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Brace for Impact: The Environmental and Economic Effects of Shifting Passenger Travel from Airplanes to High-Speed Rail

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Brace for Impact: The Environmental and Economic Effects of Shifting Passenger Travel from Airplanes to High-Speed Rail

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January 2022

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16. Abstract

This research synthesis surveys recent literature from 2011 to 2020 on the environmental and economic effects of high-speed rail (HSR) projects from across the globe, with relevant lessons for implementation of the California High-Speed Rail (CAHSR) project. Recent literature shows that—under the right conditions—HSR can lead to both environmental and economic gains across a variety of metrics. To maximize environmental gains, HSR ridership needs to be high, energy propulsion must be powered largely by renewables, and displaced demand for intrastate air travel must not be replaced by longer haul flights. For there to be economic gains, cities connected by HSR must play complementary roles, rather than competitive ones, within the economy. Otherwise, economic benefits will be consolidated in core cities along HSR routes at the expense of intermediate cities, and efficiencies from agglomeration may lead to an overall decline in employment and economic value added. This synthesis closes with some recommendations for future research questions that can inform the development or refinement of polices that support the successful implementation of CAHSR.

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Disclaimer

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Executive Summary

The Environmental and Economic Effects of Shifting Passenger Travel from Airplanes to High-Speed Rail

Executive Summary

Aviation is the most greenhouse gas (GHG) intensive mode of transport (per passenger trip) for intercity travel in California. Yet, there is no clear pathway for decarbonizing this sector. In the meantime, reducing GHG emissions from aviation requires shifting trips from the air to less GHG intensive modes of transportation. The California High-Speed Rail (CAHSR) project can serve this function, but funding for the full route of the Phase 1 segment—spanning from Southern California to the San Francisco Bay Area—remains unallocated. In light of CAHSR's precarious funding status, more information is needed about the benefits of the proposed rail network, especially in the wake of the COVID-19 pandemic, which has exacerbated uncertainty around future travel demand.

This report seeks to inform policy and planning around the continued implementation of the CAHSR project by synthesizing the literature on the environmental and economic impacts of high-speed rail (HSR) projects from around the globe, and the conditions under which HSR leads to net benefits. The literature on the various impacts of HSR is vast, so this report privileges literature that was published over the last decade (from 2011 to 2020). Moreover, the focus of the report is on passenger transport (rather than freight transport). The report is structured according to the most common metrics for analyzing the impacts of HSR. For environmental impacts, those include GHG reductions, local air pollution, and noise. For economic impacts, those include value added, employment, societal cost savings, and economic integration. **Table ES1** summarizes the trends across the literature according to the aforementioned metrics.

Table ES1. Summary of Literature from 2011 to 2020 on the Impacts of HSR

Impact Domain	Metric	Number of Studies That Measure HSR's Impact	Number of Studies Showing Potential Benefit from HSR	Dominant Trend	Strength of Evidence Base*
Environmental	GHG Reductions	12	11	Positive	Robust
	Local Air Pollution Reductions	2	2	Positive	Limited
	Noise Reductions	7	6	Positive	Fair
Economic	Value Added†	15	12	Positive	Robust
	Employment	3	3	Positive	Limited
	Property Values	9	7	Positive	Fair
	Societal Cost Savings	9	8	Positive	Fair
	Economic Integration‡	4	2	Split	Limited

*Qualitative assessment based on the number total number of studies documenting the impact of HSR.
†Refers to wealth generation for a particular region, usually measured through gross domestic product (GDP).
‡Refers to reduced disparities between regions connected by HSR.

Based on the literature surveyed, it is clear that HSR can lead to measurable environmental and economic benefits. However, these benefits are certainly not guaranteed. For every environmental and economic indicator discussed in this review, there is also evidence that HSR projects can lead to negative impacts. Thus, the benefits of HSR are only realized when certain conditions are met. These conditions include:

- Train propulsion that is powered by an energy mix that is high in renewables and low in fossil fuels;
- High ridership on HSR routes (largely driven by a mode shift away from automobiles and aircrafts);
- Absolute reductions in air travel following the introduction of HSR (such that freed up capacity at airports for short-haul flights isn't used to accommodate longer-haul flights); and
- Cities connected by HSR play complementary roles within the broader economy (such that economic activity isn't consolidated in core cities at the expense of intermediate cities).

Given the mixed effects of HSR on environmental and economic indicators, additional policies may be needed in California to ensure that CAHSR delivers anticipated benefits, and equitably so. To inform the development of new polices (or refinement of existing ones), this report closes with some recommendations for future research. **Table ES2** provides a summary of research questions as they relate to broader policy objectives.

Table ES2. Recommended Questions to Guide Future Research (By Policy Objective)

Policy Objective	Recommended Questions to Guide Future Research
Maximize HSR ridership	What opportunities exist to reduce door-to-door travel time on HSR?
	How can carbon pricing instruments widen the cost differential between air and rail?
Maximize environmental benefits from HSR	What policy tools exist to ensure absolute reductions in air travel?
	What opportunities exist to reduce GHG emissions from HSR construction?
	What opportunities exist to decarbonize transport to and from HSR stations?
	What investments are needed to curtail noise pollution from HSR?
Maximize economic benefits from HSR	How can complementarities between HSR cities be strengthened?
	How can the goods movement sector benefit from HSR?
	What has been the effect of land value capture models in other settings?
Maximize equity benefits from HSR	Where are air quality impacts from HSR most likely to occur?
	What models are there for more equitable pricing of HSR services?
	How can HSR improve accessibility and mobility for low-income users?

1. Introduction

Decarbonizing the aviation sector remains a major challenge in California's larger effort to achieve carbon neutrality by 2045. Air transportation is largely dependent on the burning of fossil fuels. To date, there is only one alternative to jet fuel that is in commercial use (synthetic kerosene produced from vegetable oils and animal fats), and the production of this fuel is greatly constrained by land availability and other sustainability concerns (Bauen et al. 2020). Moreover, there are a number of financial hurdles that must be overcome in order to deploy alternative aviation fuels on a large scale, such as investments in new manufacturing facilitates, reductions in production costs, and considerable spending on quality control measures (Chiaramonti 2019). Meanwhile, as electrification proves to be the dominant pathway towards decarbonizing ground travel, battery powered aircrafts are not technically feasible for commercial air travel, at least with currently available technologies (Barzkar and Ghassemi 2020).

In the context of the broader economy, the aviation sector is a relatively minor source of California's total greenhouse gas (GHG) emissions, accounting for about 1% of the state's total GHG footprint (CARB 2021a). However, emissions from this sector are growing. For the ten-year period preceding the onset of the COVID-19 pandemic (2010 through 2019), GHG emissions from the aviation sector grew by 14% (CARB 2021b). The COVID-19 pandemic has certainly depressed air travel (Sun et al. 2021), but it could take as little as 2.4 years for passenger demand to return to pre-pandemic levels (Gudmundsson et al. 2021). As of May 2021, monthly revenue passenger-miles for United States carriers were already at 75% of their volume two years prior (BTS 2021). Unless urgent action is taken to chart a path towards decarbonizing the aviation sector, California and other regions could be locked into a medium- and long-distance transportation mode that poses a major liability to climate stabilization by mid-century.

While policymakers and planners wait for breakthroughs in carbon-free fueling technologies for air travel, GHG emission reductions can be realized in the aviation sector through a shift to less-polluting ground transportation, where feasible. California's effort to build a high-speed rail network for intrastate travel is an example of such a strategy and is featured prominently in the state's 2017 Climate Change Scoping Plan as one of multiple pathways towards meeting the 2030 target of a 40 percent reduction in GHG emissions below 1990 levels (CARB 2017). However, funding for the entire California High-Speed Rail (CAHSR) system—spanning from Southern California to the San Francisco Bay Area—remains unallocated (CAHSRA 2021), thereby undermining the full potential of GHG emission reductions from the project.

In light of CAHSR's precarious funding status, more information is needed about the benefits of the proposed rail network, especially in the wake of the COVID-19 pandemic. The immediate shift to remote work for many professions has demonstrated the viability of virtual platforms to serve as substitutes for in-person meetings. While our understanding of the long-term impacts of telecommuting on business travel is still limited, interviews with airline industry experts have revealed that even a small decline in ridership among business travelers would be a serious threat to the aviation sector, as business travelers typically generate high trip yields. Such a threat does not bode well for the potential GHG reduction benefits of CAHSR, which are partially achieved by diverting business travelers from air to trail. On the other hand, some research has shown that teleworking may lead to a rebound effect in which teleworkers end up flying more due to suppressed travel demand in their daily lives (Hook et al. 2020). Such a scenario would further legitimize the need for HSR as a GHG reduction strategy.

Given the uncertainties around future travel behavior, this report assesses the conditions under which HSR systems still offer a societal win-win alternative to flying, in both environmental and economic terms. The report focuses on passenger travel, the largest single source of GHG emissions in California (CARB 2021a). The report is also constrained to the last ten years of literature, spanning from 2011 to 2020, a period that begins the year after Deakin (2010) and Murakami and Cervero (2010) published seminal papers on the environmental and economic benefits of CAHSR as part of a two-day symposium on the topic. Like these two symposium papers, this report draws upon literature from around the globe to highlight lessons learned in countries where HSR networks are more advanced in their development and operation.

2. Methods

This synthesis is informed by academic and nonacademic literature that assesses the environmental and economic impacts of high-speed rail (HSR) relative to the aviation sector. The synthesis was motivated by the need to better understand the conditions under which the California High-Speed Rail (CAHSR) project will likely lead to net benefits. Studies from across the global were included in the synthesis because the CAHSR project has yet to be fully implemented. Thus, empirical evidence on the impacts of HSR had to be collected from regions beyond California.

