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Evaluating High-Speed Rail as an Element of the Green New Deal

Introduction

The United States is currently facing two historic and related crises: global climate change and extreme income inequality. Regarding the first crisis, average global temperatures have increased about 1ºC since pre-industrial times due to human activities, chiefly the burning of fossil fuels (IPCC, 2018). Burning coal, oil and gas releases carbon, which acts as a greenhouse gas in the atmosphere, trapping the sun's heat on earth and warming the planet. Of the 10 hottest years on record, eight were in the last decade and the other two were in the decade before that (NOAA, 2018). The year 2018 saw the highest carbon emissions on record: 37 billion tons of carbon were emitted globally (Dennis and Mooney, 2018), with 5.3 billion tons from the United States (Plumer, 2019). Although the United States is now the second-largest carbon emitting country after China, cumulatively it is responsible for the most carbon emissions as it was the largest carbon emitter from 1850 to 2014 (Friedman et al., 2018). Currently the atmosphere has a carbon level of 410 parts per million – higher than at any point in the last 800,000 years when carbon levels never got above 300 ppm (NOAA). The last time carbon levels were this high, humans had not evolved yet (Holthaus, 2018).

As carbon emissions multiply and average global temperatures rise, climate change is having increasingly deleterious effects in the United States and around the world, including a significant increase in the amount and intensity of extreme storms, heavy precipitation events, droughts, heat waves, wildfires, rising sea levels, ocean acidification, coral reef die-offs, extinction of species, jet stream and ocean current disturbances, shrinking ice caps, and diminishing sea ice. A recent report from the Intergovernmental Panel on Climate Change (IPCC) found that if global temperatures are allowed to top 2ºC, 37% of the world's population will be exposed to severe heat, 411 million people will be exposed to severe drought, up to 80 million people will experience flooding from sea level rise, coral reefs will disappear almost entirely, a significant percentage of plants and animals will lose most of their range, and cumulative costs would reach $69 trillion (Plumer and Popovich, 2018). If left unabated, climate change will cost the United States $500 billion per year in crop damage, lost labor, and extreme weather damages (Irfan, 2018), and threatens $1 trillion in national wealth held in coastal real estate, according to the Fourth National Climate Assessment (U.S. Global Change Research Program, 2018). To minimize the most severe damage and risks of climate change, the IPCC says temperature rise must be kept to no more than 1.5ºC, which will require cutting carbon emissions almost in half by 2030 and to zero by 2050 (IPCC, 2018).

A second and related crisis, inequality, is also at historic highs in the United States. Since 1973, productivity has risen 74.4% while hourly wages have risen only 9.2% (Lawrence et al.., 2015). From 1979 to 2010, the share of income from capital gains rose from 36.2% to 54% for the top 1 percent of households, but fell from 33.5% to 22.9% for the bottom 90 percent of households (Bivens, 2014). This discrepancy was even worse after the Great Recession. From 2009 to 2012, the top 1 percent of households saw incomes grow by 34.7%, while the bottom 99 percent of households saw a gain of only 0.8%, meaning the top 1 percent captured almost all of the recovery from the recession (Covert, 2015). The three richest Americans -- Bill Gates, Jeff Bezos and Warren Buffett – now own as much wealth as the bottom half of the U.S. population, a total of 160 million people or 63 million households (Collins and Hoxie, 2017).

Inequality in the United States is particularly sharp along race and gender lines. In 2016, the average annual income of black and Hispanic households was less than half that of white households: $123,400 for whites, $54,000 for blacks, and $57,300 for Hispanics, according to data from the Federal Reserve. Discrepancies in average household net worth were similar: $933,700 for whites, $138,200 for blacks, and $191,200 for Hispanics (Dettling et al., 2017).

Income growth rates are slower for black and Latino families than white families as well, meaning inequality along racial lines will continue to grow. By mid-century, the wealth divide between white vs black and Latino families is projected to double from $500,000 in 2013 to over $1 million in 2043. At current rates of income growth, it will take black households 228 years to amass the same amount of wealth that white households have today, according to the Institute for Policy Studies (Collins et al., 2016). One in five of all households in the United States has zero or negative net worth, but that percentage rises to one in four for Latino households and one in three for black households (Collins and Hoxie, 2017).

Wage and wealth also differs by gender. Women earn an average of 79 cents for every $1 earned by men, with black and Hispanic women earning 74 cents, white women earning 80 cents, and Asian women earning 93 cents. One reason the pay gap persists is that women are less likely to hold higher-level jobs than men and move up the career ladder at a slower pace. While three-fourths of both men and women in their 20s are in non-managerial roles, by mid-career 47% of men but only 40% of women are managers or higher. By late career, 57% of men but only 41% of women are managers or higher, and 8% of men but only 3% of women ever make it to the executive level (PayScale, 2019). This pay gap leads to a persistent wealth gap between men and women. On average, single women own 32 cents for every dollar owned by single men. White women have about half the wealth of white men, but black and Latina women own less than a cent for every $1 owned by men (Mahathey, 2016).

Climate change makes all of these existing inequalities worse, both globally and locally. Poor countries are hit hardest by climate change for two reasons: lower-latitude regions are experiencing more desertification and more intense storms such as Typhoon Haiyan in the Philippines, and poor countries have fewer resources to cope with more extreme weather (Lowrey, 2013). Already climate change has worsened global economic inequality. From 1961 to 2010, global warming decreased wealth per person in the world's poorest countries by 17 to

30 percent, making the gap between low- and high-income nations 25 percent larger than it would have been without climate change (Diffenbaugh and Burke, 2019; Garthwaite, 2019). By 2100, average incomes in the poorest countries are predicted to decline by 75% compared to a world without warming (Burke et al.., 2015; Worland, 2019). Within individual countries, climate change has a disproportionate impact on the poor, yet economic models for the social cost of carbon do not take inequality into account but calculate costs based on average incomes (Harvey, 2015). Even on the local level, people in low-income neighborhoods and communities of color have energy burdens several times higher than in more affluent areas, meaning they pay a much higher percentage of their incomes for electricity and gas than do other income groups. This is not just because they have lower incomes to begin with, but also because they tend to live and work in old, inefficient homes and buildings (Drehobl and Ross, 2016). In Columbus, the Franklin County Energy Study found that households in six low-income areas spend 6% to 11% of their incomes on energy, while 3.5% is considered typical and acceptable (MORPC, 2018).

To address the twin crises of climate change and inequality, On February 7, 2019, Rep. Alexandria Ocasio-Cortez (D-N.Y.) and Sen. Ed Markey (D-Mass.) introduced a Congressional resolution for a Green New Deal. The resolution is not legislation, but rather a resolution calling for a 10-year national mobilization to achieve five goals through 14 projects and 15 requirements (Roberts, 2019). The five goals of the Green New Deal -- achieving net-zero greenhouse gas emissions, creating millions of high-wage jobs, providing a just transition for frontline communities, investing in infrastructure and industry, and securing clean air, clean water, healthy food, and a sustainable environment – are all broadly popular, as is the Green New Deal itself, which has an overall approval rating of 81% (Gustafson et al.., 2019). Some of the projects – each of which would require legislation to be passed through Congress under the Green New Deal – include investing in community-defined resiliency, repairing and upgrading infrastructure, dramatically expanding renewable energy, retrofitting existing buildings to reach maximum efficiency and requiring new buildings to have net-zero emissions, removing pollution and greenhouse gas emissions from manufacturing and industry, removing pollution and emissions from farming and ranching, overhauling transportation systems, mitigating the adverse health and economic effects of fossil-fuel pollution and climate change, preserving land and mass reforestation, cleaning up hazardous waste sites, and promoting technology transfer to help other countries reduce their own emissions (Ocasio-Cortez, 2019).

Of these Green New Deal projects and programs, perhaps none are more iconic than high-speed rail, which falls under the goal of removing pollution and greenhouse gas emissions from the transportation sector. A video about what the future could look like under a Green New Deal begins and ends with a depiction of Alexandria Ocasio-Cortez, who co-wrote and narrates it, riding on American high-speed rail (Ocasio-Cortez et al., 2019). A Frequently Asked Questions document, released by Rep. Ocasio-Cortez's office the day the resolution was proposed, then quickly withdrawn, states that one of the goals of the Green New Deal is to "build out high-speed rail at a scale where air travel stops becoming necessary" (Kurtzleben, 2019). Therefore, this paper will examine research on the potential of high-speed rail to displace air travel as well as other fossil-fuel based forms of travel such as by private car, as well as research on the effect of high-speed rail on equity nationally and regionally.

