**Technical assessment for**

**Carpooling**

Sector: Transportation

Agency Level: Individual

Keywords: Ridesharing, High Occupancy, Private Cars, HOV Lanes

Version 2

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# Acronyms and Symbols Used

* ***AASHTO*** *–* American Association of State Highway and Transportation Officials
* ***BTS*** – Bureau of Transportation Statistics
* ***CO2/ CO2 /CO2e/ CO2e*** – Carbon Dioxide/ Carbon Dioxide Equivalent
* ***DOT*** – Department of Transportation (of US)
* ***EIA*** – Energy Information Administration (of US)
* ***EU28*** – Group of first 28 Countries of the European Union
* ***EV*** – Electric Vehicle
* ***FHWA*** – Federal Highways Administration (of the US)
* ***GHG*** – Greenhouse gas
* ***GPS*** – Global Positioning System
* ***GT*** – Gigatons
* ***HOT*** – High Occupancy Toll
* ***HOV*** – High Occupancy Vehicle
* ***ICCT*** – International Council on Clean Transportation
* ***ICE*** – Internal Combustion Engine
* ***ICT*** – Information and Communication Technology
* ***IEA*** – International Energy Agency
* ***IPCC*** – Intergovernmental Panel on Climate Change
* ***kWh*** – Kilo-Watt-hour
* ***MaaS*** – Mobility as a Service
* ***PDS*** – Project Drawdown Scenario
* ***Pkm*** – Passenger-kilometer
* ***REF*** – Reference (Scenario, of Project Drawdown)
* ***RefPol*** – Reference Policy Scenario
* ***SOV*** – Single Occupancy Vehicle
* ***SUV*** – Sport Utility Vehicle
* ***TAM*** – Total Addressable Market
* ***TNC*** – Transport Network Companies
* ***UCD*** – University of California at Davis
* ***UK*** – United Kingdom
* ***WWII*** – World War 2

# Executive Summary

Carpooling refers to the practice of the driver of a vehicle providing one or more passengers a ride to their destination concurrently. Carpooling aims to reduce the number of operating vehicles required for people to reach their destinations and decrease greenhouse gas emissions and costs associated with driving. Carpooling also mitigates additional economic and social costs of driving, such as traffic congestion.

To promote carpooling, some jurisdictions have installed high occupancy vehicle (HOV) lanes on highways, others have provided HOV priority parking at workplaces, and some have banned single-occupancy vehicles outright, though only temporarily during critical periods. Other private sector initiatives, including many transport network companies and services (Uber, Lyft, Carpoolworld, Liftshare, Carticipate, etc.), encourage shared trips with information, improved trust, and price discounts, and some employers are using other services to help their employees get to and from the office collectively. Still, other services that help share taxis and other context-specific trips are popping up showing how dynamic the carpooling space is. Motivators for adoption include economic, environmental and social benefits. Barriers to uptake include flexibility and convenience of service and institutional regulation.

This report focuses its analysis on all services and policies that increase average urban car occupancy worldwide. The car occupancy rate is projected to increase in the three growth scenarios to reach a target average global urban car occupancy (1.7, 2, and 3) by 2050.

Impacts are significant in the three scenarios: 12.8gigatons of Carbon dioxide equivalent (CO2e) reduced over 2020-2050 in the least aggressive scenario (the Plausible scenario) and a significant operating cost savings of US$9.3 trillion. More aggressive scenarios (the Ambitious and the Maximum scenario) show lower results since they operate in a world where less car travel happens overall due to more adoption of other solutions like Walking and Public Transport. Therefore, emissions reduction drop to 8.1 and 6.9 gigatons of CO2e and $5.9 trillion and $5.35 trillion net operating cost savings for the second and third scenarios.

Overall, Carpooling is a key solution to help reduce emissions from car use which is not expected to be eliminated entirely despite any policies to promote mode shift to Public Transport and other more sustainable modes. Carpooling is also a great solution for combining with those solutions as well as with Electric Vehicles and Hybrids to maximize the total emissions reduction in urban transportation.

# Literature Review

Transport produces around 8.3 gigatons of CO2-equivalent greenhouse gas emissions, or 25% of energy-related emissions, or 14% of all emissions globally in 2018 (IEA, 2020). In individual countries, transport can account for much higher shares, even 33% of all emissions as in the UK (United Kingdom Department for Business, Energy & Industrial Strategy (UK BEIS), 2019), and these figures exclude the additional radiative forcing due to aviation’s high-altitude emissions. Growth rates in emissions for some subsectors like air transport are very high, so the sector requires initiatives to keep emissions from ballooning out of control, as some projections indicate. Transport, however, is a service derived from economic growth, so as a country develops, movement of people and goods increases. Car, sport utility vehicle (SUV), light truck, and motorbike transport are the largest contributors at 51% of all transport emissions followed by medium and large trucks and buses at 27%. Aviation and sea shipping each contribute 10% of total emissions (IEA, 2017). Generally, avoiding motorized transport, shifting transport to more efficient options, and improving motorized transport efficiency are the strategies for reducing transport emissions.

## Car Occupancy

*Car Occupancy* is the number of people traveling in a car trip at any point in time. Average car occupancy is a useful metric to indicate the use of cars for trips. If one divides the car occupancy by the total number of seats in the car, the resulting percentage is called the *Load Factor*. Load factor is a more general metric indicating how productive a vehicle is, and applies to vehicles of all types: planes, trains, buses, and automobiles. A similar metric is calculated for freight based on the used and the maximum cargo that a vehicle can carry. For both people and freight, the load factor can be calculated using the distance traveled by the carried load (say person-km) and the carrying capacity (seat-km).

Why is car occupancy important? Cars typically carry very high fixed weights: all the metals, rubber, glass, and plastic carried on a car trip often exceeds 1 metric ton (2,204 pounds), whereas a single driver is likely to be under 0.08 metric tons (176 pounds), and car fuel engines are not very efficient on a well-to-wheel basis (electric cars can be more efficient) so much fuel is used just moving dead weight. From an emission and energy perspective, it’s better to take as many people in the least number of cars as possible to maximize the productivity of this moving dead weight. Three cars moving 3 people to the same destination generates close to 3 times as much emissions to move dead weight than one car taking 3 people.

Vehicle-miles or vehicle-kms are units of measurement of vehicular movement, representing one vehicle (a car) moving 1 mile or 1 km respectively. Vehicle-km requires almost proportional fuel consumption, so twice as many vehicle-km use twice as much fuel. In reality, this is not exactly true since fuel consumption varies by car speed, road conditions, and car load, but the basic idea holds. What we are primarily interested in is how people are moving. A person-km is analogous to a vehicle-km but for people. However, fuel consumption doesn’t have to be proportional to person-km since we can alter the number of people in cars. This difference is at the heart of carpooling’s potential. Carpooling allows us to supply the necessary person-km to move travelers to reduce vehicle-km and fuel consumption and greenhouse gas emissions. This concept is also why public transit is more efficient than cars. But cars have the added advantage of flexibility and convenience that is difficult to provide via public transit.

Car occupancy varies by car type, trip purpose, trip origin and destination, urban density, local culture, car ownership levels, and many other metrics. Average values therefore vary widely worldwide. Data from the International Council on Clean Transportation (ICCT), collected initially from several national agencies estimated that average national car occupancy in 2010 ranged from 1.38 in the US to 2.31 in India (ICCT, 2012). More recent data from the Bureau of Transportation Statistics indicate that the US average private car occupancy (including cars, SUV, light trucks) was 1.67 in 2017 (BTS, n.d.). Additionally, data from the US National Household Travel Survey indicate that for all person trips made by car, SUV, truck, and van, over 49% were with more than one traveler suggesting that carpooling is relatively high (US DOT, FHWA, 2019). An estimated car occupancy in China is around 1.6-1.7 recently (Environmental and Economic Policy Research Center of the Ministry of Ecology and Environment, 2018a; Liu et al., 2017a), down from 2.5 in 2004 (Zhao et al, 2013).

A recent review paper shows the world car load factor in the main regions and countries (Schäfer & Yeh, 2020a). As carpooling is more common when car ownership levels are low (Fiorello et al., 2016), in countries that have lower car ownership levels, average car occupancy levels are often higher than in other countries. The car occupancy rate is only 1.3, which is much lower than the global average. The car ownership level is relatively lower in Asia countries. The car occupancy level in Japan and South Korea are high to 2.51 and 2.01, respectively (Schäfer & Yeh, 2020a).

The link between car occupancy and sharing of rides (carpooling, ridesharing etc.) is explored in this report, and the modeling of that link is described in the methodology section. The focus of this report is sharing of car rides. Although carpooling and car occupancy are chiefly concepts relevant to urban car trips, there is interest in expanding sharing on other modes such as bicycle sharing, motorcycle sharing (with the average US motorcycle occupancy at 1.16 in 2017), and intercity car trips with services such as BlaBlaCar.

## State of Carpooling

### Sharing Rides

There are numerous ways to increase car occupancy including “carpooling directly” and the use of “dynamic ridesharing” using transport network companies (TNC’s) such as Uber’s UberPOOL or Lyft’s LyftLine/Shared services. Carpooling and ridesharing, combined with “carsharing”, are so often confused and interchanged that most academic literature finds it necessary to define exactly how the authors mean the terms to be interpreted. Table 1.1 highlights in green the terms that we include as part of the solutions to low car occupancy based on the listed definitions. The key elements of all these in green are that individual rides are generally shared by multiple travelers and can reduce vehicle miles traveled. This report will use ***carpooling*** to represent all the terms highlighted in green in Table 1.1.

Table 1.1 A Sample of Some of the Most Common Terms Used to Describe Sharing of Private Cars.

The terms that highlight sharing of rides in their definitions are in green .

| **Term** | **Definition** | **Examples** | **Sources** |
| --- | --- | --- | --- |
| Carpooling OR Dynamic Ridesharing† OR Vanpooling OR Slugging | Sharing rides in a non-commercial service by travelers on similar routes who may also share operating expenses and driving responsibility. This often focuses on commuting. Some subtypes include **Fampools** (mainly family members in car), **Casual Carpools/Slugging** (impromptu version), **Vanpools** (using vans). | Waze Carpool, Carzac, Carma, BlaBlaCar, CommutewithEnterprise, C-TRAN Vanpool | Shaheen & Cohen (2019); Circella & Alemi (2018); Ciari & Axhausen (2011); DeLoach & Tiemann (2012) |
| Ridesharing OR Ridehailing OR Ridesourcing OR TNC’s\* OR  Social Taxi | A “chauffeur” service provided by car owners over an app-based platform to travelers requesting rides. This generally only supplies individual rides. | Uber, Lyft, Grab, Didi | Shaheen & Cohen (2019); Schaefer (2019); Circella & Alemi (2018); Handke and Jonuschat (2013); Agatz et al. (2012); |
| Ride splitting OR Dynamic Ridesharing† | A “chauffeur” service where travelers are pooled with unaffiliated individuals with similar origins and destinations. | UberPOOL, LyftLine/Shared | Shaheen & Cohen (2019); Circella & Alemi (2018); Gurumurthy et al (2019) |
| Taxi Sharing OR Taxi Splitting OR Shared Ride Taxis | Taxis that pickup more than 1 unaffiliated individual with different origins and/or destinations. | Bandwagon (especially from Airports). Additionally, sharing of taxis is historically a common practice in developing countries for economic reasons, and is often classified as ‘informal transport’. | Shaheen & Cohen (2019); Hosni et al (2014), Powers (2015) |
| Carsharing | Sharing of a vehicle on a for-hire basis (renting). The vehicle may be owned by a single company or by individual members of a group. | Zipcar, Car2Go, Turo | Standing et al (2019) |

\* Transport Network Companies

† Note that *Dynamic Ridesharing* has two meanings in the literature

The underlying thinking behind encouraging and advocating for carpooling is that single-occupancy vehicles (SOV) bear economic, social, and environmental costs. These economic and environmental costs can be reduced through shared ridership. Political entities and the public’s focus vis á vis the benefits of carpooling have varied in the last 50 years, including a focus on reducing fuel consumption, decreasing congestion, and (more recently) reducing greenhouse gas emissions (Chan and Shaheen 2012). During the fuel crisis of the 1970s, carpooling in the US reached its highest rate. However, by reducing resource demand, carpooling can also help achieve other goals. For instance, during World War II, the federal government encouraged people to share their cars in order to conserve gasoline, rubber, and other resources for the war effort (Sulik 2013).