2.1 Search Strategies

Multiple search strategies were used to capture as much relevant literature as possible. These strategies included: keyword search, snowballing, citation mining, and author tracking (see definitions below). These search strategies were used iteratively, rather than sequentially.

Keyword Search

This synthesis relied on the Web of Science as the primary search engine for academic literature and Google for nonacademic literature ("grey literature"). **Table 1** provides a list of the keywords that were searched in combination with "High-Speed Rail". HSR was privileged as the primary search term over aviation because most studies on HSR already assume that riders are diverted from airplanes, so impacts to the aviation sector are often embedded within studies on HSR.

Table 1. Keywords Searched in Combination with "High-Speed Rail"

Environmental Keywords	Economic Keywords
Greenhouse	Economic
Pollution	Employment
Noise	Housing
Sprawl	Cost-Benefit
	Equity

Snowballing

Snowballing is a search method in which the researcher looks up the citations within a study in order to identify additional literature that could be relevant to the question at hand. Snowballing was only used here for citations that clearly related to the environmental or economic impacts of HSR or aviation.

Citation Mining

Citation mining is a term used here to describe the process of looking up studies that have cited a paper or report of interest. In essence, citation mining is the temporal reverse of snowballing. All citation mining was conducted through the Web of Science.

Author Tracking

Lastly, when an author had published at least two relevant studies, the author’s curriculum vitae was located and their full list of publications were reviewed for relevance. Only primary authors were used as a basis for this particular research method.

2.2 Exclusion Criteria

The literature on HSR is vast. For example, searching the terms “high-speed rail” and “economic development” on Web of Science yields 328 results through the end of 2020. Thus, some constrains were needed to narrow the results to a more manageable size, as described below.

Publication Date

This research synthesis only looks at studies that were published between 2011 and 2020. This date range was selected for two reasons. First, there were two seminal papers published in 2010 that assessed the environmental and economic benefits of CAHSR (Deakin 2010, Murakami and Cervero 2010). Second, methodological techniques improve with time, so more recent literature was prioritized.

Transportation Sector

Passenger transportation is the focus of this research synthesis. HSR could potentially support freight transportation as well, but examining the impacts of this use case was outside the scope of this study. As a result, studies that focused on the goods movement implications of HSR were excluded from the review process.

Language

Only studies that were available in English were reviewed. If the study was originally published in another language, but an English translation was readily available, then it was still included in the review.

2.3 Synthesizing Process

After applying the search methods and exclusion criteria above, a total of 155 studies were identified as potentially relevant from their abstracts. Relevant studies were then downloaded, reviewed, and coded for the following attributes: author, date, publisher, method, transportation modes documented (e.g., air, HSR, road), impacts assessed, and key findings. After coding the studies, core metrics became apparent: GHG emissions, local air pollution, noise, economic value added, employment, property values, and economic integration. The chapters that follow highlight the studies that provide evidence of the potential benefit (or lack thereof) of HSR towards each metric.

It is important to note that not all 155 studies from the initial search are highlighted or discussed in the chapters that follow. Some studies were omitted from this report because they did not provide primary evidence on the impact of HSR. This was the case for review papers and opinion papers. Additionally, some studies examined trends following the introduction of HSR using descriptive statistics, but did not use evaluative methods (e.g., instrumental variable analysis, difference-in-differences estimation, etc.) to isolate the effect of HSR from other exogenous forces that may also explain those trends. These studies were omitted from the discussion so that their findings were not given equivalent weight to the findings from studies that used more rigorous methods to investigate the causal link between HSR and observed impacts. Thus, the studies highlighted in this report represent the best available evidence on the impacts of HSR, rather than the entire universe of literature that has been published on the topic over the past decade.

3. Environmental Impacts

This section highlights recent literature that compares the environmental impacts of high-speed rail (HSR) to that of aviation along three dimensions: greenhouse gas (GHG) emissions, local air pollution, and noise. These impacts were the most frequently discussed in the literature, as they lend themselves to a common metric that can be compared across transportation modes.

It is important to note that these three dimensions are not exhaustive of the potential environmental harms from HSR and aviation. Sprawl and habitat loss are also key environmental concerns associated with transportation infrastructure, but literature over past the decade has not provided empirical evidence for making claims about whether HSR or aviation more strongly exacerbates these problems. Moreover, it is difficult to attribute whether sprawl and habitat loss are the direct result of transportation infrastructure, or the result of poor land use planning that does not effectively curb sprawl after the introduction of new transportation connections. Regardless, the addition of any new transportation infrastructure (HSR or otherwise) usually involves the taking of land for human activities. In China, for example, at least 0.16 million hectares of arable land were reclaimed for rail development between 2002-2013 (Chen et al. 2016).

Except for studies on noise impacts, the literature on the environmental impacts of HSR is largely ex-ante, meaning that it estimates the anticipated environmental impacts of HSR projects rather than the observed impacts. The literature on GHG reductions and air pollution are commonly ex-ante because the net impacts of HSR on those metrics must be analyzed over the entire operational period of the HSR project, and most HSR have not yet reached the end of their operational period. Therefore, the net impacts on GHG reductions and air pollution must be estimated. Studies on noise impacts, however, typically look at the current impacts of rail infrastructure on human populations according to more acute metrics (e.g., annoyance, sleep disturbance), rather than cumulative health impacts (e.g., cardiovascular disease, etc.), which negates the need for ex-ante modelling.

It is also important to note that much of the literature highlighted in this section speaks to *avoided* environmental harms rather than absolute improvements in environmental conditions. Whether it be GHG emissions, local air pollution, or noise, the tangible environmental benefits of HSR ultimately depend on a decrease in air traffic. If airlines use freed runway capacity to accommodate new flights, then the addition of HSR to a region's transportation network will lead to no environmental benefits (Givoni and Dobruszkes 2013, Socorro and Viecens 2013, D'Alfonso et al. 2015). In Europe, for example, HSR played a significant role in reducing short-haul air travel from 1995 to 2009, but there was still a net gain in air travel across the continent during the same period because low-cost carriers increased medium-haul flights (Clewlow et al. 2014). Given that the international airports in Los Angeles and San Francisco are already so congested that they are at risk of being over-capacity (FAA 2021), any freed runway capacity at these airports is at great risk to be subsumed by more air travel. Thus, additional polices may be needed to constrain the aviation sector to environmentally optimal levels, otherwise the environmental benefits from HSR may only exist in theory, but not in tangible terms.

3.1 Greenhouse Gas Reductions

It is well understood that HSR can be a significantly less greenhouse gas (GHG) intensive travel mode than flying, at least after all necessary infrastructure is built out. **Table 2** provides a summary of recent studies that estimate the GHG emissions of HSR and aviation during the operational phase of each mode's life. Estimates are commonly provided in terms of passenger-kilometers traveled (PKT), which provide a functional unit for comparing GHGs across modes. Based on these selected studies, HSR emits 66 to 97% less GHG emissions per PKT than flying (not including embodied emissions from construction). The GHG reduction benefits of HSR relative to aviation depend on a number assumptions about each travel mode, including underlying fuel sources, fuel efficiency improvements over time, and ridership levels.

The GHG reduction benefits of HSR are generally explained by two factors. First, HSR trains require less energy to propel than passenger aircrafts, at least in terms of PKT (Chester and Horvath 2010, Jehanno et al. 2011, Bueno et al. 2017). This is due to fundamental differences between the travel modes in terms of the energy needed to overcome physical constraints that resist motion, such as friction, aerodynamic drag, and inertia (Todorovich and Burgess 2013). Second, fuel for HSR propulsion (usually electricity) has a significantly lower GHG emissions factor than fuel for aircrafts (usually petroleum), at least when local power grids are not powered by coal. In California, HSR trains will be powered by 100% renewable energy (CAHSRA 2021), thereby eliminating GHG emissions associated with propulsion. In contrast, if an electrical grid were entirely powered by coal, then HSR travel would be more GHG intensive than travel by plane because the GHG emissions factor of coal is 32% greater than that of jet fuel (Burgess 2011).

Along with fuel mix, the GHG reductions benefits of HSR are also highly sensitive to ridership levels. As ridership levels decline, the embodied energy to transport each person increases. In the context of CAHSR, Chester and Horvath (2010) demonstrated that a HSR trip could result in more GHG emissions per PKT than the same trip on an airplane when CASHR ridership is low (10% occupancy) and aircraft ridership is high (100% occupancy), assuming the use of a train that seats 1,200 passengers and an aircraft that seats 120 passengers. In a follow up study, Chester and Horvath (2012) showed that the same outcome holds true when the low ridership scenario is increased to 25% occupancy. It is important to note that these low ridership scenarios are well below what the California High-Speed Rail Authority (CAHSRA) anticipates. In its most recent business plan, CAHSRA assumes a low ridership scenario of 50% for the Silicon Valley to Central Valley Line and 68% for the full Phase 1 Increment (San Francisco to Anaheim) during the inaugural year of each line, with ridership levels reaching 100% by year five (CAHSRA 2021). While these ridership estimates are certainly not guaranteed, they are informed by socioeconomic forecasts and take into account travel costs and service quality for HSR and substitute modes (Cambridge Systematics 2020).

To understand the *net* GHG reduction benefits of HSR, one must also consider the GHG emissions emitted during the construction phase of HSR infrastructure. These activities are energy intensive and result in significant process-related emissions from the production of cement, a material for which lacks any zero-carbon alternatives at commercial scale (Di Filippo et al. 2019). **Table 3** provides a summary of recent studies that assess whether HSR has the potential to lead to net GHG reductions after accounting for emissions during construction. These studies follow the work of Chester and Horvath (2010), in which the authors demonstrated that CAHSR could lead to net GHG reductions after six years of service, assuming high occupancy for HSR and low occupancy for alternative modes (air, automobile, and existing rail). Alternatively, if relative occupancy levels are reversed, the authors found that CASHR may never lead to net GHG reductions. Chang and Kendall (2011) also documented net climate benefits from CAHSR after six years of operations. Meanwhile, Burgess (2011) more conservatively estimated that it would take closer to 15 years for net GHG reductions to occur from HSR operations. As a follow up to their 2010 study, Chester and Horvath (2012) provided a more realistic GHG reduction payback period of 20 to 30 years, an estimate that accounts for emerging automobile and aircraft technologies, train designs, and lower-carbon electricity scenarios. When a zero-carbon electricity scenario was assumed by the authors, the GHG reduction payback period advances to the first few years of HSR operation.

