CHAPTER 8

Transportation

8.1 DEMAND FOR TRANSPORTATION SERVICES

Modern life requires transportation services: people need to move long and short distances for work and pleasure, and goods must be shipped from far and near to satisfy human wants and needs. Transport service levels are usually quantified in units of passenger-km and tonne-km for personal and freight transport, respectively. Provision of U.S. transportation service by various modes of travel is shown in Figures ?? and ??.

The world's largest electric vehcile is a dump truck that never needs recharging.

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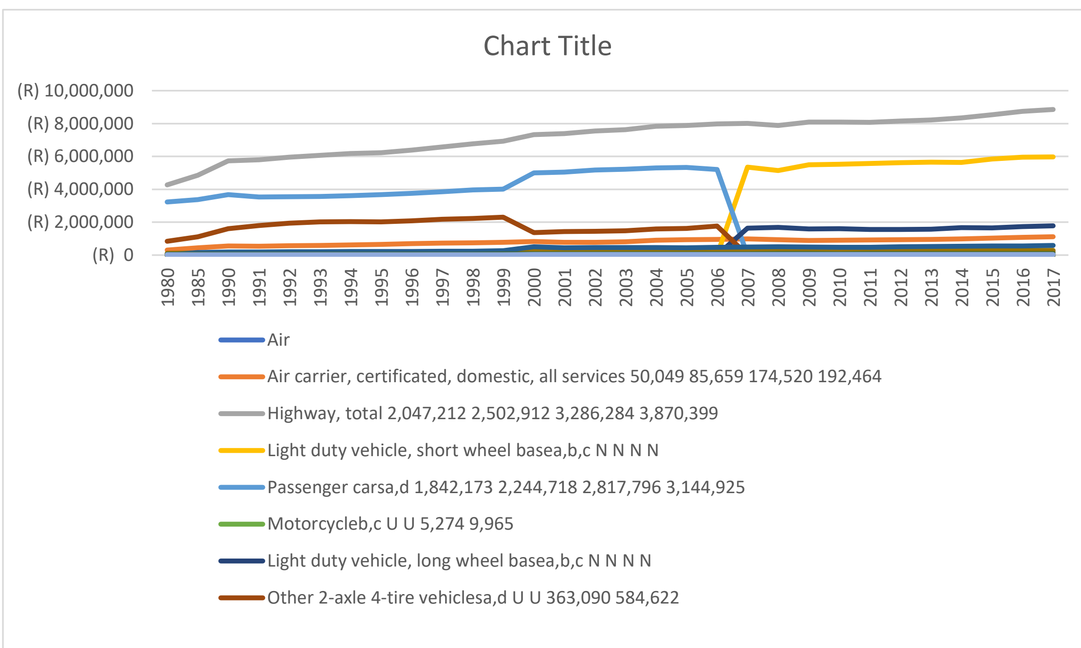


Figure 8.1: Passenger-km of personal transport by mode [? , Fig. 1].

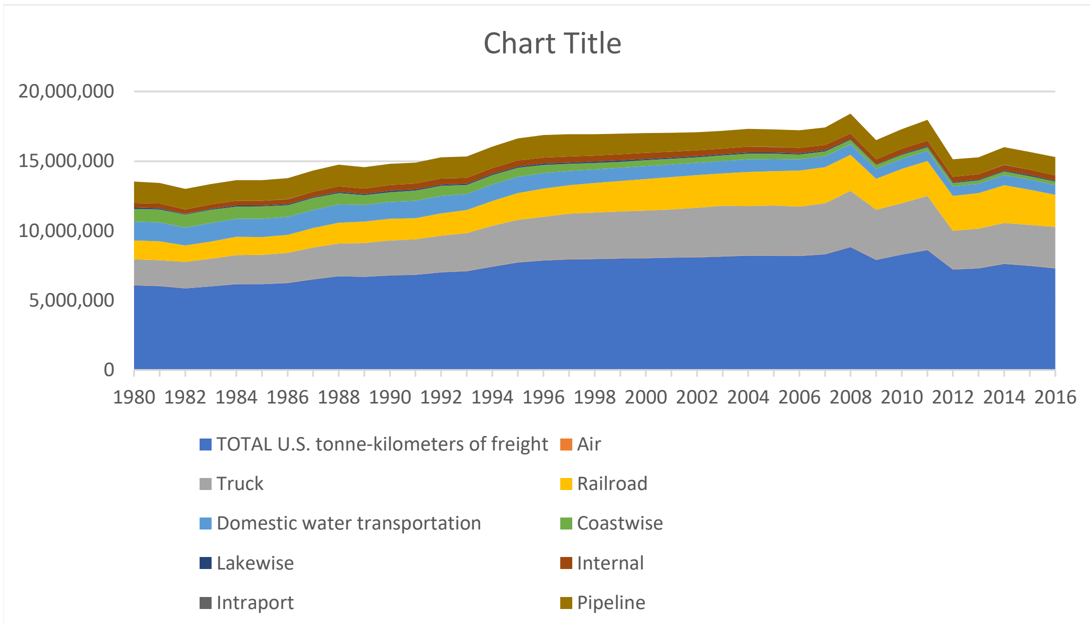


Figure 8.2: Tonne-kilometers of freight by transport mode [? , Fig. 1]km$_{freight}$.

