Chapter 1
The Evolution of Transport Across World Regions

Abstract This chapter aims at providing an overview of the multiple aspects involved in passenger and freight transport, which are the base for the understanding of the energy consumption of the sector, as well as for the current trends and prospects related to digitalization and decarbonization. A brief historical discussion and some trends will be presented, followed by a description of the main modes and technologies, both for passenger and freight transport, and a final focus on the differences across world regions in mobility patterns and behaviors. The evolution of transport systems has led to very different situations worldwide, depending on different strategies related to economic development, geographical limitations and cultural, political and social aspects. Proper sustainable mobility plans need to be based on the specific characteristics of each location, and the integration between different governance levels is of utmost importance to improve the reliability, affordability, and energy performance on the entire transport system.

1.1 Introduction

Transport has evolved in history, following a wide range of drivers, which changed how, how much, when, and why people moved and transported goods between places. Mobility demand has always been driven by the need to access opportunities, related to work, services, shopping or leisure, depending on the specific historical and cultural context.

1.1.1 A Brief Historical Perspective

The history of transport has seen a significant evolution over the centuries, both on the causes of mobility demand and on the available modes, that in turn had an impact on the distance that people and goods could travel. People travel to access opportunities, and the share of each activity has evolved in time, with significant differences across societies worldwide, as well as between urban and rural contexts.

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An example of the evolution of passenger transport modes can be seen in Fig. 1.1, which depicts the average daily distance travelled by the US citizen in the last century. It is interesting to notice how the availability of different technologies has led to a significant and continuous increase of the average distance travelled, and at the same time, new technologies have led to a decrease in the need of walking. Moreover, average daily travel times remain more or less constant, around a total average of one hour per day, leading to the increase of the distance and area to which people have access to in their daily activities. As a result, cities become larger and continue to attract more and more people worldwide, leading to an urbanization trend for which transport will become crucial.

One of the main impacts of transport is related to the energy required to satisfy the mobility demand. The transport sector currently accounts for almost 30% of the world final energy consumption (IEA, 2018b), reaching 32,494 TWh (2794 Mtoe) in 2017, with a 43% increase from the 22,771 TWh (1958 Mtoe) of 2000. At that time, oil represented almost 97% of the transport energy mix, and today, it slightly decreased to 92% thanks to an increased penetration of electricity (mainly in rail services), biofuels, and natural gas. Still, the transport sector remains today the less diversified, and therefore, there are increasing efforts to try to enhance the use of different low-carbon alternatives to oil products.

A closer look at the evolution of transport energy consumption in the last decades (see Fig. 1.2) highlights its continuous increase, with almost a threefold growth from 1971 to 2015, higher than industry consumption (around +80% increase) or residential consumption (roughly +90%). The chart shows also the clear increase of the share of diesel, which is slowly reaching gasoline in the share of consumption by fuel.

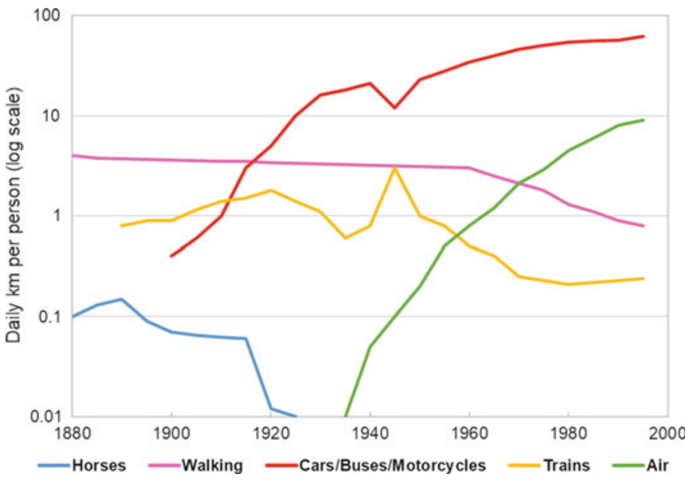

Fig. 1.1 US travel per capita per day by all modes. Authors' elaboration from Ausubel, Marchetti, and Meyer (1998)

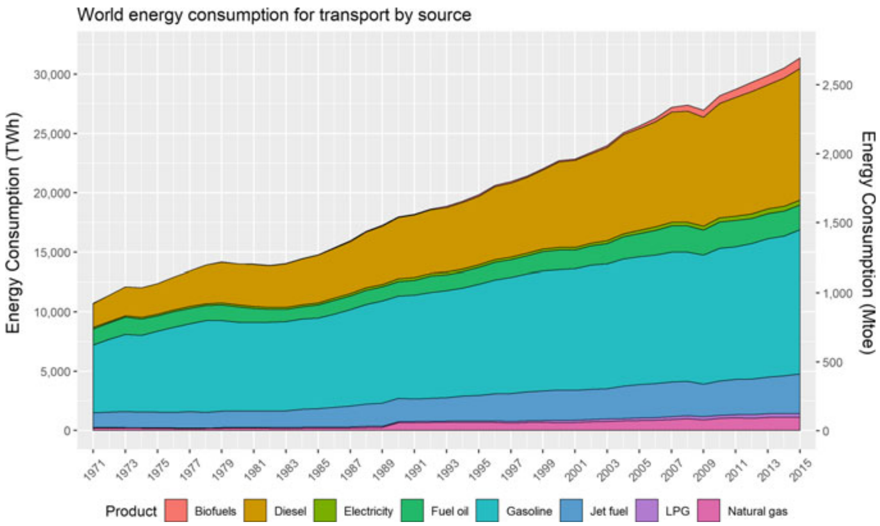

Fig. 1.2 World energy consumption for transport by fuel. Authors' elaboration from IEA (2017)

Transport includes a large variety of subsectors that have peculiar characteristics, as will be described in detail in the following sections. Also, the evolution of transport is tightly related with the urbanization trend worldwide, and mobility planning in cities includes additional aspects related to local pollution, congestions, and safety. It is not trivial to analyze the difference between extra-urban and urban transport, since there are few data specifically related to urban transport at world scale. However, some research has been performed on a limited number of cities, to estimate the transport energy consumption per person in cities related to the population density [see Fig. 1.3, authors' elaboration from WHO (2011)]. Although the data refer to some years ago, the hyperbolic relation among these two quantities appears very clearly. An interesting aspect is the strong clustering of the world regions, which in turn can be correlated to multiple factors including political, economic, cultural, and social behaviors. The cities in the US show generally a low density coupled with the highest per capita energy consumption, which is mostly caused by the diffused use of single-passenger large cars and the low use (and often availability) of public transport. Western European cities lay in the middle, while the bottom right part of the chart is showing mainly high-density cities, whose low per capita energy consumption is a result both of relatively low transport needs due to higher density and low income of the citizens leading to lower access to opportunities. At the same time, in densely populated areas, an excessive use of private vehicles would lead to severe congestions, limiting the speed and flexibility of the private car.

