**Technical assessment for**

**Bike infrastructure**

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# Acronyms and Symbols Used

* ***CO2/ CO2 /CO2e/ CO2e*** – Carbon Dioxide/ Carbon Dioxide Equivalent
* ***E-bikes*** – Electric bicycles
* ***GHG*** –Greenhouse gas
* ***Gt*** – Gigatons
* ***ICE*** – Internal Combustion Engine
* ***IPCC*** – Intergovernmental Panel on Climate Change
* ***ITDP*** – The Institute for Transportation and Development Policy
* ***ITF*** – Internaitonal Transportation Forum
* ***km***– Kilometer
* ***RRS***-Reduction and Replacement Solutions
* ***PDS*** – Project Drawdown Scenario
* ***PKM*** – Passenger-kilometer
* ***REF*** – Reference (Scenario, of Project Drawdown)
* ***TAM*** – Total Addressable Market
* ***ZEZ*** – Zero Emission Zones

# Executive Summary

Transport produces 14% of all emissions globally which amounts to around 8 gigatons of CO2-equivalent greenhouse gas emissions and is responsible for 24% of energy-related emissions (IEA, 2018). Therefore shifting passengers to lower emitting modes is a major step towards achieving drawdown. Bicycle infrastructure entails all of the characteristics of the built environment that enable and encourage bicycle riding as a mode of transport. This includes bicycle lanes of all types, but also secondary facilities such as bike parking and workplace showers for commuters to clean up before beginning the workday. This report focuses on bicycle infrastructure and is where city governments can have the most impact.

The Reduction and Replacement Solutions (RRS) model was used to evaluate the impacts of increased e-bike usage around the world from 2014 to 2060 with primary results being reported here for the period 2020-2050. The current adoption of bicycle infrastructure was found to be about 2.6% of the total addressable market globally with higher adoption rates in Asia and some parts of Europe.

Projections of increasing bicycle infrastructure is used to estimate growth in actual passenger-kilometers travelled by bicycle infrastructure. This number is then compared to the travel that would have happened in the absence of bicycle infrastructure—coming from automobiles in car lanes. The net cost and carbon emissions are calculated based on current mode share splits and how those splits may shift in the next thirty years.

The model uses several sources for bicycle infrastructure statistics: International Transportation Forum Transport Outlook, the Institute for Transportation and Development Policy’s Global High-Shift Cycling scenario, and actual project data from bicycle infrastructure including length, and use before and after the construction. Based on these sources, current adoption is estimated to be 779 billion passenger-kilometers (PKM) of bicycle infrastructure use around the world, with the great majority of those PKM coming from Asia. The model then projects bicycle infrastructure PKM to increase to over 2592 billion PKM by 2050, approximately 5.02% of the total estimated market for urban PKM.

The results of the analysis show that bicycle infrastructure represents a net financial benefit for the cities that build them, as well as a net greenhouse gas (GHG) benefit for the globe. Given the projections described above and the emissions factors of different travel modes, bicycle infrastructure could prevent the release of 2.73 cumulative gigatons of carbon dioxide-equivalents and save cities $2746 billion in savings over the lifetime of the bicycle infrastructure. Significant factors in these calculations are the construction and maintenance costs for car lanes and bicycle infrastructure.

# Literature Review

Transport produces 14% of all emissions globally which amounts to around 8 gigatons of CO2-equivalent greenhouse gas emissions. Transport is responsible for 24% of energy-related emissions (IEA, 2018). Of this, the largest contribution (51%) is from personal vehicles including cars, sport utility vehicles (SUVs), light trucks and motorbikes as a group. Medium and large trucks and buses contribute to 27% of transport emissions followed by aviation and sea shipping which contribute 10% each (IEA, 2017). Transport is derived from economic growth meaning that the movement of people and goods increases as countries develop. Transport emissions can be reduced through avoiding motorized transport, shifting transport to more efficient modes and improving efficiency of motorized modes.

## State of Bicycle Infrastructure

Bicycle infrastructure entails all of the characteristics of the built environment that enable and encourage bicycle riding as a mode of transport. This includes bicycle lanes of all types, but also secondary facilities such as bike parking and workplace showers for commuters to clean up before beginning the workday. The League of American Bicyclists, which works to improve the quality of bicycling and tracks bike-friendly cities, businesses, and universities, has identified “Five E’s” of bicycle infrastructure: engineering, equity encouragement, education, and evaluation (Murphy, 2020). This report will focus on the first E, engineering, which includes bike road infrastructure and is where city governments can have the most impact.

A complete study of the impact of bicycle infrastructure on bicycle mode share increases will need to examine the role of electric bicycles. These bicycles, often called e-bikes, have recently become economical for significant numbers of commuters. Compared to conventional bicycles, electric bicycles increase the feasible commuting range, make cycling more accessible to riders who have physical disabilities or limitations, and facilitate riding in areas with steep inclines. In essence, more robust bicycle infrastructure will promote conventional and electric bicycles simultaneously, but because e-bikes have different economic and environmental impacts from conventional bicycles (emissions associated with battery charging, disposal costs for batteries, and higher purchase costs), they will be treated as a distinct technology and examined in another Drawdown solution report.

### Bike Lane Types

Most bicyclists prefer to ride on designated paths and facilities, and research has shown that new bike paths in cities lead to increased bike ridership. It is important to note however that there are several types of bike infrastructure facilities that each have different costs and lead to different levels of increased bike ridership. The National Association of City Transportation Officials describes three types of bike route infrastructure: bike lanes, cycle tracks, and bike boulevards. Bike lanes are defined as “a portion of the roadway that has been designated by striping, signage, and pavement markings for the exclusive or preferential use of bicyclists” with no physical barrier between bicycles and cars. A cycle track is defined as “an exclusive bike facility that ... is physically separated from motor traffic and distinct from the sidewalk.” Finally, a bike boulevard is described as a street with “low motorized traffic volumes and speeds, designated to give bicycle travel priority,” (National Association of City Transportation Officials, 2014). It is difficult to assess what percentage of the whole each type of bike infrastructure makes up, but the most common type of the three is the on-road bike lane. This type of lane requires little more than paint on the road, although it is possible to create bike lanes with buffer zones that require more planning and higher cost. Cycle tracks are most common in the bike riding capitols of the world such as The Netherlands, Copenhagen, Denmark, and Davis, California. These facilities require the most planning and have the highest associated costs, though in turn they incentivize the most induced bicycle ridership. Bike boulevards require the least investment in infrastructure, but perhaps greater planning than many bike lanes. Because bicycles are expected to act like motor vehicles in bike boulevards, their locations, lengths, and signage must be chosen carefully.