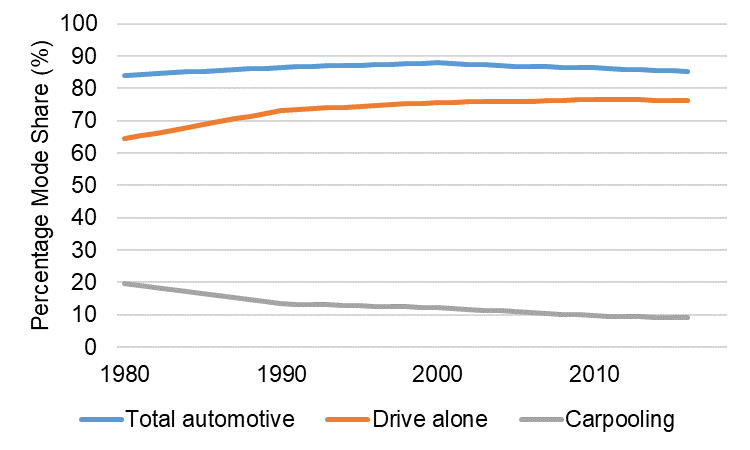
**

Figure 1.1 U.S. Census commuting by carpooling or drive alone

Anyone can carpool at any time. The concept simply relates to taking people on fewer car rides. It’s not the same as having more people ride than would have traveled singly. This is called induced demand or rebound, and this may be misinterpreted as fulfilling the goals of carpooling but only increases emissions rather than decreasing them. Carpooling is mostly of focus for commuting since this is one of the most frequent trips performed worldwide, and it places the greatest strain on transport infrastructure therefore leading to the greatest risk of congestion. Other trips are also benefitting from carpooling. In particular, intercity carpooling trips (via BlaBlaCar) and even everyday trips (via Ridesplitting) are seeing great interest through an explosion of services and groups. Surveys of US travelers found that 40% of ridehailing rides were for returning home (as opposed to only 18% for heading to work), and a wide variety of other purposes were covered in the remaining 42% (Schaller, 2018).

Replacing single occupancy trips of all purposes with carpooling trips can reduce vehicle miles traveled, hence emissions despite having possibly greater driving to collect and drop off passengers. Many scenario studies have indicated this reduction in vehicle miles traveled, especially for taxi trips, in a variety of cities such as New York (Lokhandwala & Cai, 2018; Alonso-Mora et al., 2018), Beijing (Cai et al., 2019), Austin, TX (Gurumurthy et al., 2019), Atlanta, GA (Niels et al., 2011), and Lahore, Pakistan (Arshad et al., 2015).

Carpooling replaces single-occupancy driving and taxi use and more sustainable modes such as public transit, biking, and walking. This is significant for non-commuting trips such as those taken by Dynamic Ridesharing (Schaller, 2018; Wang, 2011) and for specific groups such as immigrants. Blumenberg and Smart (2010) found that immigrants to the US took far more trips by family carpool than by public transit, and that really, immigrants use public transit less and carpooling more the longer they live in the US.



Figure 1.2 WWII era poster encouraging carpooling in order to conserve resources for the war effort

(Pursell 1943).

Note the use of “Car-Sharing” then, to mean what we call “Carpooling” now.

This substitution of sustainable modes by Carpooling may be a challenge for using carpooling as a climate change solution without proper management.

There are distinctions to be made between carpoolers and people who happen to make a trip in the same vehicle. A true carpooler can be considered as one who shares trips with friends, peers, acquaintances and/or colleagues (DeLoach and Tiemann 2012). In contrast, a ‘fampooler’ is a person who shares rides with members of the same family and (for the most part) household (DeLoach and Tiemann 2012).The distinction between the two terms is important as the nature and reasons for sharing rides with family members differ from the nature and reasons for sharing rides with people from other households. In particular, there is a convenience associated with the fampooler’s shared origin and destination (i.e., home) and fampooling coincides with transport-based family responsibilities (Vanoutrive et al. 2012). The distinction is also important because the proportion of carpoolers that can be considered fampoolers is substantial. An early study of carpooling using the 1977-78 Nationwide Personal Transportation Survey (NPTS), estimated that 40% of all carpoolers in the United States were sharing rides with members of the same household (Teal., 1987). More recent research has shown that this trend has persisted (if not increased); for example, a study conducted in Houston, Texas, estimated that approximately 60% of carpoolers were sharing rides with family members (Burris and Figueroa, 2006) and a later state-wide study found this number to be closer to 75% of carpoolers (Li et al., 2007). Policies and strategies aim to increase the cognition of carpooling or sharing rides among the public to address costs associated with vehicles, particularly SOVs. Returning to the recent data showing that 49% of person car trips in the US had more than 1 passenger (US DOT, FHWA, 2019), these new data suggest that only 25 – 40% of the non-SOV trips were non-family carpools, that is, 12 – 20% of all car trips.

### Types of Urban Carpooling

#### Driver as Passenger: Carpooling/ Slugging/ Dynamic Ridesharing

In this flavor of carpooling, the driver is also a passenger with the desired destination. It may be the very simple form (e.g., slugging) where drivers pass by special stops on their morning commute to pick up strangers so that they may use the HOV lanes on commuting. It may be a slightly more organized form where employees of the same organization (or friends who live in the same area) coordinate a plan for sharing trips chiefly for commuting, with fuel costs and driving responsibility shared. Moreover, it may be larger-scale coordination where entire metropolitan areas have networks of drivers and passengers for commuting trips (e.g., Carma) or even for one-off longer trips (e.g., BlaBlaCar). The coordination and communication have evolved from physical message boards in public locations to internet-based cell-phone coordination with trust built into the platforms by validating identification and driving licenses, possibly with Bluetooth technology. All participants are being pooled on their trips that potentially replace mobility trips with multiple cars or other modes of transport.

#### Driver as Casual Chauffeur: Ridesplitting/ Dynamic Ridesharing

Recent advancements in online and mobile technology have enabled new approaches to ridesharing that many describe as ‘dynamic ridesharing’. This practice refers to using an automated system to connect a potential rideshare passenger with a rideshare provider. Ridesharing systems began utilizing online technologies in 1999 with the popularization of the Internet (Chan and Shaheen, 2012). With the proliferation of GPS-enabled mobile phones in more recent years, these systems have increased in sophistication and use locational data to optimize driver-passenger matches (Agatz et al., 2011, Graziotin et al., 2010). Today, various dynamic ridesharing applications have been developed and are available to the public, including Uber, Lyft, Carpoolworld, Liftshare, eRideShare, Carticipate, and Zebigo. The increasing number of publicly accessible applications holds implications for both encouraging carpooling and promoting the sharing economy. By facilitating the sharing of spare resources (i.e., seats in cars) with people who require those resources, these applications may increase the efficiency of resource sharing within communities and, more broadly, societies (Malhotra and Van Alstyne, 2014). The proliferation of mobile technology has propelled precipitous growth for companies like Uber. Although not strictly used for carpooling, these mobile applications indicate that consumers require alternative types of rides in cars and can obtain those rides.

One attraction of this form of carpooling is that it allows all travelers not to have to drive. Many major reasons for using (unshared) Ridehailing are to avoid driving and park, which were seen as stressful, expensive, or risky if the traveler may have consumed alcohol (Clewlow and Mishra, 2017). This motivation can be expected to apply to Dynamic ridesharing also.

Despite focusing on shared trips, and specifically pooled TNCs in this section, it should be noted that some standard ride-hailing trips are for groups of persons. A survey of the Boston Metropolitan area found that around 42% of standard trips reported having more than 1 traveler in the ride, and around 15% were with 3 or more riders (Gehrke et al., 2018). The evidence shows that pooled services could help reduce fees. Additionally, since 20% of trips are actually pooled, though 37% request a pooled service (that is 54% matching), this suggests that 46% of the single rider-requested pooled services are not pooled in reality, and 100% of the single rider standard services are also not pooled in any way indicating an estimated total SOV share of 52% of all TNC activity. Some ridesharing occurs for 48% of all ride-hailing, though only 20% of rides are matched in pooled TNC services.

Nevertheless, not all Dynamic Ridesharing users are switching from the taxi or private cars. Research has shown that many ridesharing passengers would have used a wide variety of alternatives had the ridesharing options not been available, including public transit, biking, walking, and not traveling (Schaller, 2018). A survey of over 4,000 respondents in 7 major cities across the US found that over 60% of ride-hailing trips would have been made on non-car modes or not made at all, and that only 39% would have been made by private car or taxi (Clewlow & Mishra, 2017). Additionally, almost half of those private car trips would have been carpooling trips. Combining sustainable modes with ride-hailing is sometimes seen as a boon for sustainable transport, but unfortunately, it is rare. 9% of respondents indicated that they walk more due to the use of ride-hailing, but this is likely not for long distances and would have a negligible effect on vehicle miles traveled. Only 31% of trips in the Boston Metro area are from home, and 9% of those are to transit stops (that is, 2.8% of all trips are to a transit station, and similarly 1.6% of all trips are from transit to home) (Gehrke et al., 2018).

Clewlow & Mishra (2017) therefore indicate that vehicle miles are increasing due to ride-hailing. Since “shared ride requests” on Ride-hailing is so low (at 37% in participating cities on Lyft – Schaller, 2018) and the actual percent of “shared trips” that’s shared is not 100% and it’s unlikely that dynamic ridesharing would match more than 2 riders, it’s unlikely that Dynamic ridesharing reduces emissions from the non-car alternatives very much. This means that Dynamic Ridesharing is probably only a climate solution if it reduces the number of single-occupancy rides in private cars and taxis. This also means that Dynamic Ridesharing could be increasing congestion across the world. Dynamic ridesharing has pros and cons for urban transport systems. On the one hand, they reduce the likelihood of persons driving alone or taking taxis alone, but they also draw away persons who may have taken public transit or non-motorized modes of transport.

#### Driver as Professional Chauffeur: Taxi Sharing/ Taxi Splitting/ Shared Ride Taxis

Despite the name used for this section, many drivers of dynamic ridesharing services such as UberPOOL do drive “full time” suggesting that they are professional in the sense of being committed full time to the service. However, we focus on taxi companies and services for this section and the more stringent professional requirements that drivers have to fulfill. Taxis were generally for single occupancy trips in western countries (or entire entourages of private groups). Nevertheless, taxis in some developing countries have been used for sharing to help reduce costs. For instance, in various countries in Africa, Latin America and the Caribbean, the sharing of taxis (e.g., ‘bush taxis’, ‘route taxis’, ‘taxis collectifs’, or ‘carros públicos’) are often fixed or semi-fixed, routes for short- or long-distance journeys. This has been popular for decades since they help reduce travelers’ costs and allow drivers to adapt to market demand (Powers, 2015). Related options include larger minibusses that have similar routing structures and regulations that are available in many countries. Together these two options are called ‘sharetaxis’ (Kumar & Barrett, 2008)

Recently, taxi sharing has become popular in western countries partly due to pressure from TNC’s that are attracting passengers away for urban trips. Taxi companies have had to improve the convenience of their services by offering cellphone-based booking and allowing sharing, particularly in high-volume areas such as airports. The taxi companies themselves and third parties have developed some apps (Shaheen & Cohen, 2019). Various cities have various rules for where sharing of taxis is allowed. This is not allowed entirely for every region, for instance. Nevertheless, taxi sharing has helped taxis to compete with the dynamic ridesharing phenomenon despite their other restrictions.