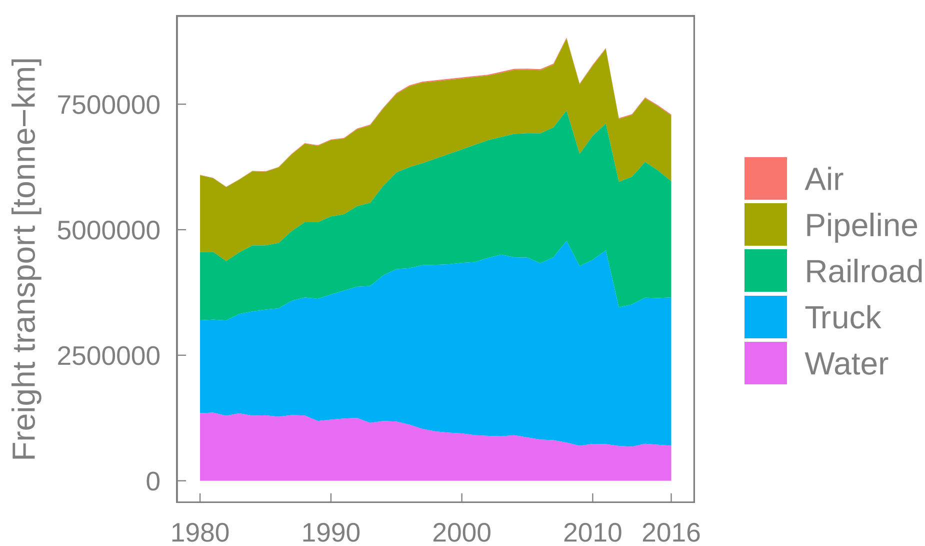


Figure 8.3: U.S. freight by transportation mode.

8.2 TRANSPORTATION SUSTAINABILITY CHALLENGES

Today, transportation services are provided by cars, trucks, trains, boats, and planes, powered almost exclusively by fossil fuels. Figure ?? shows that energy for transportation is supplied almost exclusively by fossil liquid petroleum fuels, because of their high energy densities as measured by both energy-to-mass and energy-to-volume ratios. Burning liquid fossil fuels to provide transportation services has global warming