Net GHG reductions from HSR have also been estimated for rail systems outside of California. This is the case for systems that have been either been proposed or built in Australia (Robertson 2016), China (Jehanno et al. 2011), England (Greengauge21 2012, Miyoshi and Givoni 2014), France (Baron et al. 2011, Jehanno et al. 2011, Séguret 2014), northeastern United States (Burgess 2011), Sweden (Akerman 2011), Taiwan (Jehanno et al. 2011), and Europe more broadly (Westin and Kageson 2012). Across the literature, there were only two instances in which HSR systems were not predicted to yield net GHG benefits during their defined operational period: a proposed system in the Basque region of Spain (Bueno et al. 2017) and in the midwestern region of the United States (Burgess 2011). Construction activities for the Basque system were uniquely GHG intensive because of the geography of the region and the system's corresponding design, which involved a high percentage of tunnels (60%) and viaducts (10%). In contrast, the HSR system proposed for the midwestern region of the United States did not have unusually high embodied emissions from construction, but still failed to achieve net GHG reductions during the study period because the electricity mix in the region had a relatively high GHG emissions factor (over twice that of California's emissions factor).

Table 2. Studies from 2011 to 2020 that Provide GHG Estimates for Passenger Trips by Air and HSR*

Source	Region	Route	Aircraft (gCO2e/PKT)	HSR (gCO2e/PKT)	GHG Reduction Benefit
(Prussi et al. 2019)	France	Paris-London	143	18	-87%
		Amsterdam-Frankfurt	116	34	-71%
(Bueno et al. 2017)	Spain	Basque Y	127	32	-75%
(Robertson 2016)	Australia	Sydney-Melbourne	90 to 105[†]	15 to 30[†]	-71 to 83%
(Taptich et al. 2016)	North America	N/A	54 to 110[†]	1 to 29[†]	-74 to 97%
(Koike et al. 2015)	Japan	Tokyo-Nagoya (Maglev)	139	47	-66%
	Taiwan	Taipei-Kaoshiung	274	27	-90%
(Miyoshi and Givoni 2014)	England	London-Manchester	147 to 210	12 to 20	-90 to 92%
(Séguret 2014)	France	Bordeaux-Toulouse	200 to 262[†]	7[†]	-97%
(Borken-Kleefeld et al. 2013)	Germany	N/A	139 to 216	46	-67 to 79%
(Givoni et al. 2012)	Europe	N/A	75 to 110	13 to 16	-83 to 85%
(Greengauge21 2012)	England	West Midlands-London	262	31	-88%
(Westin and Kageson 2012)	Europe	N/A	55 to 71	6 to 23	-68 to 89%
(Akerman 2011)	Sweden	Europabanan	150	8	-95%
(Baron et al. 2011)	France	Marseille-Valence	163	6	-96%
(Ha et al. 2011)	Japan	N/A	113	18[‡]	-84%
(Jehanno et al. 2011)	Europe	N/A	153	17	-89%

*The GHG estimates in this table do not capture embodied GHG emissions from the construction of infrastructure associated with each mode. This literature summary does not include studies that provide graphical representations of GHG emissions from air transport and HSR, but no discrete numbers, such as Burgess (2011), Chester and Horvath (2012), IEA and UIC (2012), Todorovich and Burgess (2013), all of which show lower GHG emissions per PKT for HSR compared to air transport (depending on ridership levels).

[†] Includes embodied GHG emissions from manufacturing/maintenance of vehicles.

[‡] Composite of HSR and conventional rail within a single rail system.

Table 3. Studies from 2011 to 2020 that Assess Net GHGs from HSR*

Source	Region	Route	Operational Period (Years)	Shows Potential Net GHG Reduction from HSR	GHG Reduction Payback Period† (Years)
(Bueno et al. 2017)	Spain	Basque Y	60	No	N/A
(Robertson 2016)	Australia	Sydney-Melbourne	30	Yes	Not Provided
(Miyoshi and Givoni 2014)	England	London-Manchester	40	Yes	Not Provided
(Séguret 2014)	France	Bordeaux-Toulouse	25	Yes	9
(Chester and Horvath 2012)	United States	CAHSR System	20	Yes	20 to 30
(Greengauge21 2012)	England	West Midlands-London	60	Yes	Not Provided
(Westin and Kageson 2012)	Europe	Systemwide	50	Yes	Not Provided
(Akerman 2011)	Sweden	Europabanan	60	Yes	Not Provided
(Baron et al. 2011)	France	Marseille-Valence	100	Yes	5
(Burgess 2011)	United States	CAHSR System	Undefined	Yes	< 15
		Midwest HSR System	Undefined	No	N/A
		Northeast Corridor	Undefined	Yes	< 30
(Chang and Kendall 2011)	Unites States	San Francisco-Anaheim	20	Yes‡	6‡
(Jehanno et al. 2011)	France	Tours-Bordeaux	Undefined	Yes	Not Provided
	France	Valence-Marseille	Undefined	Yes	Not Provided
	Taiwan	Tapei-Kaohsiung	Undefined	Yes	Not Provided
	China	Beijing-Tianjin	Undefined	Yes	Not Provided

*Net impacts were assessed across both construction and operational phases. As a result, this literature summary does not include studies that assess the GHG reduction benefits from HSR during the operations phase but not the construction phase, such as Borken-Kleefeld et al. (2013), Akerman (2012), Clewlow et al. (2012), Givoni et al. (2012), IEA and UIC (2012), Janic (2011), Koike et al. (2015), Krishnan et al. (2015), Prussi et al. (2019); Taptich et al. (2016); and Wang et al. (2019). While Ha et al. (2011) assess embodied emissions from HSR construction, they do so in terms of construction costs (rather than PKT), making it difficult to interpret the authors' conclusions about the net GHG impacts of HSR. This literature summary also excludes studies that look at the GHG reductions of HSR following a mode shift from road to rail (but not from air to rail), such as Andrade and D'Agosto (2016), Chen et al. (2016), Fu et al. (2013), and Mintzia et al. (2018).

†After operation begins.

‡Climate benefits from this study are provided in terms of cumulative radiative forcing rather than GHG emissions.

3.2 Local Air Pollution

Few studies over the past decade have directly compared the impacts of HSR and air travel on local air pollution. **Table 4** highlights the two studies that have done so. Local air pollutants examined in the literature include: carbon monoxide (CO), nitrogen oxides (NOx), nonmethane hydrocarbons (NMHCs), particulate matter (PM), sulfur oxides (SOx), and volatile organic compounds (VOCs). In California, Chester and Horvath (2012) provided results in terms of the final impacts of air pollution on human and environmental health: respiratory disease (mg $PM_{2.5}$eq), acidification (g H+ moles eq), tropospheric ozone formation (Mg O_3 eq), and eutrophication (kg N eq).

Across all metrics studied, the authors demonstrated that HSR could lead to net reductions in air pollution per PKT (even after accounting for air pollution during construction). As with their findings regarding GHG emissions, the authors underscored that net reductions in air pollution were dependent on high ridership levels. When HSR ridership was low, the authors demonstrated the potential for HSR to surpass air travel in terms of negative environmental and human health impacts. These findings are consistent with earlier research that established the air pollution benefits of HSR compared to air travel (Janic 2003, Givoni and Banister 2006, Givoni 2007).

The air quality benefits from HSR are explained by the same factors that lead to GHG reduction benefits: lower energy requirements for propulsion (per PKT) and lower emissions factors associated with those energy requirements. When California’s electricity grid is powered entirely by renewables, Chester and Horvath (2012) found that HSR can virtually eliminate air pollution during the system’s operational life. During the construction phase, however, the authors show that HSR can lead to considerable pollution. The authors attribute the pollution intensity of the construction phase to the production of cement, which usually depends on the combustion of fossil fuels to achieve temperatures that are high enough to transform limestone into lime (Di Filippo et al. 2019). Still, the embodied air pollution from cement production and other construction activities for HSR can be compensated by air pollution reductions achieved during HSR operations, as modeled by Chester and Horvath (2012).

Unlike GHG emissions, air pollution from HSR and aircrafts are locally concentrated, so their effects will not be universally felt across the state. Assuming that CAHSR will be powered by 100 percent renewables (CAHSRA 2021), air pollution impacts from CAHSR will primarily be concentrated near cement production facilities (Chester and Horvath 2012), and impacts from aviation will continue to be concentrated near airports (Hudda et al. 2014). Based on the literature reviewed here, it is unclear how a shift from aviation to HSR in California will affect the incidence rate of negative public health outcomes from air pollution because populations densities around California’s airports and cement production facilities may differ dramatically. However, there are two key differences between the travel modes that do not bode well for populations living near airports. First, pollution from air travel will continue for as long as planes are still powered by fossil fuels, whereas pollution from HSR-induced cemented production will be shorter lived. Second, pollution from airports is also highly sensitive to air traffic delays because of the additional time that aircrafts spend idling on tarmacs (Kamga and Yazici 2014), while CAHSR trains will be zero-emission, thereby negating vehicle emissions altogether.