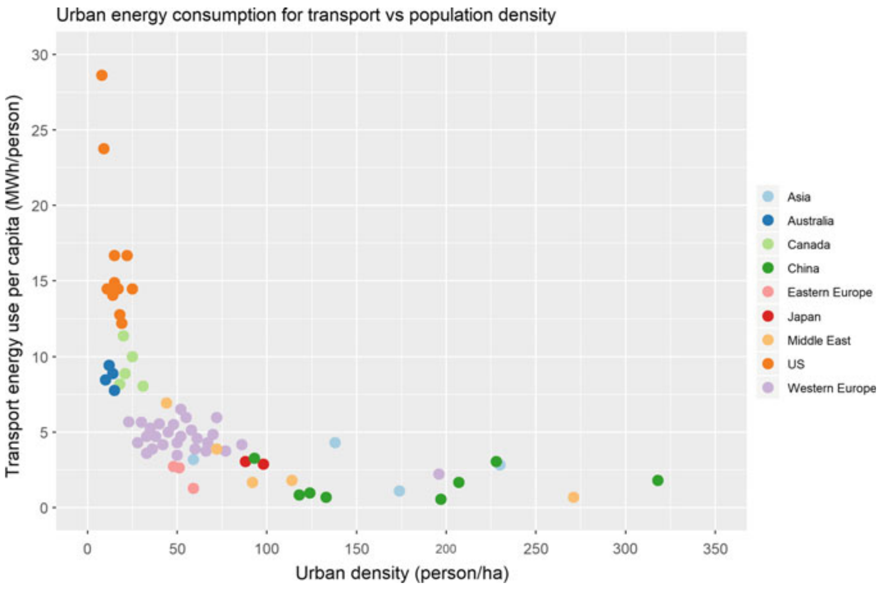

Fig. 1.3 Urban transport energy per capita versus population density. Authors' elaboration from WHO (2011)

1.1.2 *Current Situation and Prospects*

As discussed above, the evolution of transport demand is related to a number of factors, including the population, the level of GDP, as well as the urbanization. On the other hand, available technologies may unlock additional demand potential, thanks to the availability of mobility solutions at a lower cost for the users or with other advantages, including speed, convenience, and flexibility.

As long as energy consumption is concerned, transport modes can be compared by considering their average specific energy consumption, which can be parameterized on passenger-km (pkm) for passenger transport and on tonnes-km (tkm) for freight transport. Table 1.1 shows some average values for energy consumption of different transport modes, together with their range of variation. These values should be considered with care, since they are affected by a large number of parameters, including type of fuel, vehicle conditions, vehicle load, etc. Moreover, since these figures relate to the final energy consumption of the transport modes, primary energy consumption may differ. For example, transport modes based on electricity show lower specific energy consumption, but the electricity generation may involve additional energy losses in comparison with fossil fuels, depending on the energy source from which it is generated.

Taking in mind these limitations, the values reported in Table 1.1 still provide some interesting evidence: cars and trucks remain among the worst performing transport modes for passenger and freight transport respectively, while the best performing

Table 1.1 Average consumption for transport modes and variation ranges

	Average		Range of variation	
Passenger	kWh/pkm	toe/Mpkm	kWh/pkm	toe/Mpkm
Large cars	0.75	64.7	0.28–1.01	24.3–86.5
Aviation	0.50	43.0	0.29–0.85	24.8–73.1
Cars	0.50	43.0	0.23–0.85	19.8–73.1
Buses and minibuses	0.16	14.1	0.10–0.32	8.3–27.1
2- and 3-wheelers	0.12	10.7	0.10–0.21	8.4–18.5
Rail	0.05	4.1	0.02–0.22	1.5–18.7
Freight	kWh/tkm	toe/Mtkm	kWh/tkm	toe/Mtkm
Medium trucks	0.35	30.5	0.18–0.56	15.3–48.6
Heavy trucks	0.30	25.4	0.22–0.43	18.6–37.2
Rail	0.04	3.5	0.02–0.14	2.1–12.0
Shipping	0.03	2.5	0.02–0.05	2.0–4.0

Authors' elaboration on IEA (2019c)

modes are rail and shipping. Large cars have higher specific energy consumption than aviation, which is generally referred to as the transport mode with the highest environmental impacts. The good performance of rail is partially due to its high electrification, while shipping benefits from the larger volumes, the lower speed, and the lower friction in comparison with land transport.

Besides energy consumption, each transport mode has its own advantages and weaknesses, and the choice of a mode over another may be caused by different reasons. Thus, the transport sector is a complex mix of different modes, and multimodal trips are a common solution for both passenger and freight transport.

The future development of transport needs to be contextualized in an increasingly urbanized world, which will be inhabited by 9.2 billion people by 2040, with 43 megacities of more than 10 million people already in 2030, mainly in Asia and Africa (United Nations, 2018). At the same time, an increasing share of the world population will have access to more services, including private and shared mobility options.

The IEA's World Energy Outlook 2018 presents different future scenarios for the world energy consumption (IEA, 2018b). As far as transport is concerned, its share in final energy consumption by 2040 will still remain similar to the current situation, ranging from 26 to 29%, while the total consumption of the sector will show a higher variation depending on the policies that will be deployed in the future. According to the IEA, while the current policies may lead to an increase of 42% by 2040 compared to the current consumption, with an oil share still locked to 88%, the Sustainable Development Scenario presents a 6% decrease of energy consumption in transport, with oil representing 60% of the 30,703 TWh (2640 Mtoe) estimated for 2040.

The future trends for transport are strongly related to the effectiveness of several policies that may be deployed at different governance levels, as will be better described in Chap. 4. The efforts required for the decarbonization of transport will likely include multiple technological solutions, since no silver bullet appears to be able to tackle the diversified challenges related to the complexity of this sector.

1.2 Passenger Transport

Passenger transport includes a wide variety of activities that range from work commuting, to business trips, tourism, everyday activities, etc. For most trips, there are different potential alternative modes, which may be chosen by the passengers by considering different aspects including price, travel time, comfort, and safety. Passenger transport demand is usually quantified in passenger-km (pkm), which accounts for the transportation of a passenger over a distance of a km. A reliable estimation of passenger transport demand is crucial to perform proper mobility planning strategies at different levels. Figure 1.4 reports the estimations of the International Transport Forum for passenger transport in the world, by highlighting some categories related to modes and distances, as well as the contribution of OECD and non-OECD countries.[1] The chart highlights the very strong increase in transport demand, which is expected to almost triple by 2050, with the strongest contribution coming from

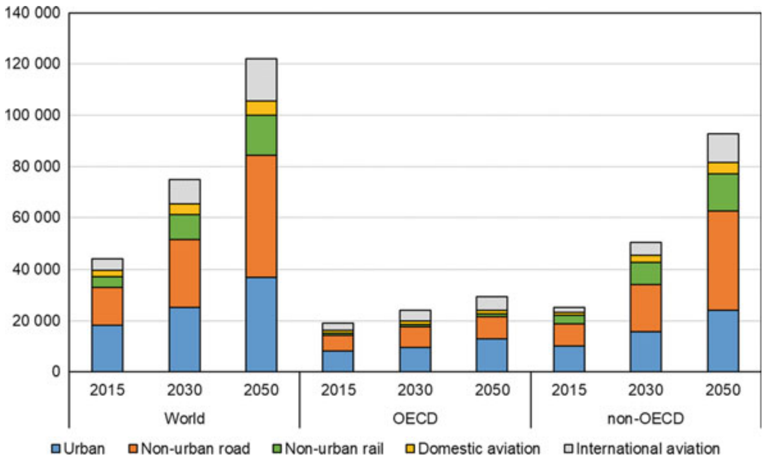

Fig. 1.4 Estimated future demand for passenger transport by type, billion passenger-km. Authors' elaboration on ITF (2019)

[1]The Organization for Economic Co-operation and Development (OECD) was established in 1961 as a forum for governments to share experiences and seek solutions to common economic and social problems. As of 2019, the OECD is composed by 36 member countries (https://www.oecd.org/about/members-and-partners/).

developing countries (especially in nonurban road and aviation, i.e., on medium and long distances). The main drivers will be the growing population and the increased well-being, allowing a larger number of people to access different mobility options, especially private cars.

However, attention must be paid to the fact that there is no single categorization for passenger transport, leading to the difficulty of comparing scenarios from different sources due to the different aggregation levels that are used.

This section will present the three main groups that are generally considered (road, rail, and aviation) together with a brief description of the aspects related to active transport (i.e., walking and cycling), which are usually not considered in world statistics but they may be more and more important to develop sustainable alternative to private car in urban contexts. Furthermore, last-mile active solutions may be integrated by micro-mobility electricity-based services, including scooter sharing as well as electric bikes.

1.2.1 Road Transport

Road transport includes all the different motorized vehicles that are available for passengers, including cars, buses, and motorcycles/mopeds. Although with some differences related to the world regions, private cars currently remain the most diffused mode, thanks to their high flexibility and reliability, together with their relatively low cost.