High-speed rail around the world

High-speed rail is a type of rail transport that operates at significantly higher speeds than conventional trains, using an integrated system of infrastructure such as specially designed tracks, rolling stock (the actual train sets), and operating procedures such as communications (UIC). While there is no specific speed at which a rail system moves from conventional to high speed, the most common definition is from European Council Directive 96/48/EC, which sets a minimum speed of 250 kilometers per hour (kph), or 155 miles per hour (mph), for rolling stock on specially built lines, or 200 kph (124 mph) for rolling stock on existing lines that have been upgraded (EC, 1996). Because of its significantly faster speeds, high-speed rail requires different infrastructure and technology than conventional rail, such as large radius curves of up to 7,000 meters (4.35 miles), limited gradients, a special catenary system (the overhead wire) and power supply system, aerodynamic rolling stock made of strong but light materials, automatic braking systems, and in-cab signaling systems (UIC, 2018). In some countries, conventional and high-speed rail use separate tracks, while in other countries, conventional rail can use high-speed tracks but not vice versa, high-speed rail can use conventional tracks but not vice versa, or high-speed and conventional rail can both use either tracks.

Although experimentation with high-speed rail went on in Europe through the first half of the 20th century, Japan became the first country to provide passenger high-speed rail with the Tokaido Shinkansen between Tokyo and Osaka, opening in 1964 just before the Tokyo Olympics. The line was an immediate success, with 100 million passengers in just three years. The Shinkansen, whose name means "new trunk line," now has seven lines reaching dozens of major cities with 2,762 km (1,717 mi) of track. The Shinkansen is known not just for speed, but also punctuality and safety. Since opening, it has transported more than 10 billion passengers with an average delay of 54 seconds and no deaths due to train accidents (Re: Japan Inc.).

After the success of the Shinkansen, several European countries redoubled their efforts to develop high-speed rail. In France, the first TGV line between Paris and Lyon opened to the public in 1981. Originally designed to run on gas turbines, prototypes for the TGV (Train à Grande Vitesse, or "high-speed train") were converted to electricity after the worldwide oil crisis of 1974 (TGVweb-a). The TGV set world speed records and took most of the airline business between Paris and Lyon, paying for itself in just 10 years. France expanded high-speed rail service west into Europe in 1989 and opened service to London through the Channel Tunnel in 1994. The design of TGV trains, which places axles between two cars rather than under each car, has been exported to several other countries (TGVweb-b).

Germany was the second European country to open high-speed rail with the Intercity-Express (ICE) between Hannover and Wurzburg in 1991. Seven generations of ICE trains now connect dozens of cities in Germany as well as Austria, Denmark, the Netherlands, and Switzerland (I Like Germany). With speeds up to 300 kph (186 mph), ICE is competitive with air travel. At Frankfurt International Airport, Lufthansa offers integrated rail and air transport from Cologne, Bonn and Stuttgart, complete with baggage transfer (Imboden). ICE also suffered the worst high-speed rail accident in history, when a wheel disintegrated on a train traveling at full speed near Eschede in 1998, derailing the train and killing 101 people (DW, 2018).

Spain opened the first line on its AVE (Alta Velocidad Española, or "Spanish high speed") between Madrid and Seville in 1992 just in time for the Barcelona Olympics. In 2005, the government published an ambitious plan to have 90 percent of the population within 50 km (30 miles) of a high-speed rail station. Spain began building the largest high-speed rail network in Europe, which now has 11 lines totaling 2,514 km (1,562 mi), the second-largest high-speed network in the world after China (ADIF). Yet high-speed rail in Spain is underused compared to other countries. 17.5 million passengers rode the AVE in 2014, less than the number of passengers in China, Japan, France, Germany, Taiwan, and Korea (Sevillano, 2016; UIC, 2019).

China began planning for high-speed rail in the 1990s after then-prime minister Deng Xiaoping was impressed by the Shinkansen during a visit to Japan. Over a series of six "speed up" campaigns, China updated its track and imported rail technology from other countries (Molitch-Hou, 2019b). In 2008, China Railway High-speed (CRH) opened its first line from Beijing to Tianjin during the Olympics, with spending from the economic stimulus program after the Great Recession (Tang, 2019). China has invested heavily in nationwide high-speed rail over the last 10 years, resulting in a network that reaches 30 of its 33 provinces, runs 29,000 km (18,000 mi), and accounts for two-thirds of all high-speed rail tracks in the world (Barrow, 2018a). The network is expected to reach over 38,000 km (23,612 mi) by 2025 and 45,000 km

(27,961 mi) after that (EESI, 2018). Notable lines include the Beijing-Guangzhou railway, the world's longest high-speed line at 2,298 km (1,428 mi) (AP, 2012); the Beijing-Shanghai railway, the world's most profitable and fastest and high-speed line at 350 kph (217 mph) (Travel China Guide); and the Shanghai Maglev, the world's first commercial magnetic levitation train that can reach speeds of 430 kph (267mph), traveling 30 km (19 mi) to Pudong International Airport in 7 minutes (EESI, 2018). China's high-speed rail is the busiest in the world, carrying more than 4 million passengers per day (Barrow, 2018a), with an annual ridership of 1.4 billion in 2016 and total ridership of over 9 billion in 2018 (Pacific Internet, 2019). Twice as many passengers take high-speed rail as a domestic airline flight in China (Bradsher, 2013). The spread of high-speed rail in China has forced domestic airlines to cancel regional flights, especially for intercity trips under 500 km (310 mi) (Ya, 2011).

High-speed rail in the United States

During the early 20th century, most inter-city travel in the United States was done by rail. That changed after World War II when the country began investing heavily in roads to support travel by personal vehicles, which more Americans could afford during the post-war boom years. After heavy lobbying from automobile and oil interests, President Eisenhower signed the National Interstate and Defense Highways Act of 1956, authorizing construction of 41,000 miles of interstate highway over 10 years (Molitch-Hou, 2019a).

The introduction of the Shinkansen in Japan prompted President Johnson to include faster rail transportation in his Great Society program, and in 1965 Congress passed the High Speed Ground Transportation Act with bipartisan support (Johnson, 1965). This legislation created the Metroliner train which ran between New York City and Washington, D.C., in 2.5 hours (Trains, 2006). In 2006, Amtrak replaced the Metroliner with the nation's first high-speed line, Acela Express, which runs along upgraded conventional tracks in the Northeast Corridor between Washington, D.C., and Boston. Of the 457 mile line, Acela can reach 150 mph (240 kph) in only

34 miles (CNBC, 2019). Its average speed is 70 mph (113 kph), and its average journey time is 7 hours (Amtrak, 2019). Nonetheless, Acela has been extremely successful. In 2016, almost 3.5 million people took the Acela Express, providing 27% of Amtrak's ticket revenue (Amtrak, 2016). Amtrak now transports 75% of travelers between Washington and New York, and 54% between New York and Boston (Nixon, 2012).

In 2009, President Obama signed the American Recovery and Reinvestment Act, a broad stimulus package developed in response to the Great Recession. Of the $787 billion total investment, $48.1 billion was earmarked for transportation, and of that, $8 billion was to be granted to states for intercity rail projects with a priority on high-speed rail (U.S. GPO, 2009). As potential funding targets, the Federal Railway Administration identified 10 high-speed rail corridors in addition to the Northeast Corridor, including (FRA, 2009; Fig. 1):

- Southeast — Washington, Richmond, Newport News, Norfolk, Raleigh, Durham, Greensboro, Charlotte, Greenville, Atlanta, Columbia, Jacksonville
- California — Sacramento, San Francisco, San Jose, Fresno, Los Angeles, San Diego, Las Vegas
- Pacific Northwest — Eugene, Portland, Seattle, Vancouver
- South Central — Tulsa, Oklahoma City, Dallas, Austin, San Antonio, Texarkana, Little Rock
- Gulf Coast — Houston, New Orleans, Mobile
- Chicago Hub — Chicago, Indianapolis, Detroit, Springfield, Cleveland, Toledo, Columbus, Dayton, Cincinnati, Kansas City, St. Louis, Louisville, Milwaukee, Minneapolis/St. Paul
- Florida — Tampa, Orlando, Miami
- Keystone — Pittsburgh, Philadelphia, Harrisburg
- Empire — Buffalo, Rochester, Syracuse, Utica, Schenectady and Albany
- Northern New England — Boston, Portland/Auburn, Montreal, Springfield, New Haven

Figure 1: Designated High-Speed Rail Corridors (Federal Railway Administration, 2009)

Of these corridors, the Chicago Hub received $2.6 billion in grants, California received $2.3 billion, and Florida received $1.2 billion. However, governors in Wisconsin, Ohio, and Florida all rejected the funding, and the grants were redistributed to other states (Grunwald, 2010; Reuters, 2011). In 2011, Vice President Joe Biden proposed an investment of $53 billion over six years in high-speed rail (Warner, 2011), but the proposal ran into stiff opposition in the House, and subsequent federal budgets included no new money for high-speed rail (Cooper 2011).

Despite the short-lived federal funding, high-speed rail projects are underway in three states: California, with state and federal money; and Florida and Texas, both with private funds. In California, voters approved Proposition 1A in 2008, authorizing the state to issue $9.95 billion in bonds to fund the first phase of a high-speed rail line slated to go from San Francisco through the Central Valley cities of Merced and Bakersfield to Los Angeles (see Fig. 2). Later phases of the project would extend the line north to Sacramento and south to San Diego. The legislation required that trains travel at a minimum of 200 mph (320 kph), that travel time between San Francisco and Los Angeles be no more than 2 hours 40 minutes, and that the railway cover operation and maintenance costs from revenue (Ballotpedia, 2008). The federal government awarded California $2.3 billion for the project in 2010, then redirected an additional $4 billion from states that had turned down federal grants in 2011 and 2012 (CHSRA, 2010; DOT, 2010, DOT, 2011). In addition, in 2014 Gov. Jerry Brown convinced state legislators to allocate 25% of revenue from annual cap-and-trade funds to high-speed rail (Megerian, 2014).