Table 4. Studies from 2011 to 2020 that Assess Net Air Pollution Impacts from HSR*

Source	Region	Route	Shows Potential Net Air Quality Benefit from HSR	Air Pollutants Assessed
(Chester and Horvath 2012)	United States	CAHSR System	Yes	CO; NOx, PM; SOx; VOCs
(Jehanno et al. 2011)	Germany	Frankfurt-Hamburg	Yes	NMHCs; NOx; PM; SOx;

*Net impacts were assessed across both construction and operational phases.

3.3 Noise

Noise is perhaps the most immediately sensible environmental impact from HSR and air transport. In addition to being an annoyance, noise pollution also has consequences for human health. When severe or persistent enough, noise pollution can cause sleep disorders (Muzet 2007), impair learning (Klatte et al. 2013), and increase risk for cardiovascular disease (van Kempen et al. 2018) and diabetes (Dzhambov 2015). Stress and disturbed sleep are believed to be the causal pathways linking noise pollution to cardiovascular disease and diabetes (Dzhambov 2015, van Kempen et al. 2018).

Recent literature on noise pollution from transportation has not comparatively assessed impacts from HSR with aircrafts. Instead the literature has focused on the differences between conventional rail (that is not high speed) and aircrafts. **Table 5** provides a summary of the studies published between 2011 and 2020 that document the relative noise pollution impacts from conventional rail and aircrafts. For the most part, the highlighted literature shows that noise pollution from trains can be less disruptive than aircrafts, both in terms of annoyance levels and sleep disturbance. A laboratory study by Basner et al. (2011) was the one exception documented in the literature. The authors exposed 72 participants to recordings of different types of traffic noise and found that that noise pollution from rail traffic corresponded to a higher probability of sleep awakenings than air traffic. However, Basner and McGuire (2018) later excluded this laboratory study from their meta-analysis on noise pollution and sleep disturbance because of the low ecological validity of laboratory research for studying the impacts of traffic noise on sleep.

It is difficult to generalize whether any noise reduction benefits of conventional rail would also be true for HSR. Noise tracks positively with speed (Jehanno et al. 2011), so the acoustic effects of HSR on human health and wellbeing would be best assessed at the speeds that HSR trains actually travel. However, if high-speed trains operate at speeds comparable to conventional trains when entering and exiting populated areas, then it is possible that HSR may be even quieter than conventional rail because of reduced noise from engine operations (Deakin 2017). It is also possible that HSR could lead to reduced cumulative noise pollution because of lower service frequency compared to that of airports (Janic 2011). On the other hand, the speed, propulsion technology, and frequency of HSR trains may be entirely moot, as research shows that personal attitudes about noise sources strongly influence overall levels of annoyance (Wothge et al. 2017). In general, people already find aircrafts to be a more disturbing noise source than trains (Sun et al. 2017), so annoyance with HSR noise will likely depend on one’s attitudes about the rail system.

It is important to note that noise pollution can be more easily controlled for HSR compared to aircrafts. Along with adopting slower speeds when entering populated areas, HSR rail can also be enclosed in tunnels, which should absorb the noise from HSR during the stretches for which it is contained (Janic 2011). Additionally, noise barriers (walls) can be set up around aboveground HSR infrastructure. Aircrafts, on the other hand, must operate at high speeds to maintain flight and can not be enclosed in a noise-absorbing structure once airborne. While tunnel and wall building may reduce noise pollution from HSR, these activities require energy and raw materials, and will come at the cost of increased GHG emissions.

Intuitively, the noise impacts of CAHSR on human health will largely depend on the degree to which CAHSR stations are co-located next to housing. While housing is typically an essential element of transit-oriented development, lessons from international HSR systems have shown that station planning is most successful (at least from an economic development perspective) when it prioritizes high-quality public spaces and land uses of regional or statewide importance, such as major offices, hotels, retail stores, entertainment complexes or educational campuses (SPUR 2017). However, Loukaitou-Sideris (2013) cautions planners from adopting a one-size-fit-all approach to station planning, and acknowledges the potential need for affordable workforce housing located near HSR stations in intermediate cities, especially if core cities focus on commercial land uses near HSR stations. Thus, the noise impacts of CAHSR on human health will likely vary by city and the degree to which each city has prioritized housing as a key component of station planning.

Table 5. Studies from 2011 to 2020 that Assess Noise Pollution Impacts from HSR and Air Travel

Source	Region / Country	Subregion	Shows Potential Noise Reduction Benefit from Rail	Health / Wellbeing Metrics Assessed
(Lechner et al. 2019)	Austria	Innsbruk	Yes	Annoyance
(Brink et al. 2019)	Switzerland	N/A	Yes	Sleep disturbance
(Basner and McGuire 2018)	Global	N/A	Yes	Sleep disturbance
(Wothge et al. 2017)	Germany	Rhine-Maine	Yes	Annoyance
(Gille et al. 2016)	France	N/A	Yes	Annoyance
(Perron et al. 2016)	Canada	Montreal	Yes	Sleep disturbance
(Basner et al. 2011)	Germany	N/A	No	Sleep disturbance

4. Economic Impacts

This section synthesizes recent literature on the economic impacts of high-speed rail (HSR) according to the following metrics: value added, employment, property value, societal cost savings, and economic integration. These were the most commonly analyzed metrics in the literature, but certainly do not capture all of the ways in which HSR may transform the economic conditions of a region or its inhabitants. Job quality, for example, is another important metric for understanding the ways in which HSR could impact the welfare of workers, but is rarely analyzed in the literature, at least in any systemic way. This is likely due to the difficulty of obtaining reliable data on job quality, such as starting wages and employer contributions to benefits, which are not recorded in a centralized database at local or national scales. In contrast, the economic metrics highlighted in the section are informed by datasets that are regularly maintained at multiple geographic scales.

Unlike the environmental literature previously discussed, the economic literature on HSR does not commonly compare the effects of HSR alongside those of passenger air travel. The lack of comparative studies may be explained by the challenge of developing a realistic counterfactual for building HSR. Transportation planners and policymakers are not often faced with the choice of investing in either HSR or a comparable network of new airports. Instead, they are more likely to be faced with the choice of whether to invest in HSR or a much boarder set of infrastructure projects (e.g., road repairs, water system upgrades, etc.) or alternative greenhouse gas (GHG) reduction strategies (e.g., incentives for electric vehicles, public transit operations, etc.).

In the absence of a common counterfactual for how to invest HSR funding, the studies reviewed in this section typically employ a “with and without” framework for characterizing the impacts of HSR. This framework involves comparing the economic performance of regions *with* HSR to the performance of similar regions *without* HSR, all while controlling for non-HSR related variables that may also explain economic outcomes (e.g., proximity to conventional rail, highways, airports). Put another way, the studies reviewed in this section assess the economic impacts of HSR relative to a theoretical business-as-usual scenario in which HSR is not built.

Depending on the study, a business-as-usual scenario might mean that intercity trips are instead conducted vis-à-vis airplane, conventional rail, passenger vehicle, or perhaps not at all (this is the case for induced trips). Unfortunately, the effects of HSR on mode choice are not always explicit in the economic literature. Thus, it is difficult to generalize from the studies reviewed here whether the economic effects attributed to HSR reflect a corresponding reduction in air travel. However, most HSR routes across the globe connect cities that host international or regional airports, so some reduction in passenger air travel is likely implicit in the studies highlighted here. Even if that is the case, it is unclear whether a reduction in passenger trips corresponds to an overall reduction in air traffic across studies. As discussed earlier, HSR can lead to a reduction in short-haul flights that then get replaced with more medium- and long-haul flights. In light of these issues, the studies highlighted here are helpful for understanding the economic impacts of introducing HSR into a region, but may not be instructive for understanding the net economic impacts of investing in HSR *and* divesting from aviation.

With the exception of cost-benefit studies, this section reviews ex-post literature that documents observed impacts from HSR. Ex-post studies were privileged over ex-ante studies because they capture the effects of HSR in real world settings rather than the effects of HSR under theoretical conditions. Moreover, ex-post studies capture the totality of HSR’s effects on the economy, including those related to the buildout of HSR infrastructure (e.g., construction activities, manufacturing activities), the operation of HSR trains (e.g., administration activities, maintenance activities, etc.), and fundamental shifts in the economy that are facilitated by HSR (e.g., increased tourism, knowledge diffusion, industry agglomeration, etc.). While ex-ante studies can certainly account for these various effects, they rely on a myriad of assumptions to do so and are inherently limited by our current understanding of how the economy works. In synthesizing cost-benefit literature, ex-ante studies were included in this review because cost-benefit analysis requires an examination of the lifetime effects of HSR, and most HSR projects have not reached the end of their lifetime, so some assumptions about the future had to be made.

Despite the advantages of ex-post studies, they still have technical limitations that limit their ability to perfectly measure the effect of HSR. One perennial issue of ex-post research is inferring causality. As argued by Ahlfeldt and Feddersen (2018), the allocation of transportation is typically nonrandom, which can make it difficult to isolate the effect of HSR from selection bias. In other words, do HSR systems spur regional economic growth or are they sited in places that are primed for economic growth? Moreover, cities (or any other geographic units for that matter) are inherently complex and unique systems, which make it difficult to control for all the variables that may influence economic outcomes. Location fundamentals such as geography and culture are particularly hard to replicate and may be underlying assets that drive HSR-induced growth in one city but not another.

Spillover effects are another challenge in measuring the true effect of HSR. A spillover effect occurs when the impacts of HSR are widespread rather than contained to the economic regions in which HSR is located. For example, HSR could lead to a boost in national tourism that spreads to regions that lack dedicated HSR stations. Thus, when comparing economic outcomes in regions where HSR is located relative to those where it is not, spillover effects can mute the observable effect of HSR. Some researchers have employed techniques to account for such spillover effects (Chen 2019, Chong et al. 2019), but such techniques are not universally employed across the literature.

In light of the aforementioned caveats, the literature highlighted here should be viewed as instructive case studies—but certainly not universal truths—about how economies from across the globe have responded to HSR. The utility of this research synthesis is that it compiles case studies on different HSR systems and their impacts to construct some general trends. The following sections discuss these trends and how they may apply to California.