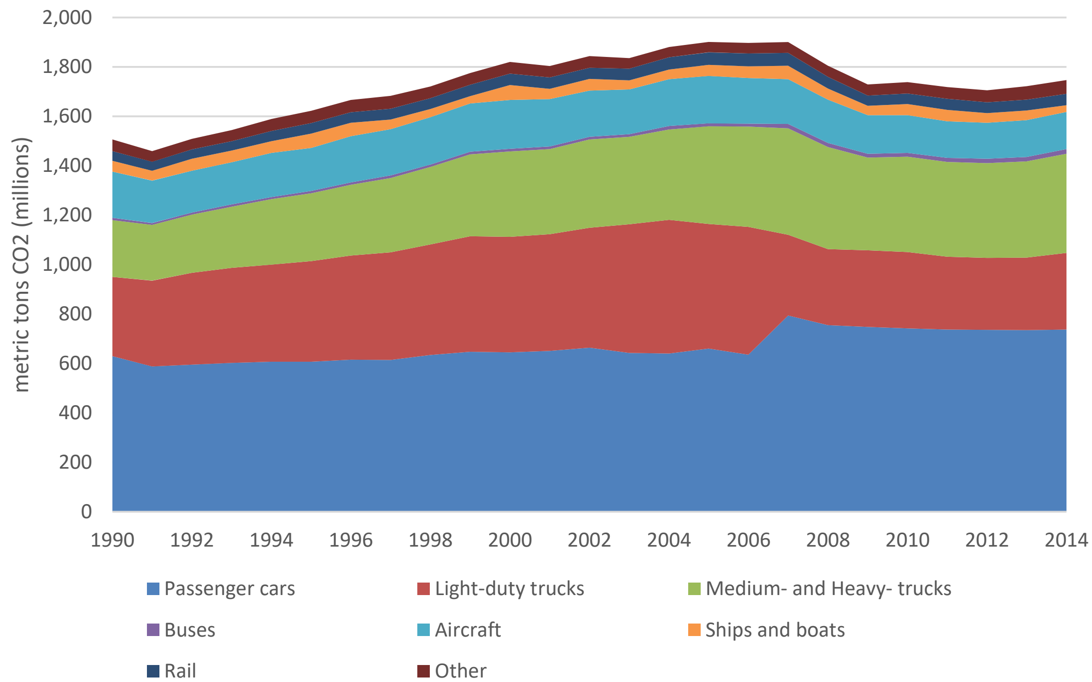
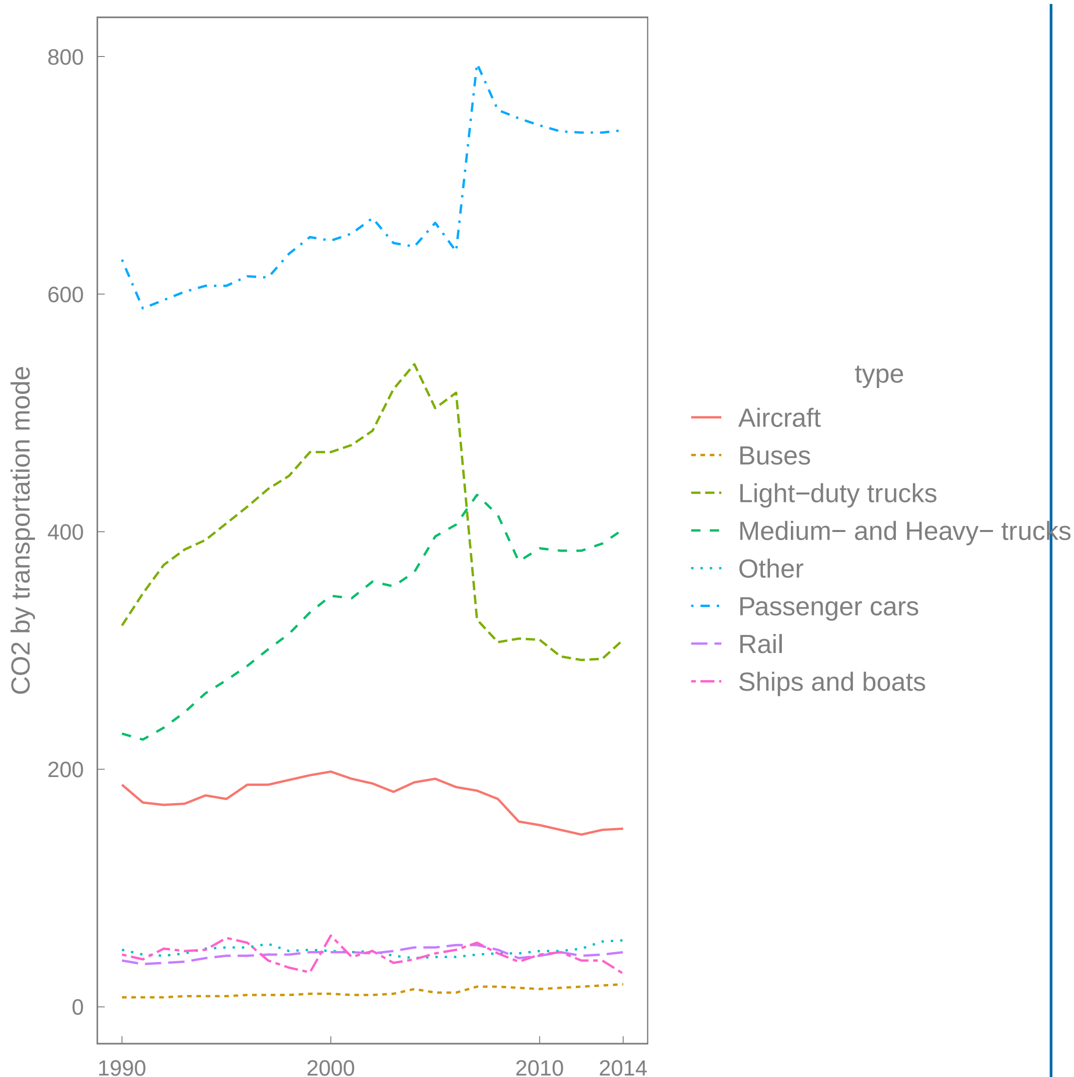


Figure 8.4: CO_2 emissions by transportation mode [? , Fig. 1].

implications, and greenhouse gas (GHG) emissions from transportation are a significant sustainability concern. Indeed, Figure ?? shows that greenhouse gas emissions from transportation comprise 14.5 % of all greenhouse gas emissions worldwide. Figure ?? shows trends of CO_2 transportation emissions by mode over time. Passenger cars are the greatest single cause of CO_2 emissions from transportation.