#### On-demand Bus Services: Vanpool

One step up from pooling using cars is pooling using larger vehicles, especially vans or buses. This is not a new idea, and vanpools have been around for decades. Dollar Vans in New York offered a low-technology alternative for very low costs, and from 2013 Kutsuplus in Stockholm offered an internet-enabled service (Stromberg, 2015). Since then, numerous on-demand bus services have been created in the US, including Bridj[[1]](#footnote-1), Via Transportation, Ford’s Chariot, and Leap Transit. But, similar to Kutsuplus, and excluding Via, these services have all been stopped. However, on-demand bus services in India are thriving with the existence and funding for services like Shuttl, Commut, CityFlo, and ZipGo. As all of these use vans and buses to move people around, they will be dealt with more in the Public Transit report, which is not the focus of this report.

### Stimulation of Carpooling

#### HOV Priority

##### HOV and HOT Lanes (Including Busways)

The first official carpooling lane was established in 1969 along the Shirley Highway (I-395) in Northern Virginia and Washington, DC (Chan and Shaheen 2012). This high occupancy vehicle (HOV) lane reserved a portion of the roadway for buses and automobiles with at least two (or in some cases three) occupants. In forty years from the establishment of the Shirley Highway lane, HOV lanes have proliferated across the United States and Canada, with over 3,700 directional lane-miles in the United States and 174 lane-miles in Canada as of 2008 (Chan and Shaheen 2012).

HOV lanes incentivize carpooling by allowing exclusive access to a travel way. Theoretically, they have the capacity to reduce congestion and traffic by encouraging carpooling behavior, thus reducing the number of vehicles on the road. However, this point has been heavily contested. Varaiya (2005) noted that HOV restrictions can increase congestion by increasing traffic in general-purpose lanes and decreasing the capacity in the lane designated as HOV due to the inability for faster traffic to pass slower traffic. Another study from California noted that HOV lanes led to increased use among peak-time commuters who used the entire lane length but not among commuters in general (Guiliano et al., 1990). Alternatives to HOV that are gaining increasing attention are high occupancy toll (HOT) systems, which allow free access to vehicles with multiple passengers, while charging a toll to SOVs (Dachis 2011). The first HOT lane was established in 1995 in Orange County California on State Route 91 to address congestion issues that HOV lanes failed to solve (Dahlgren 2002). Because they are not exclusive and toll charges can be altered depending on usage and demand, HOT systems have more flexibility and capacity to respond to traffic conditions than traditional HOV lanes (Dachis 2011). Despite these benefits, there still exists uncertainty around how much more effective these lanes are for decreasing congestion than simply maintaining general-purpose lanes (Li et al., 2007).

It is important to note that carpooling lanes are primarily a North American strategy for reducing congestion. HOV lanes have been incorporated into the infrastructure of some cities in Europe, such as Leeds, Brussels, Graz, and Madrid, but they are most widely found in Canada and the USA (Fontes et al., 2014). Furthermore, evidence suggests that this strategy for encouraging carpooling and reducing congestion might not be appropriate for broader contexts outside of North America. For example, Wang (2011) conducted a viability study of applying HOV lanes in cities in China using roughly the same road capacity as in the United States. Wang concluded that due to higher proportions of bus traffic in China and lower vehicle-to-worker ratios, this strategy would likely provide little travel advantage and (thus) incentive for carpooling. HOV and HOT strategies are generally North American centric and only analyze and discuss their effects for that region. This is mainly due to some potential cheating risks and enforcement issues (Schaefer, 2019). Nevertheless, it’s acknowledged that there are examples of HOV lanes in Europe and Australia (Schijns & Eng, 2006)

##### HOV Priority Parking

One effective method for promoting carpooling is providing specially reserved priority spaces for parking. This has been trialed in Europe and has seen measurable success in the US (Schaefer, 2019). Research by Donald Shoup has indicated the powerful effect that incentivizing parking can have on stimulating carpooling using data for the US (Shoup, 2005). Put another way, when parking is easy, it decreases Carpooling attractiveness (Correia & Viegas, 2011).

#### Ridesharing Apps

The move by ridesharing apps such as Uber and Lyft to promote shared rides comes when resistance to these ridesharing companies is growing due to research suggesting that their single-passenger services may be generating traffic and congestion in already congested cities, particularly in the US. This promotion of shared trips is one way these companies are using to establish themselves as generators of the public good. In some cities, Uber offers UberPOOL and Lyft offers LyftLine/Lyft Shared to their customers, which allows the customer a lower price in exchange for sharing all or part of their ride with someone else whose trip may overlap with theirs. The adoption has grown to several cities since launch by both companies in 2014[[1]](#_ftn1), but despite Lyft reporting 37% of customers requesting shared trips in 2018, both Uber and Lyft report that only around 20-23% of trips are actually shared in New York, one of the largest and densest markets (Schaller, 2018). Uber’s portion of global trips that was shared was 20% in 2016 (Fortune, 2017). Note also that only a portion of a shared trip is actually shared.

One challenge with shared rides on TNC’s is that offering sharing does not mean that sharing will happen. It depends on the customers selecting that option (which depends on the price discount and trip flexibility) and on the potential spatial and temporal overlap with other trips.

To help stimulate the adoption of their shared options, Lyft and Uber both offer discounted prices, limits on the number of riders per request/pickup (to 2) and Uber offered a rebate if a shared ride delivered a passenger later than the expected arrival time (Hawkins, 2016). Additionally, both Uber and Lyft have started offering even cheaper shared services for passengers willing to walk to better pickup spots and walk from better drop-off spots. These Uber Express POOL and Lyft Shared Saver services help enable less circuitous driving to pick up and drop off passengers by having them meet in locations where the car has a more direct route. This clearly is a trend towards the Dynamic Ridesharing services becoming closer to public transit services and continues their experimentation with different service configurations following services like UberHop and Uber Commute (Hawkins, 2015). In the future, we may see these services incorporating autonomous vehicles in their fleets to lower prices further since driver costs are a significant part of the charge for consumers. It’s unclear whether this would impact the uptake of dynamic ridesharing. But both unshared and shared TNC trips would be lower in price.

#### Ridesharing/Carpooling Clubs

Research indicates that some travel characteristics predispose persons to carpool, including familiarity between people to increase trust, so a natural question arising from that is whether a Carpooling group or club can stimulate greater acceptance of carpooling. A Club here would be a group of known participants that frequently carpool together either in fixed travel groups or more dynamic groups formed by club members. There has been some research on using groups of persons on which some information is already known, to build trust between participants, and increase adoption. This does improve the level of acceptance in carpools, however research suggests that possibly due to lingering trust issues and possibly due to travel restrictions inherent in carpools, the levels of adoption may still not be sufficient to allow widespread cost-effective service (Correia & Viegas, 2011).

#### SOV Bans: Temporary Carpooling

Though not the focus of this research, critical events can sometimes force action on cities to avoid gridlock, and New York City has demonstrated this on occasion through its temporary bans on single-occupant cars going into Manhattan after disasters such as the September 11 Attack and after Hurricane Sandy in 2010 (TSTC, 2002; Kaufman et al., 2012). Due to the shut down of mass transit systems, and the need to manage the flow of commuters, the city bans applied to several bridge crossings and high-demand regions in the city. For some areas, the ban specified that 2-persons were required for each car, which was raised to 3 in some cases (HOV3+). In these cases, only the high police presence enabled enforcement, and these policies were credited with making major reductions in the gridlock experienced for commuters.

#### Education and Employer Programs

A key factor for the success of carpooling systems based at employers is clear communication of benefits to the carpoolers, preferential parking, efficient scheme management, and employer promotion (Cairns et al., 2004).

## Adoption Path

### Current Adoption

Obtaining data on carpooling adoption is very challenging since it’s very hard to monitor and enforce even when rules are in place. This report (and model below) takes the average global car occupancy as the best proxy for carpooling adoption. If one assumes that carpooling is represented by 3 *passengers* taking a car trip[[2]](#footnote-2), and the only alternative for a car trip is a single occupancy trip[[3]](#footnote-3), then carpooling can be estimated by Eq. 1.

|  |  |
| --- | --- |
|  | Eq. 1 |

Where:

*Adoption* is the adoption of carpooling as defined above in percent, and

*Occupancy* is the average car occupancy, and

*Carpool* is the number of persons in a carpool trip = 3.

This report takes 1.68 as the global average car occupancy compiled from multiple sources (Center for Sustainable Systems University of Michigan, 2020a; Environmental and Economic Policy Research Center of the Ministry of Ecology and Environment, 2018b; ICCT, 2012; Liu et al., 2017b; McQueen et al., 2020b; Schäfer & Yeh, 2020b) to estimate the current adoption share globally by the method laid out above[[4]](#footnote-4). The US’ *commuter* carpooling adoption from the 2017 National Household Travel Survey however, is estimated at only 12% and of this, 77% are 2-person carpools. Related data suggest that the average car occupancy was 1.67 in 2017 for all car trips (BTS, n.d.). This would imply a 33.5% adoption of carpooling. Historical BTS data indicated however that car occupancy varies by trip purpose, and is very low for commuting and very high for social trips (BTS, 2017). Besides, recent data from National Transportation statistics also shows that the average car occupancy was 1.67 in 2019 (United States. Department Of Transportation. Bureau Of Transportation Statistics, 2019).

The first 28 European Union countries (EU28) had an average car occupancy of 1.7 persons/car but with high variability across the countries (Fiorello et al, 2016). The lowest was 1.4 in Denmark and the highest 2.7 in Romania. The authors noted that car occupancy was negatively correlated with motorization rate indicating that carpooling was seen as an economic necessity rather than a cultural choice. Nevertheless, these lower and upper limits would imply adoptions of 20% and 85% respectively using the method laid out above.

### Trends to Accelerate Adoption

Carpooling as a mode of transportation has grown in and out of favor over time, depending on travelers' social and economic circumstances. As cars are attractive mainly due to the perceived convenience and accessibility that they provide. Carpooling can help create a reduction in environmental and financial cost. However, it also reduces those attractive benefits both for the driver (who may have to drive further to pickup or drop off the passenger) and the passenger, who may have to wait for the driver under current information and communication technology. In the future, the highly developed information and communication technology will help better optimize the route and service, which further overcome this innate resistance to carpooling.

#### Costs

#### Historically, economics has been a primary driver of carpooling adoption across countries and periods (Standing et al., 2019; Chan and Shaheen, 2012; DeLoach & Tiemann, 2012). This has been manifested in changing fuel prices, road tolling, and changing motorization rates. More recently, it’s been manifested in changing technology and business models. In countries with low motorization rates (especially when they also have insufficient public transport services and car-based urban design), carpooling is significant to illustrate the human need for access and mobility. This is widespread in the developing world where shared taxis and shared private cars are common. As motorization increases from economic development, the rate of carpooling declines. Similarly, when fuel prices are high, carpooling is generally higher than when fuel prices are low assuming all else is equal (Chan and Shaheen, 2012). Correia and Viegas (2011) found travel behaviors in Lisbon, Portugal, that low-income youth were among the most likely demographics to engage in carpooling through survey-based study. Carpooling for commuting is mainly promoted with HOV and HOT lanes on major access points into cities, especially in North America. This leads commuters to see carpooling as a way to save toll fees.