4.1 Value Added

Value added is an economic indicator that communicates the amount of wealth generated in a particular region. Improvements in value added are typically measured through a change in gross domestic product (GDP), which is the market value of all the final goods and services produced within a region. GDP is often normalized by population to account for the number of individuals that those goods and services are shared amongst, thereby serving as a proxy for the standard of living in a particular region. To better understand how HSR adds value to an economy, some recent studies have also looked more narrowly at the impact of HSR on fixed asset investment (FAI) and household income (HHI). FAI measures the value of all capital resources that can be used to generate revenue while HHI measures the share of revenue that ends up in human hands.

Based on the literature published over the past decade, HSR has had mixed effects on value added. **Table 6** provides a summary of recent studies analyzing HSR's impact on GDP (in total terms), GDP per capita, FAI, or HHI. The majority of recent studies have credited HSR with a net improvement in one of these metrics, but several studies have found that HSR has led to a decline in GDP per capita (Qin 2017, Lin et al. 2018) or no effect at all (Jia et al. 2017, Nickelsburg et al. 2020), at least in statistically significant terms.

Studies that show that economic gains from HSR generally attribute this growth to improvements in accessibility, reduced transportation costs, and greater connectivity between cities. Chen and Haynes (2017) argue that the aforementioned benefits facilitate secondary benefits, such as greater information dissemination, access to markets, capital and labor mobility, and productivity improvements. In addition, Cascetta et al. (2020) argue that transportation systems can facilitate the following economic transformations: (a) industrial agglomeration, whereby similar firms locate near one another to maximize economies of scale; and (b) the influx of direct foreign investments from actors that seek to capitalize on an improved transportation network.

Several studies on HSR development have used econometric models to disentangle which explanatory variables have the greatest influence on GDP growth. In Germany, Ahlfeldt and Fedderson (2018) found that an increase in labor productivity (rather than agglomeration) was the primary driver for GDP growth for counties connected by HSR along the Cologne and Frankfurt route. The authors also found that indirect benefits were delivered to peripheral regions through knowledge diffusion, labor market pooling, and improved access to intermediate goods and consumer markets. In China, Lin (2017) found that direct connectivity between HSR cities with new markets was not a statistically significant predictor of GDP growth, but that a one percent growth in non-connection-induced market access (e.g., individuals from non-HSR cities spending money in HSR cities during transfers to other destinations) led to a significant 3.9% increase in GDP.

Studies that show economic losses from HSR credited the decline to agglomeration, whereby economic activities relocate from peripheral regions to core cities, and the resulting consolidation leads to a net contraction of economic activity along HSR routes. Qin (2017), for example, found that being located along China’s various HSR routes decreases a county’s total GDP per capita by 3-5% on average, and that this is likely investment driven, as evidenced by the 9-11% reduction of FAI in affected counties. Similarly, Lin et al. (2018) found that HSR connections in China have led to a reduction in GDP per capita at the prefecture scale (an administrative division ranking below a province and above a county), and pointed to reduced capital inputs and an outflow of skilled labor as some of the likely causes. It is important to note that the negative effects of HSR on value added have only been documented in China, where regional disparities between agricultural and industrial regions are already being driven by a number of broader economic transformations underway, such as globalization and liberalization (Chen and Haynes 2017).

In cases where HSR had a neutral or ambiguous effect on GDP growth, it appears that HSR may have just redistributed economic activity. In Japan, Nickelsburg (2020) found that HSR had a neutral effect on GDP growth (per capita) over the long-term (1955 to 2010), whereby initial growth was followed by low to negative growth. The authors pointed to decentralization as a potential explanation, such that patterns of production and consumption were rearranged, but overall economic activity was not boosted in any permanent way. In China, Jia et al. (2017) found that HSR had a positive (but not statistically significant impact) on GDP per capita in cities along HSR routes. While the authors did not directly provide an explanation for the lack of statistical significance, they acknowledged that economic growth is not a given and is dependent on thoughtful regional development strategy and policy, otherwise HSR may just reshape the spatial organization of a country’s economy.

Given the mixed results discussed here, the economic trajectory of communities served by CAHSR could take multiple paths. With careful planning, CAHSR could stimulate the economies of station cities (particularly in the San Joaquin Valley) by attracting investment to downtown neighborhoods that are currently underutilized; providing access to new markets (thereby promoting economic diversification); and facilitating the agglomeration of knowledge industries where they did not previously exist (SPUR 2017). Alternatively, without strategic planning, the economic benefits of HSR might be concentrated in globally connected business centers (e.g., Los Angeles and San Francisco) at the expense of intermediate cities (e.g., Fresno and Bakersfield), thereby redistributing economic activity across the state rather than generating an overall increase in value added (Murakami and Cervero 2017). The former path requires coordinated planning at the regional scale, so that the complementarities between HSR cities are maximized (Loukaitou-Sideris 2013). In other words, ensuring that HSR cities play different economic roles will help prevent a brain drain from smaller cities to globally connected cities.

Table 6. Studies from 2011 to 2020 that Assess Impacts of HSR on Value Added*

Source	Region / Country	Route	Geographic Scale of Analysis	Study Period	Value Added Metrics Assessed	Shows Potential Benefit from HSR
(Cascetta et al. 2020)	Italy	Systemwide	Provinces	2008-2018	GDP / capita	Yes
(Nickelsburg et al. 2020)	Japan	Systemwide	Prefectures	1955-2010	GDP / capita	No
(Chen 2019)	China	Systemwide	Region	2002-2013	GDP	Yes
(Chong et al. 2019)	China	Systemwide	Cities	2008-2015	GDP / capita	Yes
(Diao 2018)	China	Systemwide	Cities**	2009-2013	FIA	Yes
(Li et al. 2018)	China	Systemwide	Cities**	2007-2014	GDP / capita	Yes
(Lin et al. 2018)	China	Systemwide	Prefectures†	1999-2013	GDP / capita	No
(Meng et al. 2018)	China	Systemwide	Counties	2006-2014	GDP	Yes
(Ahlfeldt and Feddersen 2018)	Germany	Cologne-Frankfurt	Counties	1992-2009	GDP	Yes
(Chen and Haynes 2017)	China	Systemwide	Region	2000-2014	GDP / capita	Yes
(Ke et al. 2017)	China	Systemwide	Cities**	1990-2013	GDP / capita	Yes
(Lin 2017)	China	Systemwide	Cities**	2000-2013	GDP	Yes
(Jia et al. 2017)	China	Systemwide	Cities**	2000-2013	GDP / capita	Unclear‡
(Qin 2017)	China	Systemwide	Counties	2002-2009	GDP / capita	No
(Sun and Mansury 2016)	China	Systemwide	Provinces	2010-2012	HHI	Yes
(Chen et al. 2016)	China	Systemwide	National	2002-2013	GDP	Yes

*This literature summary does not include the following studies: those that estimate anticipated impacts from HSR on value added (ex-ante studies) rather than observed impacts (ex-post studies), such as Graham and Melo (2011), Kim and Yi (2019), and Koike et al. (2015); those that look at the impact of conventional rail on value added, such as Banerjee et al. (2020), Donaldson and Hornbeck (2016), Donaldson (2018), Sperry et al. (2013), and Wang and Wu (2015); and those that explore trends in value added using descriptive statistics, but do not use evaluative methods (e.g., instrumental variable analysis, difference-in-differences estimation, etc.) to isolate the effect of HSR from other exogenous forces that may explain those same trends, such as Chen and Hall (2011), Chen and Vickerman (2017), and Vickerman (2018).

**Looked only at prefecture-level cities.

†Looked only at peripheral prefectures and excluded prefectures that contained megacities.

‡Showed potential positive effects on economic growth but they were not statistically significant.

4.2 Employment

Along with value added, employment is another common metric for analyzing economic growth from major infrastructure projects. Studies that document the employment impacts of HSR usually do so by analyzing data from nationally maintained databases on the number of workers employed across industries. Aggregated sums of workers, however, often mask important nuances for understanding the quality of jobs supported by infrastructure projects, such as whether these jobs are full-time or part-time, include health and retirement benefits, and are ongoing rather than temporary. Nonetheless, gross employment impacts are still helpful for understanding the degree to which investments in HSR lead to an overall increase in the demand for labor.

Ex-post literature on HSR and employment is relatively thin. **Table 7** provides a summary of the three studies published over the past decade that analyze the impact of HSR on jobs. All three studies focused on China and documented a positive relationship between HSR and employment. However, Chen (2019) found that HSR had a negative impact on jobs in one of the nine regions studied (China's East Coast) and a neutral impact in another region (Yellow River Mid-Reaches) during the study period (2002-2013). The author attributed job losses to negative spillover effects from HSR (e.g., changes in commodity and factor input flows that divert jobs from one region to another region).

HSR-induced job gains were explained by a variety of mechanisms. Chen (2019) found that increased economic productivity accounted for about 75% of the employment gains, while capital investments such as construction and manufacturing accounted for 23%. Lin (2017) found that a 7% increase in aggregate employment was primarily driven by a 13% increase in tourism, followed by a 7% increase in non-services (such as manufacturing, utility, and constriction jobs), a 5% increase in skilled labor, and a 2% increase in other service jobs. While Lie et al. (2018) did not explicitly measure the effect of underlying drivers of employment gains, the authors credited the development of service industries (including tourism) as the likely source of employment growth after the introduction of HSR.