When approved by voters in 2008, Phase 1 from San Francisco to Los Angeles was estimated to cost $33 billion, with ridership projected at 31.6 million and fares at 50% of the cost of air travel (CHSRA, 2008). By 2012, the estimated cost of Phase 1 had risen to $68.4 billion, with fares at 83% of the cost of air. An Initial Operating Section from Merced to Bakersfield in the Central Valley was to be completed by 2022, with the rest of Phase 1 by 2028 (CHSRA, 2012). Construction began with a groundbreaking ceremony in Fresno in 2015 (CHSRA, 2015).

Fig. 2. California High-Speed Rail Map (CHSRA)

Then in 2018, estimated costs rose again to $98.1 billion with completion pushed out to 2033 (CHSRA, 2018a). In 2019, newly elected Gov. Gavin Newsom, citing the delays and cost overruns, announced that while the state would complete the Merced to Bakersfield section in the Central Valley, the rest of the project would be indefinitely put on hold (Bollag, 2019).

If California high-speed rail was controversial, in Florida it opened partisan warfare. Plans date back to 2000, when Florida voters approved an amendment to the state constitution mandating creation of a system of high-speed rail linking its five largest cities, and the state legislature created the Florida High Speed Rail Authority (FHSRA, 2006a). Phase 1, with construction slated to begin in 2003 and be complete by 2009, would have connected Tampa to Orlando, with later connections to Fort Myers, Jacksonville, Miami, Pensacola, and Tallahassee (FHSRA, 2006b). However, Gov. Jeb Bush vetoed legislation funding the project (Kennedy, 2003), and endorsed a successful effort to repeal the amendment (Garcia, 2004). With no funding and no mandate, the project came to a halt until 2009, when the Obama administration designated Florida as a high-speed rail corridor under the American Recovery and Reinvestment Act. The state received a $1.2 billion grant to begin the Tampa-Orlando segment in 2010, with additional funding redirected after Ohio and Wisconsin turned down their grants (Grunwald, 2010). One reason Florida was so competitive was that it had previously done much of the environmental review and already had rights to most of the land needed along Interstate 4, so could commence construction quickly. Orlando International Airport was investing in a new station, and Walt Disney World had planned to integrate high-speed rail with its existing bus and monorail system (FSHRA, 2009). However, in 2011 Gov. Rick Scott rejected federal funds for the project, and they were redirected yet again to other states (Reuters, 2011).

Instead of public funding, high-speed rail in Florida is now being built and operated through private funds. In 2012, Florida East Coast Industries, the state's oldest and largest commercial real estate, transportation, and infrastructure holding company, announced plans to privately finance passenger rail from Miami to Orlando, with eventual extensions west to Tampa and north to Jacksonville (Railway Gazette, 2012). In 2013, its subsidiary All Aboard Florida applied for a $1.6 billion Railroad Rehabilitation and Improvement Financing loan from the Federal Railway Administration (Tracy, 2013), but in 2014 decided to finance the project with bond sales instead. It was the first passenger rail project to be paid for by private activity bonds, which are tax exempt (Miller, 2014). After obtaining environmental approvals, the company

Fig. 3. Virgin Trains USA route (Disney Blog)

began work on track and stations in Miami, Fort Lauderdale, and West Palm Beach under the brand name Brightline (Hayward, 2015). Service between the three south Florida cities began in May 2018 (Jacoby, 2018), while groundbreaking for service to Orlando occurred in June 2019 with completion expected in 2022 (Gimenez, 2019) (see Fig. 3). In 2018, Brightline formed a partnership with Virgin Group, a British group owned by Sir Richard Branson that operates Virgin Airlines and Virgin Trains UK. With Branson as a minority investor, Brightline was renamed Virgin Trains USA (Spear, 2018). It remains the only privately owned and operated intercity passenger rail service in the United States, watched closely by owners of freight rail, which discontinued passenger service throughout the 20th century as travel by private car became dominant, especially with the construction of the interstate highway system (Grabar, 2014).

Texas never went through the politics of public funding for high-speed rail, but there have been previous attempts at private funding. In 1991, the Texas High Speed Rail Authority awarded a 50-year franchise to TGV Corp. for building and operating high-speed rail in the Texas Triangle cities of Dallas, Houston, and San Antonio (Barrow, 2018b). However, the franchise was rescinded in 1994 after the project ran into heavy opposition from Southwest Airlines, which had built its business model on commuter air travel between these cities (Batheja, 2014). In 2002 a collaboration of elected officials, grassroots activists, and businesses including two major airlines formed the Texas High Speed Rail and Transportation Corporation, which proposed the Texas T-Bone and Brazos Express corridors to link major cities in central Texas (THSRTC). The Texas Department of Transportation later used much of their work in applying for funding for high-speed rail under the American Recovery and Reinvestment Act (TxDOT, 2009). Texas did not get funding to build high-speed rail, but did receive money to study a line between Houston and Dallas (Morris, 2011).

The next year, a private company called Texas Central Railway announced plans to build high-speed rail from Dallas to Houston using Japanese technology with $12 billion in private financing (Cowan, 2017). While most of the funding is from Japanese investors, the company has also discussed applying for federal loans or issuing private equity bonds (Nicholson, 2015). However, the main challenge the project faces is land acquisition, specifically opposition from rural landowners. While Texas Central Railroad says it is trying to reach buyout agreements with landowners on the route, about 30 landowners have refused to allow rail surveyors onto their property. Texas Central sued one landowner and lost after the judge sided with the defendant who argued Texas Central was not a railroad because it had not laid any track in Texas, so it did not have the right to eminent domain. Texas Central plans to appeal (Bliss, 2019). Meanwhile, high-speed rail is running into opposition in the state legislature, where dozens of bills have been filed in an effort to stop the project. These bills would, for example, prevent high-speed rail companies from surveying land until they had complete funding, prevent state agencies from issuing permits until the rail had an "alphabet soup" of federal permits, or prevent the Texas Department of Transportation from working on state highway crossings until the company could affirm it had power of eminent domain (Sundaram, 2019). Currently it is unclear what the outcome of this legal wrangling will be.

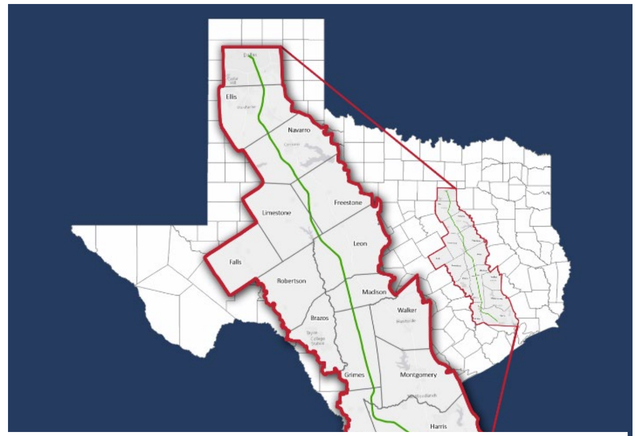

Fig. 4. Texas Central Railway route (texascentral.com)

Potential of high-speed rail to lower carbon emissions

One of the major goals of the Green New Deal is to achieve net-zero greenhouse gas emissions, and one of the major projects for how to do that is “overhauling transportation systems in the United States to remove pollution and greenhouse gas emissions from the transportation sector as much as is technologically feasible, including through investment in … high-speed rail” (Ocasio-Cortez, 2019). So what is the potential for high-speed rail to lower carbon emissions in the United States? To understand that, one must first understand the source of emissions.

According to the U.S. Environmental Protection Agency, the transportation sector accounted for the largest share of greenhouse gas emissions at 29% of all emissions in 2017 (USEPA, 2019a). The U.S. Energy Information Administration also places transportation at 29% of overall greenhouse gas emissions in 2017 and 28% in 2018, but EIA counts emissions sectors differently, placing transportation second after the industrial sector (USEIA, 2019a). Both organizations agree that almost all energy used for transportation comes from petroleum-based products, with more than half due to gasoline consumption in automobiles. Other fuels such as diesel fuel for freight trucks, jet fuel for aircraft, biofuels, and natural gas accounted for the rest (USEPA, 2019b; USEIA, 2019b). In raw numbers, emissions from transportation accounted for 1,804 million metric tons of carbon dioxide equivalent (CO_2e) in 2017, according to the EPA (2019c). According to the EIA, the transportation sector emitted 1,888 million metric tons of CO_2 (not CO_2e) in 2017 and 1,915 million metric tons of CO_2 in 2018 (USEIA, 2019c).