The evolution of private vehicles across countries still shows large inequalities, mostly related to the average income of the citizens. The relation between the vehicle ownership and the gross national income across world countries emerges quite clearly in Fig. 1.5.

It has to be highlighted that the data in the chart are related to the total number of vehicles, including different modes. As a result, for some countries, cars are predominant (in the US, they represent more than 92% of the total registered vehicles), while in other countries, especially in Asia, two- and three-wheelers are the most diffused road transport mode (94% in Vietnam, 73% in India, 54% in Thailand). Similar figures come from research activities based on surveys: Poushter (2015) compared ownership rates of cars, motorcycles, and bikes in 44 countries worldwide, finding large differences from a country to another, as well as depending on the citizens' incomes inside countries.

All road transport vehicles are currently heavily relying on oil products, especially gasoline and diesel. While the latter is generally the most diffused option for heavy-duty vehicles (trucks and buses), for light-duty vehicles the competition is more pronounced, especially in European countries (the US cars almost totally run on gasoline). While diesel engines are generally more efficient, they usually have a higher investment cost and are therefore preferred for users that have a high car usage. Alternative fuels, such as natural gas, LPG and biofuels, are being used in

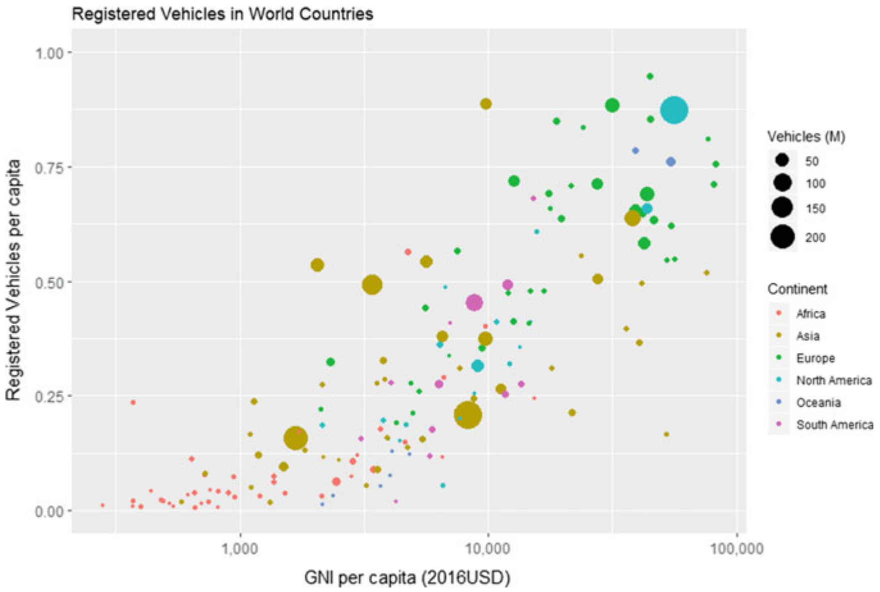

Fig. 1.5 Registered vehicles as a function of gross national income. Authors' calculation on WHO (2018)

some countries, but they are still representing a marginal share of the total energy consumption of the passenger transport.

The energy consumption required for passenger transport on road can show a significant variation based on multiple parameters, including the type of vehicle, the load factor, the average speed, the type of driving, the technology and aging of the vehicle, etc. While average numbers from country statistics are used to estimate the energy consumption of the sector, it has to be noted that the potential variability is significant, especially across countries and in different groups of users inside each country.

There is a significant debate on the road transport total costs considering externalities (Litman & Doherty, 2009), since the vehicle ownership and the operational costs paid by the users are only representing a limited share of the total costs. Other aspects, both internal and external, include the risk of accidents, the cost of congestions (related to the cost of the time that is wasted), energy security, GHG emissions, air pollution, noise, impact of infrastructures, etc. The current taxation system hardly compensates for the external costs of road transport, resulting in an inequitable distribution of costs and benefits. Part of these costs are currently compensated by fuel taxes in some countries, but some alternative solutions are being evaluated, mainly to compensate the decrease of revenues due to the improved efficiency of vehicles and the gradual introduction of electric vehicles. Some US states are considering the possibility of taxing the vehicles based on their usage rather than on fuel consumption, although this would not reflect the issues related to congestion, that would require a pricing both location and time based. The development of digital technologies (onboard sensors, GPS, connectivity, etc.) may support in the future the possibility of dynamic taxation for road transport.

While road transport analyses are generally focused on vehicles, both for economic and energy evaluations, another important aspect that needs to be accounted for is the infrastructure. In fact, road transport needs a proper infrastructure, which in turn requires significant investments and a proper maintenance. The road network has seen a significant evolution in the last centuries, especially in developed countries, in parallel with the development of both passenger and freight transport. The possibility of exploiting a very large and distributed network of roads, from local to highways, makes road transport the only solution that can almost always guarantee a door-to-door service without the integration with other modes. This enhanced flexibility is one of the most important aspects that lead to the success of road transport over other modes (notably railways).

1.2.2 Rail Transport

Rail transport is a significant alternative to road for land transport, thanks to the availability of a separate infrastructure that is not affected by the road network congestions, although it needs a careful planning and management for its optimal operation. Additional advantages of rail over road transport include the higher average speed, especially in urban contexts and in high-speed rail networks, the lower fatality risk for passengers, the better energy efficiency, and lower environmental impacts.

Rail services are generally provided to the users by public or private companies, which allow passengers to travel between specific locations. Competition is possible, but there is the need of a third-party management of the infrastructure to avoid potential collisions or congestions and to optimize the operation and scheduling of the trips. The flexibility of the system is lower than for road transport, although in some countries well-developed rail networks ensure a redundancy that enhances the system flexibility, especially over long distances. However, rail transport is generally part of a multimodal trip that includes other modes for the first- and last-miles.

Rail transport includes different segments that are generally divided into urban railways (i.e., trams and subways), extra-urban conventional railways, and high-speed railways. These segments have different features, targets, and competing transport modes. Urban rail has the potential to support the current urbanization trend by providing an effective alternative to private cars with benefits on local pollution, GHG emissions, congestions, and land use, especially in densely populated districts. High-speed rail, if well planned and operated, can provide an effective substitute for short-haul flights, being aviation one of the most challenging modes to decarbonize.

Globally, around three quarters of conventional passenger rail activity are based on electricity, and the remaining quarter relies on diesel (IEA, 2019c), while high-speed rail and urban rail are totally powered by electricity. According to (IEA, 2019c), the total share of passenger rail transport on electrified tracks is expected to rise to 97% by 2050, with the global activity becoming 2.7 times higher than the current levels.

Globally, rail represented 8% of passenger transport in 2016 (IEA, 2019c), but with an uneven distribution across different world areas. The highest share of passenger transport on extra-urban conventional railways is in Asia, with India accounting for 39% of the total, followed by China with 27% and Japan with 11%. China accounts for about two-thirds of high-speed rail activity, having overtaken both Japan (17%) and the European Union (12%) in the last years. The regional distribution of urban rail activity is more even; China, European Union, and Japan each have around one-fifth of urban passenger rail activity.

While conventional railways have not seen any disruptive improvements in the last century, the evolution of high-speed networks has reached significant penetrations in multiple countries, providing a fast, reliable, and cost-effective alternative for traveling from a city to another. This segment may be further improved in the future by the deployment of alternative technologies that have still a few applications, such as maglev (from "magnetic levitation"), or that are still in a research phase, such as Hyperloop.

Maglev trains are based on a well-known technology that has currently failed in reaching the strong expectations of the past decades, mainly due to the very high capital costs involved. Maglev trains are in commercial operation in six locations in Asia as of 2018 (Maglev.net, 2018), but the only application running at higher speed than normal high-speed trains is the one connecting Shanghai airport with the city center, reaching a top speed of 430 km/h over the 30 km of its length. Another project currently under construction in Japan plans to connect Tokyo and Nagoya, but the benefits provided by halving the travel time come at the cost of a four to five times higher energy consumption in comparison with the current high-speed train connecting those cities (Kingsland, 2018).