Given the obvious differences between China and California, it is difficult to extrapolate from recent literature about the anticipated employment impacts of CAHSR. However, recent studies still yield useful lessons that can inform economic development strategies in California. For example, recent literature does not suggest that blue-collar jobs in construction and manufacturing industries or white-collar jobs in knowledge industries will be the primary source job creation in HSR cities. Instead, service sectors (particularly those relating to tourism) appear more likely to play that role. However, it is unclear whether growth in service sector employment translates to high-skill jobs that pay family sustaining wages or low-skill jobs that provide little opportunity for economic advancement. To induce high-skill jobs in either blue-collar or white-collar industries, state and local economic development agencies may need to incentivize firms in those industries to locate in HSR cities, as well as invest in workforce training for residents in HSR cities to perform these jobs. This is particularly true in the San Joaquin Valley where educational attainment is much lower than the Silicon Valley, and where the share of knowledge industries (in terms of total employment) has been declining since 1990 (SPUR 2017). Thus, without more empirical evidence showing a positive effect of HSR on high-skill jobs, it appears that career-ladder employment opportunities are not an automatic benefit from HSR connections. These opportunities likely require separate policy tools to materialize, even if HSR makes them more significantly more accessible.

Table 7. Studies from 2011 to 2020 that Assess Impacts of HSR on Employment*

Source	Region/ Country	Route	Geographic Scale of Analysis	Study Period	Shows Potential Benefit from HSR
(Chen 2019)	China	Systemwide	Region	2002-2013	Yes†
(Li et al. 2018)	China	Systemwide	Cities**	2007-2014	Yes
(Lin 2017)	China	Systemwide	Cities**	2000-2013	Yes

*This literature summary does not include the following studies: those that estimate anticipated impacts from HSR on employment (ex-ante studies) rather than observed impacts (ex-post studies), such as Hernandez and Haas (2013); those that capture the employment effects of partial construction of HSR routes, such as DeShazo et al. (2018); those that look at the impact of conventional rail on employment, such as and Talebian et al. (2018); and those that explore employment trends in HSR cities using descriptive statistics, but do not use evaluative methods (e.g., instrumental variable analysis, difference-in-differences estimation, etc.) to isolate the effect of HSR from other exogenous forces that may explain those trends, such as Chen and Hall (2011), Cheng et al. (2015), Chen and Vickerman (2017), Murakami and Cervero (2017), and Vickerman (2018).
**Looked only at prefecture-level cities, which are an administrative division ranking below a province and above a county in Mainland China's administrative structure.
†Positive results were shown in all nine regions studied except for two regions: the East Coast where there was negative effect on employment and Yellow River Mid-Reaches where there was a neutral effect.

4.3 Property Value

Increased property values have positive and negative economic consequences. For existing landowners, HSR-induced growth in property values can enhance access to capital through home equity loans and other lines of credit that use land as collateral for low-interest borrowing. Higher property values can also enhance income streams for local governments, which depend greatly on property taxes for general operating expenses. However, for residents and businesses already priced out of land ownership, increased property values can trigger rent increases, evictions, and displacement. Strategic planning and policy are essential to balancing the positive and negative consequences of increased property values.

Recent literature shows that HSR has mixed effects on property values. **Table 8** provides a summary of studies from the past decade that have analyzed the impact of HSR on property values. Most of these studies have credited HSR with increasing property values within the given catchment area that was analyzed. There were three exceptions to this trend. In Japan, Nickelsburg (2020) found that HSR connections were negatively associated with average land prices and relieved pressure on home prices in major cities. Similarly, in Guangzhou, Diao et al. (2017) found that being closer to the city's main HSR station tends to significantly lower the transaction price of a property. Meanwhile, in Shanghai, Rungskunroch et al. (2020) found that HSR had no significant effect on property values. These mixed results echo earlier work by Hensher et al. (2012), in which the authors conducted a global review of HSR literature (spanning 15 cities) and found heterogenous effects from HSR on property values. Like this review, the dominant trend across the 15 cities was a positive link between property values and HSR stations.

The literature commonly cites improvements in accessibility and reduced commuting costs as the underlying reasons for property value appreciation around HSR stations. The magnitude of this appreciation depends on multiple site-specific factors, such as urban form, existing transportation connections, and proximity to negative externalities from HSR (e.g., noise, pollution, congestion, etc.). In China, for example, Chen and Haynes (2015) found that HSR had a considerable regional impact on housing values in medium and small cities, but a negligible impact on larger capital cities. Daio et al. (2017) added that housing price appreciation around new suburban HSR stations in China was limited by weak connections with urban centers and poor public transport services. Similar conclusions were drawn by Andersson et al. (2012) in Taiwan, where commuters prefer non-suburban station locations with quick downtown-to-downtown connections. And Geng et al. (2015) found that the positive effects from HSR on housing price only compensated for the negative effects after about 0.9 km in distance from the nearest HSR station.

In regions where HSR was not shown to increase property values at all, the authors provided differing explanations as to why price increases were mitigated. In Japan, Nickelsburg (2020) credited HSR with helping the nation’s cities to decentralize, which reduced property values in cities with tight land markets. However, the authors note that their findings are limited to the prefecture level, and that there is evidence that some sub-prefecture land prices increased due to their proximity to HSR. In Guangzhou, Diao et al. (2017) attributed the negative relationship between HSR and property values to geographic isolation of the station from the city’s center. And in Shanghai, Rungskunroch et al. (2020) characterized land prices as strictly controlled by the government, and thus HSR had no meaningful impact on property values.

With the exception of one study in Japan, recent literature does not suggest that HSR will have a strong ameliorating effect on rising housing costs in California. Instead, the literature generally shows HSR boosting property values, potentially making housing affordability worse for communities near HSR stations. Still, HSR can be an integral part of California’s broader affordable housing strategy if local governments are able to devise land value capture arrangements with developers. Such an arrangement could allow local governments to receive some of the revenue generated from property leases or real estate transactions for buildings near HSR stations. This revenue could then be spent on affordable housing production, rental subsidies, or homeownership assistance programs for low- and middle-income households. Land capture value models have already been used to finance HSR-related development projects in central Tokyo (SPUR 2017) and Hong Kong (Cervero and Murakami 2009). In the absence of revenue sharing agreements with developers, local governments are still likely to benefit from higher tax assessments on properties located near HSR, which could also be put towards affordable housing initiatives and other displacement avoidance interventions.

Table 8. Studies from 2011 to 2020 that Assess Impacts of HSR on Property Values*

Source	Region / Country	Route	Node / Station	Geographic Scale of Analysis	Study Period	Shows Potential Value Increase from HSR
(Bao and Mok 2020)**	China	Guangshengang XRL	West Kowloon	0-10 km	2000-2019	Yes
(Nickelsburg et al. 2020)	Japan	Systemwide	All stations	Prefecture	1983-2010	No
(Rungskunroch et al. 2020)	China	Beijing–Shanghai	Shanghai	0-600 km	2005-2017	No
(Diao et al. 2017)**	China	Shanghai-Hangzhou	Hangzhou	0-20 km	2005-2013	Yes
		Guangshengang XRL	Guangzhou	0-20 km	2005-2013	No
(Lin 2017)**	China	Systemwide	All stations	Cities***	2000-2013	Yes
(Chen and Haynes 2015)**	China	Beijing–Shanghai	All stations	0-50 km	2014	Yes†
(Geng et al. 2015)**	China	Beijing–Shanghai	Beijing	0-12 km	2013	Yes‡
(Zheng and Kahn 2013)**	China	Systemwide	All stations	Cities***	2006-2010	Yes
(Andersson et al. 2012)**	Taiwan	Taipei-Kaohsiung	All stations	Cities	2007-2008	Yes

*This literature summary does not include the following studies: those that estimate anticipated impacts from HSR on property values (ex-ante studies) rather than observed impacts (ex-post studies); and those that look at the impact of conventional rail on property values, such as Ahlfeldt (2012), Debrezion et al. (2011), Donaldson and Hornbeck (2016), and Duncan (2011).
**Study looked exclusively at residential properties.
***Study looked only at prefecture-level cities, which are an administrative division ranking below a province and above a county in Mainland China's administrative structure.
†Effect was only for small and medium cities; the effect on larger capital cities was negligible.
‡Effect was only for properties at least 0.9 km away from the station.

4.4 Societal Cost Savings

Societal cost savings are the difference between the total costs and benefits that HSR brings to a particular region. This economic metric is the final output of a cost-benefit analysis, in which all the costs and benefits of HSR are monetized and summed over a defined operational period. Cost-benefit analyses vary widely in terms of scope. In terms of costs captured, most studies estimate the costs borne by investors to build and operate HSR, while much fewer studies estimate the external costs borne by society (e.g., pollution, sprawl, etc.). In terms of benefits captured, most studies estimate travel time savings and monetize those time savings according to how different passenger groups value their time. Less commonly estimated benefits include climate change mitigation, air pollution reduction, safety improvements (e.g., avoided injuries and fatalities from traffic accidents), enhanced reliability (e.g., reduced delays and subsequent wait times), and travel cost savings (e.g., reduced fares and vehicle expenses for passengers who would otherwise fly or drive). Moreover, cost-benefit analyses typically do not capture the wider economic benefits from HSR in terms of value added, employment, or property values. As previously discussed, these macroeconomic benefits are difficult to estimate and there is a lack of consensus as to whether they will even accrue for regions where HSR is introduced.

Recent cost-benefit studies generally shows that HSR can lead to net benefits across the regions studied. **Table 9** provides a summary of cost-benefit studies from the past decade that have analyzed net benefits from HSR. Only one study has shown that HSR will not lead to net societal cost savings at all (Beria and Grimaldi 2011). In this study the authors looked at four different HSR segments that have been built along the Turin-Salerno axis in Italy between 2006 and 2009, and concluded that there has been insufficient ridership to justify the cost of the project. However, it is worth noting that the authors only looked at societal benefits from time savings and commented that the Bologna-Florence and Milan-Bologna segments of the rail system would likely be justified if other benefits were included in the analysis. Similarly, in China, Wu et al. (2014) concluded that most of the country's HSR network is unjustified based on current ridership levels and value of time assumptions, except for Beijing-Shanghai and Wuhan-Guangzhou routes, which are located in the richest and most densely populated areas of China. While the authors only looked at time savings, they were doubtful that capturing wider economic impacts from HSR would change their conclusions.