CO2 by transportation mode
800
600
400
200
0
1990
2000
2010
2014
type
Aircraft
Buses
Light−duty trucks
Medium− and Heavy− trucks
Other
Passenger cars
Rail
Ships and boats

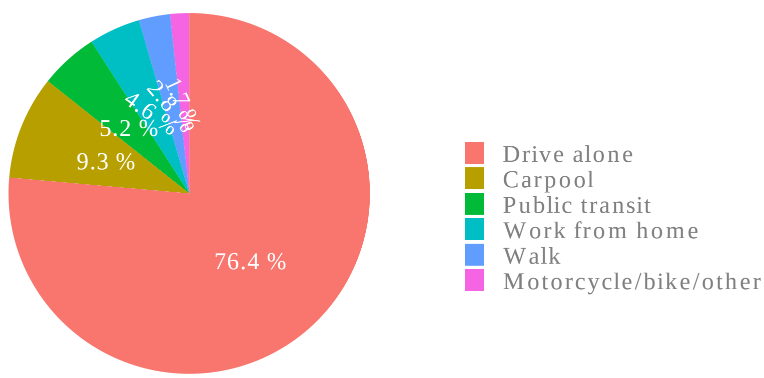
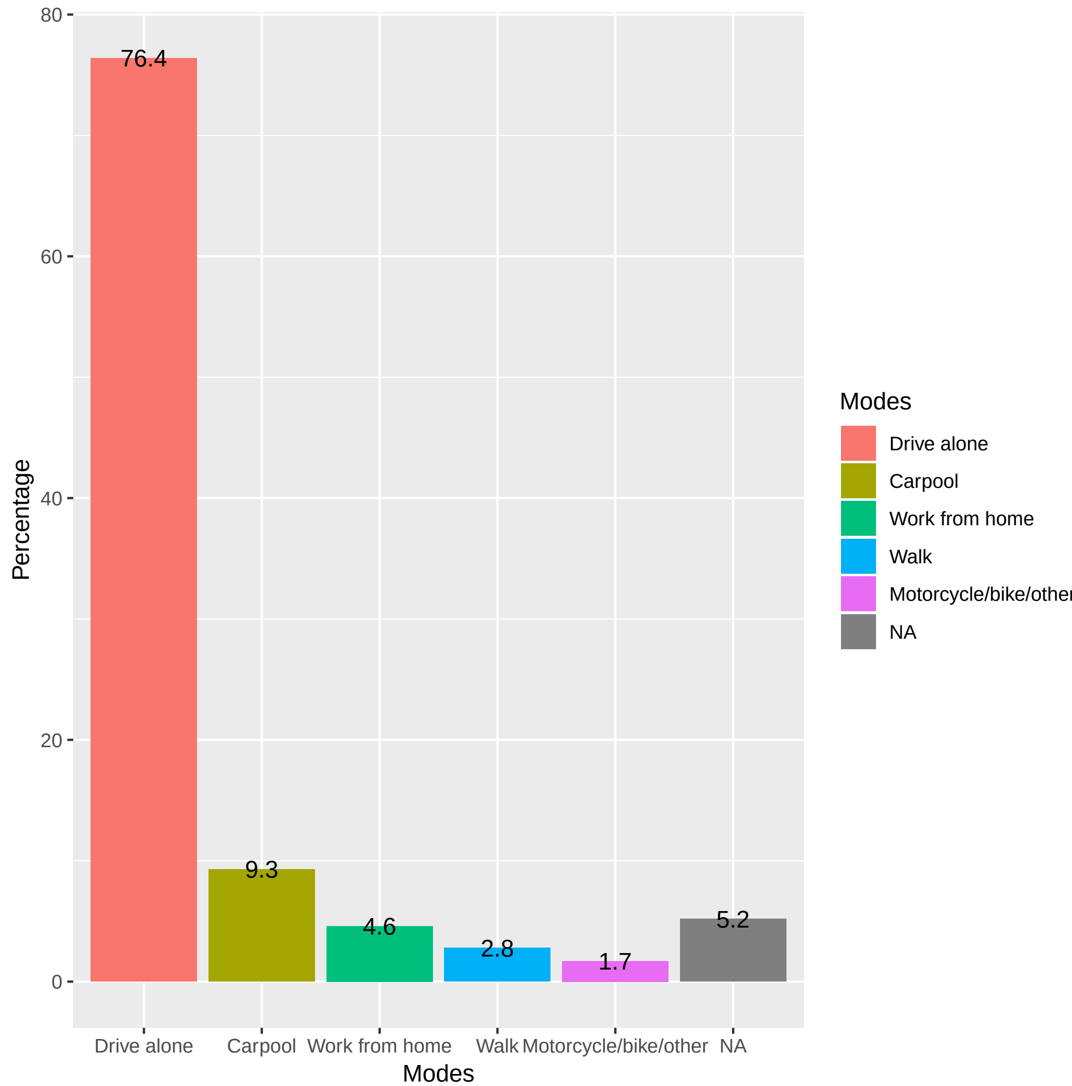