Conversely, Hyperloop technology is a new concept that has been proposed for the first time in 2013 by the CEO of Tesla Motors and SpaceX, Elon Musk (SpaceX, 2013). It is based on pressurized capsules that travel in low-pressure tubes at speeds similar or higher than air travel. Different feasibility studies have been developed in recent years, suggesting that this technology could be two to three times more energy efficient per passenger transported than conventional high-speed rail (IEA, 2019c). However, actual figures may vary, and commercial projects are not expected before the mid-2020s (Hyperloop One, 2019).

1.2.3 Air Transport

Aviation is among the most critical transport segments, due to its constantly increasing passenger demand, especially for long-haul flights, and the high energy density that is required. Demand for domestic and international air transport combined is expected to rise from 7 trillion passenger-kilometers in 2015 to 22 trillion in 2050,

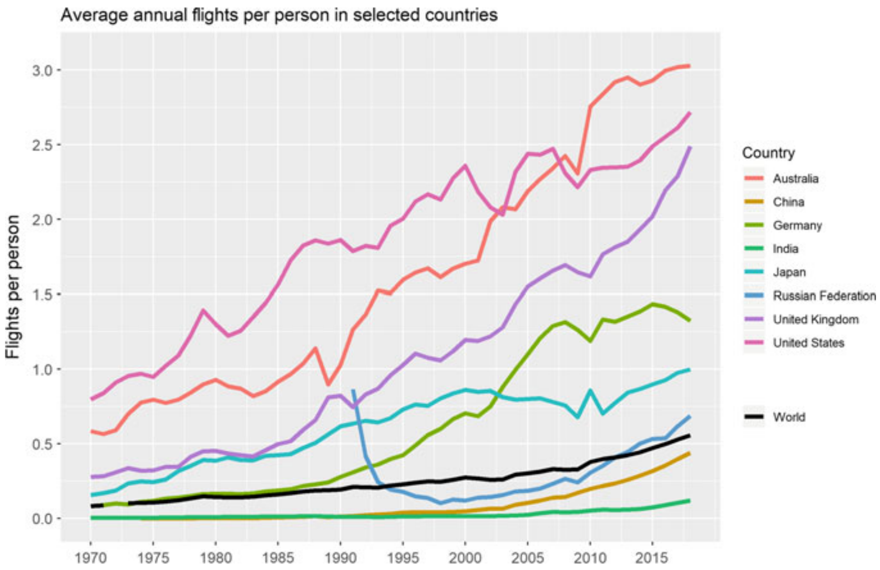

Fig. 1.6 Annual flights per person in selected countries. Authors' calculation on World Bank (2019)

according to (ITF, 2019), especially in developing countries. International air transport passenger demand in China and India alone is expected to increase more than threefold by 2030 and almost sevenfold by 2050.

As for other transport statistics, it is not easy to find reliable and coherent data across world countries with an acceptable historical record. The plot of Fig. 1.6 represents the historical evolution of the average flights per person in some countries, showing the significant differences across developed and developing countries, as well as the growing trend for China and India, which is very similar to the growth at global scale. Unfortunately, there is a caveat: these data are grouped by country based on the nationality of the air carriers rather than on the airports of departure. As a result, while for large countries the values are meaningful, this may not be the case for small countries that are the basis of large international air companies (e.g., the United Arab Emirates, with Etihad and Emirates, or Ireland, with Ryanair). Moreover, while the first decades of air travel were mainly based on national flagship air companies, in the current globalized market air companies may operate flights outside of their home country.

The aviation sector in 2016 accounted for an energy consumption of 2163 TWh (186 Mtoe) for international travels and 1384 TWh (119 Mtoe) for domestic travels (IEA, 2017), all made up of oil products. Aviation accounted for 12% of the total CO_2 emissions of the transport sector in 2016, reaching almost 1 Gt of carbon dioxide (IEA, 2018a). If it was counted as a country, aviation would be ranked sixth for CO_2 emissions from fuel combustion, between Japan (1.1 Gt) and Germany (0.7 Gt).[2]

[2] Authors' calculations based on data from IEA (2019b).

The increase of air travel demand has been caused by multiple drivers, including the increasing share of low-cost companies, which showed in the last years a higher growth than the entire sector, carrying in 2018 around 31% of passengers worldwide (ICAO, 2018). The competition among different companies ensures lower fares. According to (Kasper & Lee, 2017), real domestic price per mile in the US has declined by 40% in the years 1990–2016 (and by 36% including bag and change fees), notwithstanding the 110% increase in jet fuel prices since 1998. However, in the same period, the sector has seen a significant improvement of the energy efficiency.

Globally, the efficiency of the aviation sector improved by 2.9% per year during 2000–2016, thanks to a better aircraft utilization and to the renewal of the fleet. The average load factor of the planes reached a record level of 82% in 2018, with a slight increase from the previous year. The average load factor varies across world regions, ranging from 71.8% for Africa to 84.5% for Europe (ICAO, 2018). At the same time, the average fuel burn of new aircraft models fell approximately 45% from 1968 to 2014, or a compounded annual reduction rate of 1.3% (Kharina & Rutherford, 2015), but with significant variations across decades. Energy efficiency measures are driven by the significant cost of fuel in airline operation (reaching a share of roughly 20%), which drives investments in better aircraft designs and lighter materials.

1.2.4 Active Modes

Active transport modes include all the modes that do not require an external energy source for passenger transport, primarily walking and cycling. These transport modes have never been considered in the energy statistics, since they are not related to the energy consumption of any fuel, and at the same time, they represent a marginal share when considering passenger-km. However, they make up a non-negligible share of the number of trips in our everyday life, and they have the potential of replacing a significant number of short motorized trips, especially in densely populated cities. Any proper sustainable mobility planning strategy should be defined by maximizing the contribution of active modes, especially in first- and last-mile solutions. Active transport can also help in preventing the deaths attributable to physical inactivity, which have been estimated to reach 3.2 million worldwide on a yearly basis (WHO, 2011). Moreover, being affordable by virtually everyone, they are the most equitable of all transport modes (Buehler & Pucher, 2012). They also provide advantages related to urban congestion, noise, air pollution, and use of land space.

Due to the lack of a consequential fuel consumption, there is no reliable accounting of the total amount of trips done on foot or by bike on a global level, although some numbers are available on a country basis or for selected cities, calculated with different estimation methods, usually based on surveys. Some researchers have analyzed walking and cycling figures for some countries by considering the most comparable and detailed data, including the US, the United Kingdom, Denmark, France, Germany, and the Netherlands (Buehler & Pucher, 2012). Considering the percentage of total trips in the last decades, a generalized decrease of active modes is noticeable, although with marked differences across countries, which is related to a corresponding rise of travels by private car. The most recent data (2008) show a 11% share of walking in the US, with values in European countries but Denmark above 20%. Cycling shows a larger variability, with slight variations over time in each country, but huge differences from high-cycling countries (the Netherlands, Denmark, and Germany with 25%, 18%, and 10%, respectively, in 2008) to low-cycling countries (France, UK, and USA with 3%, 2%, and 1%, respectively).

A data-driven estimation of physical activity patterns in different countries has been performed by analyzing data from smartphones' accelerometers, to calculate the daily steps performed by the users (Althoff et al., 2017). The researchers found that the average user recorded roughly 5000 steps per day over an average span of 14 h, but with significant differences across countries (from a low 3500 steps in Indonesia to a high of 6900 in Hong Kong). The findings highlighted the role of the built environment in helping citizens improving their daily activity, with beneficial consequences on public health. It must be noted that this research, based on smartphone data, included mostly high- and middle-income countries, while low-income countries may result in even higher steps per day, although not resulting from a choice but rather due to necessity. Data from smartphone may also be affected by smartphone ownership distribution within each country that could be biased based on gender, age, or income.