Looking at trends over time, transportation emissions peaked in 2005 at 1,861 million metric tons CO_2e before falling slightly until 2012, but have been rising again since then. Emissions from transportation are now almost up to 2005’s peak, and 22% higher than in 1990, according to the EPA (2019c). The EIA puts the peak of transportation emissions at 2,018 million metric tons of CO_2 in 2007, falling slightly until 2012, then rising so that CO_2 emissions are again close to peak levels. Emissions from transportation are now 21% over 1990 levels and

45% over 1973 levels, according to the EIA (2019c). This increase is mainly due to increased demand for travel. The number of miles driven by personal vehicles increased 45.1% from 1990 to 2017, as a result of population growth, economic growth, urban sprawl, and periods of low fuel prices, according to the EPA (2019b). The EIA notes that even though fuel efficiency standards for passenger cars and light-duty trucks have improved over time, total gasoline consumption has gone up because people are driving longer distances and more vehicles are on the road, especially light-duty trucks such as sport utility vehicles, pickup trucks, and minivans that have lower gas mileage, since the 2008 economic recession (2019b).

Sources of transportation-related greenhouse gas emissions in 2017, according to the EPA, included passenger cars (41.2%); freight trucks (23.3%); light-duty trucks (17.5%); commercial aircraft (6.9%); other aircraft (2.4%); ships and boats (2.4%); rail (2.2%); and pipelines (2.2%) (USEPA, 2019b). Thus, almost 60% of transportation-related emissions in the United States come from personal vehicles – cars, trucks, sport utility vehicles, and minivans, and almost one-fourth of emissions come from transportation of freight in trucks. Less than 10% of transportation-related emissions in the United States are from air travel. This means that 17% of **all** greenhouse gas emissions in the United States comes from personal vehicles, while only 2.7% comes from airplanes, according to the EPA. The EIA uses different data but reaches similar conclusions. In 2017, Americans consumed an average of 14,016 barrels of oil each month, of which 8,988 barrels, or 64%, was motor gasoline and 1,682 barrels, or 12% was jet fuel. In 2018, Americans consumed an average of 14,158 barrels of oil each month, of which 8,981 barrels, or 63%, was motor gasoline and 1,711 barrels, or 12% was jet fuel (USEIA, 2019c). The EIA put transportation at 28% of all greenhouse gas emissions in 2018, meaning that 17.6% of all emissions in the United States came from personal vehicles while 3.4% came from air travel that year. Thus for both EPA and EIA, car travel accounts for five to six times as much fuel use and greenhouse gas emissions as air travel in the United States.

The next question is: How much car travel and air travel could be transferred to high-speed rail if it were widely available in the United States? In other words, what is the potential for modal shift of passengers to select high-speed rail over other modes of transportation such as cars and airplanes? The U.S. High Speed Rail Association sees high-speed rail as part of a complete transportation system, with cars for distances under 100 miles, rail for distances 100 to 1000 miles, and planes for distances over 1000 miles and overseas travel (see Fig. 5). The Federal Railroad Administration has envisioned "an efficient, high-speed passenger rail network of 100- to 600-mile intercity corridors, as one element of a modernized transportation system" (FRA, 2009). America 2050's report "High Speed Rail in America" envisions high-speed rail transporting passengers not across the country but between cities in distinct "megaregions" (see Fig. 6) (Hagler and Todorovich, 2009; Todorovich and Hagler, 2011). Virgin Trains, now constructing high-speed rail in Florida, aims to tie together heavily populated cities separated by 200- to 300-mile distances that are "too long to drive, too short to fly" (Egan, 2019). Thus, while high-speed rail would not make air or car travel obsolete, its backers say it has the potential to displace a significant amount.

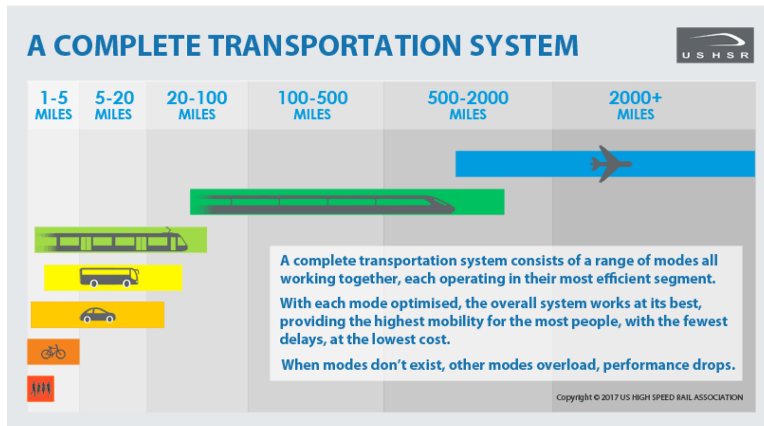

Fig. 5. Complete Transportation System (USHRSA, 2017)

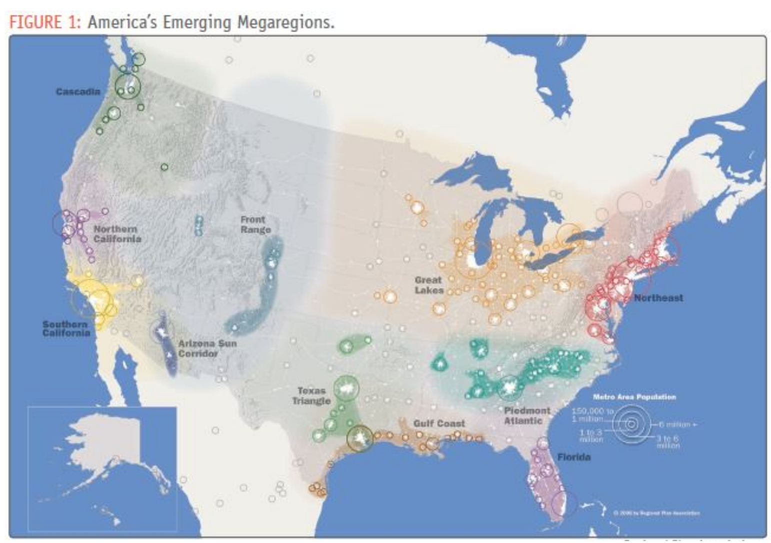

Fig. 6. America's Emerging Megaregions (America 2050, 2011)

Peer-reviewed research on competition and complementarity between high-speed rail and air travel provides strong evidence for this assessment. Givoni and Dobruszkes (2013) reviewed existing literature on modal shift, citing nine studies of mode shares and passenger counts before and after high-speed rail lines were introduced in countries around the world. The findings were decisive: On route after route, ridership for airlines declined significantly, and in some cases airlines suspended service altogether. For example, out of Paris, the number of airline passengers to Marseilles declined by 42%, to Lyons by 50%, to Brussels by 88%, and to Metz by 100%. Out of Madrid, the number of airline passengers to Barcelona declined by 22%, to Malaga by 25%, to Seville by 57%, and to Zaragoza by 75%. Out of Taipei, the number of airline passengers to Kaohsiung declined by 80%, to Tainan by 84%, and to Chiayi and Taichung by 100% each. Out of Guangzhou, China, the number of airline passengers to Wuhan declined by 50%, and to Changsha by 67%. Out of Seoul, the number of airline passengers to Busan declined by 54%, and to Daegu by 100%. And from Brussels the number of passengers flying to London declined by 55% after high-speed rail was introduced on that route.

Subsequent research reached similar conclusions. Using monthly ridership data in Taiwan, Y. Li et al. (2015) found that after the introduction of high-speed rail in 2004, market share for airlines fell an average of 7.22% each year but increased an average of 19.45% each year on high-speed rail between 2005 and 2012. H. Li et al. (2019) examined 642 air and high-speed rail routes in China, finding striking evidence that high-speed rail reduces demand for air travel. From 2010 to 2014, the number of airline passengers on routes without competition from high-speed rail rose 15% but fell 10% on routes with competition from high-speed rail. “In 2008, air carried 20 times as many passengers as high-speed rail, but by 2010, high-speed rail had grown to half as many passengers as air travel. In 2015, high-speed rail surpassed air, transporting more than double the number of air passengers,” the researchers wrote. Finally, examining 30 routes in China, R. Zhang et al. (2019) found that rather than increasing the frequency of flights to compete with high-speed rail, airlines lowered flight frequency by 60.2%.

Givoni and Dobruszkes argue that the main reason for these high rates of modal shift is travel time, specifically door-to-door time to get from origin to destination. Airports are typically located on the outskirts of large cities, meaning people must plan how to get to the departure airport, then time to get through ticketing and security, then time once they land to get from the airport to the location of their business in the destination city. High-speed rail, on the other hand, typically departs and arrives in city centers, so there is much less extraneous time spent on other parts of the trip. Follow-up research backs up the importance of travel time in the switch from air to high-speed rail. Besides citing nine previous studies that found travel time is the most important factor in modal shift, Dobruszkes et al. conducted their own analysis of 161 routes EU-wide to see how air service was impacted by the introduction of high-speed rail. They found that high-speed rail travel time had a strong significant impact on provision of air services -- the lower the travel time, the fewer flights – but that this effect tapered off after high-speed rail reached travel times of 2.5 hours, and fell after travel times reached 4 hours.