Figure 8.5: Share of commuting distance by mode.



Particulate matter emissions from combustion of transportation fuels raise significant health concerns as well. Furthermore, consumption of nonrenewable fossil fuels for transportation has implications for energy resource depletion. (See Chapter **??**.)

8.3 DRIVERS OF TRANSPORTATION DEMAND

Activities that cause demand for transportation services include daily commuting to work and school, travel for business and pleasure, supply chain distribution, and

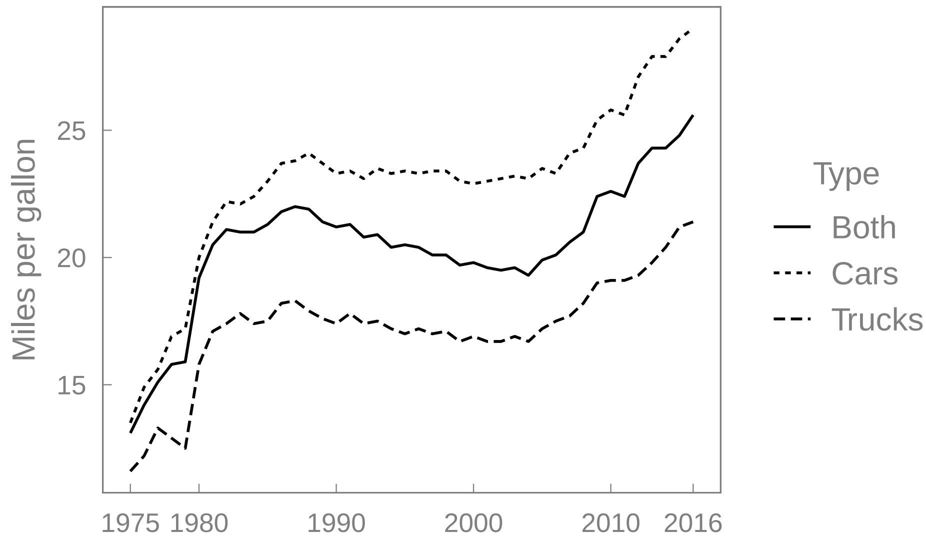


Figure 8.6: U.S. car and truck fuel efficiency

delivery of goods and services. Figure ?? shows the share of commuting distance by mode of transport.

Interestingly, Figures ?? and ?? both show distinctive declines in the demand for transport services from 2009 to 2010, an effect of the Great Recession. A reasonable conclusion is that demand for transportation services is caused, in large part, by economic activity.

Furthermore, Figures ?? and ?? show that the oil price spike in the runup to the Great Recession (2006–2008) caused drivers to move away from light-duty trucks toward passenger cars. Notably, drivers seek low-cost alternatives in the face of transportation fuel prices spikes.

8.4 TRANSPORTATION TRANSITIONS

To improve the sustainability of the modern transportation system, two broad options exist: (a) improve efficiency and (b) transition to sustainable fuels.

8.4.1 EFFICIENCY

Vehicle efficiency is usually quantified in distance travelled per volume of fuel consumed. Figure ?? shows U.S. fleet average fuel economy over time for cars, trucks, and the overall vehicle fleet. Truck efficiency has lagged car efficiency by 20–30%

for decades. In the 1970s, overall vehicle fleet efficiency was nearly the same as car efficiency, because most vehicles on the road were cars. However, the increasing popularity of light-duty trucks and sport utility vehicles in the U.S. means that the overall fleet efficiency is now about midway between car and truck efficiency. If the proportion of cars and trucks were the same today as it was in the early 1970s, overall vehicle fleet efficiency in the U.S. would be about 28 miles/gallon, or 16 % higher than the current value of 24 miles/gallon.

The most effective way for manufacturers to increase vehicle fuel efficiency is to reduce vehicle mass. Lighter vehicles can be achieved by replacing steel components with aluminum or carbon fiber alternatives. Other design considerations that affect fuel efficiency include aerodynamics and fuel type (diesel or regular).