One popular method for integrating bike lanes into urban areas is to implement what is popularly referred to as a “road diet”. This is done through either reducing the width of the lanes or reducing the number of lanes. If a typical roadway includes two traffic lanes in each direction, a road diet would reduce that to one lane in each direction with a shared center turning lane. The leftover space would then be used for bike lanes or cycle tracks. It could also reduce the width of the existing lanes and use the new space for bike lanes or cycle tracks.



Figure 1.2 A typical bike lane. Source: Wikimedia Commons[[1]](#footnote-1)



Figure 1.3 A bike boulevard

, this example denoted by a street sign without road markings. Source: Wikimedia Commons[[2]](#footnote-2)



Figure 1.4 Cycle track

, a physically segregated lane for the exclusive use of non-motorized vehicles. Source: Wikimedia Commons[[3]](#footnote-3)

In general, effective cycle infrastructure is clearly distinguishable and provides a high degree of route coherence and directness to attract more daily cyclists. Cyclists should also be protected at major intersections, preferably with bike-specific traffic lights that allow cyclists to take off first and thus become more visible to other vehicles. There are also examples around the world of unique bike infrastructure types and policies, such as bike tunnels in Davis California, Berenkuils and Hovenring in Netherlands, bike highways in Germany and South Korea, the “ciclovia” in Bogota, Colombia, rail to trail conversions and car-free cities and neighborhoods in various locations around the world.

### Who Rides?

Not everybody can ride a bike, and not everybody who can will. Moreover, some geographical regions may be more amenable to urban bicycling, due to climatological and topographical reasons—a very hilly city with extreme weather will likely have fewer regular cyclists than a flat city with temperate weather year-round. For these reasons and others, bicycle mode share will never reach 100 percent in cities, but there is large room for growth from its current status. Moving forward, it will be necessary to identify likely bike riders and implement policies that will convince them to choose to make trips by bicycle.

In 2006 Portland, Oregon Bicycle Coordinator Richard Geller conducted a study of bike riders and potential bike riders in his city. Geller found that commuters could be separated into four distinct categories based on their level of willingness to ride a bicycle. Less than one percent of the people Geller studied could be described as “Strong and Fearless”. These commuters would be willing to ride on any street under most conditions. A larger—but still minority—category were the “Enthused and Confident” riders. These commuters, about seven percent of the population, would ride bicycles on bike boulevards, in bike lanes, and on cycle tracks while seldom venturing onto heavily trafficked streets and thoroughfares. The largest category, representing 60 percent of the population, were described as “Interested but Concerned”. These commuters would be willing to ride bicycles, but are limited by their own fear of traffic and inadequate infrastructure to protect them from motorized vehicles. Finally, about 33 percent of commuters could be categorized as “No Way, No How”—these commuters are not interested in riding a bike regardless of the infrastructure. In order to dramatically grow urban bicycle mode share, Geller emphasized that policies should be aimed at easing the fears of “Interested but Concerned” citizens through separate and safe bicycle infrastructure. Researchers at Portland State University performed the same study for Portland in 2011 and for 50 metro areas in 2015 and found that the distribution was still quite similar. “Strong and Fearless” and “Enthused and Confident” both increased but so did the “No Way, No How”. The increases in those types came from a decrease in “Interested but Concerned” (Dill & McNeil, 2016).

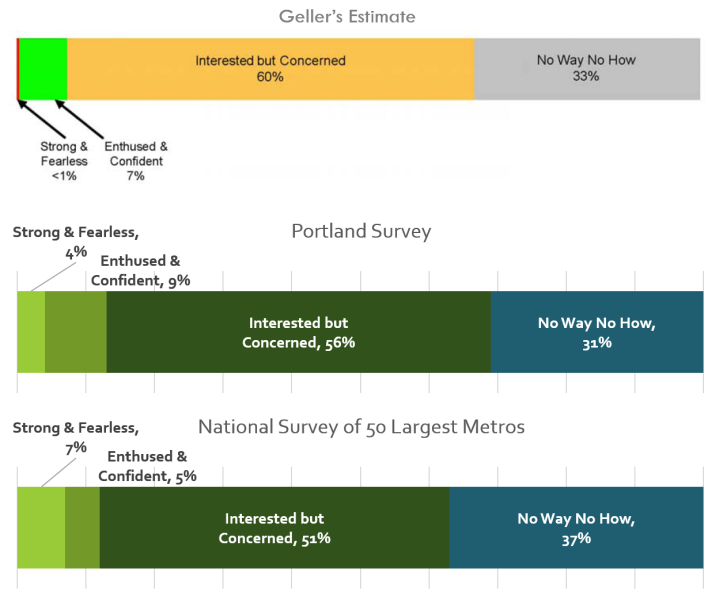


Figure 1.5 The Four Types of Transportation Cyclists (Dill & McNeil, 2016)

Other researchers have found a gender split in regular bicycle commuters. In most cities, men are more likely than women to make utilitarian bicycle trips, more likely to use on-street bike lanes, and less likely to worry about dangers from traffic. Reasons for this gender disparity have been attributed to differing risk appetites and different travel demands for men and women (women are more likely to make trips with children who cannot ride bikes). Research has also found that women are more likely to take circuitous routes if it means that they can use off-street or protected bike paths such as cycle tracks (Goel et al., 2021).

Making bicycle infrastructure that is safe and comfortable for All Ages and Abilities is a national and international best practice. All Ages and Abilities bicycle infrastructure is safe, comfortable and equitable. Bike facilities that meet this criteria aid cities in improving traffic safety, reducing congestions, improving air quality and public health, providing better and more equitable access to jobs and opportunities and bolstering the local economy (National Association of City Transportation Officials, 2017).

These findings suggest that bicycle infrastructure policies should be aimed at segregating bicyclists as much as possible from motorized traffic in order to attract more women, “interested but concerned” commuters and meet All Ages and Abilities criteria. Cycle tracks are the most obvious answer, but bike lanes with buffer zones and bike boulevards on low-traffic streets parallel to arterial roadways may also successfully attract a broader range of cyclists.