#### Convenience and Technology

Another key driver is the convenience for travelers (Standing et al., 2019). Technology (information and communication technology (ICT), global positioning system (GPS), and mobile data on cellphones) is now allowing Dynamic Ridesharing models that increase trust, ease, and convenience for travelers and enable car owners to generate income in a sharing economy. These new business models did not exist in the past, which is a driver of Ride-hailing and Dynamic Ridesharing. A related but indirect driver of this specific form of Carpooling may be the public perception of Ride-hailing companies (Uber, Lyft) generating congestion. This perception, supported by independent study, can affect the local policy environment these companies have to operate in since policymakers at the city level can affect what they are allowed to do in their cities, and these actions can have global ripple effects. A recent State of California decision to categorize freelancers or independent contractors not meeting specific employee requirements[[5]](#footnote-5) will have significant consequences for Ride-hailing company operation across the state and numerous other industries (Young, 2020).

Congestion and Air Quality

Congestion and air quality improvement are also drivers, particularly on the public-sector side where urban planners and transport planners use these to justify HOV and HOT lanes (Standing et al., 2019; Chan and Shaheen, 2012). Carpooling in North America as a percentage of overall commuting trips has been decreasing over the last few decades from 19.7% in 1980 to 9.7% in 2010 (AASHTO 2013, Chan and Shaheen, 2012). The decline occurred even though policies were being put into place to encourage carpooling (Li et al. 2007), and ultimately these decreases in carpooling were strongly related to drops in fuel prices (Chan and Shaheen 2012; DeLoach and Tiemann 2012). SOV as a mode of commuting has increased slightly from 64% in 1980 to 77% in 2010 (AASHTO 2013). From resource conservation for WWII to the oil crises of the 1970s, the concept of actively carpooling for its inherent benefits saw various surges in popularity throughout the 20th century (Handke and Jonuschat 2013 and Sulik 2013). Each of these surges was followed by a period of returning to SOV. However, policy-makers recognized HOVs’ contribution to reducing traffic and congestion. And they have enacted policies that promoted carpooling, such as the 1990 Clean Air Act Amendments that endorsed trip reduction ordinances (US EPA 1992) and the 1991 Intermodal Surface Transportation Efficiency Act that favored HOV lanes (Li et al., 2007).

Table 1.2 Different stages in the ‘evolution’ of carpooling in the US over the last five decades

(adapted from Chan and Shaheen 2012).

|  |  |  |
| --- | --- | --- |
| Time Period | Stage | Features |
| Late-1960s to 1980 | Major responses to energy crises | Focus on conserving fuel  Casual carpooling  High occupancy vehicle (HOV) lanes |
| 1980–97 | Early organized ridesharing schemes | Focus on addressing congestion and air quality issues  Policies alignment with carpooling  Trip reduction ordinances (TRO) |
| 1999–2004 | Reliable ridesharing systems | Focus on reaching public and developing critical mass  Early online systems |
| 2004-present | Technology-enabled ride matching | Mobile and GIS technologies  Dynamic ridesharing |

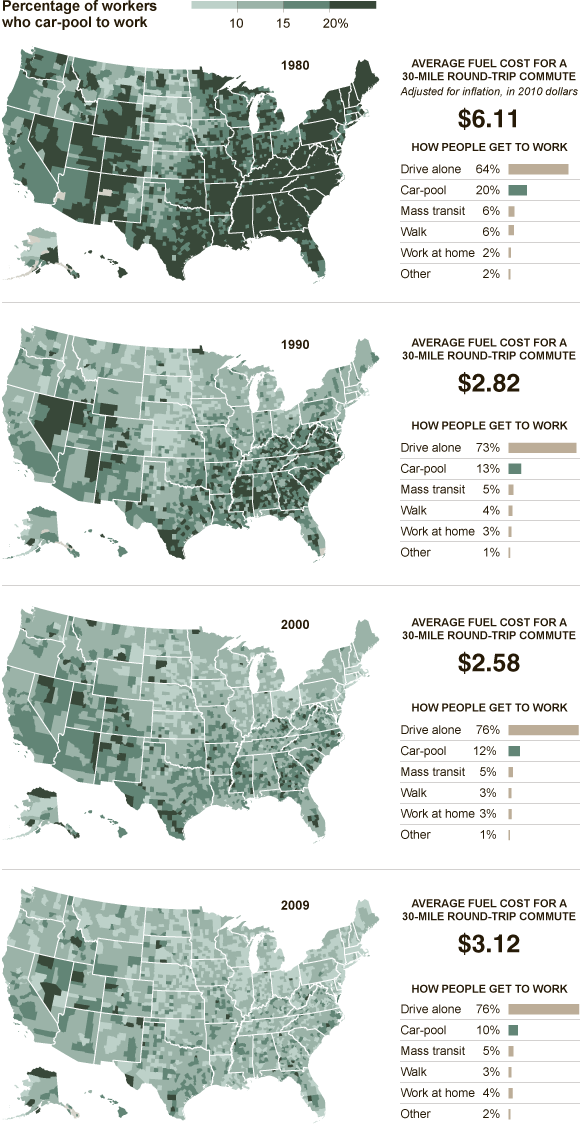
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Figure 1.3 Mapped correlation between lower fuel prices and reduced carpooling in the US

(Park and Gebeloff 2011)

#### Social Change and Environmental Benefits

Evidence for a cultural shift that is more amenable to carpooling can be found in Baxandall et al.’s (2012) research showing that young people are less likely to drive and own cars. Another important source was McKenzie (2015) which showed that young people and non-white people are the most prolific carpoolers among commuters. Polzin and Pisarski (2015) also showed that new immigrant groups carpool at higher rates than non-immigrants, and that these rates remain higher than average for future generations.

A survey-based study of travel behavior in Texas found that perceived social benefits of traveling with others were commonly stated reasons for engaging in carpooling (Li et al., 2007). Similarly, in another study conducted in Flanders, Belgium, Cools et al. (2013) found that engaging and interacting with others was an attractor to carpooling (particularly among office-based professionals and executives). Research has also shown that demographics play an important role in motivating carpooling. For instance, people are more likely to carpool if they are unmarried and enjoy social activities such as dining out with friends (DeLoach and Tiemann 2012). In addition to social benefits, some studies have found that perceived environmental benefits can motivate carpooling. For example, a survey study of almost 2,000 people of the University of California in Santa Cruz found the reduced environmental impact is the most frequently selected reason for carpooling than saving money or meeting people (Massaro et al., 2009). However, it is important to note that perceived benefits to the environment as a motivator align with a particular type of worldview. Therefore, this perception really only serves as a strong motivator for carpooling within particular demographics and settings (such as a liberal university setting) (Massaro et al., 2009).

#### Car Ownership

One interesting recent trend that may portend growth in carpooling is young people’s willingness to forgo driving and owning a vehicle. In generations past, owning a car was a powerful medium for, and symbol of, independence for young adults. Data show however that in the first ten years of the 21st century, per capita annual vehicle miles driven by people under 34 years old decreased 23%. Young adults today are less likely to own vehicles and more likely to travel by alternative modes. This has been facilitated by mobile technologies that have reduced some of the barriers and inconveniences of public transportation, while also providing communication and entertainment capabilities that make transportation less necessary (Baxandall et al. 2012). The report from McKinsey& Company published in 2020 shows that the carpooling penetration is higher in a household with higher car ownership compared with a household with lower car ownership (see Figure 1.5)(McKinsey & Company, 2020). This further indicates the low car ownership could potentially promote the penetration of

![图形用户界面

描述已自动生成](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDiRXhpZgAATU0AKgAAAAgABAE7AAIAAAAIAAAISodpAAQAAAABAAAIUpydAAEAAAAQAAAQyuocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFd1IENoZW4AAAWQAwACAAAAFAAAEKCQBAACAAAAFAAAELSSkQACAAAAAzA0AACSkgACAAAAAzA0AADqHAAHAAAIDAAACJQAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure 1.4 The vehicle ownership per household and carpooling penetration in the US from (McKinsey & Company, 2020).

#### Patriotism

During wartime in the US, authorities promoted carpooling to reduce resource consumption, and with illustrations as shown in Figure 1.2 , carpooling was promoted as the right and patriotic thing to do to fight evil. Carpooling rates for commuting were also relatively high in the US during this era. Since that time, interest in the US has dwindled, and for many places around the world, carpooling was mainly a commuting tool for reducing driving needs, chiefly among family members and some employee groups.

### Barriers to Adoption

Despite the numerous benefits, many barriers are preventing the widespread adoption of carpooling. Gidófalvi (2008) identified the top barriers as “the lack of effective mechanisms for scheduling and coordinating ride–shares, safety risks, social discomfort in sharing private spaces, and/or an imbalance of costs and benefits among parties.” Other commonly cited barriers to carpooling include flexibility, convenience (Chan and Shaheen 2012; Li et al., 2007), and high costs of single occupancy mobility. Carpooling requires coordination with others’ schedules and thus can be perceived as a loss of autonomy. This is particularly the case for fampools requiring a fair amount of flexibility to adequately meet family travel needs (DeLoach and Tiemann 2012). When considering the fact that a large proportion of carpooling is comprised of fampooling, the significance of perceived issues around flexibility and convenience as a barrier to carpooling becomes apparent.

Technology has begun to address the flexibility and convenience issues around carpooling, but a coincident increase in carpooling has not materialized. This may be because in addition to a loss, or perceived loss, of autonomy, another crucial psychological barrier to carpooling consists of concerns around safety and trust. These concerns can be amplified in ridesharing systems where passengers and drivers have not previously met one another (Graziotin 2010). Referring back to Cools et al.’s (2013) study, the authors found that although some people noted interacting with others to be a part of the appeal of carpooling, they found the same people had strong anxieties and reservations around carpooling with people they did not know.

A recent study reveals that human practical poor perceptions are still the main reason that stops the acceptance of carpooling in daily mobility (Adelé & Dionisio, 2020).

Even if psychological barriers are removed and carpooling systems are developed with (and are perceived to have) high degrees of convenience and safety, institutional barriers will still exist, particularly with newer dynamic ridesharing services. Ride offerings through dynamic ridesharing can compete with traditional ride-providing services, such as taxis. However, unlike taxis, rideshare providers do not have to take licensing exams or carry commercial insurance, making them both more financially competitive and more vulnerable in disputes with passengers (Malhotra and Van Alstyne 2014). As a result, some public officials may consider these systems as harmful to local employment and potentially dangerous to people, thus prompting regulation against their usage. For example, Germany banned the use of Uber with regular drivers throughout the nation (Malhotra and Van Alstyne 2014), so Uber had to adjust its business model to use only professional drivers, and even that was banned again (Lomas, 2019).

Trust has been a historical barrier to the adoption of carpooling for groups other than families and coworkers. With social networks allowing evaluations and ratings, as with other trust-based businesses in the sharing economy (AirBnB, and the TNC’s themselves for ride-hailing), this barrier has been lowered and is much less of a challenge, although there are still some safety concerns. Uber announced that almost 6,000 sexual assaults and 107 deaths were reported on its services for 2017 and 2018 (Vittert, 2019). This remains an important concern for many, but Uber’s report also noted that the rate of sexual assault and fatality is lower than the US national average. Regulation to protect consumers (from assaults, high prices, unsafe shared rides etc.) is also identified as a barrier to growth (Standing et al., 2019). Additionally, enforcement of carpooling on HOV is a significant barrier in many jurisdictions (Schaefer, 2019)

Matching trips is currently not an easy thing for daily dynamic ridesharing. The fact that only 54% of the 37% of Lyft riders requesting shared rides are paired in dense urban areas (Schaller, 2018) indicates that there are some technological or business limitations to matching riders. This means either the algorithms that match riders are not extracting as much pairing potential as needed or the designers have decided to limit the additional wait or walking that passengers would have to endure for a shared ride, which would have to be relaxed increase pairing.