In examining travel data between 24 origin-destination city pairs in Japan, Fu et al. (2014) found that rail took 53% of market share of distances 300 to 500 km and 69% for distances 500 to 700 km, while air took 56% of market share in distances 700 to 1000 km, and 93% for distances over 1000 km. Travel time was the leading determinant for these modal choices. A reduction of 10% in travel time for rail led to a reduction of 7.04% in demand for air, while reducing rail travel time by 50% led to a reduction of in demand for air travel of 27.33%. Customers were willing to pay $42 additional on ticket price to save an hour of travel time. Danapour et al. (2018) surveyed 437 airline travelers in Iran to see what might get them to switch to a proposed high-speed rail line between Tehran and Isfahan. They found travel time as the most important variable, though ticket price, seat comfort, and food service also played a role.

Finally, F. Zhang et al. (2018) constructed a dataset of domestic air and high-speed rail routes in Japan, South Korea, Taiwan, and China. They found that modal shift from air to high-speed rail was mainly felt in short- to medium-haul markets (below 1000 km), and most significant in short-haul routes (below 500 km); however, for long-haul markets over 1000 km, high-speed rail could actually encourage air travel by providing easier access to the airport.

Although airlines and high-speed rail often compete for passengers, they can also work together in an arrangement known as complementarity. This arrangement can work to the advantage of both the airlines, which dominate the long-distance market, and high-speed rail, which replaces short-haul feeder flights. Complementarity can be done either through cooperation, in which airlines and high-speed rail operate separately but have a friendly understanding of which one dominates which market, or through integration, in which one entity controls ticket sales and luggage transfers so that passengers experience both the high-speed rail and air travel legs as part of a seamless trip (Givoni and Banister, 2006). Currently four airports in Europe act as hubs for integrated travel by air and high-speed rail: Frankfurt Main, Paris Charles de Gaulle, Madrid Barajas, and Amsterdam Schiphol (Janic, 2011). In Frankfurt, Lufthansa offers AIRail service from 14 cities. Passengers buy a single ticket, then pick up their luggage at their final destination (Socorro and Viecens, 2013).

Research finds complementarity between air and high-speed rail to be advantageous to both. Givoni and Banister (2006) found that for airlines, integration frees up capacity and improves hub and spoke connections; for rail, integration increases demand and shifts passengers from other modes; and for airports, integration eases congestion and improves accessibility. They looked especially at the role London Heathrow could play as a hub airport. With integrated high-speed rail service to Manchester, Leeds, Brussels, Newcastle, and Paris, Heathrow could free 10% to 20% of its capacity, which would reduce congestion, reduce the need for a proposed third runway, save time for passengers, and result in a significant reduction of greenhouse gas emissions, they found. Janic (2011) looked further into the potential for integration at Heathrow, modeling the replacement of flights less them 750 km with high-speed rail. He found that shifting five flights per hour (85 per 17-hour day or 70% of short-haul flights) to high-speed rail would eliminate congestion, reduce CO_2e emissions by 300 tons per day, and save €2 million in external costs. Socorro and Viecens (2013) found that integration of air and high-speed rail enhances welfare the most for capacity-constrained airports, but even airports with low competition would see greater competition, lower prices, more variety for consumers and, therefore, higher social welfare. F. Zhang et al. (2018) found that integration increases enplanement at hub airports for long-distance flights. Givoni and Banister (2006) pointed out that even if integration results in more long-haul flights, it would not outweigh the environmental benefit resulting from shifting many more short- and medium-haul flights to high-speed rail.

Clearly high-speed rail has the potential to make a significant dent in short- and medium-distance air traffic. However, as previously noted, air travel makes up only about 10% of transportation-related carbon emissions in the United States, while car travel makes up about 60%, or 17% of all greenhouse gas emissions in the country. Unfortunately, little research has been conducted about the potential for high-speed rail to cut into travel by car. Givoni and Dobruszkes (2013) found a shift of 10% to 20% from car to high-speed rail on routes they examined in Europe and Asia, but noted that overall demand for car travel is increasing. Sung et al. (2014) found that Koreans are more likely to choose high-speed rail over private car as distances increase, at peak morning departure hours, at ages in their 20s or 60s, at higher incomes for business travel or housewives for leisure travel, or if they live in an apartment and don't own a car. Kamga and Yazici (2015) noted similar trends in the United States, where young Americans are driving less, buying fewer cars, and settling in urban areas where they can walk, bike, and use public transit, while baby boomers are also seeking alternatives to car dependence as they grow older. They cited a sharp decline in vehicle miles driven and in percentage with driver's licenses among youth ages 15 to 19 since 1983 to make their case. Y. Lee et al. (2015) found in Taiwan that car ownership has risen to 30% since 2010, and that owning a car is negatively correlated to choosing high-speed rail for intercity travel. Finally, one often overlooked sector for shifting travel from road vehicles to high-speed rail is freight. Pazour et al. (2010) found that in a scenario with a high-speed rail network of 20,000 miles, or about half the U.S. interstate system, a majority of freight traffic would switch to high-speed rail, reducing freight travel time by 38% and total truck highway miles driven by 78%.

Due to the dearth of research, and to the dissimilarity between the United States, where the majority of travel is done by private vehicle, and countries in Europe and Asia with high-speed rail, most of which already had an extensive conventional rail system, it is difficult to judge the extent to which high-speed rail could replace car travel. Government agencies and private companies that are building high-speed rail in the United States have looked into this issue, but have widely varying estimates of modal shift for their projects. For example, the California High-Speed Rail Authority has estimated ridership over time in the various regions of its high-speed rail project. They placed ride share between 0.5% and 9.8% in 2029, between 0.6% and 25.6% in 2033, and between 0.5% and 26.5% in 2040 (CHSRA, 2018b). Given transportation patterns in California, much of this ridership would likely come from private cars. Meanwhile, Texas Central forecasts more than 6 million passengers on its line between Dallas and Houston by 2029 and more than 13 million by 2050 – or 35% of the market, which in Texas would almost entirely be shifted from car travel. Finally, Virgin Trains in Florida has a much lower forecast for its line – the only one in current operation. They are aiming for 2.9 million trips between Miami, Fort Lauderdale, and West Palm Beach – only 0.74% of the 365 million trips per car between the three cities each year – and do not make forecasts beyond that (Next Miami, 2017). Clearly ridership forecasts are all over the place, and much more research on the potential of high-speed rail to shift passengers specifically from car travel is needed.

High-speed rail, climate, and environment

A second set of questions about high-speed rail focuses on greenhouse gas emissions and environmental impact, both as compared to other forms of travel such as air, and in the life-cycle of high-speed rail itself. Here again the results are mixed, but do show potential for high-speed rail to lower overall carbon emissions. Two papers compared the operations of high-speed rail and air, both finding high-speed rail to have much lower greenhouse gas emissions and overall lower environmental impact. Givoni (2007) looked specifically at high-speed rail and air travel between London and Paris, examining both local air pollution and climate change impacts. For local air pollution he found that air is much higher on all but SO_2 emissions due to the coal burned to create electricity to power rail. The overall cost of damage is €1.03 per seat for air and €0.52 for high-speed rail. For climate change impacts, he found that air travel emits 44,095 grams of CO_2 and 41,363 of NO_2 per seat, while high-speed rail emits 7,194 grams of CO_2 and 53 grams of NO_2 per seat. The cost of damage from these emissions is €2.21 for air and €0.29 for high-speed rail. Dalla Chiara et al. (2017) have similar results. Using simulations of high-speed rail and air travel in Europe, they found that high-speed rail consumes 0.023 to 0.058 kilowatt hours of energy per passenger per kilometer, while travel by business jet consumes 1.5 to 4.2 kilowatt hours per passenger per kilometer; travel by regional turboprop jets consumes 0.24 to 0.92 kilowatt hours per passenger per kilometer; and travel by regional turbofan jets consumes 0.38 to 1.38 kilowatt hours per passenger per kilometer, all depending on distance from 150 km to 800 km. Because all types of planes studied use about 1000 kg of fuel to climb to flying altitude, shorter distances require much more energy per passenger kilometer because the plane spends much less time in flight. Only after 1000 km does the amount of fuel spent cruising surpass the amount spent climbing, suggesting that plane travel should be reserved for distances of 1000 km or more. Yet even at longer distances of 800 km, high-speed rail uses 15 to 72 times less energy per passenger per kilometer than do various types of aircraft.

Two other papers attempt to measure the actual reduction in greenhouse gas emissions from high-speed rail. Krishnan et al. (2015) used National Long-term Energy and Transportation Planning (NETPLAN) software to model transportation infrastructure investment over 40 years to move both passengers and freight in the United States under a renewable energy-friendly scenario. They found feasible scenarios for high-speed rail penetration of 30% that could result in a cost savings of up to $630 billion, reduction of gasoline and jet fuel consumption by 34%, and reduction of CO_2 emissions by 800 million short tons (equivalent to 726 million metric tons). As noted previously, the EIA put all U.S. transportation emissions at 1,888 million metric tons of CO_2, which means the scenario outlined by Krishnan et al. could reduce these emissions by 40%. In Turkey, Dalkic et al. (2017) found a reduction of only 24,300 metric tons of CO_2 from two lines of high-speed rail, noting that the lines are short and mostly caused modal shift from bus. Turkey has four lines of high-speed rail and is building two more; if estimated ridership is realized on all lines, CO_2 emissions could be reduced by 452,700 metric tons. Even more CO_2 reductions could take place if high-speed rail could create a network rather than a corridor effect, and if policies could be developed to shift passengers from car and air, the researchers said.