1.3 Freight Transport

Freight transport has become more and more important in the last decades. This is mainly due to its integration in the manufacturing supply chain driven by the increase of trade at global scale, thanks to better information and communication technologies and favorable regulations (Rodrigue, 2017). More convenient and cheaper freight transport solutions unleashed the possibility of locating production unites in sites with more favorable conditions, exploiting an increasingly complex distribution of final products as well as input materials. With increasing complexity of final products, supply chains are currently involving multiple intermediate products, shipped from different world regions depending on their market conditions. As a result, freight transport is now the backbone of the industrial system at the base of the world economy, and often transport infrastructures (roads, railways, ports, pipelines) are among the key assets for trade and geopolitics.

The main modes involved in freight transport are water (mainly over sea but also in inland waterways), road, and rail, with a minimum contribution of pipelines and air transport. This latter mode is limited to goods for which speed is a crucial requirement, since the cost is significantly higher than for other competing modes. As reported in Fig. 1.7, freight transport demand, usually measured in tonnes-km, is largely dominated by sea transport, and the total demand is expected to increase more than threefold by 2050 (ITF, 2019). Moreover, sea transport will even increase

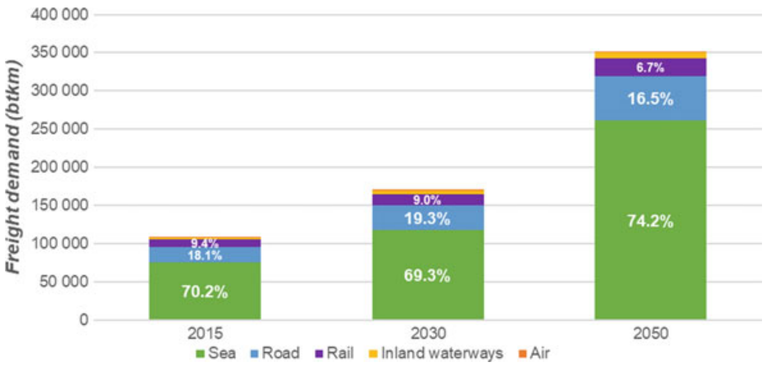

Fig. 1.7 Estimated future demand for world freight transport by type, billion tkm. Authors' elaboration from ITF (2019)

its share, reaching three quarters of the total demand by 2050, with a decrease of both road and rail shares. These projections are heavily dependent on economic growth estimations, and therefore, in the current context of uncertainty, they may be subject to significant variability. Another key factor is the expansion of trade capacity in countries with a substantial potential, notably in Asia.

The energy consumption of freight, as discussed for passenger transport, is largely dominated by oil products, mainly diesel oil for trucks, inland waterways and some rail, and mainly heavy oil for international marine transport. Alternative energy solutions for the decarbonization of the different modes will be discussed in deeper detail in Chap. 2.

In comparison with passenger transport, usually freight transport has less stricter requirements in terms of comfort, speed, and flexibility. Goods can be stored along the trip without significant issues, although in some cases refrigeration is needed to avoid goods deterioration (foods, cold chemicals, etc.). On the other hand, while passengers can face multimodal trips by changing mode by themselves, freight displacement from a mode to another may need longer time and dedicated infrastructure and logistics.

Finally, it is worth noticing that we usually have a more direct knowledge of passenger transport, thanks to our everyday experience, and we are much less familiar with all the aspects involved in freight transport logistics as well as their impacts.

1.3.1 Road Freight

Road freight is the most flexible mode, and it is often used for the last part of the supply chain, although it may cover alone the entire path from production to supply to the final user, especially for short- and medium-distance supply chains. Road freight, thanks to its flexible, convenient, and fast operation, has contributed to the evolution of the goods supply chain from the past, when industries and logistic centers were located near the ports or rivers to allow for maritime transport. The relatively low cost of vehicles and the unrestricted access to road infrastructures make easier for new actors to enter the market, resulting in high competition and low margins in comparison with other modes.

Different truck sizes are available depending on the quantity of goods that are delivered, and the availability of a large and diversified vehicles fleet allows for a better management of goods distribution. There is a limited potential for increasing the size of the trucks, and the corresponding weight and volume of goods that can be carried. National regulations usually limit the maximum weight of trucks due to safety reasons and to the effect of heavy vehicles on the road infrastructure, which results in increased damages and maintenance costs. Moreover, the energy consumption of the engines increases strongly with the weight, resulting in unsustainable economic operation (Rodrigue, 2017).

Currently, road freight transport is totally relying on diesel oil, thanks to the better efficiency of the engines, especially when running at constant speed for long distances. Although it accounts for only 20% of global tkm, road freight consumes more than 70% of energy in freight modes (Teter, 2018). The majority of fuel consumption is due to medium and heavy trucks, and although light commercial vehicles represent a marginal share, they are by far the less efficient freight transport mode. The average energy intensity of trucks in 2017 was 0.35 kWh/tkm (30 toe/Mtkm) for medium trucks (but with significant variations depending on the country) and 0.30 kWh/tkm (25 toe/Mtkm) for heavy trucks (IEA, 2019c). Some alternative fuels are gaining interests thanks to their advantages related to the decarbonization pathways (as it will be better discussed in Chap. 2), including biofuels blends, liquified natural gas, hydrogen, or electricity.

The shift to trucks by many transport companies has led to an increase of road freight transport, with consequences on congestions, especially in urban areas. Urban traffic conditions are often reaching the limits of the available infrastructure, especially due to commuting patterns during day hours, and freight transport in cities is competing with the larger number of vehicles for passengers. As a result, congestions lead to delays and lower frequency of delivery, resulting in the need of increasing the vehicles fleet to ensure the same level of service, with even larger consequences on congestion.

The rise of e-commerce is putting additional pressure on last-mile freight transport, due to the increase of the competition and the speed expected by the customers. The increase of last-mile freight services with door-to-door delivery may be compensated by fewer shopping trips by customers, although the trade-off between these two aspects is very context-specific and it is difficult to draw generalized conclusions. However, e-commerce is often causing additional trips that are required also for very small parcels, as well as the more frequent returns of defective or unwanted goods. Advanced algorithms may increase the effectiveness of door-to-door delivery by an optimization of the organization of trips.

1.3.2 Rail Freight

Rail transport has been at the core of the industrial era, supporting the economic development of countries in the US, Western Europe, and Japan. However, in the last decades, it has faced a strong competition from road transport, whose increasing efficiency and flexibility, together with decreasing costs, were the basis for gaining a considerable market share.

Rail is the land transport mode with the highest capacity, since a single wagon can carry up to 100 t, more than the triple of a truck, and multiple wagons are generally connected in the same train, exploiting economies of scale. There is a wide variety of rail vehicles specialized for different purposes. Open wagons (hopper cars) are used for bulk cargo (e.g., minerals or coal), box cars to carry general and refrigerated goods, and tank cars to carry liquids. The development of intermodal transportation has also supported a new class of flat railcars that can carry containers, in combination with trucks or ships. The trend has thus been toward a specialization of freight wagons for different goods, and a single train can often be composed of various types of wagon, although with higher costs for assembling and organizing goods (Rodrigue, 2017).

Due to the high investment costs, rail companies are often nationalized and operating in conditions of monopoly, or in some cases of oligopoly. There are significant constraints related to the limited time slots available, which lead to the need of a rigid schedule and organization. This aspect is even more critical if the tracks are shared with passenger rail transport, the latter being often prioritized due to its higher requirements in terms of speed. For this reason, in the last decades, freight rail has seen a larger development in regions with dedicated tracks. However, the recent shift toward high-speed trains that are mostly operated on separate tracks is opening additional time slots for freight transport on conventional passenger railways.