### Adoption Potential

Carpooling is much more logistically possible in dense urban cities where the likelihood of finding trips that overlap in space and time is larger than in smaller cities or less dense cities. Current global car occupancy is estimated to be well below 2.0 persons per trip, indicating that there is much space for growth of carpooling tools. From historical US data, we know that it’s possible for a commuter carpooling to achieve 30% there, and therefore even higher levels can be expected for non-commuting trips since most car trips in the US have car occupancies above the commuting rate (BTS, 2017). Additionally, the global car occupancy appears to exceed that of the US, suggesting that a global total can be much higher than the 30% indicated above. Already in some places, average car occupancies above 2 are common. There is giant potential for carpooling to grow globally and to remain high in some countries where it already is. However, this would be dependent on strong policy to manage increasing motorization while expanding public transit and encouraging carpooling specifically.

## Advantages and disadvantages of Carpooling

### Similar Solutions

In essence, carpooling uses a vehicle to move more people than just the driver from one place to another. This can be achieved by any number of methods and in a large variety of settings. This report focuses on urban trips, but similar strategies can be used for instance for long distance inter-city trips. Several ridesharing services exist to facilitate these types of travel arrangements. However, they are not included in this report because they represent a small fraction of middle-distance travel, and because a light-duty vehicle with four or five passengers has roughly the same lifecycle carbon impact as an intercity train or even a well filled airliner (Chester and Horvath 2009). The small number of these trips and the small difference in their environmental impact compared to competing travel modes means that they would likely lead to negligible greenhouse gas (GHG) emission reductions.

There are many similar services that can be considered here since there are numerous pure and hybrid modes of transport in use today in cities. From the commuting perspective as well as general mobility, there are obvious alternatives such as SOV cars, public transit, taxis, and non-motorized transport (walking, biking). A high level comparison of all these alternatives is made in Table 1.3.

### Arguments for Adoption

Carpooling, when compared to SOV commuting, provides the benefits of reduced emissions and reductions in congestion. For the commuter specifically, carpooling provides a financial benefit as commuting costs are shared among those who carpool together. Savings vary based on car efficiency and the price of fuel, but in general, the cost of commuting halves with the first passenger and the savings increase further with each additional passenger. Fewer cars on the road due to carpooling may also result in systemic benefits such as less need for infrastructure replacement and reduced time spent in traffic.

In addition to the financial and environmental benefits from carpooling, there may be other advantages. Humans are social animals and the link between social capital and mental health is quite strong (Poortinga 2012). As carpooling is an inherently social activity, it follows that it may also contribute positively to mental health. Such a position is supported by the studies discussed above (see Adoption Path, Trends and Drivers), where social interaction is cited as a motivator for carpooling, indicating that people benefit from the social aspect of the activity. As carpooling systems become more advanced, these benefits extend beyond the general positive feelings people experience through social interaction to benefits received through making strategic connections with certain local community members. For example, Selker and Saphir (2010) discuss the TravelRole system (a rideshare system they developed for research purposes), where potential drivers and passengers can connect with one another based on interests, expertise, and knowledge sets.

### Additional Benefits and Burdens

The disadvantages of carpooling and dynamic ridesharing have been touched upon above, particularly with dynamic ridesharing and its challenge in competing with taxi services and in simply matching riders and generating trust when riders are strangers. Ridesharing systems can also be considered a mode of transport that competes with transit systems, and thus in transit-rich areas, promoting carpooling and ridesharing could be counterproductive (Vanoutrive, et al. 2012). Carpooling does reduce the number of SOVs, but SOVs have a smaller passenger capacity in comparison to transit vehicles. Therefore, strategies that encourage carpooling and ridesharing at the expense of transit ridership could have an overall negative effect in strategies aimed at reducing emissions (Schaller, 2018; Vanoutrive, et al. 2012). Carpooling has also been found to replace walking and other non-motorized modes as well as the traveler not making a trip at all, indicating that carpooling is attracting travelers away from more sustainable modes of transport that take up less space and generate fewer emissions. To combine the trips of multiple urban travelers, Dynamic Rideshare drivers have to drive extra distance and in waiting for passengers, drivers generate traffic which raises the social cost even further (Schaller, 2018).

An unavoidable disadvantage of carpooling is that it ultimately relies on personal vehicles to operate, and therefore has the same drawbacks of driving, albeit at a reduced level. In terms of reducing GHG emissions, a greater reliance on non-motorized transport such as walking and biking would have a much larger benefit. Additionally, although carpooling may provide mental health benefits from social interaction, similar benefits are also highly associated with active non-motorized transportation (Ramanathan et al., 2014). The walkability of a community should therefore be a priority consideration of city planners in order to support public health (Frank, et al. 2010). Employing car-based strategies for addressing climate change should be a lower public policy consideration. Therefore, although carpooling and ridesharing can aid in addressing climate change and other issues, they are unlikely to play a major or pivotal role.

Table 1.3 Alternative Comparison

|  | **Total User Cost** | **User Convenience** | **Comfort** | **User Safety/ Security** | **Possible User Range** | **Uncertainty (Including Congestion)** | **Negative Environmental Impact** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Carpooling/ Shared TNC (Solution) | Med | High | Med | Med | High | Med | High |
| Single Occupancy Private Vehicle | High | High | High | High | High | Med | High |
| Ride-hailing (Unshared TNC)/ Taxi | High | High | High | Med | High | Med | High |
| Taxi Share | Med | Med | Med | Med | High | Med | High |
| Walking | Low | High | Med/Low | High/Med/Low | Low | Low | Low |
| Biking (Including Bikeshare) | Low | High/Med/Low | Med/Low | High/Med/Low | Med | Low | Low |
| Public Transit | Low | Med/Low | Med/Low | High/Med/Low | Med | Med/High | Low |

# Methodology

## Introduction

Project Drawdown’s models are developed in Microsoft Excel using standard templates that allow easier integration since integration is critical to the bottom-up approach used. The template used for this solution was the Reduction and Replacement Solutions (RRS), which accounts for reductions in energy consumption and emissions generation for a solution relative to conventional technology. These technologies are assumed to compete in markets to supply the final functional demand exogenous to the model but maybe shared across several solution models. Therefore, the adoption and markets are defined in terms of functional units, and adoptions are also converted to implementation units for investment costing. The adoptions of both conventional and solution were projected for each of several scenarios from 2015 to 2060 (from the base year of 2014), and the comparison of these scenarios (for the 2020-2050 segment[[6]](#footnote-6)) is what constituted the results. The most updated year (current year) is 2018.

In many regions, the number of cars per capita remains high, and in others, it is growing. In developing countries such as China and India, cars per capita are low, even with historical GDP growth. It is anticipated that the share of vehicles in these regions will increase. The use of cars varies widely worldwide. Annual vehicle-km traveled per car per year in the US can be very high, partly due to cultural factors, but in other parts of the world, like Asia, the figures can be much lower while also growing and are leading to changes in the car occupancy (more leisure trips could increase the car occupancy). The use of cars for commuting in many countries is lower than in the US, with other modes of transport (public transit, cycling, walking) claiming a larger market share. The situation is complicated by the widespread implementation of policies that are focused on increasing the mode share of public transit, cycling, and walking rather than SOV.

Carpooling is a challenging solution to model globally. There are so many ways that it is interpreted, and it is so varied worldwide that we must find ways of standardizing the definition and the modeling at the global level. We have assumed that the chief metric for carpooling, as with the adoption estimation done above, is global average urban car occupancy, and we consider all urban car-based trips as the market for carpooling. The global average is estimated to be 1.6 persons per trip from multiple sources(Center for Sustainable Systems University of Michigan, 2020a; Environmental and Economic Policy Research Center of the Ministry of Ecology and Environment, 2018b; ICCT, 2012; Liu et al., 2017b; McQueen et al., 2020b; Schäfer & Yeh, 2020b), and averages trips for a wide variety of purposes. We have assumed that that older data are still relevant today. This model also defines a carpooling trip to be one with 3 persons, and all other trips to be single occupancy trips. Passenger-km are used as the functional unit provided, and a vehicle-trip is used as the implementation unit.

Energy and emissions are dependent on the type of cars used, and start at the current global average fuel intensity again using multiple sources for global, national, and regional including peer-reviewed sources (Liu et al., 2017a; McQueen et al., 2020a; Schäfer & Yeh, 2020a), international research institutions (Center for Sustainable Systems University of Michigan, 2020b; ITF/OECD, 2020) and government (Environmental and Economic Policy Research Center of the Ministry of Ecology and Environment, 2018a). However, the integration process accounts for an increasing share of electric cars and hybrid vehicles in the car fleet which shifts the fuel and electricity consumption over time. Additionally, as carpooling results depend on the number of cars in use, as mobility demand shifts to non-car options like bikes and Public Transit, the impact of carpooling is affected.

The solution is modeled using assumed target average global car occupancy levels that are defined based on historical data from various countries, and theoretical limits. Then the intervening years are estimated from simple growth curves.

## Data Sources

As Drawdown models are based on meta-analysis of published values for each variable and input where ever possible, several data sources are used for this work, and averages used for the majority of inputs. As stated earlier, the key data on occupancy come from the sources collected by the ICCT in their Global Transportation Roadmap model (ICCT, 2012) which includes data on several individual countries allowing us to examine the distribution of car occupancy to see what ranges are possible. Additional car occupancy sources include the Bureau of Transportation Statistics of the US government which publishes their Household Travel survey data including a range of detailed statistical data for the US population. This enables us to see evolution of car and light truck occupancy over time by trip purpose since the surveys are done with some regularity and consistency. Besides, we also include other sources such as peer-reviewed sources (Liu et al., 2017a; McQueen et al., 2020a; Schäfer & Yeh, 2020a), international research institutions (Center for Sustainable Systems University of Michigan, 2020b; ITF/OECD, 2020) and government (Environmental and Economic Policy Research Center of the Ministry of Ecology and Environment, 2018a). Sources for the Total Addressable Market (TAM) include the International Energy Agency’s Energy Technology Perspectives 2016 (IEA, 2016a), the ICCT’s 2012 publication, and the Institute for Transportation and Development Policy with the University of California at Davis in their joint publication of a global high shift scenario for transport (Mason et al, 2014). Other variables came from several peer reviewed scientific and grey sources including the UN Environmental Programme, the Electric Power Research Institute, and other Federal US agencies. Energy data (emissions factors, energy prices) come chiefly from the Intergovernmental Panel on Climate Change (IPCC, 2006) and the IEA’s Fuel Prices (IEA, 2019; IEA, 2016b).

As Drawdown models are based on a meta-analysis of published values for each variable and input where ever possible, several data sources are used for this work, and averages are used for the majority of inputs.

Global TAM was projected mainly using data obtained from highly respected international institutions, such as the International Energy Agency’s Energy Technology Perspectives 2016, the ICCT’s 2012 publication, and the Institute for Transportation and Development Policy with the University of California at Davis in their joint publication of a global high shift scenario for transport (IEA, 2016b; The International Council on Clean Transportation, 2012; UC Davis et al., 2015)

Adoption projections are gathered from as many credible sources as possible. The key data on adoption data are from multiple institution report, such as IEA Energy Technology Perspective (IEA, 2016a) ,IEA Global EV Outlook (IEA, 2018, 2021), Bloomberg Global EV Outlook (Bloomberg NEF, 2020), OPEC World Oil Outlook (OPEC, 2020), ITF Transport Outlook (OECD/ITF, 2021).

Variable inputs are used in the Variable Meta-Analysis and are updated to reflect current conditions at each update. These variables regarding climate input, financial input, and technique input came from wide range of literature, such as peer-reviewed scientific papers, reports, and grey sources (see section 2.5).