### Bicycling and Covid-19

Bicycling has enjoyed a renaissance due to the global pandemic that began in 2020. This 200 year old invention provides users with exercise and commuters with faster speeds than walking while allowing social distancing. Many cities acted quickly and put in place temporary measures to accommodate the increase in cyclers. Numerous cities hope to make the new pop-up lanes permanent as the levels of cycling post lockdown are above the levels pre lockdown. This phenomenon has shown how easily and economically feasible streets can be redesigned for biking. More than 150 cities worldwide added bicycle and walking infrastructure less than 2 months into lockdown with hundreds more in planning (ITF, 2020). At least 43 European cities added bicycle infrastructure totaling 2, 592 km at a value of almost €1.7 billion (ECF, 2020). Several cities (Edinburgh, Glasgow and Stirling) made bike sharing services free. France wants to ensure that the biking renaissance continues into the future and allocated €20 million for pop-up bike parking, financing bicycle riding education and repairing bikes for the post lockdown phase. See (Nikitas et al., 2021) for a list of cities, measures implemented and results achieved. Moreover, investment in bicycling and walking infrastructure is being recommended to make transport more resilient and sustainable (Buehler & Pucher, 2021; ECF, 2020; IEA, 2020; ITF, 2020, 2021; Kraus & Koch, 2021; Nikitas et al., 2021).

### Bicycles and Climate Change

Emissions from Transport have steadily grown over the past 30 years despite fuel-efficiency advancements in motor vehicles and as well as the mitigating effects of the 2008 financial crisis. The global pandemic that began in 2020 led to a decrease in emissions but a rebound and continued increase is expected. Reducing and halting transport emissions is necessary in order to achieve climate goals.

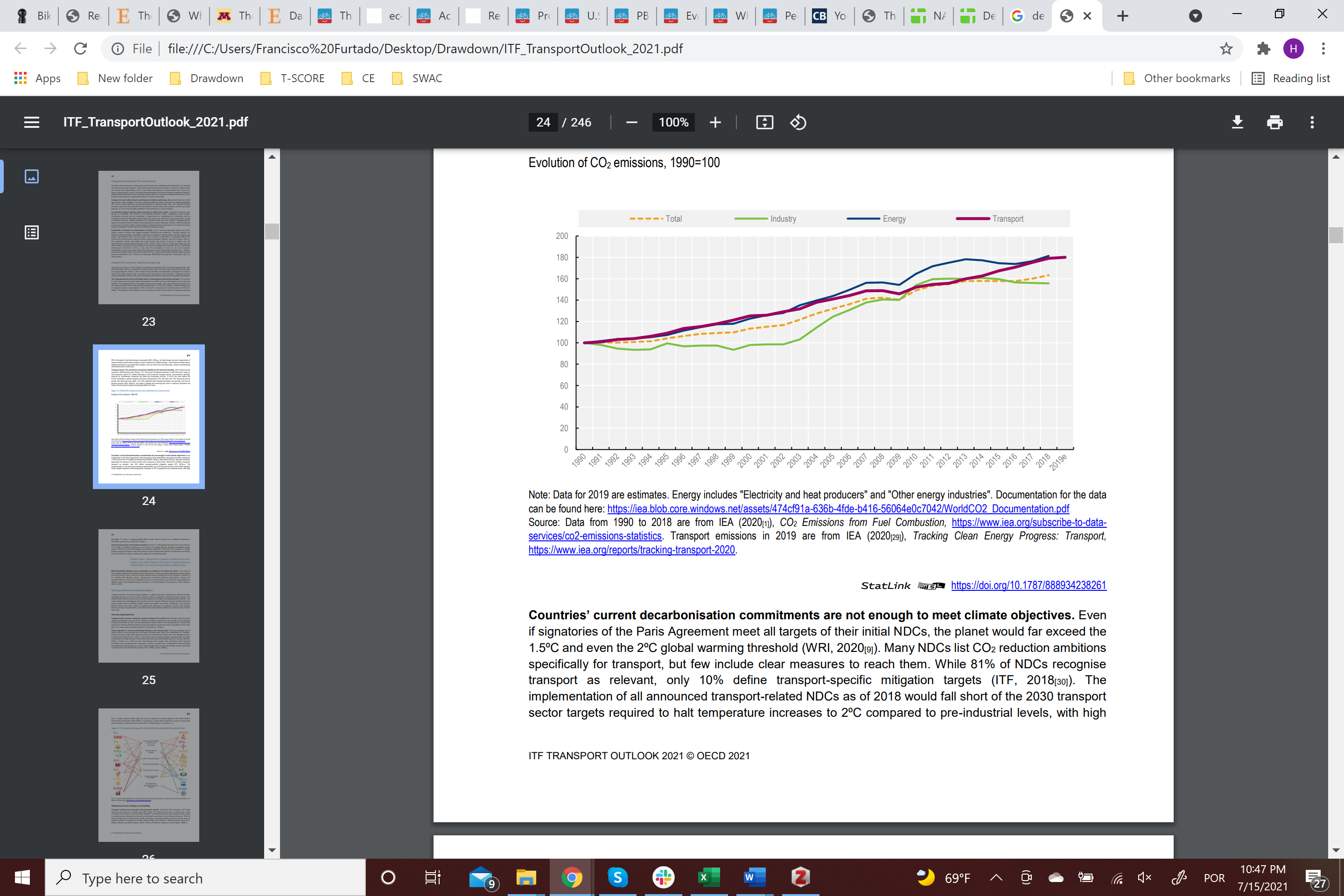


Figure 1.1 Global CO2 emissions from fuel combustion by end-use sector; 1990=100 (ITF, 2021)

Bicycles are typically made of roughly five to fifteen kilograms of a range of materials (of either steel, aluminum, titanium, carbon fiber and rubber) and because they are propelled by human power, require a greater caloric intake from their riders. The raw material requirements for bicycle production lead to GHG emissions, but these are greatly offset by the fact that bicycles can last well over a decade and are a highly efficient form of transport. Because each marginal kilometer ridden by bike produces no direct GHG emissions, a global mode shift toward bike riding from light-duty vehicles (LDV), buses, and commuter rail would make a significant contribution to mitigating climate change. Moreover, because bicycles also emit no local particulate matter pollution and lead to improved health outcomes for their users, increased bicycle ridership could provide a range of additional benefits.

The European Union (EU) for example has set a goal of reducing its GHG emissions by 80 to 95 percent in 2050 compared to 1990 levels. Consequently, the European transport sector would have to reduce its emissions by an estimated 60 percent. If levels of cycling in the 27 countries of the EU were to rise to levels equivalent to those found in Denmark (on average 937 km per person per annum), it is estimated that cycling could help meet 12 to 26 percent of the 2050 GHG target (European Cycling Foundation, 2016). A 2009 study by the Dutch company CE Delft investigated 30 measures to reduce GHG emissions through investments in infrastructure, including measures to improve traffic circulation, support modal shift, and reduce energy use of vehicles. The authors concluded that improving bicycle infrastructure provided the highest return of all mobility measures studied (Schroten & Otten, 2009).