A critical issue for freight transport over long distances is related to the standardization of gauge in railway networks: although the standard gauge (1.435 m) is diffused on 60% of the global mileage (mainly in North America and Western Europe), freight transport over long distances involving different gauge systems requires changing vehicles, with consequent higher times and costs. This is one of the obstacles hindering the development of rail transport between Asia and Europe. Other factors limiting the interoperation across multiple countries are related to signaling and electrification standards, which often limit the operation across country borders.

Rail freight transport is currently powered by diesel or electricity, with variable shares across world regions. At a global scale, electricity-powered trains carried 48% of the total tonnes-kilometers (tkm) in 2016 (IEA, 2019c), but this share was over 80% for Japan, Russia, and Europe, while North America and South America were heavily relying on diesel. Since electric trains are more efficient, the final energy consumption of freight transport in 2017 (IEA, 2019c) was 25 Mtoe of diesel (291 TWh) and 130 TWh of electricity (equal to 11 Mtoe), although it is important to notice that the electricity production may involve different amounts of primary energy depending on the region, resulting potentially in higher primary energy consumption. The energy intensity of rail freight transport showed a world average of 0.04 kWh/tkm (3.5 toe/Mtkm) in 2017 (IEA, 2019c), with lower values for China and Russia thanks to the high loading of the trains and electrification rates. Potential alternative energy sources for non-electrified rail lines include natural gas, biofuels, hydrogen, or electric batteries, although none of them has shown so far economic viability. However, decarbonization policies such as carbon taxes may change the equation, and pilot projects are already being evaluated in different countries.

1.3.3 Maritime Freight

Maritime freight represents by far the most common mode of freight transport worldwide considering volume, final energy consumption, and GHG emissions. In the last decades, international shipping has been the backbone of globalization, allowing the development of complex products supply chain based on manufacturing sites located in different world regions, to fully exploit the advantages of local conditions (e.g., resource availability, low wages, national regulations).

One of the most significant game changers has been the development of containerization, which led to faster and more standardized port operations, with a better integration with other transport modes (trains, trucks, and inland navigation). Containerships have now annual sailing times of around 70%, while previously bulk carrier ships used to transport different goods needed longer port operations, as high as 75% of the time (Rodrigue, 2017). Containerization also allowed inter-range services, i.e., a continuous loop involving a sequence of different ports with a flexible frequency based on market conditions, usually including a transoceanic service. The main advantage is the possibility of optimizing the use of the ships by increasing their average load factor, although attention must be paid to avoid the risk of empty trips, particularly in backhauls. Recent trends include intermediate hubs, to avoid the need for large ships to deviate from the main marine shipping routes. Figure 1.8 reports

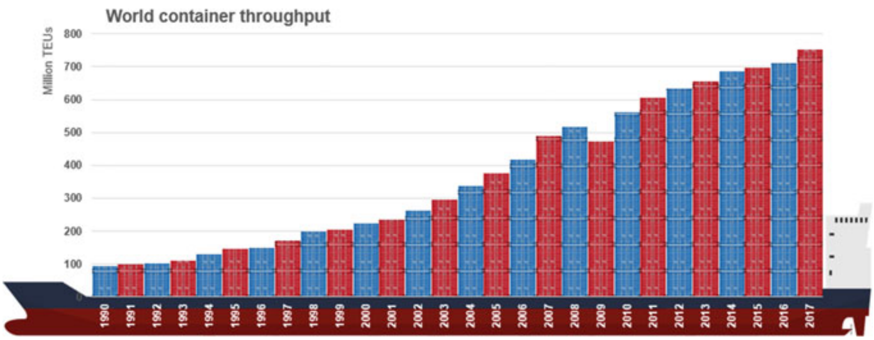

Fig. 1.8 World container throughput, million TEUs. Authors' elaboration from World Bank (2019)

the evolution of world container throughput (i.e., each charge/discharge of containers) measured in twenty-foot equivalent units (TEUs), which are used considering as reference the size of a standard container.

However, maritime trade is still dominated by bulk carriers, which represented around 60% of total tkm in 2015, including ores, grain, coal, and oil. Oil alone had a share of 25%, much lower than its 60% share of 1970 (Rodrigue, 2017). Bulk carriers are the largest vessels currently in operation, and the largest oil tankers can reach up to 500,000 deadweight tons. Crude tankers are among the more dangerous ships for potential environmental impacts, as demonstrated by the oil spilled into the water during several accidents, the worst being Atlantic Empress in 1979, ABT Summer in 1991, Castillo de Bellver in 1983, and Amoco Cadiz in 1978 (ITOPF, 2019). Oil spills are consistently decreasing in the last five decades, with 55% occurred in the 1970s, and only 6% after 2000, thanks to increased security standards. However, it is estimated that roughly 5.9 million tonnes have been spilled from tanker accidents since 1970, which is equal to roughly 5% of the total seaborne oil, crude, and gas carried in 2017 (ITOPF, 2019), or to less than half of the daily global oil consumption in 2017 (IEA, 2018b). While this amount appears to be relatively small, it is important to remind that its local environmental impact is significantly larger than for the oil combustion, especially considering the limited area that is affected.

Ships are the less energy-intensive freight transport mode, with a specific energy consumption that is between 5 and 20 times lower than trucks on a country basis, with a world average around 0.03 kWh/tkm (2.5 toe/Mtkm) (IEA, 2019c). Two key factors impacting the fuel consumption are the ship size and the cruising speed, the latter leading to an exponential increase of energy consumption. The choice of cruising speed is generally a trade-off between the fuel costs and the duration required by the trip, which may also require the use of more ships to maintain the same frequency on port calls on an inter-range service (Rodrigue, 2017). On the other hand, the ship size has seen a significant evolution in the last decades, and currently, the maximum sizes are limited by the characteristics of major canals (mainly Panama) and ports, as well as the need of finding paying cargo to fill the ships and justify the additional investment costs.

1.4 Focus on Selected World Regions

The feature of transport systems and mobility patterns across the world shows significant variations, since the historical development of transport infrastructure and the availability of and preference for different transport modes has been driven by several aspects including geography, economy, culture, development, resource availability, geopolitics. For this reason, any future strategy dealing with sustainable mobility planning needs to be carefully designed based on local conditions, since there is no one-size-fit-all solution to deal with the different problems related to passenger and freight transport. Moreover, within each country, strong difference exists between

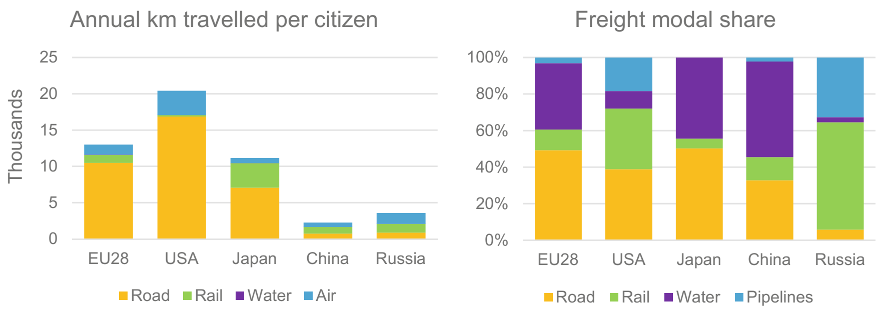

Fig. 1.9 Annual km travelled per citizen and freight modal share for selected countries. Authors' elaboration on European Union (2018)

rural and urban areas, although this dichotomy has many similarities across world regions.

Figure 1.9 presents a comparison of some indicators for selected countries, showing that significant regional differences exist both for passenger and freight modal shares. However, such comparisons should be evaluated carefully, since statistical data are often collected and aggregated with different logics, which may lead to non-comparable figures.