In addition to vehicle design, driving habits influence fuel efficiency. Gentler driving (less acceleration, minimal dramatic braking) and constant speeds (using cruise control where appropriate) lead to improved vehicle efficiency as measured in distance per volume of fuel consumed..

Vehicle efficiency, by definition, focuses on the efficiency of the vehicle itself. But drivers don't buy fuel to move vehicles. They pay for fuel to move people and freight! So another way to measure vehicle efficiency is the ratio of transport service to fuel volume consumed. Transport service efficiency is quantified in units of passenger-km/liter or tonne-km/liter for passenger transport and freight transport, respectively. This simple shift from vehicle efficiency to transport service efficiency exposes the opportunity presented by Figure **??**. When 76.4 % of all communiting kilometers are taken in single-occupant vehicles, a simple way to improve transport service efficiency is to increase the occupancy rate of vehicles. Similarly for freight transport, the simplest way to increase transportation efficiency is to ensure that trucks and trains are filled to capacity when delivering freight.

> The viability of a "sustainability through services" strategy for the world economy is the subject of some debate. See **?**] and **?**] and the references therein for a fuller discussion of the issues surrounding these concepts.

A significant challenge to higher occupancy cars and higher capacity trucks is known as the *last mile problem*, which refers to the difficulty of distributing goods and services the last mile to end users. Figure **??** shows percentages of total delivery cost for several parts of a delivery journey, and the largest portion is the last mile.

8.4.2 TRANSITION TO SUSTAINABLE FUELS

Another way to improve the sustainability of modern transportation is to transition away from fossil fuels toward sustainable fuels, thereby eliminating the negative environmental effects of fossil fuel combustion. Two solutions are often discussed:

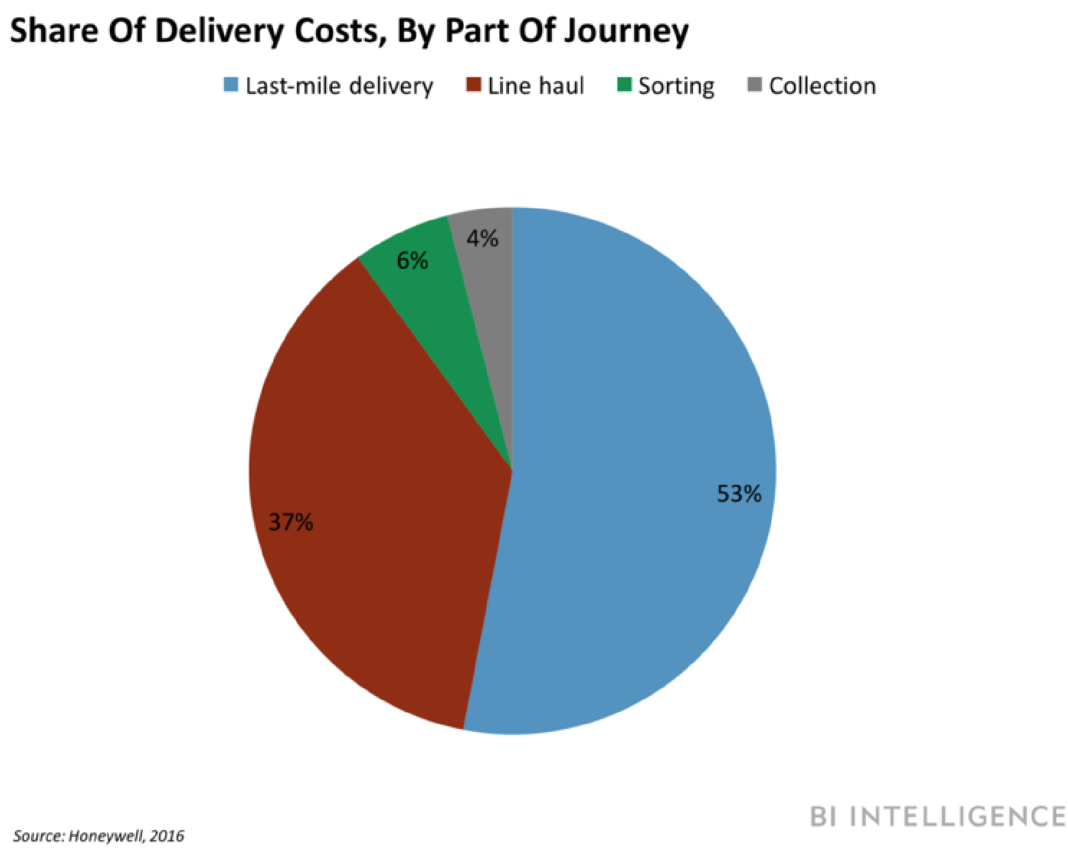


Figure 8.7: Percentage of delivery cost by part of journey [? , Fig. 1].