In order to achieve net-zero cities, cycling is 10 times more important than electric cars. Based on a two year study with 4,000 participants and 10,000 travel diary entries in 7 European cities, people who cycled daily had 84% lower carbon emissions. Using a bike instead of a car for only day per week has a reduction of 3.2kg of CO2 per week and by 500kg over a year. A change by only one in five urban travelers would reduce European travel emissions by 8% (Brand et al., 2021).

## Adoption Path

### Current Adoption

The current modal share of bicycle infrastructure is determined based on the percentage of urban PKM done using bicycle (not including e-bikes due to the different cost structure and emissions). Adoption projections are gathered from as many credible sources as possible. Sources include International Transport Forum (ITF, 2021) and Institute for Transportation and Development Policy (UC Davis et al., 2015).The current adoption of bicycle infrastructure is estimated by calculating the average based on these sources. Current modal share can be seen in Table 1.3. Table 1.4 shows e-bike use by region based on (ITF, 2021).

The International Transport Forum (ITF) reports mode share of urban passenger transport in its Outlook report that it publishes every other year. The ITF reports urban passenger mode share for private bikes and shared bikes. Other data sources and the Project Drawdown Electric Bicycles Solution were used to estimate the shares belonging to e-bikes and traditional bikes. The ITF also provides mode share in three different scenarios. Active modes are expected to increase in all scenarios. The baseline or Recover scenario assumes a 20% to 300% increase in road space available to active modes and a 2% to 30% reduction of speed on main roads by 2050. The conservative or Reshape scenario assumes a 40% to 500% increase in road space available to active modes and a 5% to 50% reduction of speed on main roads by 2050. The ambitious or ReshapePLUS scenario assumes a 50% to 600% increase in road space available to active modes and a 5% to 50% reduction of speed on main roads by 2050 (ITF, 2021).

The Institute for Transportation and Development Policy (ITDP), in cooperation with the University of California, Davis, produced *A Global High-Shift Cycling Scenario,* a comprehensive global estimate of transportation mode shares and PKM through 2050. In ITDP’s estimate of a high-shift to sustainable transportation, bicycles quickly become a significant portion of urban PKM travelled, ITDP uses global e-bike sales figures average person-KM travel rates to reach their conclusion. ITDP projected global cycling would increase primarily by cities creating an integrated system of bike infrastructure leading from neighborhoods to popular destinations, and secondarily by disincentivizing driving through policies such as reduced parking requirements and congestion pricing in high-traffic areas (UC Davis et al., 2015).

Table 1.3 Current Global Modal Share and Adoption of Bicycle Infrastructure in billion PKM

|  | **Percent (%)** | **Billion PKM** |
| --- | --- | --- |
| Current Adoption | 2.6% | 779.0 |

Table 1.4 Current Global Bicycle Infrastructure use by region

| **Region** | **Percent (%)** |
| --- | --- |
| OECD 90 | 20.6% |
| Eastern Europe | 2.1% |
| Asia (Sans Japan) | 59.0% |
| Middle East and Africa | 5.6% |
| Latin America | 12.7% |
| Total | 100% |

### Trends to Accelerate Adoption

#### Land use and Transport Policies

Land use and transport policies have a major influence on the modal share of cycling and other commuting choices. Infrastructure and urban design are particularly strongly linked, impacting travel demand and vehicle miles traveled. For instance, personal vehicle focused street design requires destinations to provide adequate parking areas, which increase distances between destinations, which in turn encourages more driving. Furthermore, the long lifespan and cost of rebuilding roads makes urban infrastructure prone to lock-in of energy and emissions pathways, lifestyles, and consumption patterns (Seto et al., 2016). Complete streets urban design strategies recognize that increasing populations and urban density will put pressure on transportation systems, and seek to ease this pressure by designing for all modes of transportation: public motorized, private motorized, and private non-motorized. By acknowledging that not all commuters will drive cars, roads are designed to accommodate cars, bikes, buses, and pedestrians. This road design then encourages adoption of multiple modes of transportation by making them a viable choice. While land use and transport policies have been shifting towards prioritizing more sustainable modes, the global pandemic has truly shifted policy away from car centric towards sustainable modes and active modes in particular (Buehler & Pucher, 2021; ECF, 2020; IEA, 2020; ITF, 2020, 2021; Kraus & Koch, 2021; Nikitas et al., 2021).

#### Design

Key urban drivers of transportation mode choice are density, land use mix, connectivity, and accessibility. When planners take into account these interrelated and interdependent issues, cities become more accessible and communities achieve lower daily commuting distances and travel times, enabled by multiple modes of transportation. The provision of separate and dedicated facilities for bicycles along heavily traveled roads and at intersections, along with traffic-calming of residential neighborhoods, can considerably increase cycling as a transport mode (Rayaprolu et al., 2020). A meta-analysis concluded that building bicycle infrastructure induces demand by 22% and the number of riders by 62% (Mölenberg et al., 2019). Another study showed that during the first 4 months of the lockdown of 2020, 106 European cities added an average of 11.5km of pop-up bike lanes which increased biking by 11-48% and will generate $1-7 billion in health benefits if the habits remain (Kraus & Koch, 2021).

#### Bicycle Sharing Schemes

Bicycle share schemes allow riders to pick up bikes at public locations and use them for a small fee. In recent years, the popularity of these programs has grown rapidly around the world, with large-scale urban systems throughout China, the United States, and Europe, and programs being piloted in places such as Kazakhstan and Abu Dhabi. More than 95% of the schemes started after 2007 with the number almost doubling from 1,600 in 2017 to more than 2,900 in 2019 (Galatoulas et al., 2020; Moon et al., 2019). Based on the Meddin Bike-sharing World Map there were 9.74 million shared bikes in July 2021 (Meddin et al., 2021). According to one study, Barcelona, Spain’s bicycle sharing scheme, introduced in 2007, increased cycling trips by 30 percent, reduced the mortality rate from traffic incidents, and avoided over 9,000 metric tons of carbon emissions from motorized transport in 2009 (Rojas et al., 2011).

### Barriers to Adoption

#### Demographics and Geography

An aging population in most of the world is a barrier as bicycling declines with age (although e-bikes don’t experience the same level of decline). Women tend to ride less and is compounded by the larger proportion of women in the older population (Goel et al., 2021; UN, 2020). Environmental factors such as weather, terrain (hilly) and distance are additional barriers to adoption (Linden et al., 2020) however, terrain and distance matter less in the case of e-bikes.