Of the studies reviewed, only one cost-benefit analysis focused on California's system (Matute and Chester 2015). In that study, the authors compared public subsidies for CAHSR to travel cost savings for passengers and found that CAHSR can lead to net benefits, but only under certain conditions: the cost of automobile ownership is high, the cost of airfares is high, and counterfactual trips by car are long (in terms of miles driven). The authors also compared results for CAHSR against other GHG reduction projects in the transportation sector (bus-rapid transit, light-trail transit, and bicycle/pedestrian pathways), and found that when costs are normalized by GHG reductions, CAHSR achieved the least cost savings per metric tonne of avoided GHG emissions. This finding should be interpreted with caution, as the authors only estimated benefits from CAHSR in terms of travel cost savings and did not look at other potential sources of cost savings (e.g., climate change mitigation, local air pollution reduction, time savings for passengers, etc.).

Table 9. Studies from 2011 to 2020 that Assess Societal Cost Savings from HSR*

Source	Region / Country	Route	Operational Period (Years)	Costs Captured	Benefits Captured	Shows Net Benefit from HSR
(Belal et al. 2020)	Egypt	Cairo-Aswan	40	Construction Operations External**	Air quality improvement Lives saved GHG reductions Ticket revenue Time savings	Yes
(Cetkovic et al. 2020)	Serbia	Belgrade-Hungary	30	Construction Operations	Air quality improvement Injuries avoided Lives saved Time savings Travel cost savings	Yes
(Ali et al. 2016)	Egypt	Cairo-Alexandria	40	Construction Operations External**	Air quality improvement Lives saved Reliability improvement Ticket revenue Time savings	Yes
(Koike et al. 2015)	Japan	Tokyo-Nagoya (Maglev)	50	Construction	Time savings Travel cost savings	Yes
	South Korea	Seoul-Busan	N/A	Construction	Time savings Travel cost savings	Yes
	Taiwan	Taipei-Kaoshiung	N/A	Construction	Time savings Travel cost savings	Yes
(Matute and Chester 2015)	United States	CAHSR System	100	Construction*** Operations***	Travel cost savings	Yes
(Wu et al. 2014)	China	Systemwide	50	Construction	Time savings	Yes†
(Froidh 2014)	Sweden	N/A	60	Construction Operations	Cost efficiencies Ticket revenue Time savings	Yes
(De Rus 2011)	N/A	Generic 500km line	N/A	Construction Operations	Time savings	Yes
(Beria and Grimaldi 2011)	Italy	Turin-Salerno Axis‡	40	Construction Operations	Time savings	No

*This literature summary does not include the following studies: those that look at the net benefits of conventional rail projects, such as Manzo et al. (2018); and those that calculate net benefits solely during the operational phase without including upfront investment costs, such as Janic (2011) and Salzberg et al. (2013).
**Examples of external costs were not explicitly defined by the authors in their cost-benefit analysis.
***Authors only included public subsidies for construction and operations.
†Authors concluded that there would be net benefits for only a limited number of HSR lines, such as the Beijing-Shanghai and Wuhan-Guangzhou routes.
‡Authors excluded Rome-Florence and Naples-Salerno from their analysis because they still use normal Italian voltage (3kV DC) rather than French standards for HSR (25kV AC).

4.5 Economic Integration

For some countries, HSR has been used as a tool to economically integrate peripheral regions with core cities, thereby reducing economic disparities between the two. This was a particularly strong motivation for the HSR link between Madrid and Seville in Spain, despite the high cost of doing so (Albalate and Bel 2012). However, there have been a number of transportation scholars that have argued that HSR actually exacerbates regional disparities by consolidating economic growth in core cities along HSR routes (Knaap and Oosterhaven 2011, Monzon et al. 2013, Koike et al. 2015, Vickerman 2015, Wang et al. 2017, Kim and Yi 2019, Zhang et al. 2019). Additionally, it has also been argued that HSR can exacerbate inequities along racial and class lines by directing economic benefits (e.g., reduced transportation costs, access to new markets, etc.) to a ridership base predominately composed of white, middle-to-upper income passengers, and offering little benefit to other demographic groups (Nuworsoo 2017).

Recent literature on HSR and economic inequality has been largely theoretical, with few ex-post studies providing empirical evidence of HSR's actual effect. Over the past decade, a total of four studies have measured this effect, all focusing on regional economic inequality. **Table 10** provides a summary of these studies, including the metrics that were used to measure inequality (e.g., GDP, HHI, transportation costs, etc.). The literature yields mixed results, with two studies showing a benefit from HSR towards the goal of economic integration (Chen and Haynes 2017, Chen 2019), and two studies showing a negative impact (Yu and Yao 2019, Cascetta et al. 2020). However, even though Cascetta et al. (2020) found that current HSR routes had exacerbated regional inequalities across Italy, the authors were optimistic that proposed expansions of the HSR network to underdeveloped areas of the country (referred to as the HSR_N scenario in the study) could improve equity indices by 20% relative to the pre-HSR baseline scenario, as based on ex-ante modelling. Thus, the regional inequities in Italy did not appear to be the result of a tunnel effect whereby intermediate cities languish at the expense of flourishing node cities; instead, the inequities were born out of uneven investment between regions served by HSR and those skipped over.

Recent literature also warns that CAHSR could exacerbate economic inequality. For example, Wang et al. (2017) modelled the effects of CAHSR on multiple economic development metrics (i.e., population, employment, and land use), and found that CAHSR is likely to encourage more polarized development between core cities and intermediate station cities/counties. Nuworsoo (2017) also predict that CAHSR is more likely to benefit high-income Californians than low-income residents, as based on an analysis of 2001 and 2012 California Household Travel Surveys, which shows that most Californians make long-distance trips infrequently, and those who do tend to more affluent. As a potential remedy, Nuworsoo (2017) suggests offering lower fares for youth and seniors or discounted passes for riders who belong to lower income brackets. While this remedy may enhance the accessibility of HSR to more Californians, it does not necessarily address the broader economic disparities articulated by Wang et al. (2017) at the regional sale. Addressing these latter inequities will require strategic economic development partnerships between public and private sector actors in the San Joaquin Valley. Some specific actions proposed by SPUR (2017) include: supporting the development of industries that are more likely to thrive in the San Joaquin Valley relative to other parts of the state (e.g., agricultural technology firms), expanding research facilities at universities located in the San Joaquin Valley (e.g., California State University, Bakersfield; California State University, Fresno; University of California, Merced), and using State of California employee pension funds to support early-stage or seed investments in the San Joaquin Valley.

Table 10. Studies from 2011 to 2020 that Assess Impacts of HSR on Economic Integration*

Source	Region / Country	Route	Scale of Analysis	Study Period	Metric Analyzed	Shows Potential Benefit from HSR
(Cascetta et al. 2020)	Italy	Systemwide	Provinces	2008-2018	Transport cost	No
					GDP/capita	No
(Chen 2019)	China	Systemwide	Region	2002-2013	GDP	Yes
(Yu and Yao 2019)	China	Systemwide	Region	2008-2015	HHI	No
(Chen and Haynes 2017)	China	Systemwide	Region	2000-2014	GDP/capita	Yes

This literature summary does not include the following studies: those that estimate anticipated impacts (ex-ante studies) from HSR on economic integration rather than observed impacts (ex-post studies), such as Kim and Yi (2019), Knaap and Oosterhaven (2011); Koike et al. (2015), and Wang et al. (2017); those that estimate the impacts of HSR on accessibility and mobility metrics—which can serve as precursors to economic integration—but do look not at economic integration itself, such as Chen and Haynes (2017); Cheng at al. (2015), Kim and Sultana (2015); Monzon et al. (2013), Monzon et al. (2019), Ortega et al. (2012), Wang and Duan (2018), Wang and Zhang (2019), Zhu et al. (2016), Zhu et al. (2019); and those that explore trends in economic integration using descriptive statistics, but do not use evaluative methods (e.g., instrumental variable analysis, difference-in-differences estimation, etc.) to isolate the effect of HSR from other exogenous forces that may explain those trends, such as Chen and Hall (2011), Cheng et al. (2015), Chen and Vickerman (2017), and Vickerman (2018).

5. Future Research Recommendations

Recent literature suggests that high-speed-rail (HSR) can lead to measurable environmental and economic benefits along multiple dimensions. With respect to the environment, this translates to potential reductions in greenhouse gas reductions (GHG) emissions, local air pollution, and noise. And with respect to the economy, this translates to potential growth in value added, employment, societal cost savings, and economic integration. There is also evidence that HSR can lead to an increase in property values, but such an impact is not inherently beneficial for all households living in proximity to HSR, especially renters. For example, increased property values could exacerbate housing unaffordability, gentrification, and displacement in neighborhoods that are close to HSR stations. However, if property appreciation is strategically captured through public-private partnerships, then the value of that land could be used to fund projects that benefit low-income households, such as affordable housing developments and community land trusts.

The aforementioned benefits of HSR are certainly not a given. For every environmental and economic indicator discussed in this review, there is also evidence that HSR projects can lead to negative impacts. Thus, the benefits of HSR are only realized when certain conditions are met. For there to be environmental gains, the literature on HSR makes it clear that ridership needs to be high, energy propulsion must be powered primarily by renewables, and displaced demand for intrastate air travel must not be replaced by longer haul flights. For there to be economic gains, the literature makes it clear that cities connected by HSR must play complementary roles, rather than competitive ones, within the broader economy. Otherwise, economic benefits of HSR will likely be consolidated in core cities along HSR routes at the expense of intermediate cities, and efficiencies from agglomeration may lead to an overall decline in employment and economic value added.