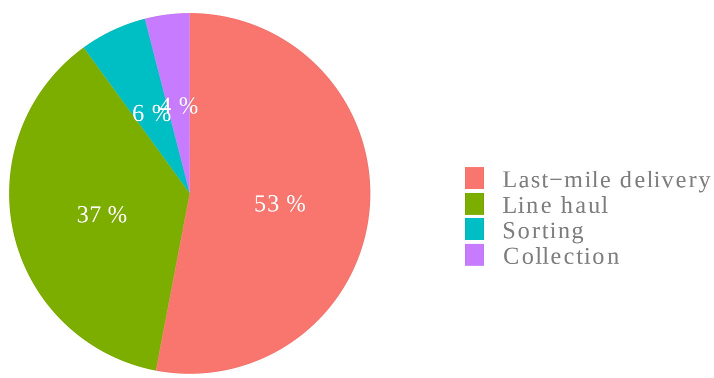


Figure 8.8: Last mile costs.

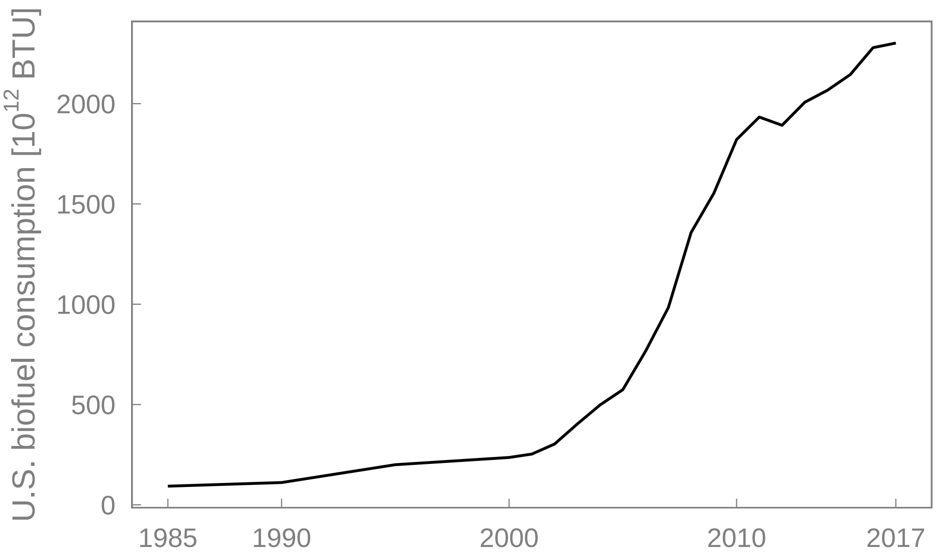


Figure 8.9: Biofuel consumption in the U.S., 1985–2017 [? , Table 10.1].

(a) widespread use of biofuels in internal combustion engine (ICE) vehicles and (b) widespread adoption of electric vehicle technology.

Biofuels Biofuels are liquid or gaseous hydrocarbon fuels produced from biomass material and used for transportation. Taking carbon neutrality as the indicator of sustainability, biofuels can be sustainable if they sequester more carbon than they emit across the full life cycle of a project, including land preparation, planting, harvesting, refining and processing, and direct combustion of the fuel itself. Perennial crops planted in low-carbon soils can be carbon negative, because GHG emissions from energy consumed for land preparation and planting can be allocated across several harvest years of the biofuel crop [?]. Biofuel consumption in the U.S. is shown in Figure ??.

Electric vehicles Figure ?? shows two types of environmental impact (global warming potenatial and mineral resource depletion) across the full life cycle of automobile use, from base vehicle manufacturing to end of life disposal, assuming 150,000 km service. Regular gasoline (gas) is consumed by internal combustion engine (ICE) vehicles. Electric vehicles (EVs) consume electricity with different primary fuel mixes: the European mix (Euro) or pure coal.