#### Safety and Lack of Infrastructure

The perception that biking is not safe which is further exacerbated by the lack of dedicated lanes is another barrier to adoption (Dill & McNeil, 2016). The lack of parking and fear of theft (Chen et al., 2018) and lack of shower facilities (Linden et al., 2020) are additional barriers.

### Adoption Potential

The adoption potential for bicycle infrastructure is high. Cities are increasingly seeking to become more sustainable and to combat climate change. The ease and economic feasibility of implementing pop-up lanes will encourage more adoption in the future as will the increased use and demand for cycling by inhabitants. The potential is limited by funding and lower demand from urban passengers that do not want to use an active mode of transport. However, as cities and passengers are concerned with the close proximity of users of public transit, cities are encouraging bicycling through infrastructure and traffic calming and riders are responding positively. For those urban passengers that steadfastly use only private car, increasing regulations such as zero emission zones (ZEZs) and decreasing parking spaces will influence their mode choice. Bicycling is not expected to ever overtake public transit or private car by mode share but large gains in adoption can be made.

## Advantages and disadvantages of Bicycle Infrastructure

### Similar Solutions

Solutions that are similar to or can replace bicycle infrastructure are all other modes that serve the urban passenger market. These modes include car, public transit, e-bike, walking, e-kick scooters and e-mopeds. All but the last two modes (which are considered motorized 2/3 wheelers) are current Drawdown Solutions (car use encompasses three solutions–electric cars, hybrid cars, and carpooling).

### Arguments for Adoption

Bicycles are a good mode choice for urban passenger transit. It is an important component of the mix of mode choices and has the ability to shift use from modes with higher emissions. The solution`s advantages and disadvantages are better understood when compared to the other available urban passenger mode choices (note: 2/3 wheelers are not currently Drawdown solutions and will not be evaluated in this assessment).

The municipal costs of building bicycle infrastructure are much lower than constructing car lanes or public transit and do not incur subsidies like most public transit.

The emissions from converting a car lane to a bicycle lane are negligible and are more than made up for through increased cycling and decreased car use. When comparing mode share use, bicycling does not produce direct emissions. Indirect emissions from manufacturing the different vehicles used by each mode should also be taken into account. Generally, bicycles use drastically less materials than cars and do not have a battery like e-bikes (ITF/OECD, 2020).

Converting a car lane into a bike lane is much faster than constructing a car lane or public transit. From a user mode share perspective the solution is much faster than walking and can be faster than car in congestion and public transit depending on whether access and egress times are included and whether the type of public transit is effected by congestion.

Bicycling requires more physical activity than car or public transit. However, the solution requires less physical effort than walking.

The space efficiency of e-bikes, conventional bikes and walking are significantly less than that of cars. Comparing the solution to the public transit composite is complex as a bus can take up the same space as a car but dedicated lanes for buses or trams (or even bikes) take up less space as cars usually have multiple lanes.

### Additional Benefits and Burdens

Additional benefits of bicycle infrastructure and increased bicycling include health benefits. It can reduce the risk of diabetes, obesity, some forms of cancer, cardiovascular disease and depression (UNEP, 2019).

Local businesses fear that removing or reducing parking or driving lanes will reduce economic activity. A meta-study has shown that investments in bicycle and pedestrian infrastructure has positive or non-significant impacts on retail and food service companies (Volker & Handy, 2021).

Bicycle infrastructure brings the benefit of safety. More infrastructure means more riders which improves safety. Cities that increased bike lanes by 50% saw more than twice the use while cutting death and serious injury to riders by half. Increased infrastructure also increases safety for pedestrians and drivers by reducing crashes with injuries (National Association of City Transportation Officials, 2017).

Any rebound effects of induced trips is not a burden as there are no marginal emissions and it could contributes to decreasing the indirect emissions over the life cycle.

Table 1.3 Urban Passenger Mode Comparison

|  | **User Costs** | **Emissions** | **Speed** | **Physical Effort** | **Congestion** | **Space Efficiency** |
| --- | --- | --- | --- | --- | --- | --- |
| E-Bike | Low | Low | High | Medium | Low | Low |
| Conventional Bike | Low | None | Medium | High | Low | Low |
| Car | High | High | Medium | Low | High | High |
| Public Transit | Low | Low | High | Low | Low | Medium |
| Walking. | Low | None | Low | High | Low | 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 a conventional technology. These technologies are assumed to compete in markets to supply the final functional demand which is exogenous to the model, but may be shared across several solution models. The adoption and markets are therefore defined in terms of functional units, and for investment costing, adoptions are also converted to implementation units. The adoptions of both conventional and solution were projected for each of several scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios (for the 2020-2050 segment[[4]](#footnote-4)) is what constituted the results.

The functional unit of the analysis is billion PKM and the implementation unit is kilometer of bicycle infrastructure installed (bike lane km / car lane km). This implementation unit is used to calculate financial outcomes. The functional units feed the climate outputs. The agency level is city meaning that the costs are analyzed from a city/municipal perspective (rather than at the bike manufacturer or bike purchaser for example) because the city makes the investment into the infrastructure.

The Total Addressable Market (TAM) covers all demand for the function provided by the solution e.g. if the solution focuses on bicycle usage, the TAM is global demand for urban passenger travel including conventional technologies and practices and emerging solutions. Most reports available in the literature exclude non-motorized trips when calculating urban modal share. There are two reasons for this. First the modal share is calculated through PKM, and therefore the smaller trip distance of a non-motorized trip results to a much smaller share. Second, non-motorized trips are much harder to record and predict. The TAM has been increased to account for the non-motorized PKM.

The Project Drawdown Scenario, (PDS), shows an increase of the modal share of bicycles in urban environments as the total number of PKM grows. The increased number of bicycle PKM will come from some newly generated trips, but mostly from mode switch mainly from car and public transit.

The conventional technology for implementation units is kilometer of road constructed and maintained. The conventional technology for functional units in this model is defined as all modes used for urban passenger travel, more specifically Cars (ICE and others proportionally), Motorized 2/3 Wheelers, Public Transit, Electric Bicycling and Walking.

## Data Sources

Data from multiple sources were compiled to construct this model, with an emphasis on recent, credible, and peer-reviewed methodology. The data sources used for the model have been divided in three main sections: Total Addressable Market (TAM), Adoption Projections and Variable Inputs.

### Total Addressable Market

The Total Addressable Market (TAM) covers all demand for the function provided by the solution. For the Bicycle Infrastructure solution, TAM is world urban passenger kilometers made by all modes. Global TAM was projected mainly using data obtained from (IEA, 2016; The International Council on Clean Transportation, 2012; UC Davis et al., 2015).