In light of these contingencies, the California High-Speed Rail (CAHSR) project needs to be complemented by other policies that ensure high ridership, curtail air travel to environmentally optimal levels (regardless of HSR ridership levels), and strengthen local economies of intermediate cities along the HSR network, namely those in the San Joaquin Valley. This review closes with some recommendations for future research questions that can inform the development or refinement of polices that support the successful implementation of CAHSR.

5.1 Research to Encourage HSR Ridership

Question 1 – What opportunities exist to reduce door-to-door travel time on HSR?

Research suggests that total travel time is the main factor that influences an individual’s decision to use HSR in lieu of air transport for interregional trips (Givoni and Dobruszkes 2013, Clewlow et al. 2014, Sun et al. 2017, Xia et al. 2018). Ensuring that HSR is a quick transportation mode for traveling between Los Angeles and San Francisco is critical for diverting passengers away from airplanes. Transportation scholars have argued that the competitive edge of HSR relative to flying decreases rapidly when the total travel time exceeds three hours (Haas 2014). To support the goal of reducing travel time, future research could look at engineering solutions to further accelerate the speed of HSR service. Maglev technologies, for example, use magnetic resistance to propel high-speed trains, and can achieve speeds of 450 km/h, a 50% improvement over traditional HSR technologies (Janic 2021). Some transportation scholars have even recommended downgrading intermediate HSR stations to commuter rail stations that serve as feeders to more central HSR stations, thereby balancing rail coverage with improved speed between major cities (Zhong 2011). The cost and benefits of these modifications to the existing CAHSR proposal certainly warrants more examination before such measures are seriously considered.

Question 2 – How can carbon pricing instruments facilitate the shift from air to HSR?

Price is another key consideration in an individual's decision to travel by HSR instead of flying (Hortelano et al. 2016), albeit less important than travel time (Givoni and Dobruszkes 2013). Thus, increasing the price of air travel could be one way to further shift travelers from air to rail. This could be accomplished through an aviation fuel tax or broader carbon tax. It is also possible that the price of air travel could be indirectly increased through California's existing Cap-and-Trade program, which places a cap on GHG emissions from major emitters such as electricity generators and large industrial facilities, but does not directly regulate emissions from all firms that do business in California. The feasibility of using the Cap-and-Trade program for such a purpose warrants more investigation, as does its ultimate efficacy. Some research has shown that emission-related charges have had an insignificant effect on transportation mode choice (Hoen et al. 2014, Sobieralski and Hubbard 2020), while other research has shown that such charges can be effective at reducing air traffic (Akerman 2012), and subsequently increasing HSR traffic (Sun et al. 2017). More work is needed on this topic in specific context of California.

5.2 Research to Maximize Environmental Benefits from HSR

Question 1 – What policy tools exist to ensure absolute reductions in air travel?

Even if CAHSR proves to be effective at attracting travelers from airplanes, it is unclear how airlines will respond. Despite a loss in ridership, airlines may continue to run short-haul flights at the same frequency to facilitate connections for multi-leg trips (Chester and Ryerson 2014). Alternatively, freed up capacity at airports for short-haul flights could be replaced by longer-haul flights that were not previously offered or offered at a lower frequency (Givoni and Dobruszkes 2013). Thus, more research is needed on regulatory mechanisms by which government actors can force absolute reductions in air travel, and how airlines would ultimately respond to government controls. Service cuts for specific routes may have greater societal costs than others, especially in remote regions of the states that lack HSR connections as an alternative to flight.

Question 2 – What opportunities exist to reduce GHGs from HSR construction?

Most of the GHG emissions from CAHSR occur during construction, primarily due to the large amount of cement that is needed for structural elements (Chester and Horvath 2012). Given that the full HSR network remains uncompleted (CAHSRA 2021), there may be opportunities to bring down the GHG emissions from remaining construction activities. While it is not technically feasible to completely eliminate emissions from cement production with currently available technologies, there are number of production efficiencies and material substitutions that can reduce GHG emissions along the concrete supply chain (Di Filippo et al. 2019). A research synthesis on strategies for decarbonizing the construction sector (particularly transportation infrastructure) could uncover more opportunities for reducing the embodied GHG emissions associated with CAHSR. However, special attention should be paid to the cost of these strategies given the challenges that already exist to fully finance the CAHSR network.

Question 3 – What opportunities exist to decarbonize transport to and from HSR?

The likely travel behaviors of CAHSR riders before and after arriving at HSR stations are not well understood. Ideally these portions of travelers' door-to-door journeys will be made vis-à-vis zero- or low-carbon modes like walking, biking, and public transit. Fortunately, CAHSR is being sited in locations where many of these connections already exist or will exist after coordinated planning efforts with station cities (CAHSRA 2021). However, travelers with heavy baggage may prefer to connect to HSR stations in a taxi or through a ride hailing service. Additionally, given the number of car rental agencies located at airports, some segment of travelers (particularly business travelers) are likely to rent a car once they arrive at their final destination along the CAHSR network. Given that electric vehicles still comprise a small share of the total passenger vehicle fleet, it is likely that many of the cars used in each of these scenarios will be powered by fossil fuels. The literature on HSR has not closely examined the most effective ways for decarbonizing these auto trips. An electric car sharing program sited near HSR stations is certainly one option, as is an electric shuttle or microbus that connects travelers from HSR stations to their place of origin or final destination. Research is needed to help measure and compare the tradeoffs of these various solutions, as well as their likely uptake.

Question 4 – What investments are needed to curtail noise pollution from HSR?

As discussed earlier in this review, noise pollution from trains generally has fewer negative consequences for human health than airplanes. However, there is a dearth of research to confirm whether the advantage of rail transport relative to aviation holds true for HSR. More research is needed on this topic. Regardless, households will likely experience an overall increase in noise exposure if they live close to HSR infrastructure but far from airports where noise reduction benefits should theoretically occur (assuming airlines reduce air traffic in response to HSR competition). Thus, more research is needed on how noise pollution from HSR can be mitigated cost-effectively and with minimal consequences for added GHG emissions.

5.3 Research to Maximize Economic Benefits from HSR

Question 1 – How can complementarities between HSR cities be strengthened?

Without proper planning, HSR has the potential to redistribute economic activity from intermediate cities to global cities such as Los Angeles and San Francisco (Murakami and Cervero 2017). Planning scholars have argued that such a fate could be mitigated by strengthening the complementarities between HSR cities (Loukaitou-Sideris 2013). Future research could support this effort by developing case studies that characterize the economic strengths and vulnerabilities of each city along the CAHSR network, and identify the industries in which cooperation is possible and competition is likely. An understanding of these dynamics is essential for designing effective economic development policies in CAHSR cities at the local level, as well as encouraging interregional coordination amongst CAHSR cities.

Question 2 – How can the goods movement sector benefit from HSR?

A number of studies have suggested that one of the benefits of HSR is releasing capacity on conventional railroads for freight transport (Wu et al. 2014). The potential for such a benefit in California is not well documented in the literature. Research could fill this gap by summarizing how various goods are currently moved across California, analyzing the degree to which congestion along freight routes limits economic activity in the state, and identifying opportunities to use freed capacity along conventional railroads for the most productive use. Seeherman et al. (2018) have already shown that that making better use of rail transport for transporting agricultural goods can greatly reduce societal costs to the state from pollution, pavement wear, and collisions involving semitrailers. Research could also look at the feasibility of using HSR trains to transport low-mass but high-value goods that would otherwise be transported in a cargo aircraft, and the societal cost savings of such a mode shift.

Question 3 – What has been the effect of land value capture models in other regions?

Land value capture programs are a promising solution to mitigate some of the potential negative impacts of CAHSR on housing affordability. However, there is not much literature on the efficacy of these programs on achieving benefits for communities that live near HSR or that may be negatively impacted by HSR development. Planners and policymakers in California could benefit from research that looks at how land value capture programs have been historically designed, implemented, and received by local stakeholders.

5.4 Research to Maximize Equity Benefits from HSR

Question 1 – Where are air quality impacts from HSR most likely to occur?

The air quality impacts from CAHSR are likely to be heterogenous across the state. If CAHSR is successful in reducing air travel, then communities that live near airports are likely to experience the greatest air quality benefits, as the bulk of harmful pollution from air travel occurs during takeoffs, landings, and taxing around the tarmac (Hudda et al. 2014, Nahlik et al. 2016, Wing et al. 2020). The location of CAHSR's negative air quality impacts—namely those that occur during the construction process and the manufacturing of necessary inputs—is less well understood. Research could improve knowledge on this matter by mapping the air pollution impacts of supply chains that feed into CAHSR construction. With this knowledge in hand, communities that bear the burden of negative air quality could be prioritized for other state programs aimed reducing air pollution.

Question 2 – What models are there for more equitable pricing of HSR services?

Research by Nuworosoo (2017) suggests that CAHSR riders are likely to be predominantly white, middle- and high-income individuals. To ensure that CAHSR services are affordable to a more diverse readership base, progressive pricing structures for HSR could be an effective solution. Research could support this effort by examining what sort of discounted fares have been adopted for HSR in other countries and the degree to which they have incentivized ridership among different population groups.

Question 3 – How can HSR improve accessibility and mobility for low-income users?

Price may not be the only limiting factor that prevents uptake of HSR services by low-income users. HSR routes may not fundamentally connect low-income users to the places they need or want to go. However, HSR could be an integral part of a larger transportation network that meets the needs of low-income users. To verify whether this is true, future research could investigate the travel needs of individuals from disadvantaged communities, particularly those in cities connected by HSR. If HSR can indeed play a role in facilitating long-distance trips for these individuals, then additional research could examine the challenges that they face in reaching (or departing from) HSR stations, and what sort of transportation services would help mitigate those challenges.

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