1.4.1 Europe

Europe includes today more than 50 countries, corresponding to more than 700 million inhabitants. The transport of passengers and goods has continuously increased since the industrial revolution, and European countries have mostly cooperated in developing and maintaining compatible transport networks. Europe is connected through a capillary network of roads, railway lines and inland waterways, as well as through marine ports and airports. The estimated transport activity in the EU-28 in 2016 reached 6.8 trillion pkm for passenger transport on any motorized vehicle (although 71% on cars), and 3.7 trillion tkm of freight transport, of which 49% on road and 32% on inland waterways (European Union, 2018).

Thanks to the significant development of multiple transport infrastructures, European countries are very well connected, and citizens can often choose from different modes for any given trip, especially in urban contexts. International trips are relatively easy, especially in the Schengen Area, which enables border control-free travel between 26 European countries. However, there are significant differences across countries, both between Northern and Southern Europe, due to cultural habits and weather conditions, as well as between Western and Eastern Europe, due to a different level of economic development. Although the European Union is developing common regulations and strategies, national policies over the years have supported different mobility paradigms.

Some Nordic countries, especially Netherlands, Denmark, and Germany, have a significant penetration of bicycle usage for commuting and other urban trips, thanks to cultural habits, dedicated policies, and geographical conformation of most cities. The key to achieving high-cycling usage in cities appears to be the provision of separate cycling facilities along heavily travelled roads and at intersections, combined with traffic calming of most residential neighborhoods (Pucher & Buehler, 2008). Other significant measures included the development of proper dedicated parking areas, full integration with public transport and promotional and educational events for citizens using bikes and cars. Bike usage in several European cities has also been supported by the development of bike sharing systems throughout the last decade, with the aim of providing the users with a first- and last-mile transport mode to be coupled with public transport to decrease the use of private cars in densely populated cities.

Most European countries have high usage rates of public transport, both at urban level and across cities. Thanks to the diffused road and rail network, trains and buses are a convenient and affordable solution for passengers needing to travel from a city to another, also between different countries. The largest European cities have underground metro lines that have been in operation since decades, and the first system in the world opened in London in 1890. As of 2017, European metro systems are present in 46 cities, carrying 10.8 billion passengers per year (UITP, 2018).

The European Union is developing climate and energy policies aiming at decreasing the carbon emissions, as well as supporting primary energy savings and the use of renewable energy. EU Directives have also set specific targets for the use of renewable fuels in transport, particularly biofuels but also electricity from renewable energy sources. In last years, the adoption of electric vehicles (EVs) is rising, although with a strong variability from a country to another. Norway is becoming the world leader for EVs, with a market share of electric cars that peaked to 46% in 2018 (IEA, 2019a), driven by the generous incentives provided by national regulations. Europe is the second marked of EVs worldwide, after China and before the USA, but with a market share that remained below 3% in 2018.

1.4.2 North America

North America is a very large continent with a relatively low population, with consequences on both passenger and freight transport modes. The USA and Canada have a large network of highways connecting the major cities, but some large rural areas are still equipped with poor-quality gravel or unpaved roads. As a result of the more recent development of this continent in comparison with Europe or Asia, many city plans have been developed based on the use of private car as the primary mobility mode, leading to lower densities and very large cities. Due to the significant distances between cities, domestic aviation has gained a strong importance in the last decades for passenger transport, especially thanks to the development of low-cost air carriers that led to an increase of air transport demand. The extended railway network is currently used almost only for freight transport, with some limited exceptions in regional areas where passenger transport is used for commuting, especially on the East Coast of the USA.

The dominance of car in the last century shaped both the society and the current US infrastructure, which would require significant investments to shift toward alternative modes such as public transport or active modes. Road transport has also been strongly supported by federal and state regulations, as well as to lower taxes on transport fuels in comparison with other developed countries. The federal support for highway projects in the US is higher than for public transit, and for passenger rail, no funding is given to the single state, resulting in significant consequences on modal competition (Rodrigue, 2017).

However, in the last years, many cities are testing innovative solutions to address the rising problems related to congestion, local pollution, and land space use in city centers. Digital technologies including sharing mobility, Mobility-as-a-Service, and autonomous vehicles are being the object of multiple startups, especially in California and other major cities across the country (see Chap. 3). The USA has seen the rise of Uber and Lyft, two ridesharing companies that reached tens of billions of market capitalization, and delivered 5 billion and 620 million of trips in 2018, respectively (Trefis Team, 2019).

Another significant trend, although with strong difference across US states, is the rise of EVs, especially in California, Hawaii, and Washington, with the USA being the second country worldwide for EVs sales in 2018, reaching 360 thousands units, 17% of the global sales (IEA, 2019a). Moreover, the US company Tesla, one of the companies at the origin of the current EVs hype, became the top selling EVs manufacturer in the world in 2018, with 245 thousand units (Demandt, 2019), mainly sold in the domestic market. However, Tesla has not yet generated a full-year profit over its 15-year history, although its performance has been getting better in recent years.

1.4.3 China and East Asia

International transport has played a crucial role in supporting the strong economic development of Asian countries in last decades, and especially in China, the construction of seaports and transport infrastructures has made possible the development of manufacturing supply chains producing goods for the global market. However, the increasing well-being and urbanization rates resulted in massive mobility demand for commuting and access to services, and since the deployment of mass transit systems has not kept the pace with the increasing demand, private cars and other motorized vehicles are creating increasing congestions and local pollution in large cities. Asian countries, especially in Southeast Asia, are also characterized by a massive use of two-wheelers and three-wheelers in cities, with significant impacts on congestions and road safety.

At a regional level, the challenge of developing transport programs that ensure inclusiveness and safety is still a major hurdle, especially for rural areas that are still lacking connections with social and economic networks (Rakhmatov et al., 2017). An improvement of rural transport is necessary to address multiple aspects including economic development, employment, access to health and education facilities, as well as poverty reduction by connecting producers and consumers. Significant differences exist from a country to another, depending on the level of development and on cultural, historical, and political issues.

As in other sectors, transport programs in China have a significant impact at a global scale, given its large population, its strong economic development as well as very large and growing urban areas. The unacceptable levels of local pollution in last years have led the government to push for electrification of passenger transport, with the largest cities deploying draconian policies to support the use of both electric cars and electric buses. Some cities are even limiting the number of fossil-powered new cars that can be sold each year, by auctioning a limited number of license plates. However, the development of EVs is also seen as a strategic action to develop the national industry, to compete with other countries that have a stronger know-how on traditional automotive based on internal combustion engines.

Similar pollution and congestion problems are being faced by other Asian countries, including India, whose population is likely to exceed the one of China, thus making India the most populated country in the world. Both road and rail networks are significantly developed and public transport remain the only option for most citizens, although private cars and two- and three-wheelers are increasing, with negative consequences on road safety. In large cities, web-based ridesharing apps are providing cheap solutions in alternative to traditional taxi cabs, providing to a larger number of citizens the possibility of moving by car on demand. However, the current infrastructure is unable to meet the strong rise in demand, and the lack of investments is slowing economic growth, especially in rural areas. Rail activity in India is expected to grow more than in any other country, with passenger movements in India reaching 40% of global activity. Rail remains the primary transport mode connecting numerous cities and regions, and passenger transport is currently second only to China (IEA, 2019c).

Transport demand in Asia is expected to show a strong increase in the following decades, both for passenger and freight, and it must face the constraints related to the international agreements on decarbonization. In particular, freight transport is supporting the increased wealth of the continent's population, but a significant share is also related to global trade. As a result, a crucial aspect in international agreements will be the shift from a production-based allocation of impacts toward a consumption-based logic, for a deployment of effective decarbonization policies (Golinucci, Rocco, & Colombo, 2019).

1.4.4 Latin America

Central and South America is characterized by a large variety of environments, with the largest cities being concentrated nearby the Eastern and Western coasts, with large rural regions in the hinterland. An efficient and integrated system of transportation is essential to foster the development of the region and the trade and passengers' movement between the different countries. The main roads network is interconnecting the largest cities of the continent, but there are huge disparities with the road conditions in rural areas, where roads are often unpaved and with a lower quality. Different projects have been developed in the past to ensure a good interconnection of the national highways, including bridges connecting Argentina, Uruguay, Paraguay, and Brazil.