### Adoption Projections

Adoption projections are gathered from as many credible sources as possible. Sources include (IEA, 2016; OECD/ITF, 2021; UC Davis et al., 2015). Regional data come from ITF (OECD/ITF, 2021)

### Variable Inputs

Variable inputs are used in the Variable Meta-Analysis and are updated to reflect current conditions at each update.

#### Financial Variables

Financial variables include first costs and operating costs for both conventional and the solution. Operating costs are variable and fixed and are derived from lifetime capacity and average annual use for conventional and solution.

Conventional first costs are mostly reported at the regional level and are based on (ARTBA, 2019; FDOT, 2020; San Francisco Bicycle Coalition, 2014; World Bank, 2016, 2018).

Solution first costs are mostly reported at the regional level and are based on (Bongardt et al, 2013; Buekers et al, 2015; Erznoznik, 2014; FDOT, 2020; Friedrichshain-Kreuzberg District Office, 2020; Kraus & Koch, 2021; UC Davis et al., 2015) (Bushell et al, 2015; Fucoloro, 2012; Ruhr Nachrichten, 2014; .

The conventional and solution lifetime capacity data come from (Wisconsin DOT, 2021).

The conventional average annual use data come from (City of Toronto, 2021; Transport & Environment, 2020; UC Davis et al., 2015).

The solution average annual use data come from (City of Toronto, 2021; Félix et al., 2020; Kraus & Koch, 2021; Transport & Environment, 2020; UC Davis et al., 2015).

Conventional variable operating costs are regional and based on (FDOT, 2020; UC Davis et al., 2015; World Bank, 2018).

Solution variable operating costs are regional and come from (UC Davis et al., 2015; World Bank, 2018).

#### Emissions Reduction Variables

Electricity and fuel consumed per conventional functional unit are estimates made by the Drawdown team based on (UC Davis et al., 2015).

#### Additional Variables

The average annual use conversion calculation is based on (Metropolitan Washington Council of Governments, 2016).

The discount rate for public entities is based on data from (Bauer et al., 2013; Jones et al., 2014; Zhuang et al, 2007) (New Zealand Treasury, 2008; Treasury Board of Canada, 2007, McKinsey et al, 2007; US EPA, 2007; Nordhaus, 2007; Weitzman 2007).

## Total Addressable Market

The total addressable market is the total of functional transportation units provided to the world urban market by all modes. Data were obtained from the International Council on Clean Transportation (ICCT), Institute for Transportation and Development Policy (ITDP) and International Energy Agency (IEA). The values shown represent the average from all the sources (Table 2.1). Since most of the collected data report values in 5-year intervals, values for the in-between years were estimated with the use of data interpolation. Regional data come from the ITDP-UC Davis study, taken from their High Shift scenario. While the global TAM more than doubles throughout the study period, that the regional TAMs for OECD90 and Eastern Europe initially grow before returning to around 2015 levels. The growth comes mainly from Middle East and Africa region, where the TAM is almost 4 times bigger; and Asia, where the TAM more than doubles by 2050. In Latin America the TAM grows about 80%.

Table . Global and Regional TAM, in billion pkm

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Drawdown Region** | **2015** | **2030** | **2045** | **2050** |
| World | 26,539 | 38,473 | 51,468 | 56,606 |
| OECD90[[5]](#footnote-5) | 9,476 | 9,741 | 9,323 | 9,281 |
| Eastern Europe | 1,261 | 1,317 | 1,277 | 1,273 |
| Asia (sans Japan) | 9,459 | 15,411 | 20,582 | 22,091 |
| Middle East and Africa | 2,847 | 4,614 | 7,963 | 9,485 |
| Latin America | 2,715 | 3,863 | 4,721 | 4,943 |

## 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

This model defines the REF adoption scenario as a fixed percentage of TAM over the modeling period, using the percentage of adoption in the base-year as the fixed percentage of TAM projecting forward which is 2.44%.

### 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.

The model and scenarios do not include electric bicycle pkms, although e-bikes can be used on bicycle infrastructure, the emissions and costs are calculated separately as they are very different including at the agency level. An increase in e-bike pkms means a decrease in bicycle infrastructure pkms.

#### Plausible Scenario

This scenario assumes that bicycle infrastructure continues to grow without any major interventions and that most of the temporary covid pop-up lanes return to car lanes. The conservative TAM and adoption cases are considered plausible.

#### Drawdown Scenario

In this scenario, most pop-up lanes are made permanent and cities around the world continue to build bicycle infrastructure and encourage biking. The ambitious TAM and adoption cases are part of a world focused on the target of achieving drawdown by 2050.

#### Maximum Scenario

This scenario assumes that covid lanes are mostly permanent, many new lanes are added and the trend towards bicycling during lockdowns remains. The maximum level of bicycle infrastructure use reaches 10%.

## Inputs

Many variables have been defined and calculated for this analysis. They are grouped by climate inputs, financial inputs and technical inputs. Each variable is described below. In the analysis, the agent that will decide whether to build bicycle infrastructure is the city or municipality. Therefore, the impacts on the perspective of the city are analyzed.

### Climate Inputs

The climate analysis in this model uses the values for fuel consumption for the conventional alternative. To calculate key emissions results, the model uses reported emissions factors for the fuel emissions factors. 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 (#)** |
| --- | --- | --- | --- | --- | --- |
| Fuel Consumed per Functional Unit - CONVENTIONAL | *Liter/B PKM* | 61,573,390 | 61,573,390 | 1 | 1 |

Note: Project Drawdown data set range is defined by the low and high boundaries which are respectively 1 standard deviation below and above the mean of the collected data points[[6]](#footnote-6).

### Financial Inputs

This section addresses the financial inputs of the model, by splitting them to first and operational cost. The costs have been converted to US$2014 based on inflation. First cost and maintenance costs for bicycle infrastructure are lower than conventional roadways because bike lanes do not need to be paved as thick as roads designed to carry heavy vehicles and bicycles cause much less wear-and-tear than cars and trucks.

#### First Cost

The conventional first cost is the cost of constructing one kilometer of roadway designed for use by motor vehicles throughout the world. There is a wide range of costs which reflects the impact of labor costs, which vary throughout the world, and other harder to quantify costs such as inefficiencies and bureaucracy expenses. Raw data input is converted from currency/length of road constructed to US$2014/km.

Solution first costs cover a wide range of situations from construction of new dedicated (or segregated) bike routes to re-striping of existing roads to provide bike lanes and including secure bike parking facilities. The data is weighted by the estimated amount in practice, 10% for separated bike lanes, 90% for bikes on road.

