, if the NSER does not capture sufficient market share to hit the required passenger load rate, then all it will do is create an additional environmental burden on top of that given by the aviation industry. Accordingly, four policy recommendations are given. First, an up-to-date and comprehensive market and demand analysis should be carried out to accurately determine the likelihood of reaching the required rate of ridership. This will have the beneficial secondary effect of allowing for informed policy decisions to be made on train sizes and service frequency. Second, in line with the policy recommendations of Jiang et al., Qin et al. and Chang et al. [18,87,88], the railway should implement a floating fare mechanism to incentivize travel in off-peak hours and in low-demand areas, which would have the beneficial side-effect of increasing revenue by more accurately meeting market demands [87,88]. Third, significant attention should be given to passenger comfort and service quality as a unique selling point for the NSER—differentiating based on these factors would make the NSER a genuine alternative to aviation by permitting work and other activities during the journey itself [90,92], potentially allowing it to capture both more business and leisure market share. Fourth, attention should be given to de-sludging and reducing transaction costs by ensuring that the NSER is as easy to use and as convenient as possible through the optimal design of ticketing systems, refund systems and websites. The latter two are linked—essentially, they suggest that the NSER should lean into the perceived strengths of HSR over aviation to create a genuinely differentiated market contender, increasing end-to-end users in Hanoi and Ho Chi Minh City. This could be supported by development assistance donor countries through technical cooperation programs focusing on website and app design as well as service provision.

The hidden factors discussed in this paper—the energy mix and the level of income inequality—severely curtail the train’s potential to either succeed in its own right or capture aviation market share as things stand currently. The prevalence of coal in the energy mix means that the required passenger load rate is relatively high. In essence, the solutions outlined above to address this issue are to bring down the levels of CO\textsubscript{2}-generating power sources in the energy mix (reducing the number of passengers required for the train to be better than an equivalent flight), to take measures to ensure that the train operates as efficiently as possible, and to incentivize train use over flying. This should be additional to efforts to grow the economies of the middle provinces in Vietnam—ultimately their economic growth will be key to the relative environmental performance of the NSER.

Ultimately, what this means is that holistic, “big-picture” solutions are necessary when planning large-scale infrastructure projects. This paper has provided clear evidence that there is a link between environmental performance and equality—the train will have an incrementally better relative emissions performance with every additional passenger on board, but the key to this is encouraging equitable economic growth to ensure that those in the middle portion of the line can maximize their use of the railway, because while the policy suggestions given above will help the NSER in its own right, they will ultimately not address this underlying issue. The greater the economic growth in the middle portions of the line, the greater the number of potential passengers can be attracted to it over potentially cheaper LCCs and by extension, the lower the relative costs of travel by HSR. This is not meant to contradict the results of the JICA feasibility study—rather, the intention of this paper is to be complementary to the study by drawing attention to hidden environmental factors and thereby increase the robustness of the results. Indeed, the lessons from this paper have significant wider implications for HSR planning, and
future research would benefit HSR development by drawing attention to further hidden factors which can be taken into consideration for future projects.