Another set of research examines the life cycle impact of high-speed rail, considering not just operations but also manufacture, maintenance, and disposal of the rolling stock, and construction and maintenance of the stations and tracks, as well various types of environmental impact beyond greenhouse gas emissions. An early life-cycle analysis by Akerman (2011) examined Europabanan, a proposed high-speed rail track in Sweden, finding an overall reduction of 550,000 tons of CO_2e per year by 2030. Like Pazour and Krishnan, Akerman included freight in his analysis, finding it could account for 60% of the mode shift to high-speed rail, with the other 40% from air and road travel. Also examining carbon emissions across the life cycle was Cornet et al. (2018), who evaluated a proposed high-speed line from London to Birmingham, then on to Manchester and Leeds. They found that construction of the proposed route would create 5.6 megatons of CO_2e, mainly because tunnels would be used through the Chilterns Area of Outstanding Natural Beauty. Noting that it would take the Chilterns ancient forests 800 years to sequester this much carbon, the researchers recommended moving the route to travel along an existing roadway that bypasses the Chilterns, even though train speeds would be slightly slower.

Yue et al. expanded the environmental impacts examined for their life-cycle analysis of high-speed rail in China to include not just global warming potential (measured by CO_2e emissions), but also acidification potential (measured by sulfur dioxide emissions), abiotic depletion potential (measured by coal resources equivalent required), primary energy demand (measured by standard coal equivalent required), chemical oxygen demand (measured by oxygen required), eutrophication potential (measured phosphate released), and respiratory inorganics (measured by fine particulate matter emitted). Using the Chinese Core Life Cycle Database, they found that most of the impact of high-speed rail occurs during operation, mainly due to the high amount of coal in the energy mix that generates the electricity emitting high amounts of sulfur dioxide, nitrous oxides, carbon dioxide, and particulate matter. Abiotic depletion potential – that is, depletion of non-living things such as minerals – was related mainly to the use of copper in manufacturing the rolling stock. Chemical oxygen demand was related mainly to the use of steel in infrastructure construction, especially for bridges, as oxidation of impurities in pig iron is required to make steel. Yue et al. also examined the effect of various scenarios on these impacts. Fewer bridges greatly reduced the impact on chemical oxygen demand, while increasing the amount of hydropower, nuclear, and wind in the energy mix resulted in significant decreases in global warming potential, particulate matter, acidification potential, primary energy demand, and eutrophication potential, though additional wind power also increased abiotic depletion due to manufacture of turbines (the researchers did not assess solar power). High penetration of high-speed rail and high utilization scenarios both significantly reduced impacts per passenger across all categories, underscoring the importance of high occupancy and network effect.

Finally, Chester and Horvath conducted two life-cycle studies of high-speed rail in California. Their 2010 paper compared life-cycle impacts of high-speed rail with cars, conventional rail, and air travel, examining energy consumption, greenhouse gas emissions, and emissions of pollutants such as sulfur dioxide in both high and low occupancy scenarios. They found that vehicle operations accounted for the majority of energy consumption and greenhouse gas emissions in all four types of transit, though infrastructure (due to concrete and steel) and fuel production (due to use of fossil fuels) were also significant. High-speed rail was responsible for much higher sulfur dioxide emissions than other modes, due to the coal needed to generate electricity. The most significant variable was occupancy rate. At low occupancy (10% of seats filled), high-speed rail would require as much energy per passenger kilometer as air and conventional rail, and half again as much as traveling by car; it also was responsible for more carbon emissions at low occupancy than any of the other three modes. At high occupancy (100% seats filled), however, high-speed rail would use less energy per passenger kilometer than any other mode. In 2012, Chester and Horvath updated their research to project impacts to 2040 by recalculating the life cycles of cars to include models that get 55 miles per gallon and electric vehicles; of air travel to include next generation fuel-efficient aircraft; and of high-speed rail to include electricity generated from high percentages of renewable energy, including a scenario with 80% wind and 20% solar. Again, occupancy rates played a big role in carbon emissions per passenger kilometer traveled. At high occupancy rates, high-speed rail had by far the lowest CO_2e emissions per passenger kilometer, though even at low occupancy rates, high-speed rail emitted less CO_2e than other modes when relying on most or all renewable energy. Chester and Horvath conclude that while high-speed rail has the potential to reduce transportation impacts on the environment, in order to meet that potential, construction should minimize the use of concrete and steel, electricity generation should include high percentages of renewable energy, and service must be deployed with accessibility and frequency that ensures high ridership.

Equity impacts of high-speed rail

High-speed rail would likely displace a significant amount of short- and medium-haul air travel, could displace a significant amount of car travel, and has the potential to significantly reduce carbon emissions, even when considering the entire life cycle. But what is its effect on equity? How does high-speed rail affect the cities where it stops, and those where it doesn't? One of the strongest arguments for high-speed rail is that faster travel times give people greater access to economic, recreational, and social opportunities. But does that actually pan out? The research points to a qualified yes, but under the right conditions and with some exceptions.

Wang and Duan (2018) took on this question by examining high-speed rail in the Yangtze River Delta megaregion in China, which has 192 rail stations, of which 122 stations can accommodate high-speed rail, in 99 counties across four provinces. Using a multiscalar spatial analysis resolved to a 100 meter by 100 meter grid, the researchers calculated door-to-door travel time, including travel to and from the rail station, to compare accessibility on conventional and high-speed rail. Through this comparison, they were able to identify seven types of winner and loser cities based on relative gains or losses in accessibility. Characteristics of winner cities included 1) megacities like Shanghai with several rail stations, 2) cities where conventional rail was upgraded to high-speed rail, 3) cities with no rail service before high-speed rail, and 4) small cities that benefited from nearby high-speed rail stations. Characteristics of loser cities included 1) cities where the high-speed rail station was too far from the city center, 2) cities with conventional rail only, and 3) cities with no rail of any sort. Wang and Duan conclude that while high-speed rail significantly improves regional accessibility and connectivity, it also creates an uneven landscape of winners and losers and generates a powerful core-periphery structure.

Yu and Fan (2018) used a similar door-to-door spatial analysis to evaluate travel times and accessibility for the proposed high-speed rail corridor in the Piedmont Atlantic megaregion of the United States. They examined three stages of construction: Stage 1, with no high-speed rail; Stage 2 that would build high-speed rail from Raleigh, N.C., to Atlanta, running through Greensboro, N.C., Charlotte, N.C., and Greenville, S.C.; and Stage 3, which would extend the line from Atlanta to Birmingham, Ala., as part of a broader network connection to Florida. Overall they found that high-speed rail would significantly improve accessibility across the megaregion, but as in China it would also increase inequality between the areas that had high-speed rail and those that did not. For example, overall high-speed rail would shorten travel times by 24% during off-peak hours and 29% during peak hours in Stage 2, and by 29% during off-peak hours and 35% during peak hours in Stage 3. It would increase accessibility to economic, recreational, and social opportunities overall by 40% during off-peak hours and 56% during peak hours in Stage 3. Some cities would have even greater accessibility improvements; for example, Greenville's accessibility would improve by 124% because it is between the two largest cities, Atlanta and Charlotte, and Birmingham's accessibility would improve 114% once it was hooked up to the high-speed rail network. However, counties not close to a high-speed rail station would not see such improvements; the longer the travel time to the nearest station, the lower the county accessibility score. The researchers also used coefficient of variation to measure inequality. In general, the smaller the county population was, the higher its inequality score. The effect was more pronounced in Stage 2 – expanding the network in Stage 3 brought the inequality measures back to almost the level they were with no high-speed rail. Yu and Fan made several suggestions for how to address the increases in spatial inequality brought about with high-speed rail, including shortening travel time even more by speeding up trains and reducing wait times at stations; improving the highway infrastructure leading to train stations; and improving public transit within cities so people can more easily get to their final destination.

A third study by Deng et al. (2019) examined how high-speed rail can affect spatial distribution, examining 43 cities in China that lost population from 2006 to 2015. They found that while high-speed rail can centralize populations and promote economic development in cities that are doing well due to an agglomeration effect, it can also drain populations from cities that are doing poorly through a siphoning effect. The 43 cities studied were already losing population either because they were mining towns that had run out of resources or manufacturing towns where factories had closed. High-speed rail significantly increased the population outflow, although the effect was delayed by four to five years. To counteract this trend, Deng et al. recommended that state governments put strong urban development policies in place to create pillar industries in shrinking cities, and that local governments take advantage of high-speed rail to promote regional cooperation and collaboration to revitalize their cities.