## Total Addressable Market

The total carpooling available market is defined as global urban mobility provided by cars, and therefore it changes annually according to total urban mobility, adoption of other urban modes, and this also varies by scenario. Data therefore came from a range of sources (shown in the Data Sources Section) and were adjusted.

Two major adjustments were made to the raw averaged urban mobility data on urban TAM collected from the sources to extract the component relevant for Carpooling:

1. Non-motorized data were added to those sources that excluded it. Mobility data often excludes non-motorized data like walking and biking, but this is critical to understand how non-motorized solutions can impact total mobility emissions, particularly in the urban realm. Project Drawdown therefore re-introduces urban non-motorized mobility estimates into the total TAM that is used across all Urban transportation solutions in the Drawdown work. These TAM datasets are therefore internally consistent across all solutions in the Urban Passenger Transportation cluster. Depending on source and scenario, this increases the total mobility by 4 – 13% in 2020.
2. The mobility Provided by higher priority non-car Solutions is removed. Since carpooling can only be a solution for car use, but car use is of lower efficiency than non-motorized options like walking and biking, and shared mobility options like Public Transport, Carpooling is of a lower priority than these solutions. This means that the mobility provided by higher adoptions of Walking, biking, e-biking, and Public Transport reduces the total TAM than Carpooling is constrained by implying a shift over time (especially in more aggressive Drawdown scenarios) to those higher priority modes than car-based modes. This also means that Carpooling’s impact is reduced in scenarios of higher ambition. In the Plausible Scenario (see Adoption Scenarios Section), non-car solutions removes 54% of the total Urban TAM in 2020.

## Adoption Scenarios

Two different types of adoption scenarios were developed: a Reference (REF) Case which was considered the baseline, where not much changes in the world, and a set of Project Drawdown Scenarios (PDS) with varying levels of ambitious adoption of the solution. Published results show the comparison of one PDS to the REF, and therefore focus on the change to the world relative to a baseline.

### Reference Case / Current Adoption

The Reference scenario for most Project Drawdown Solution models assumes that the percent current adoption of the solution (as defined in 2018) remains fixed for the future. This therefore ignores growth that may result in the Business as usual due to existing policy and committed investments worldwide, however it allows us to capture the impact of both those initiatives and additional initiatives which are needed to achieve the high growth scenarios. However, the Reference case is defined as a fixed percent of the total Urban mobility and grows with the total urban mobility. The current adoption, as described and calculated in the Current Adoption Section is 28.5% of all car trips, and since car trips of all modes are around 40% of total urban mobility according to numerous sources as described in the Data Sources Section, the adoption of Carpooling is 28.5% of 40% of total urban mobility or 11.4%.

### Project Drawdown Scenarios

Three Project Drawdown scenarios (PDS) were developed for each solution, to compare the impact of an increased adoption of the solution to a reference case scenario. In each case, a car occupancy target in 2050 was identified and a linear interpolation from the current value to that value in 2050 was created to estimate adoption each year. These car occupancy adoptions were converted to percent of adoption using Eq. 1 each year, and the percent’s are converted to passenger-km by multiplying by the TAM each year.

#### Plausible Scenario

In this scenario, the average car occupancy is projected to grow linearly to 1.71 in 2050. This figure was chosen as an ambitious yet achievable value based on data for several countries. ICCT data suggest that most of the global south was already above this value in 2010 including China, Russia, Latin America, the Middle East, Africa, and India (ICCT, 2012). This is mainly based on International Transportation Forum Outlook(OECD/ITF, 2021).

#### Ambitious Scenario

This scenario sees an average car occupancy of 1.94 in 2050, representing very ambitious target for carpooling worldwide. This would be supported by a wide expansion of shared Mobility as a Service (MaaS). This is based on 20% increase in 2050 in car occupancy(*The Global Calculator | Lever Occupancy and Load*, n.d.).

#### Maximum Scenario

In this maximum case, we define 100% carpooling or a car occupancy of 3 by 2050, but with carpools with more than 3 travelers regularly in use. This would represent a world heavily supported by shared MaaS whether on autonomous or human-driven vehicles.

## Inputs

### Climate Inputs

The climate analysis in this model uses fuel and electricity consumption values for both the conventional and solution alternatives. We therefore assume that electric cars can be used as SOV’s or for Carpooling just as internal combustion engine vehicles. For Carpooling that includes gasoline and electricity for cars of various types that are used. Energy consumption intensity of conventional and solution alternatives are general “Technical” inputs in the Technical Inputs Section). To calculate key emissions results, the model uses reported emissions factors for the electric grid as well as fuel emissions factors. Emissions factors for electricity generation are derived from the projected global energy generation mix from three AMPERE RefPol scenarios in IPCC AR5 model Database (GEM3, IMAGE, MESSAGE) and the IEA’s ETP 6DS scenario. Fuel combustion emissions factors come from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for Fuel combustion (IPCC, 2006). The values used are shown in Table 2.1.

Table 2.1 Climate Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Global average REF Grid Emissions Factor | g CO2e/kWh | 503-593 | Starting at High Input in 2020 declines to Low Input in 2050 to represent the decarbonization of the grid in the reference. | 12 each year | 4 |
| Gasoline Fuel Emissions Factor | kg CO2e/liter of fuel | 2.24 – 2.51 | 2.27 | 1 | 1 |

Note: Project Drawdown data set the low and high boundaries range on 1 standard deviation below and above the mean of the collected data points[[7]](#footnote-7).

### Financial Inputs

#### First Cost Factor

This analysis calculates costs and benefits for individuals who engage in carpooling. Many of the first costs to encourage carpooling, such as painting or building HOV lanes, are borne by governments. The capital cost of installing carpool lanes varies significantly and is site specific, ranging from simply repainting lanes to constructing separated or divided lanes. Additionally, the increased carpooling need not have a first cost at all because commuters can carpool without specific infrastructure such as separated HOV lanes.

It could be assumed that under the REF scenario (where SOV increases and carpooling decreases), additional road capacity may be required over time, resulting in a higher first cost compared with OPT. This however is a much more complex case, as increases in traffic may result in varied responses, such as building road infrastructure, expanding public transportation, or encouraging less driving overall. Expansion of highways due to capacity issues is itself contentious, as it has been shown only temporarily to alleviate capacity issues.

For the consumer or carpooler, there could be a negative first cost (savings). Some carpoolers may be inclined to sell a car or choose not to buy a new one, but this is unlikely. For instance, carpoolers often trade driving duties with other carpoolers and have other driving needs that cannot be met with carpooling. Therefore, there is little evidence that carpoolers will incur a higher or lower first cost and this report will assume zero values.

*For these reasons, this report does not analyze the first cost of increased carpooling to governments that regulate infrastructure nor individuals who engage in carpooling.*

#### Operational Cost – Maintenance and Fuel

Operating costs most prominently fuel and maintenance for carpoolers are the same as for any vehicle operator. But for carpoolers, the costs are assumed to be split among the travelers. Individual operational costs decrease as more commuters share a ride. Data from 5 sources indicate average maintenance costs, and IEA energy prices are indicated for the fuel and electricity costs (for Electric cars).

It could be argued that the uptake of carpooling results in fewer cars on the road, and thus lower maintenance and replacement of road surface in the future. However, these costs would be saved by road and highway regulatory agencies that are not included in this report's analysis. Moreover, this argument will only hold true if the number of cars traveling on roads remains constant in the future and if the uptake of carpooling significantly outweighs the increase of cars on the road. In general, the maintenance and replacement of road surface is dependent upon the amount of high load traffic it is subjected to (i.e., long base axle heavy vehicles such as cargo trucks etc.), and weather conditions. Decreasing the amount of passenger vehicle travel will not significantly affect road maintenance reduction as decreasing heavy load vehicle traffic.

Table 2.2 Financial Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Vehicle Maintenance Cost (Conventional) | *US$2014/ 1000 pkm* | 7.8 – 55.2 | 31.5 | 21 | 5 |
| Vehicle Maintenance Cost (Solution) | *US$2014/ 1000 pkm* | 2.2 – 18.3 | 10.3 | 21 | 5 |
| Electricity to Consumer Price | *US$2014/kWh* | N/A | $0.139 | 509 (for 57 countries) | 1 |
| Gasoline Price | *US$2014/liter* | N/A | 1.036 | 32 | 1 |
| Discount Rate | *%* | 3.0 – 5.0 | 4.0 | 6 | 6 |

### Technical Inputs

Besides only climate- and financial-oriented variables, some variables have been defined which apply to both climate and financial results. These are called Technical inputs, and are described below.

#### Carpooling Occupancy

An important input is exactly how many people would a carpooling trip take as opposed to a traditional trip. In some research, average occupancies of 3 were simulated to be possible at high levels of adoption Lokhandwala & Cai (2018). This was used as the input in the present study, and was assumed to exclude the driver, if not also a passenger. Using a lower value such as 2 would limit the total potential for this solution to avoid emissions since we would be implying that the highest car occupancy worldwide would be only 2 persons whereas some places have had higher average occupancies in the past, and many trips around the world often have higher occupancies including via ridesharing platforms. The lower car occupancy rate (2 in the Ambitious scenario) is assumed that the car occupancy rate in 2018 increase by 20% in 2050 based on the assumption in the research. The lowest car occupancy rate (1.7 in the Plausible scenario) is assumed to increase the car occupancy rate in 2018 by 6% in 2050 based on ITF Outlook assumption.

#### Fuel Consumption

Average global fuel consumption is the subject of global initiatives such as the Global Fuel Economy Initiative (GFEI) of the IEA, ICCT and many other partners, and of many research papers. The average global fuel intensity was estimated from multiple sources globally and nationally.

#### Electricity Consumption

A growing portion of light duty vehicle travel is with electric vehicles, and indeed one of Project Drawdown’s solution is Electric Cars. Therefore, electricity consumption is captured in this model with a use-weighted electric car consumption estimate coming from mainly the Energy Information Administration (EIA) using data for several battery EV and plug-in hybrid EV models.

#### Lifetime Capacity and Average Annual Use

This is defined as the total amount of functional unit that a single implementation unit can provide over its lifetime. Dividing this value by the average annual use gives us a lifetime. As the functional unit is passenger-km and the implementation unit is a single vehicle-trip, the lifetime capacity for a single occupancy (conventional) trip is therefore the same as the average annual use which is the average car trip length. For the solution, a carpooling trip, since there are three times as many persons traveling, the value is three times the average trip length, but both the lifetime capacity and the average annual use values are still equal. The average trip length was obtained from the ITDP and UCD joint research (Mason et al., 2014).

Table 2.3 Technical Inputs Conventional Technologies

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Conventional Car Occupancy | Persons / trip | 1 | 1 | 1 | Assumed |
| Carpooling Occupancy | Persons / trip | 3 | 3 | 1 | Assumed |
| Fuel Intensity 2020-2050 (Conventional) | liter/ 1000 pkm | 29.2 – 47.7 | (Depends on Scenario) | 19 | (derived from other inputs/models) |
| Electricity Consumption 2020-2050 (Conventional) | kWh/ 1000 pkm | 7.1 – 34.4 | (Depends on Scenario) | 5 | (derived from other inputs/models) |
| Fuel Efficiency Factor (Solution) | % (saved) | 66.7% | 66.7% | 1 | (derived from other inputs) |
| Electricity Efficiency Factor (Solution) | % (saved) | 66.7% | 66.7% | 1 | (derived from other inputs) |
| Average Car Trip Length | *km* | 9 | 9 | 1 | 1 |

## Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions. These are that infrastructure required for the solution is available and in-place, policies required are already in-place, no carbon price is modeled, all costs accrue at the level of agency modeled, improvements in technology are not modeled, and that first costs may change according to learning. Full details of core assumptions and methodology will be available at [www.drawdown.org](http://www.drawdown.org). Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below.