#### Operational Cost Factors

Conventional and solution maintenance costs are on a $2014/pkm basis, with conventional roadways supporting fewer annual pkm than bicycle roadways on average.

#### 2.5.2.4 Discount Rate

The discount rate for public entities is based on actual discount rates used by public entities for transportation infrastructure projects and major publication (such as the Stern report) recommendations.

Table . Financial Inputs for Conventional Technologies

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Conventional) | *US$2014* to acquire and install per bike lane km/car lane km | 48,500-105,494,699 | 29,976,282 | 8 | 4 |
| Variable Operation and Maintenance Costs (Conventional) | *US$2014/B Pkm* | 0-310,469,259 | 147,788,397 | 7 | 4 |

Table . Financial Inputs for Solution

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Solution) | *US$2014* to acquire and install per bike lane km/car lane km | 14,116-422,769 | 154,643 | 14 | 10 |
| Variable Operation and Maintenance Costs (Solution) | *US$2014/B Pkm* | 4,079,568-7,110,656 | 5,595,112 | 4 | 2 |

### Technical Inputs

Besides strictly climate and financial inputs, several general variables were used in the analysis which had important impacts on both the climate and financial results.

#### Replacement Factors

The conventional and solution lifetime capacity is the lifetime of the road infrastructure for both asphalt and pavement and is converted for analysis by multiplying it by the average annual use for each alternative.

The installation of a new bike lane leads to an increase in bike ridership on the road. The average annual use is calculated for bicycle pkms for the road before installation and after.

Table . Technical Inputs Conventional Technologies

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Lifetime Capacity (Conventional) | *B pkm/bike lane/car lane km until replacement* | 0.013-0.027 | 0.020 | 3 | 2 |
| Average Annual Use (Conventional) | *B pkm/bike lane/car lane km until replacement* | 0.000-0.001 | 0.001 | 11 | 3 |

Table . Technical Inputs Solution

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Lifetime Capacity (Solution) | *B pkm/bike lane/car lane km until replacement* | 0.047-0.099 | 0.0732 | 3 | 2 |
| Average Annual Use (Solution) | *B pkm/bike lane/car lane km until replacement* | 0.000-0.006 | 0.003 | 13 | 5 |

#### Technical Factors

Bike lanes do not replace roadways on a one-to-one basis. In order to determine how many kilometers of roadway are offset by new kilometers of bike lanes, an adjustment factor was calculated and applied to roadways to represent bike lanes. This analysis assumes that one-quarter of the costs of road construction (equal to the eliminated lane which becomes two bike lanes in a road diet) are the expense that is comparable to bike lane costs. This calculation multiplies the total cost of annual road infrastructure by 25 percent as an adjustment rate. Using the adjustment factor ensures that bicycle infrastructure is only compared to the roadways that might have bicycle infrastructure, rather than the entire urban road network.

Table . Technical Inputs Solution

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Average Annual Use Conversion | Vehicle km converted to bike lane km |  | 25% | 151 | 1 |
| Discount Rates – Public Entities | Percent | 1.8%-9.6% | 5.7% | 17 | 9 |

## 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 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. All cars identified as a “convectional technology” use ICE;
2. Travel mode fuel efficiencies and fuel prices remain constant through 2050;
3. Average urban trip lengths with cars and public transit remain constant through 2050;
4. Mode Energy Usage: Urban bus and Mini bus use liquid fuel and electricity; Cars and BRT use only liquid fuel; Metro, Tram, and Commuter rail use only electricity.

## 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 for a complete understanding of the integration process. 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 (including Walkable Cities and Bike Infrastructure) was modeled independently and integration was performed to ensure consistency within the sector. Intra-sectoral integration of the transportation solutions was based on two main components:

* TAM/Adoption Consistency: Ensuring that all solutions that are in the same “market” use the same TAM data, use consistent market shares, and have projected adoptions that do not exceed the total projected demand
* Variable Consistency: Ensuring that all variables that are used in several solutions have the same values.

The total motorized and non-motorized transport demand (TAM) was collected and synthesized from several sources in functional units (mostly passenger-km and ton-km), then classified according to type (urban passenger, non-urban passenger, and all freight). The TAM was then assigned to each solution according to the service that the solution technology provides. The TAM served as the upper limit of the sum of adoptions of the modeled solutions. Additionally, some reasonable bounds that were lower than the TAM were placed on adoptions to represent the technologies not affected by the matrix of solutions of Project Drawdown (such as 2-wheelers, intercity bus, and conventional rail).

To determine the new mode shares as adoption grew independently in the models, a simplified approach was used. Solutions were prioritized according to their impact on the climate/environment and efficiency (in space, energy and cost terms). Higher priority solutions were allocated larger proportions of their total individual projected adoption than lower priority ones. Put another way, if the sum of all projected adoptions exceeded the limit discussed above, then in reverse order of priority, and until that was no longer the case, the projected adoption of each solution was reduced until either the relevant bound was no longer exceeded or the adoption was zero. In practice, this mostly affected the Hybrid Cars solution, and to a lesser extent Electric Vehicles which were (respectively) the lowest and second lowest priority solutions in the urban and non-urban passenger TAM’s. The adjusted adoption projections are then used in the individual solution models and in the technical report. Therefore, the adoptions shown in this report already account for integration.

For several variables, especially those relating to the conventional technology (ICE cars), discount rates, fuel prices, emissions factors, and mode shares, consistency across solutions was maintained by ensuring that the same values were used in different models needing those variables.

In addition to intra-solution integration within the transport sector, there was an integration process across the grid solutions and the electricity efficiency solutions (buildings, transport, materials etc.) which 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 efficiency solutions is reduced (where they reduce electricity demand) or increased (where they increase electricity demand[[7]](#footnote-7)). Grid solutions are adjusted to remove the double counting as described in the Project Drawdown integration documentation.

## Limitations/Further Development

Active mode urban travel is not reported widely on a global or regional basis partly due to the short trip distances. It is a growing area of research and global and regional estimates began being reported in 2016 from the ITF (OECD/ITF, 2021). Active mode shares are reported by interested organizations such as the European Cycling Federation and ITDP (ECF, 2020; European Cycling Foundation, 2016; UC Davis et al., 2015) which tend to have a favorable bias towards cycling and the areas reported (such as Europe) tend to have higher mode share than average.

The pop up lanes from the global pandemic lockdowns of 2020 are still reporting data. While the number and length of pop up lanes is mostly known, the ridership data and also the ultimate fate of the lanes is still being processed.