Other research examining the effect of high-speed rail found it could increase specific aspects of well-being, thus increasing quality of life that underlies equity. For example, Choi et al. (2019) found that the introduction of high-speed rail in Korea almost doubled the number of outpatients from rural areas traveling to receive cancer treatment in Seoul, from 1.1 per month to 2.1 per month. Although higher-income rural patients were more likely to seek treatment in Seoul, high-speed rail did enable more people to receive specialized care than previously could, thus improving health outcomes. Likewise, Yin et al. (2019) found that small cities, even end-line cities, on high-speed rail lines in China experienced a significant increase in tourism due to decreased travel times, thus providing an opportunity for economic and tourism development they would not have had without high-speed rail. Chen and Wang (2019) examined the impact of severe weather on high-speed rail and air travel in China. Based on on-time performances, they found high-speed rail is less vulnerable to severe weather than air travel, an important consideration for economic development during a time of climate change. Finally, Kamga and Yazici (2014) argue that technological improvements within the current U.S. paradigm, such as fuel-efficient cars, hybrids, and electric vehicles, are not enough to address systemic challenges, and that high-speed rail is needed to achieve a more diversified, sustainable, resilient, and balanced multimodal transportation system for the 21st century.

Conclusions and recommendations

The United States is facing twin crises of climate change and inequity. Climate scientists say we must cut carbon emissions in half by 2030 and to zero by 2050 if we are to have a livable planet, and economists say inequality has reached levels not seen since the Great Depression. The Green New Deal was proposed as a way to address both issues, and high-speed rail is perhaps the most recognizable signature program that could be developed under its umbrella. High-speed rail does have potential to significantly reduce carbon emissions as well as to address inequality, but it must deployed in the right way for this to happen. Based on the research cited, here are some recommendations for policymakers to optimize its effectiveness:

- Do not attempt to build a national network of high-speed rail all at once. Rather, concentrate on smaller networks in megaregions with cities 300 to 600 miles apart. High-speed rail works best in the "sweet spot" that is "too long to drive, too short to fly."
- Invest first in areas where ridership will be high. Design schedules and frequencies for maximum use. Strive for networks rather than single lines to achieve economies of scale.
- Plan routes that require fewer bridges and tunnels, preferably along existing roadways. This will minimize environmental impact and make it easier to gain rights of way.
- Locate stations in city centers to stimulate economic development, but invest in affordable housing or pass rent control laws to keep citizens from being priced out.
- Invest in public transportation within cities to solve the "first mile, last mile" problem. Consider buses or other transportation to nearby towns not on high-speed rail lines.
- Consider stops at major airports to increase complementarity with air travel. This will decrease resistance from airlines and increase ridership and benefits for travelers.
- Ensure the electricity powering high-speed rail is from most or all renewable energy.
- Do not overlook the role of freight. Transferring freight to high-speed rail would not only stimulate its development, but also significantly lower carbon emissions from shipping.

Sampling of research on competition between high-speed rail and air travel

Article	Region	Time Frame	Method	Main findings
Givoni and Dobruszkes, 2013	Europe and Asia	2000-09	Review of existing literature	HSR can attract large shares, often all, of the demand for travel on a particular route. This is mainly a factor of route distance and travel time. On the Tokyo-Fukuoka route, for example, travel time is too long for HSR to effectively compete with air and its share was only 12% in 2009. But on the Frankfort-Cologne, Paris-Lyons and Paris-Avignon routes, HSR has captured almost of all the market.
Dobruszkes et al.., 2014	Europe	2011	Ex-post analysis of 161 routes using transnational data	HSR travel time is found to have a strong significant impact on the provision of air services; that is, lower HSR travel times involve less air service. This result confirms that HSR helps to restrict the provision of air services when travel time is not too high. HSR travel time has much more impact on air services than HSR frequency. This suggests that passengers prefer fast services over frequent services.
Fu et al.., 2014	Japan	2005	Survey data from 24 origin-destination markets	(a) There is clear product differentiation between air and rail travel; (b) Japanese consumers are sensitive to travel time and frequency; (c) The proposed Tokyo-Osaka HSR services would drive airlines out of the route while stimulating substantial new traffic; and (d) CO_2 taxation would have a moderate impact on modal shift.
Li, Y. et al.., 2015	Taiwan	2007-13	Monthly ridership data	After HSR introduction, market share shifted between travel modes. Private cars, buses, and airlines experienced negative trends while conventional rail demand remained stable in the first year. Average annual growth since 2005 is 0.04% for cars, -3.43% for buses, 3.86% for conventional rail, -7.22% for airlines, and 19.45% for HSR.
Danapour et al.., 2018	Iran	2015	Survey regarding planned HSR from Tehran to Isfahan	Travel time, ticket price, convenience, and hospitality all influenced choice between air and rail; however, travel time is the most important variable. In addition, long durations of trips, ticket prices, lack of food services, and highly packed arrangements of seats decreased utility of high-speed rail versus air transport.
Zhang, F., et al.., 2018	China, Japan, South Korea, Taiwan	2000-14	Difference in difference, dataset constructed from air and HSR data in each country	Substitution effect of HSR on air travel demand is mainly felt in short- and medium-haul markets (within 1000 km), and the effect is the most significant in short-haul routes (below 500 km). HSR may encourage long distance air travels (over 1000 km). Airport distance from city center is a critical factor in predicting travel mode.
Li, H., et al.., 2019	China	2007-14	Dataset of 642 air and HSR routes; difference in difference approach	In 2008, air carried 20 times more passengers than HSR, but by 2010, HSR had grown to half as many passengers as air. In 2015, HSR surpassed air, transporting more than twice the passengers. For HSR routes more than 4 hours or 1000 km, the negative impact on air declines by half. HSR has little effect on longer air travel routes.
Zhang, R.., et al.., 2019	China	2016	Ex-post analysis using dataset of 30 routes	Competition with HSR can induce air to reduce fares and frequencies greatly: Air fares are 34% lower and air frequencies are 60.2% less on routes with HSR. Air fares and frequencies are found to be higher on routes with lower HSR frequencies and lower air travel times.

Sampling of research on complementarity/integration between high-speed rail and air travel

Article	Region	Time Frame	Method	Main findings
Givoni and Banister, 2006	UK – London Heathrow Airport	n/a	Policy discussion	This paper examines the potential for integration of air and HSR at Heathrow airport. The conclusion is that some railway infrastructure should be seen as part of the air transport infrastructure. On HSR routes under 600 km, the operation of airline and railway integration is beneficial to airlines, passengers and the environment.
Janic, 2011	UK – London Heathrow Airport	n/a	"What-if" scenario	Models replacement of flights less than 750 km with HSR going 250 kph. Finds congestion would disappear if five flights per hour (70% of short-haul flights) were substituted with HSR. Substitution in morning flights has most impact. Relieving congestion would save up to 2M Euros and up to 300 tons of CO_2e in emissions per day.
Socorro and Viecens, 2013	Spain – Madrid-Malaga route	n/a	Theoretical model	This paper examines airline and HSR integration in two scenarios. It finds that integration is more likely to enhance welfare at capacity-constrained airports, but even for airports with low competition, integration may result in greater competition, lower prices, more variety for consumers and, therefore, higher social welfare.
Zhang, F., et al.., 2018	East Asia and Central Europe	2000-16	Difference in difference, 180 airports in Central Europe, 170 airports in East Asia	Finds air-HSR integration has significantly positive impacts on enplanement at primary hub airports (91% difference between integrated and non-integrated), but limited impact at secondary hubs and regional airports (67% difference) due to less service frequency. Frankfurt and Paris Charles de Gaulle are among the pioneers.

Sampling of research on high-speed rail and car travel

Article	Region	Time Frame	Method	Main findings
Pazour et al, 2010	US freight	2002	Data from U.S. Census Commodity Flow Survey and J.B. Hunt Transport Services	Found that a high speed network for freight distribution could have a significant impact on freight transit times and highway congestion. In a scenario with a 20,000 mile HSR network (half of the U.S. interstate system), a majority of freight traffic would find it advantageous to switch to HSR. That would reduce overall freight times 38% and reduce total truck highway miles driven by 78%.
Givoni and Dobruszkes, 2013	Europe and Asia	2000-09	Review of existing literature	The effect of HSR on car travel seems more modest than on other modes. The reduction in the number of passengers on the routes examined is in the order of 10 –20%. Given the general trend in most countries of increase in demand for car travel over time[7], it is difficult to discern the actual effect of HSR.
Sung et al, 2014	Korea	2010	National Household Survey	Users are more likely to choose HSR over private car as distance increases, at peak morning departure hours, at age in 20s or 60s, at higher incomes if for business travel or housewives for leisure travel, or if live in an apartment and don't own a car. Population and employment density of destination city is most important factor.
Kamga, 2015	US	n/a	Policy discussion	This paper suggests that deploying HSR in the U.S. could help accelerate a transportation paradigm shift. This shift is notable among young Americans who are driving less, buying fewer cars, and settling in urban areas where they can walk, bike, and use public transport, and baby boomers as they grow older and seek mobility alternatives to car dependence. Using the success of passenger rail in the Northeast Corridor, this paper examines how HSR could rebalance the three main passenger modes - road, air, and rail - so that each flourishes within its most sustainable niche.
Li, Y. et al, 2015	Taiwan	2007-13	Monthly ridership data	Data show that in 2007 there were 29.6 cars per 100 Taiwanese, then ownership declined in 2008 until nearly the end of 2009. Since 2010 the ownership has been rising again and has reached 30% by the middle of 2011. The relationship between HSR and car ownership is found to be negatively significant, suggesting that if one owns a car this has also influence on inter-city travel mode choice.