1. The current adoption of carpooling is defined by the world average car occupancy data which comes from 35 sources for global, national and regional level (mainly the main countries in car market like China, the US, Australia, Canada, Japan, and EU), therefore implying that it’s still relevant today as a baseline and current figure. In reality many countries have grown in their car occupancy evolution (up or down) due to a wide range of factors.
2. A “carpooling” trip is defined as one with 3 persons, and all other trips are assumed single occupancy. This makes modeling easier but ignores two-person and other trips. We know that single-occupancy trips are very pervasive, as illustrated by surveys from many countries. We also know that 3-person trips are very low in adoption. However, the adoption targets used in the modeling are to reasonable average occupancy levels (1.7, 2, or 3 in the optimum/maximum case). We have therefore simplified the situation to enable clean modeling and understanding of the results. We think that this is justified and that the modeled results should correlate well with real-world results if the average occupancy levels are reached.
3. Costs for operating a car are split 3 ways in a 3-person carpool indicating that each of the travelers would be responsible for a fraction of the total cost. In reality, there may be circumstances where the passenger's carpool trip are not paying for the vehicle maintenance, but might contribute towards fuel consumption. However, it is reasonable to expect that over time, and over multiple carpooling trips, passengers are rotated and driver roles are also distributed among all travelers, and hence maintenance costs are shared over the long term. Even in the case of non-work carpooling, this is a reasonable assumption.

## Integration

The complete Project Drawdown integration documentation (will be available at [www.drawdown.org](http://www.drawdown.org)) details how all solution models in each sector are integrated, and how sectors are integrated to form a complete system. Those general notes are excluded from this document but should be referenced to understand the integration process fully. Only key elements of the integration process that are needed to understand how this solution fits into the entire system are described here.

Each solution in the Transportation Sector was modeled individually, and integration was performed to ensure consistency across the sector and other sectors. These solutions require an integration analysis chiefly to avoid double counting, as they may result in the overall location of passenger or freight mobility to multiple modes simultaneously or incorrect distribution of passenger mobility to the urban or nonurban realms.

The integration process, while having several parts, including ensuring consistency of inputs across the sector, was mainly concerned with limiting the adoption of solutions where it was deemed necessary. The transport modes that were unaffected by any Drawdown solution, such as motorbikes and intercity bus had their mobility share blocked so that it could not be allocated to any other modes, and then the remaining mobility demand was allocated according to the priority of the modeled transport solutions.

Transport solution priority was loosely based on the Avoid-Shift-Improve framework where solutions that resulted in avoiding motorized mobility (walking, biking, telepresence) were classed as highest priority in their appropriate realm (walking is in the urban realm and telepresence is in the nonurban realm). Then the solutions that resulted in shifting of mobility to more efficient modes such as public transport or e-bikes were of second highest priority where space efficiency was qualitatively used as a classification metric. Finally, solutions that improved the efficiency of existing motorized modes were put in the third category with all car modes falling into this category.

Carpooling was classed alongside EV’s and Hybrids in the urban cluster, and so adoption was limited to the urban mobility after all higher efficiency modes’ adoptions were allocated, and adoption of carpooling was not mutually exclusive of adoption of EVs or Hybrids. A further integration of Carpooling with EVs and Hybrids was required since Carpooling was modeled to apply to an increasingly EV- and Hybrid-based global fleet. Similarly, the EV and Hybrid solutions were increasing with higher car occupancies in the urban portion of mobility due to Carpooling adoption over time. Note that the conventional alternatives were also assumed to change in both cases, so in a world increasingly using Carpooling, car occupancy for both conventional cars and EVs would be higher. Similarly, in a world with the increasing use of EV’s, both SOV and Carpooling trips would be increasingly based on electricity. Therefore, the car solutions were further integrated by estimating the new car occupancies that the EV and Hybrid models would be based on using averages for the entire analysis period for each scenario. For the carpooling model, the new average electricity and fuel consumption values, after adopting both EVs and Hybrids, were recalculated and averaged for the entire analysis period of each scenario. These changes served to reduce the impact of each of the 3 solutions.

In addition to transport sector integration, there was an integration process across the grid and electricity efficiency solutions (buildings, transport, materials, etc.) that adjusted for the double counting. Double counting of emissions reduction was a factor of using the reference grid emissions factors for electricity-based solutions. As grid solutions (Utility-scale Solar PV and others) are adopted, the grid gets cleaner and the impact of transport electrification solutions is amplified but not accounted for[[8]](#footnote-8). Grid solutions are adjusted to account for the increased impact as described in the Project Drawdown integration documentation. In the case of Carpooling, the integration of EV results in Carpooling working to decrease electricity demand so a cleaner grid actually results in double counting of the emissions reduction. Therefore the grid integration removes the double-counting effect.

Results in this report show already account for these integration effects.

## Limitations/Further Development

As with any modeling effort, there are some limitations of the approach used. The primary one is that we assumed only two car capacities: 1 person (SOV) or 3 persons in a Carpool. This therefore ignores the possibility of 2-person or 4+-person carpools, which both do happen. Data from the US illustrate that car trips and vehicle-km drop rapidly with increasing occupancy. For instance, the Household Travel Survey data indicate that for car and SUV trips to work, 90% were with a single person, 8% were with 2 persons, and 1% was with 3 persons, though we would expect that more multi-person trips would be counted for non-work travel (US DOT, 2019). An update could be including a range of adoptions for various Carpooling occupancies.

Another important limitation is the global averaging of car occupancies that vary widely worldwide and are affected by a wide range of local and national circumstances. Data from the ICCT, albeit from a 2012 publication, indicate a range of 2010 car occupancies from 2.31 in India to 1.22 in Japan (ICCT, 2012). This can be improved with more recent data for one, but also by making regional- or nation-based targets for car occupancy.

Using the assumption of no ICEVs fuel consumption improvement likely overestimates the impact that carpooling can have. The global movement towards more efficient vehicles is progressing, powered by government policy and the actions of programs like the Global Fuel Economy Initiative. However, there is an indication that many biggest improvements have already been made, and future improvements may be smaller in magnitude. There is also consumer interest worldwide in purchasing larger SUVs and light trucks following American trends, and these increase fuel consumption. However, assuming improvements in average ICE vehicle fuel consumption in line with the best projections might be a worthwhile improvement to the model.

# Results

## Adoption

Below are shown the world adoptions of the solution in some key years of analysis in functional units and percent for the three Project Drawdown scenarios.

Table 3.1 World Adoption of the Solution

| **Solution** | **Units** | **Current Year (2018)** | **World Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Ambitious** | **Maximum** |
| Carpooling | *Passenger-km* | 2088 billion | 13677 billion | 11092 billion | 10,336 billion |
| *(% Market)* | 6.8% | 35.7% | 47.1% | 100.0% |

Figure 3.1 World Annual Adoption 2020-2050 in Billion Pkm

## Climate Impacts

Below are the emissions results of the analysis for each scenario which include total emissions reduction, atmospheric concentration changes, and sequestration where relevant. For a detailed explanation of each result, please see the Glossary (Section 6).

Table 3.2 Climate Impacts

| **Scenario** | **Maximum Annual Emissions Reduction** | **Total Emissions Reduction** | **Emissions Reduction in 2030** | **Emissions Reduction in 2050** |
| --- | --- | --- | --- | --- |
| *(Gt CO2-eq.)* | *Gt CO2-eq. (2020-2050)* | (Gt CO2-eq) | *(Gt CO2-eq)* |
| ***Plausible*** | 0.73 | 12.82 | 0.32 | 0.73 |
| ***Ambitious*** | 0.50 | 8.10 | 0.20 | 0.50 |
| ***Maximum*** | 0.36 | 6.92 | 0.20 | 0.36 |

The solution was integrated with all other Project Drawdown solutions and may have different emissions results from the models. This is due to adjustments caused by interactions among solutions that limit full adoption (such as by feedstock or demand limits) or that limit the full benefit of some solutions (such as reduced individual solution impact when technologies are combined).

Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| *PPM CO2-eq (2050)* | *PPM CO2-eq change from 2049-2050* |
| **Plausible** | 1.06 | 0.06 |
| **Ambitious** | 0.67 | 0.04 |
| **Maximum** | 0.56 | 0.03 |

Figure 3.2 World AnnualGreenhouse Gas Emissions Reduction

## Financial Impacts

Below are the financial results of the analysis for each scenario. For a detailed explanation of each result, please see the glossary.

Table 3.4 Financial Impacts

| **Scenario** | **Cumulative First Cost** | **Marginal First Cost** | **Net Operating Savings** | **Lifetime Operating Cost Savings** | **Lifetime Cashflow Savings NPV (of All Implementation Units)** |
| --- | --- | --- | --- | --- | --- |
| *2015-2050 Billion USD* | *2015-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *Billion USD* |
| **Plausible** | N/A | N/A | 9229.75 | 9517.94 | 3851.81 |
| **Ambitious** | N/A | N/A | 5902.08 | 6123.50 | 22501.06 |
| **Maximum** | N/A | N/A | 5303.51 | 5549.67 | 1,023.06 |

Figure 3.3 Net Profit Margin /Operating Costs Over Time

# Discussion

Travelers reduce emissions by sharing rides. Two people sharing a ride reduce per passenger-kilometer vehicle emissions by 50%; three people reduce emissions by 66%, and four people reduce emissions by 75%[[9]](#footnote-9). Few environmental solutions achieve this level of emissions reductions with such simple behavioral changes. In this analysis, the effective occupancy of an SOV is 1, and the average occupancy of an HOV is 3. Therefore, the emissions efficiency factor of HOVs is 66.7% of SOVs in this report.

With a global trend towards carpooling for all urban trips as defined in the Plausible (least aggressive) scenario, the emissions impact can be significant at 7.7 GT CO2e over 30 years (2020-2050). This assumes a linear growth from today’s current estimate of 28.5% of all car trips (or 11.4% of all urban mobility) being shared equivalently in 3-person carpools (ignoring other occupancies). In more aggressive scenarios, the car market is smaller since there is assumed to be higher adoption of non-motorized modes and sustainable modes like Public Transport and e-bikes in cities leading to much less need for car travel and the concomitant benefits in congestion, air quality, noise, stress, travel delay and GHG emissions. This results in less climate impact of Carpooling however despite there being a higher proportion of car trips adopting carpooling. Overall the transport system is far less polluting.

In this way, carpooling is a backup solution for the global transition to clean transportation: in the event that policy makers can affect a transition to non-car travel with a healthy expansion of walking, biking, and public transit worldwide carpooling impact would be small. But even if they are not able to create this shift, they can rely on carpooling to reduce emissions and other externalities in urban transportation though it would still rely on a behavior shift, one that is increasingly accepted by younger, technophilic members of the society.

The financial outcomes of increased carpooling depend on many of the same factors as the GHG outcomes. Instead of the emissions factor, the driving figure is the cost per passenger-kilometer. Like GHG emissions, the more people who share rides, the lower the cost will be and the better will be the outcome. Given the assumptions and projections of carpooling used for this report, the model calculates significant net operating cost savings from carpooling of over $5 trillion from 2020 to 2050. This hints at the enormous financial cost of car use that many owners often don’t realize, focusing instead on fuel prices. Our data, for instance, indicate that vehicle maintenance increases the cost for operating a car by 66% (above that of fuel alone) and doesn’t even include fixed costs such as registration and insurance. These are very significant and almost always higher than more sustainable alternatives like public transport and biking.

Cost savings are only accounted for in the period of analysis (2020-2050) hence the sudden drop illustrated in Figure 3.3.