The strong development of roads has caused railways to lose their dominant position after the 1960s, resulting in a decrease of the quality of the service, caused by operational problems and equipment aging. Moreover, most lines are single track, discouraging the passenger transport due to the delays, and the presence of different gauge standards is hindering an efficient interconnection between the different rail networks. The privatization of rail systems performed in the 1980s in different countries in the region has further led to a huge decrease of both passenger routed and rail freight transport (Knapp et al., 2019).

Sea transportation has been significant in the history of most South American countries, since the majority of imports and exports in the continent are relying on shipping. There are some major inland waterways, but the freight traffic is generally limited and with low potential for expansion in future years. On the contrary, domestic air transport has strongly developed in the last decades, due to the significant advantages for passenger mobility between distant cities with long and often uncomfortable roads connecting them.

Considering urban transport, South America has seen a strong development of Bus Rapid Transit (BRT), which is now present in 55 cities in Central and South America carrying more than 20.5 million passengers per day, which corresponds to a 60% share at global level (BRT Data, 2019). BRT is a system designed to improve, reliability, capacity, and speed in comparison with conventional bus systems in cities. Its main features are the use of dedicated lanes and priority at intersections, to prevent the impact of congestions on the bus speed. Other aspects to speed up the boarding times include the use of off-board fare collection, platform-level boarding, and the use of high-capacity buses.

The main rationale of BRT systems is to combine the advantages of high capacity and speed generally provided by rapid transit, with the flexibility and the lower capital cost of the bus systems. This does come at a cost, since there are usually higher operational costs and a lower lifetime of the vehicles. Moreover, although more efficient than private cars, in comparison with an electricity-powered rail transit, BRT shows higher environmental impacts both for local pollution and GHG emissions issues. Moreover, overcrowding and poor service quality are major concerns in many cities, including Santiago and Bogotà, whose TransMilenio is among the largest in the world. People are complaining about the long waiting times and the low comfort of the trips, resulting in a modal shift of a large number of users toward private cars and motorcycles in the last decade. To reverse this trend, it is important that bus operators develop new financial plans that go beyond the simple fare collection, by following the example of other cities in Europe and Asia.

1.4.5 MENA

The mobility demand in the region has rapidly increased since the 1970s, following a rise of the population, together with one of the highest urbanization rates in the world. Poor urban planning and the lack of good public transport have driven an increase of car usage, also supported by rising incomes in some areas. However, rural areas and urban citizens with lower incomes are still using nonmotorized vehicles or overcrowded minibuses (The Economist, 2016), with increasing inequality concerns in some countries.

The dramatic increase of private cars, also favored by cheap fuel prices in oil-producing countries, has not been supported by an adequate planning and deployment of infrastructures, resulting in major congestions, especially in large cities. Together with road safety issues, traffic is also significantly impacting the GDP of some countries, due to the lack of access to opportunities for the citizens and the limitations caused to trade. Moreover, the difficulties of commuting further pushe toward urbanization, leading in some cases to strong problems in providing services to the citizens in highly populated areas (The Economist, 2016).

However, congestion problems are leading to an interest in developing public transport systems in larger and richer cities, starting from the mass transit system opened in Dubai in 2009, among the longest fully automated systems in the world (Hashem, 2016). New subway systems, including the huge rapid transit system being deployed in Riyad, are exploiting the most recent technology developments to face the harsh weather conditions in the region, both for the potential intrusion of sand in the vehicles and the extreme temperatures requiring dedicated cooling systems.

Moreover, thanks to the availability of financing, cities in UAE are becoming test sites of multiple innovations in transport. In particular, Dubai aims at providing one quarter of all vehicle trips by autonomous cars by 2030, and driverless cabs are already being tested in the city. Furthermore, innovation is being pushed even farther, since autonomous electric-powered flying taxis are being considered for testing in the city. However, the innovations are not limited to urban mobility, since the connection between Dubai and Abu Dhabi is being chosen for one of the first potential applications for Hyperloop, which would allow transporting 10,000 passengers per hour between the two cities in only 12 min (Red Herring, 2018).

However, it must be kept in mind that all of these projects are still at very early stage. And while innovation is being put at the center of the transport planning agendas in few cities, much still needs to be done in smaller cities and rural areas, as well as in the poorer countries of the region. National mobility strategies should clearly aim at decreasing inequalities and promote a sustainable development for all their citizens, for which a reliable and affordable transport system is unavoidable.

1.4.6 Sub-Saharan Africa

The history of transport infrastructures in Sub-Saharan Africa had been strongly affected by the European colonial powers. While there had been highly developed transport networks in many parts of Africa in pre-colonial time, during the colonial era these infrastructures were adopted to connect seaports to the internal areas that were rich of resources, with the sole aim of serving the interests of the external powers (Kröner et al., 2019). This happened both to roads and to railways, the latter being also affected from an uncoordinated development of different gauges, hindering interconnections between different countries. All of this was further complicated by the vast unpopulated areas lying between the main centers.

This is the single region with the highest expected population increase in the following decades, which together with high urbanization rates will require reliable and effective transport systems to improve the access to opportunities and services required for higher standards of living in comparison with the current situation in the continent. While the issues of energy access and access to clean cooking are being at the center of multiple discussions, the access to opportunities supported by sustainable mobility is often underestimated. In comparison with other continents, in Africa, walking is still the most common mode of transport in most countries. And yet nonmotorized transport is not receiving the necessary attention, especially in large cities, that should become more pedestrian-friendly.

Most African cities are on a development trajectory of increasing private car usage and informal public transit, which will evolve toward unsustainable mobility patterns without a proper policy development. The demand for efficient and affordable transport systems is very high, because a large part of people's income and time is spent on their daily commute. African cities should look for leapfrog opportunities by exploiting the best practices and technology development that are being deployed in other world cities. Sustainable urban transport solutions are crucial to mitigating the growing congestion, road safety issues, and pollution in the region's sprawling urban centers (SSATP, 2018).

The region is facing a strong urbanization, with large cities all over Africa affected by congestion problems leading to higher costs. Moreover, there are still significant social, political, economic, and physical barriers to mobility that are hindering social inclusiveness. New technologies supported by an effective use of big data may play a crucial role in helping dynamic traffic management and the coordination of other resources on the road. However, the comprehensive, consistent strategies needed at the national and subnational level to tackle these challenges are lacking. Better planning, better institutional coordination, and more appropriate and sustainable financing are clearly needed (SSATP, 2018).

1.5 Conclusions and Key Take-Aways

This chapter described the main aspects related to transport, highlighting the complexity of the sector and the high variability of mobility demand and supply with respect to multiple dimensions, including geography, demography, sectors, technologies, and transport modes. Both passenger and freight transport are at the basis of an effective development of countries and societies, and the sustainability of transport is becoming more and more necessary, due to the rising concerns related to climate change, local pollution, congestions, and safety, especially in large cities all over the world. However, significant differences exist among world regions, since cultural, economic, historical, political, and geographical aspects are crucial in the development of transport modes and infrastructures.

The evolution of mobility is being shaped by two main trends, digitalization and decarbonization, which will be further discussed in Chaps. 2 and 3. Both trends are tightly related with the development of international, national, and local policies, as will be described in Chap. 4. Policy priorities may vary from an area to another, with strong effects on the support of specific transport modes and technologies, which may lead to different transport mixes in comparison with the current situation, especially due to the huge increase of demand that is expected in the following decades.

Huge differences are expected between developed and developing countries, since the lack of well-developed transport infrastructures, which is currently seen as a burden, may become an opportunity of leapfrogging toward better transport systems. Learning from the current issues of multiple transport systems in large cities worldwide, avoiding the lock-in of oversized road networks supporting mobility models solely based on non-shared private cars will be crucial, especially in urban areas.

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