Sampling of research on high-speed rail and climate/environment

Article	Region	Time Frame	Method	Main findings
Givoni, 2007	London-Paris route	n/a	Five consecutive steps leading to measurement of environmental impact in monetary units	This paper compares local air pollution and climate change impacts for air and HSR between London and Paris. For local air pollution it examines five pollutants, finding air is much higher on all but SO_2 emissions from coal used to create electricity to power rail. The cost of damage is €1.03 per seat for air, €0.52 for rail. For climate change impacts, it finds air emits 44,095 grams per seat CO_2 and 41,363 NO_2, while rail emits 7,194 grams per seat CO_2 and 53 NO_2. The cost of damage from these emissions is €2.21 for air and €0.29 for rail.
Zanin et al.., 2012	Spain – Madrid Barajas Airport	n/a	User preference model for passengers going by car from anywhere in Spain to Barajas Airport	Paper supposes a new gas tax is introduced to discourage car travel; the cost is increased from 0.2 €/km to 0.202 €/km, or a 1% increase. It finds a reduction in CO_2 emissions near Madrid or wherever a high-speed rail station exists, but CO_2 emissions increase in areas far away from the center or that do not have a high-speed rail. In those regions, aircraft are the only alternative transportation mode. Users will therefore switch to air transport, with a negative overall result.
Krishnan et al.., 2015	US	n/a	Model using NETPLAN software	This paper studies the impact of investment in HSR over 40 years. It finds feasible scenarios for HSR penetration of 30% that could result in a cost savings of up to $0.63 trillion, reduction of gasoline and jet fuel consumption by 34%, reduction of CO_2 emissions by 0.8 billion short tons, and increased resilience against petroleum price shocks.
Dalkic et al.., 2017	Turkey	n/a	Compares CO_2 emissions on two current and five planned HSR lines with a no-HSR scenario	HSR caused a total reduction of 24.3 kilotons CO_2 on two current corridors, with a potential reduction of 452.7 kt CO_2 by 2023 if estimated ridership is realized on all lines. HSR performance in reducing CO_2 emissions is currently limited as high-demand HSR lines serve short routes with modal shift mostly from bus service.
Dalla Chiara, et al..., 2017	Italy	n/a	Bibliographical review, simulations using EUROCONTROL Small Emitters Tool, Lissys Ltd. Piano-X, and EUROCONTROL Advanced Emission Model	This paper quantifies and compares energy consumption of HSR with air, determines ranges in which operating these modes is beneficial, and where there is still competition. For HSR it finds energy consumption in a range of 0.023 to 0.058 kilowatt hours per passenger kilometer. For air it finds energy consumption in a range of 1.5 to 4.2 kwh/seat km for business jets, 0.24 to 0.92 kwh/seat km for regional turboprop jets, 0.38 to 1.38 kwh/seat km for regional turbofan jets, and 0.30 to 0.34 for medium-haul aircraft, depending on distance of trip. HSR is preferable for distances up to 1000 km, but air is preferable at longer distances because of its greater speed.

Sampling of research on life cycle assessment (LCA) of high-speed rail

Article	Region	Time Frame	Method	Main findings
Chester and Horvath, 2010	California	n/a	LCA of HSR, automobiles, conventional rail, and aircraft to cover both operations and construction	Study finds that while high-speed rail has the potential to be the lowest energy consumer and greenhouse gas emitter, appropriate planning and investment is needed to ensure sustained high occupancy. Further, environmental tradeoffs may occur. HSR may lower energy consumption and greenhouse gas emissions per trip but can create more SO_2 emissions given the current electricity mix.
Akerman, 2011	Sweden	n/a	Uses LCA to analyze the proposed HSR Europabanan	Life cycle emissions reductions are found to be 550,000 tons of CO_2e per annum by 2025 to 2030 with almost 60% due to a shift from truck to rail freight and 40% due to a shift from air and road travel to HSR. The study also indicates that a substantial share of emissions due to construction of the new railway could be counterbalanced through the reduced need for building and maintaining roads and airports, and for manufacturing cars.
Chester and Horvath, 2012	California	n/a	LCA of HSR, future cars, and long-distance air travel to evaluate existing infrastructure expansion against the construction of a new HSR system	Results show that greenhouse gas footprints increase significantly and human health and environmental damage potentials may be dominated by indirect and supply chain components. Environmental payback is most sensitive to the number of automobile trips shifted to HSR, and is likely to occur in 20-30 years. An HSR system deployed with state-of-the-art trains, electricity that has met renewable goals, and in a configuration that endorses high ridership will provide significant environmental benefits over existing modes.
Yue et al., 2015	China – Beijing-Shanghai route	2002-101	LCA using China Core Life Cycle database	Vehicle operation dominates most impact categories, while vehicle manufacturing/maintenance/disposal and infrastructure construction contribute mostly to mineral consumption (43% and 38%) and organic compounds in water (54% for infrastructure construction). Recommends shifting electricity mix to clean renewable sources, improving operational strategies, using lightweight materials, and avoiding bridges, tunnels, and reinforced subgrade where possible.
Cornet et al., 2018	UK	2011-15	LCA to examine biodiversity impacts of proposed HSR from London to Birmingham then on to Manchester and Leeds	Paper finds that construction of HSR line on current route would cost 5.6 megatons CO_2e, mainly due to tunneling under Chilterns ancient forest, and that it would take the Chilterns 800 years to sequester this much carbon. Instead recommends routing train along existing motorway away from Chilterns, even though train would be slightly slower, to reduce the need for tunnels and encourage shift from cars.

Sampling of research on high-speed rail and equity/social welfare

Article	Region	Time Frame	Method	Main findings
Urena et al., 2009	France, Spain	n/a	Policy discussion	This paper focuses on big intermediate cities along HSR lines, develops a multilevel analysis at national, regional and local levels, and examines HSR's capacity to transform time distances and accessibility. The paper draws together data which make clear how HSR opens up new opportunities. Specifically, it analyses three cases: Córdoba and Zaragoza in Spain and Lille in France.
Lane, 2012	US	n/a	Policy discussion	High-speed rail has the potential to alleviate automobile and short-haul air traffic congestion in several regional corridors throughout the U.S., with significant economic, environmental, and quality-of-life benefits. However, issues of engineering and track right of way, service provision, and last mile access need to be addressed.
Kamga and Yazici, 2014	US	n/a	Policy discussion	This paper argues that technological improvements within the existing transportation paradigm are insufficient to address systemic energy and environmental challenges. It considers HSR's potential for addressing these larger issues through its role in transportation resiliency, in a multimodal transportation network, in public transportation as a whole, and in changing travel trends.
Wang and Duan, 2018	China – Yangtze River Delta	n/a	A multi-scalar spatial analysis is used to conduct a regional accessibility assessment	This paper uses a door-to-door approach to calculate the total travel time between cities using conventional rail and/or HSR. Four types of winner cities and three types of loser cities are identified.
Yu and Fan, 2018	US – Piedmont Atlantic megaregion	n/a	ARCgis used to estimate travel times, regional accessibility maps to determine accessibility	This paper uses a door-to-door approach to evaluate travel time and accessibility of a proposed HSR. Results indicate that the building of the HSR corridor will improve the accessibility at the megaregional level. However, the coefficient of variation results indicate that the inequality will also increase due to the new HSR corridor.
Chen and Wang, 2019	China	2016-17	Dataset with 350,000 detailed, on-time performance records of HSR and air services	Based on data visualization and statistical analysis, the study reveals that the impacts of severe weather events on HSR and aviation's on-time performance vary spatially and temporally. In general, HSR is less vulnerable than aviation to most severe weather events.
Choi et al., 2019	Korea	2002-06	3,449 patients living in rural areas and diagnosed with cancer.	After the introduction of HSR in 2004, outpatient utilization increased from 1.1 per month to 2.1 per month. HSR did not influence utilization of inpatient services.
Deng et al., 2019	China	2006-15	A difference in difference model is used to examine 43 cities in China that have lost population	This paper investigates whether, for cities experiencing population loss, did HSR further aggravate this urban shrinkage after they were connected to the HSR network? Results show that urban shrinkage in China was further aggravated by HSR due to a siphoning effect of people to growing cities, but there is a time lag of four to five years.
Yin et al., 2019	China	2017-2022 (predicted)	Data were collected from the official reports on HSR and tourism.	With an HSR network, travel time shrinks significantly, and, consequently. Small cities, even end-line cities, benefit significantly from HSR. Small cities connected directly to core cities benefit more from the HSR network than those connected to non-core cities.

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