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**Appendix A**

| Station Name | Province | Population Size | Population Growth Rate | Population Size (2030 est.) | Working Age Population % | Working Age Pop. (2030 est.) | Provincial Per Capita Income (2018) | National Growth Rate (2018) | Regional Growth Rate (2018) |
|--------------|----------|-----------------|------------------------|-----------------------------|---------------------------|-------------------------------|-------------------------------|-----------------------------|-----------------------------|
| Ngoc Hoi     | Hanoi, Vietnam | 8,093,900.00 | 2.23%                  | 10,546,252.47               | 71.70%                     | 7,561,663.02                 | 6,054.00                     | 7.08%                       | 7.37%                       |
| Phu Ly       | Ha Nam, Vietnam | 854,500.00  | 0.88%                  | 949,233.27                  | 71.70%                     | 680,600.25                   | 3,608.00                     | 7.08%                       | 11.52%                      |
| Nam Dinh     | Nam Dinh, Vietnam | 1,780,900.00 | −0.22%                 | 1,734,448.98                | 71.70%                     | 1,243,599.92                 | 3,383.00                     | 7.08%                       | 8.10%                       |
| Ninh Binh    | Ninh Binh, Vietnam | 984,500.00  | 0.96%                  | 1,104,098.51                | 71.70%                     | 791,638.63                   | 3,777.00                     | 7.08%                       | 9.27%                       |
| Thanh Hoa    | Thanh Hoa, Vietnam | 3,645,800.00 | 0.77%                  | 3,997,311.04                | 71.70%                     | 2,866,072.02                 | 3,014.00                     | 7.08%                       | 14.07%                      |
| Vinh         | Nghe An, Vietnam | 3,337,200.00 | 1.38%                  | 3,933,776.46                | 71.70%                     | 2,820,517.72                 | 2,542.00                     | 7.08%                       | 8.77%                       |
| Ha Tinh      | Ha Tinh, Vietnam | 1,290,300.00 | 0.49%                  | 1,368,248.09                | 71.70%                     | 981,033.88                   | 2,844.00                     | 7.08%                       | 9.01%                       |
| Vung Ang     | Ha Tinh, Vietnam | 1,290,300.00 | 0.49%                  | 1,368,248.09                | 71.70%                     | 981,033.88                   | 2,844.00                     | 7.08%                       | 9.01%                       |
| Dong Hoi     | Quang Binh, Vietnam | 896,600.00  | 0.61%                  | 964,478.44                  | 71.70%                     | 691,531.04                   | 2,666.00                     | 7.08%                       | 7.03%                       |
| Dong Ha      | Quang Tri, Vietnam | 633,400.00  | 0.70%                  | 688,702.57                  | 71.70%                     | 493,799.75                   | 2,542.00                     | 7.08%                       | 7.12%                       |
| Hue          | Thua Thien-Hue, Vietnam | 1,129,500.00 | 0.19%                  | 1,155,523.43                | 71.70%                     | 828,510.30                   | 3,084.00                     | 7.08%                       | 7.15%                       |
| Da Nang      | Da Nang, Vietnam | 1,141,100.00 | 1.51%                  | 1,365,933.76                | 71.70%                     | 979,374.51                   | 5,506.00                     | 7.08%                       | 7.86%                       |
| Tam Ky       | Quang Nam, Vietnam | 1,497,500.00 | 0.50%                  | 1,589,862.52                | 71.70%                     | 1,139,931.43                 | 2,905.00                     | 7.08%                       | 8.11%                       |
| Quang Ngai   | Quang Ngai, Vietnam | 1,231,900.00 | 0.13%                  | 1,251,255.64                | 71.70%                     | 897,150.30                   | 2,899.00                     | 7.08%                       | 9.60%                       |
| Phu My       | Binh Dinh, Vietnam | 1,487,800.00 | 0.00%                  | 1,487,800.00                | 71.70%                     | 1,066,752.60                 | 3,024.00                     | 7.08%                       | 7.32%                       |
| Dieu Tri (Qui Nhon) | Binh Dinh, Vietnam | 1,487,800.00 | 0.00%                  | 1,487,800.00                | 71.70%                     | 1,066,752.60                 | 3,024.00                     | 7.08%                       | 7.32%                       |
| Tuy Hoa      | Phu Yen, Vietnam | 873,200.00   | 0.17%                  | 891,180.78                  | 71.70%                     | 638,976.62                   | 2,837.00                     | 7.08%                       | 8.21%                       |
| Nha Trang    | Khanh Hoa, Vietnam | 1,232,800.00 | 0.67%                  | 1,335,652.40                | 71.70%                     | 957,662.77                   | 3,455.00                     | 7.08%                       | 7.36%                       |
| Thap Cham    | Ninh Thuan, Vietnam | 591,000.00  | 0.60%                  | 634,984.68                  | 71.70%                     | 455,284.02                   | 2,631.00                     | 7.08%                       | 10.25%                      |
Appendix A: Dataset used for estimates in Tables 2 and 3 [33–54], including population size by province, population growth rate by province, national working age population percentage, actual working age population based on this percentage, per-capita income by province, GRDP growth rate by province and national growth rate.

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