Figure ?? shows that EVs are clearly worse than ICE vehicles in terms of mineral resource depletion (MRD). The material demands for engine and battery fabrication

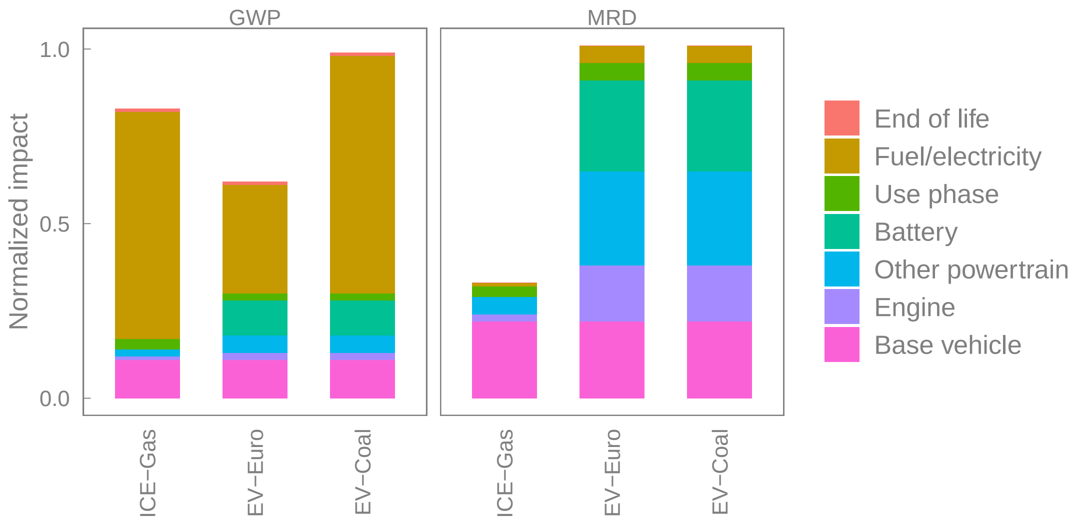


Figure 8.10: Environmental impacts of three different automobiles. Data from ? , Fig. 1]. GWP is global warming potential; MRD is mineral resource depletion; ICE is internal combustion engine; EV is electric vehicle; Euro indicates the European electricity mix; use phase excludes fuels.

are much higher for EVs than ICE vehicles. However, EVs provide benefits in terms of global warming potential (GWP) relative to ICE vehicles if the electricity source is the European mix of primary fuels and renewables, because of lower lifetime fuel/electricity emissions. In the case of the European electricity mix, the global warming benefits of EVs are achieved despite much larger emissions from battery manufacturing. The global warming benefits of ICE vehicles evaporate when coal electricity is consumed, because of higher electricity-related emissions. ? , p. 61] point out that "[e]nvironmental evaluations relying solely on fuel and powertrain efficiencies miss key differences associated with the production of different vehicle types and could lead to misguided comparisons across technologies."

TRADEOFFS AND PROBLEM SHIFTING

Automobile technology is one of many arenas in which sustainability tradeoffs are observed. Under the right conditions, EVs can reduce global warming impact relative to ICE vehicles at the expense of depleting the stock of mineral resources, a phenemonon known as *problem shifting*.

The sustainabilty challenges of transportation transitions don't end with the GHG emissions/mineral resource depletion tradeoff discussed above. In fact, there is a temporal component that must be examined when comparing EVs against ICE vehicles. Whether or not GHG emissions are lower for an EV relative to an ICE vehicle depends upon the service lifetime of the vehicle. The benefits of EVs relative to ICE vehicles appear only after tens of thousands of kilometers of service, because manufacturing causes a larger fraction of lifetime GHG emissions for EVs than for ICE vehicles. Put another way, an EV that is totalled shortly after manufacture will never achieve its potential emissions reductions.

QUESTIONS

8.1. In Section **??**, the move from machine efficiency (measured in miles/gallon) to service efficiency (measured in passenger-km/gallon) revealed insights about the transportation sustainability challenge, namely that filling empty seats in cars is a simple and effective form of increasing efficiency. Consider a different sustainability challenge besides transportation. Develop or find a machine efficiency for your challenge that is analogous to vehicle efficiency in miles/gallon. Develop or find a service efficiency for your challenge that is analogous to passenger-km/gallon. What changes when you move from machine efficiency to service effiency? How does the move from machine efficiency to service effiency affect the way you think about the sustainability challenge? Does the move from from machine efficiency to service effiency suggest new solutions to the sustainability challenge?

8.2. Research the term *problem shifting*. Identify at least three examples of problem shifting in which a "solution" to one sustainability challenge causes problems of a different sort.

8.3. Under the right conditions (European electricity mix, 150,000 km service life), **?**] show that electric vehicles provide GHG emissions reductions relative to internal combustion engine vehicles at the expense of increased mineral resource depletion. The GHG emissions/mineral resource depletion tradeoff is an example of a tradeoff that is nearly impossible to decide on a quantitative or objective basis. Indeed, deciding this and similar tradeoffs cannot be divorced from human values and value judgments. Is it wise to trade reduced GHG emissions for increased mineral resource depletion? Why or why not? What values are guiding your decision?