Regarding the different agency levels, it was decided to address the financial impacts from a city perspective. Another possible viewpoint is that of the individual user. In such an analysis, the costs would not be estimated by construction and maintenance costs of car lanes versus bicycle infrastructure; instead, the costs to purchase and maintain a bicycle or car and fuel would be considered.

# 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** | **Drawdown** | **Optimum** |
| Bike Infrastructure | billion passenger-km | 779.00 | 2,592.41 | 3,038.84 | 5,069.27 |
| *(% Market)* | 2.6% | 5.0% | 6.0% | 10.0% |

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



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



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



Figure 3.3 Net Profit Margin /Operating Costs Over Time

# Discussion

Shifting passengers to lower emission modes is a huge step towards achieving drawdown. Bicycle Infrastructure is an important solution to help with this shift. Currently it is estimated that 9.5 Gt CO2 eq was produced due to the transportation sector around the world in 2018 (IEA, 2018). The current estimates show that building bike lanes can reduce CO2 eq per year by 0.18 Gt (on average for 2020-2050 in the Plausible Scenario-PDS1). The cumulative reduction total for 30 years (2020-20150) is 2.68 Gt CO2 eq. In more aggressive scenarios, bicycle infrastructure increasingly replaces car lanes, other dedicated infrastructure is constructed and using bicycles for commuting, shopping and recreation moves from a lockdown trend to a true modal switch. The decrease in car trips and increase in bicycle trips has the concomitant benefits in congestion, air quality, noise, stress, travel delay and GHG emissions.

The global pandemic that began in 2020 saw a shift towards bicycling for recreation and for replacing trips that would have been done using public transit. Bicycles and e-bikes sold out in many places around the world and several governments began offering incentives to repair old bicycles. Temporary bicycle lanes popped up all over the world. Policy makers are trying to make this shift permanent

In addition to climate impacts, bicycle infrastructure is cheaper to build and uses less materials than car lanes (FDOT, 2020; Wisconsin DOT, 2021) and is shown to reduce traffic and congestion. Additional benefits of passengers using bike lanes include improvements to health (de Geus et al., 2013) and positive impacts on the local economy as bike users tend to shop in their local community (Arancibia et al., 2019).

The financial results presented in Table 3.4 show the NPV of the bicycle infrastructure solution to be $18,935 billion with a net operating savings of $2,692 billion from 2020 to 2050. While bicycle infrastructure replaces car lanes and some new dedicated infrastructure, like GHG emission reductions, most of the cost savings comes from the reduced cost to build bicycle infrastructure versus building car lanes. The maintenance costs are also much lower despite the bike lanes having a higher a higher average annual use level of pkms because bicycles are less destructive than cars. This cost reflected an assumption that 10 percent of new bike infrastructure would be cycle tracks, which have a much higher first cost than regular bike lanes, which were expected to make up the other 90 percent. Bicycle infrastructure is an easy to implement, cost-effective solution that has significant reductions in emissions (as proven by covid pop up lanes, increased number of cycle tracks and “rails to trails”).

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

Riding a bike instead of driving a car not only improves the health of the rider, but also reduces the localized particulate emissions from internal combustion engines, thus improving air quality and health outcomes for non-bike riders. Increasing bike ridership in urban centers may seem like a difficult task, and it will require concerted efforts to design infrastructure that supports all modes of transportation. However, there are significant steps in this direction taking place throughout the world. For example, the state of California, representing the world’s eighth largest economy, released a statewide transportation plan for the next 25 years. Among the goals listed in the plan are improving multimodal mobility and accessibility for all people and using complete streets strategies to expand the use and safety of bicycle facilities (Caltrans 2016). Moreover, it may be heartening to remember that private vehicles did not always dominate urban roads, and bicycles were once considered an effective and even fashionable mode of transportation. The City of Los Angeles, known today as one of the most car dependent in the world, had an exclusive bicycle highway at the beginning of the 20th century (Masters 2013). Moving away from bicycles to motorized forms of transportation was the result of changing social attitudes and deliberate efforts from city planners. A similar shift back to high bicycle ridership is happening under a reverse shift in attitudes and corresponding changes in infrastructure design practices. If this shift continues, the world will see large-scale benefits in a range of environmental, social, and economic areas.

Some improvements in the modeling could be expanding the scenarios to include the results of the achievement of more specified mode share goals (5%, 7.5% or 8%) by 2050 and more details on the results from the pop up lanes.

## Limitations

Bicycle infrastructure is an important component for decarbonizing urban passenger transportation. However, some passengers are simply unwilling to utilize bicycles and therefore bicycle infrastructure (No way, No how users) and some geographical areas have climates and terrains that are not inviting for the use of bicycle infrastructure. In some developing countries, car ownership is seen as a status symbol and using bicycle infrastructure is not. These obstacles can be overcome with the right type of infrastructure matched to the place (covered bicycle infrastructure, elevated tracks etc.) and awareness campaigns and social agreements (car shaming in the Netherlands and a specific “cool” term for bike commuters in Paris ‘vélotaf’).

## Benchmarks

Adoption data is not widely reported and requires adjustment for comparison. Therefore, it is difficult to find comparable (without adjustment) sources for benchmarking. Only one source reported adoption data as a percent of urban passenger travel and is benchmarked in Table 4.1.

Table . Benchmarks

| **Source and Scenario** | **Market Share in 2050 (%)** |
| --- | --- |
| ITDP/UC Davis | 7.0% |
| Project Drawdown – Plausible Scenario) | 5.0% |
| Project Drawdown – Drawdown Scenario | 6.0% |
| Project Drawdown – Maximum Scenario | 10.0% |

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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. <https://commons.wikimedia.org/wiki/File:ParkBlvd_BikeLane.jpg> [↑](#footnote-ref-1)
2. <https://commons.wikimedia.org/wiki/File:Bicycle_boulevard_on_14th_Street,_Albuquerque_NM.jpg> [↑](#footnote-ref-2)
3. <https://commons.wikimedia.org/wiki/File:Cycle_Path_to_Southend_-_geograph.org.uk_-_66639.jpg> [↑](#footnote-ref-3)
4. 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-4)
5. The Organisation for Economic Cooperation and Development, with membership as at the end of 1990 (this was chosen to match the AMPERE model used by the IPCC and developed by the International institute for Applied Systems Analysis (IIASA). See [www.iiasa.ac.at](http://www.iiasa.ac.at) ) [↑](#footnote-ref-5)
6. 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-6)
7. Some solutions such as Electric Vehicles and High-Speed Rail increase the demand for electricity and reduce the demand for fuel. [↑](#footnote-ref-7)