Some improvements in the modeling were suggested and included: expanding the range of carpooling occupancies (2, 4+ etc.), using regional car occupancy targets instead of a global average, and including an assumption of improved ICE car over time. However, bigger improvements could be had with better data on car occupancy worldwide since the most comprehensive global source was found to be a decade old. Additionally, to support the setting of car occupancy targets, the impact of certain policies around the world in raising average occupancies should be collected. It may be challenging to assume that historical occupancy can be a guide for future occupancies when the urban environment has changed drastically in the past and is expected to change further in the coming years in terms of MaaS services, use of technology generally, development of more transport alternatives and the rapid expansion of TNC services and autonomous vehicles.

In the real world, carpooling is adopted by different populations for different reasons, though it is strongly influenced by economics: as cars are expensive, sharing them can save much money. It’s also strongly influenced by motorization rate (which affects car economics). This explains why carpooling is quite common in developing countries, including for taxi services, and why price discounts is the key driver of Dynamic Ridesharing (shared Ridehailing) in richer countries. This also means that policy-makers have different jobs in these two groups of countries: developing countries still have lower motorization rates and higher levels of car occupancy and as wealth increases, there is a tendency to increase SOV trips. Policymakers therefore have to promote increased sharing of car trips and disassociate car sharing from the stigma of low income. This may help fight the perception of middle-income residents of developing countries that increasing wealth calls for increasing SOV trips. This should go hand in hand with increasing quality for public transport and non-motorized transport.

In wealthier countries, car occupancy increases may require a strong policy to make the cost of SOV travel higher relative to Carpooling. Younger travelers are more likely to accept carpooling for social and environmental reasons, and so there is an opportunity now for policymakers to encourage them to maintain their carpooling habits as long as possible, and supporting Dynamic Ridesharing providers where they don’t cannibalize public transport services might be a good idea.

## Limitations

Carpooling can’t solve all urban mobility issues since not all trips can be shared, and not all travelers would want to share all their trips. There will always be a portion of trips that cannot be pooled due to the inability to find a traveler heading in the same general direction, desire to avoid travel delays, need for safety and privacy. Only some of these can be overcome with cost discounts and policy, which are the main tools used by TNC’s and local transport authorities. However, much can be done to improve car occupancy, especially in those most critical times and places during commuting and other high congestion periods and locations.

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# Glossary

**Adoption Scenario** – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. A range of scenarios is programmed in the model, but the user may enter her own. Note that the assumption behind most scenarios is one of growth. If for instance a solution is one of reduced heating energy usage due to better insulation, then the solution adoption is translated into an increase in use of insulation. There are two types of adoption scenarios in use: **Reference (REF)** where global adoption remains mostly constant, and **Project Drawdown Scenarios (PDS)** which illustrate high growth of the solution.

**Approximate PPM Equivalent** – the reduction in atmospheric concentration of CO2 (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

**Average Abatement Cost** – the ratio of the present value of the solution (**Net** **Operating Savings** minus **Marginal First Costs**) and the **Total Emissions Reduction**. This is a single value for each solution for each **PDS Scenario**, and is used to build the characteristic “*Marginal Abatement Cost*” curves when Average Abatement Cost values for each solution are ordered and graphed.

**Average Annual Use** – the average number of functional units that a single implementation unit typically provides in one year. This is usually a weighted average for all users according to the data available. For instance, total number of passenger-km driven by a hybrid vehicle in a year depends on country and typical number of occupants. Global weighted averages are taken for this input. This is used to estimate the **Replacement Time**.

**Car Occupancy** – the average number of passengers riding in a car during trips. This should exclude drivers who are not also passengers (such as taxi drivers).

**Cumulative First Cost** – the total **First Cost** of solution **Implementation Units** purchased in the **PDS Scenario** in the analysis period. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Direct Emissions** – emissions caused by the operation of the solution, which are typically caused over the lifetime of the solution. They should be entered into the model normalized per functional unit.

**Discount Rate**- the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. Most importantly, the greater the discount rate, the more the future savings are devalued (which impacts the financial but not the climate impacts of the solution).

**Emissions** **Factor**– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO2e/kWh.

**First Cost**- the investment cost per **Implementation Unit** which is essentially the full cost of establishing or implementing the solution. This value, measured in 2014$US, is only accurate to the extent that the cost-based analysis is accurate. The financial model assumes that the first cost is made entirely in the first year of establishment and none thereafter (that is, no amortization is included). Thus, both the first cost and operating cost are factored in the financial model for the first year of implementation, all years thereafter simply reflect the operating cost until replacement of the solution at its end of life.

**Functional Unit** – a measurement unit that represents the value, provided to the world, of the function that the solution performs. This depends on the solution. Therefore, LED Lighting provides petalumen-hours of light, Biomass provides tera-watt-hours of electricity and high speed rail provides billions of passenger-km of mobility.

**Grid Emissions** – emissions caused by use of the electricity grid in supplying power to any operation associated with a solution. They should be in the units described below each variable entry cell. Drawdown models assume that the global electric grid, even in a Reference Scenario, is slowly getting cleaner, and that emissions factors fall over time resulting in lower grid emissions for the same electricity demand.

**Implementation Unit** – a measurement unit that represents how the solution practice or technology will be installed/setup and priced. The implementation unit depends on the solution. For instance, implementing electric vehicles (EV) is measured according to the number of actual EV’s in use, and adoption of Onshore Wind power is measured according to the total terawatts (TW) of capacity installed worldwide.

**Indirect Emissions** – emissions caused by the production or delivery or setup or establishment of the solution in a specified area. These are NOT caused by day to day operations or growth over time, but they should be entered into the model normalized on a per functional unit or per implementation unit basis.

**Learning Rate/Learning Curve** - Learning curves (sometimes called experience curves) are used to analyze a well-known and easily observed phenomenon: humans become increasingly efficient with experience. The first time a product is manufactured, or a service provided, costs are high, work is inefficient, quality is marginal, and time is wasted. As experienced is acquired, costs decline, efficiency and quality improve, and waste is reduced. The model has a tool for calculating how costs change due to learning. A 2% learning rate means that the cost of producing a *good* drops by 2% every time total production doubles.

**Lifetime Capacity** – this is the total average functional units that one implementation unit of the solution or conventional technology or practice can provide before replacement is needed. All technologies have an average lifetime usage potential, even considering regular maintenance. This is used to estimate the **Replacement Time**. and has a direct impact on the cost to install/acquire technologies/practices over time. E.g. solar panels generate, on average, a limited amount of electricity (in TWh) per installed capacity (in TW) before a new solar panel must be purchased. Electric vehicles can travel a limited number of passenger kilometers over its lifetime before needing to be replaced.

**Lifetime Operating Savings**–the operating cost in the PDS versus the REF scenarios over the lifetime of the implementation units purchased during the model period regardless of when their useful life ends.

**Lifetime Cashflow NPV**-the present value (PV) of the net cash flows (PDS versus REF) in each year of the model period (2015-2060). The net cash flows include net operating costs and first costs. There are two results in the model: Lifetime Cashflow NPV for a Single **Implementation Unit**, which refers to the installation of one **Implementation Unit**, and Lifetime Cashflow NPV of All Units, which refers to all **Implementation Units** installed in a particular scenario. These calculations are also available using profit inputs instead of operating costs.

**Load Factor** – The percentage of total possible passengers that a vehicle carries, which is usually calculated by dividing the number of passengers carried by the number of seats in the vehicle (car, train, bus, or plane).

**Marginal First Cost** – the difference between the **First Cost** of all units (solution and conventional) installed in the **PDS Scenario** and the **First Cost** of all units installed in the **REF Scenario** during the analysis period. No discounting is performed. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Net Annual Functional Units (NAFU)** – the adoption in the PDS minus the adoption in the REF in each year of analysis. In the model, this represents the additional annual functional demand captured either by the solution in the **PDS Scenario** or the conventional in the **REF Scenario**.

**Net Annual Implementation Units (NAIU)** – the number of **Implementation Units** of the solution that are needed in the PDS to supply the **Net Annual Functional Units (NAFU).** This equals the adoption in the PDS minus the adoption in the REF in each year of analysis divided by the average annual use.

**Net Operating Savings** – The undiscounted difference between the operating cost of all units (solution and conventional) in the **PDS Scenario** minus that of all units in the **REF Scenario**.

**Operating Costs** – the average cost to ensure operation of an activity (conventional or solution) which is measured in 2014$US/**Functional Unit**. This is needed to estimate how much it would cost to achieve the adoption projected when compared to the **REF Case**. Note that this excludes **First Costs** for implementing the solution.

**Payback Period** – the number of years required to pay all the **First Costs** of the solution using **Net Operating Savings**. There are four specific metrics each with one of **Marginal First Costs** or **First Costs** of the solution only combined with either discounted or non-discounted values. All four are in the model. Additionally, the four outputs are calculated using the increased profit estimation instead of **Net Operating Savings**.

**PDS/ Project Drawdown Scenario** – this is the high growth scenario for adoption of the solution

**PPB/ Parts per Billion** – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

**PPM/ Parts per Million** – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

**REF/ Reference Scenario** – this is the low growth scenario for adoption of the solution against which all **PDS scenarios** are compared.

**Regrets solution** has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

**Replacement Time**- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

**TAM/ Total Addressable Market** – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

**Total Emissions Reduction** – the sum of grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as “emissions avoided” as they may have occurred in the REF Scenario, but not in the PDS Scenario.

**Transition solutions** are considered till better technologies and less impactful are more cost effective and mature.

**TWh/ Terawatt-hour** – A unit of energy equal to 1 billion kilowatt-hours

**Well-to-wheel/WTW**– A modified life cycle energy pathway representing the path of energy from the well, where hydrocarbons are extracted (crude oil), through processing, to distribution (stations), to vehicle tanks and then finally to combustion in engines to power wheel movement. WTW Analysis = WTT (well-to-tank) analysis + TTW (tank-to-wheel) analysis. This type of analysis excludes emissions and energy for the processing facilities, building vehicles or end of life processing. Note that this term is also used when describing alternative fuel vehicles such as electric cars in order to allow balanced comparison of efficiencies.

1. Brij continues service in Australia after exiting the US market, <https://www.bridj.com/how-it-works>, accessed December 31, 2019 [↑](#footnote-ref-1)
2. Note that we do not count drivers who are not also passengers [↑](#footnote-ref-2)
3. Of course we have greatly simplified the exercise by ignoring the possibility of 2-person carpools and 4+-person carpools. However, data from the US household surveys indicate that the vast majority of shared car rides are with only 2 or 3 persons and that greater figures are very low in adoption. This may differ in places like India which has a lower motorization rate and higher average car load factor. Additionally, with the upper bound set at 2-person carpools, we have very limited room to grow and the potential for carpooling is greatly constrained. [↑](#footnote-ref-3)
4. [↑](#footnote-ref-4)
5. Assembly Bill 5 – AB5 [↑](#footnote-ref-5)
6. For most results, only the differences between scenarios, summed over 2020-2050 were presented, but for the net first cost, the position was taken that to achieve the adoptions in 2020, growth must first happen from 2015 to 2020, and that growth comes at a cost which should be accounted for, hence net first cost results represent the period 2015-2050. [↑](#footnote-ref-6)
7. In some cases, the low boundary is negative for a variable that can only be positive, and in these cases the lowest collected data point is used as the “low” boundary. [↑](#footnote-ref-7)
8. Some solutions such as Electric Vehicles and High-Speed Rail increase the demand for electricity and reduce the demand for fuel. [↑](#footnote-ref-8)
9. We have ignored potential increased fuel usage due to more people per HOV in these figures. A quick estimation using an average car weight of 1.4 metric tons and human weight of 75kg indicates that increasing car occupancy from the global average of 1.57 to 3 represents a 7% increase in weight carried, and therefore fuel consumption. [↑](#footnote-ref-9)