Technical assessment for Efficient Trucks

Sector: Transport
Agency Level: Business
Keywords: Truck Fuel Efficiency

Book Edition 3 (October 2021)

Suggested citation
Allard, R., Jones, H., Chen, W., Alkire, C., Becque, R., & Frischmann C.J (2022). Solution Name. Project Drawdown

*Note: For some of the technical reports, the result section is not yet updated. Kindly refer to the model for the latest results.

27 GATE 5 RD., SAUSALITO, CA 94965 info@drawdown.org www.drawdown.org

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND SYMBOLS USED

- **ICE** – Internal Combustion Engine
- **ITDP** – Institute for Transportation and Development Policy
- **ITF** – International Transport Forum
- **PDS** – Project Drawdown Scenario
- **PKM** – Passenger-kilometer (1 passenger moved 1 kilometer)
- **REF** – Reference Scenario (of Project Drawdown)
- **TAM** – Total Addressable Market
- **GHG** – Greenhouse Gas
- **GT** – Gigatons
- **ICT** – Information and Communication Technology
- **IEA** – International Energy Agency

EXECUTIVE SUMMARY

The transport sector produced a combined 9.5 gigatonnes of CO_2 equivalent of direct GHG emissions in 2018 and was responsible for approximately 23% of total energy-related CO_2 emissions (IEA, 2018). Heavy trucks use about 50% of all freight industry energy and light trucks another 20% and these are therefore responsible for a majority of emissions in the freight industry (IEA, ETP, 2016). Growth in emissions continues in spite of more efficient vehicles and policies being adopted.

Carbon emissions from transport have increased by about 250% since 1970, at a faster rate than any other energy end-use sector and with 80% of the increase being attributable to road vehicles. Projected GHG emissions from all transport sources combined could increase with another 80% by the year 2050, with emissions from trucking and other commercial operations predicted to grow even more rapidly than those of personal transportation.

A number of design and technology measures are readily available to increase a truck's fuel efficiency including low rolling resistance tires, more efficient engines, measures to reduce aerodynamic drag and idling, and predictive cruise control. These can significantly improve fuel economy and in many countries such measures have to some degree been implemented.

Although the global road freight sector is diverse, with variations in regulations, fuel costs, road quality, and truck makes and models from region to region, solutions may be customized by each country and truck operator. The adoption of such fuel-saving clean technologies for commercial truck fleets offers a clear potential to achieve significant reductions in global GHG emissions while generating considerable operational lifecycle cost savings for the road freight sector.

We estimate that globally, there is only a 1.6% adoption of these technologies in the total freight industry, which we believe is driven by the fuel efficiency and emissions standards for cleaner trucking in some countries. This number could be higher but for a few barriers.

Key barriers to widespread adoption include:

- Fragmented markets and limited access to capital: In many countries the trucking industry is highly fragmented, with a large number of owner-operators (less than five trucks) and with multiple stakeholders involved in trucking transactions. In an industry with often small margins, the high upfront capital costs and the limited access to capital may provide little incentive to upgrade;

- Split benefits: With many tractor-trailer combinations, the trailer has a different owner than the truck hence creating split benefits between who pays for the upgrades and who reaps the benefits of fuel savings;

Nonetheless, the relatively short payback periods of many currently available fuel efficiency measures combined with most trucks being commercially deployed on the road for over a decade ensure that fuel efficiency not only provides GHG reductions but also compounded cost savings for the party paying for fuel. In addition, fuel efficiency helps reduce toxic ambient air pollutions such as SOx, NOx and PM, which contribute to poor air quality.

The calculation results as derived from the Drawdown model for global data show that the long-haul heavy-truck industry could expect to see a considerable return on investment through the adoption of typical fuel efficiency technologies.

With adoption of fuel efficiency technologies a lifetime savings in net present value for the period 2015 to 2050 of $659 billion 2014 USD could be possible. In an industry often characterized by small profit margins and where fuel costs make up a considerable share of operational costs, such a potential for fuel savings and therewith net cost savings should prove highly attractive considering key barriers impeding current uptake are being properly addressed. Furthermore, as much as 9.15 to 10.77 gigatonnes of direct $CO_{2\text{-}e}$ emissions could be avoided by 2050.

1 Literature Review

Globally, transport of people and goods produces 9.5 gigatons (Gt) of carbon dioxide-equivalent (CO_2-eq) greenhouse gas emissions annually, equivalent to 23 percent of *energy-related* emissions, or 14 percent of *all* emissions (IEA, 2018)[1]. In individual countries, where transport is based on high-emission modes, transport can account for much higher shares. The sources of those 9.5 Gt are chiefly from cars and light trucks, which account for over 50% of all transport emissions. Heavy freight trucks and buses contribute an additional 26% and air transport and shipping each generate 10% of global transport emissions (IEA, 2018). Growth rates in emissions for some subsectors like air transport and shipping are very high, so the Transport Sector requires special focus to keep emissions from ballooning out of control, as some projections indicate. Transport, however, is a service derived from economic growth. Research shows that wealthier people travel more, locally and internationally, and demand more goods and services. So, as a country develops economically, movement of people and goods increases. Solutions generally can be classified using the "*avoid-shift-improve*" framework: *avoid* travel altogether, *shift* travel to low-carbon modes or *improve* modes to generate lower emissions.

[1] Non energy-related emissions include land use change emissions (including deforestation), and methane and F-gas release from agriculture, refrigeration, and industrial activity.

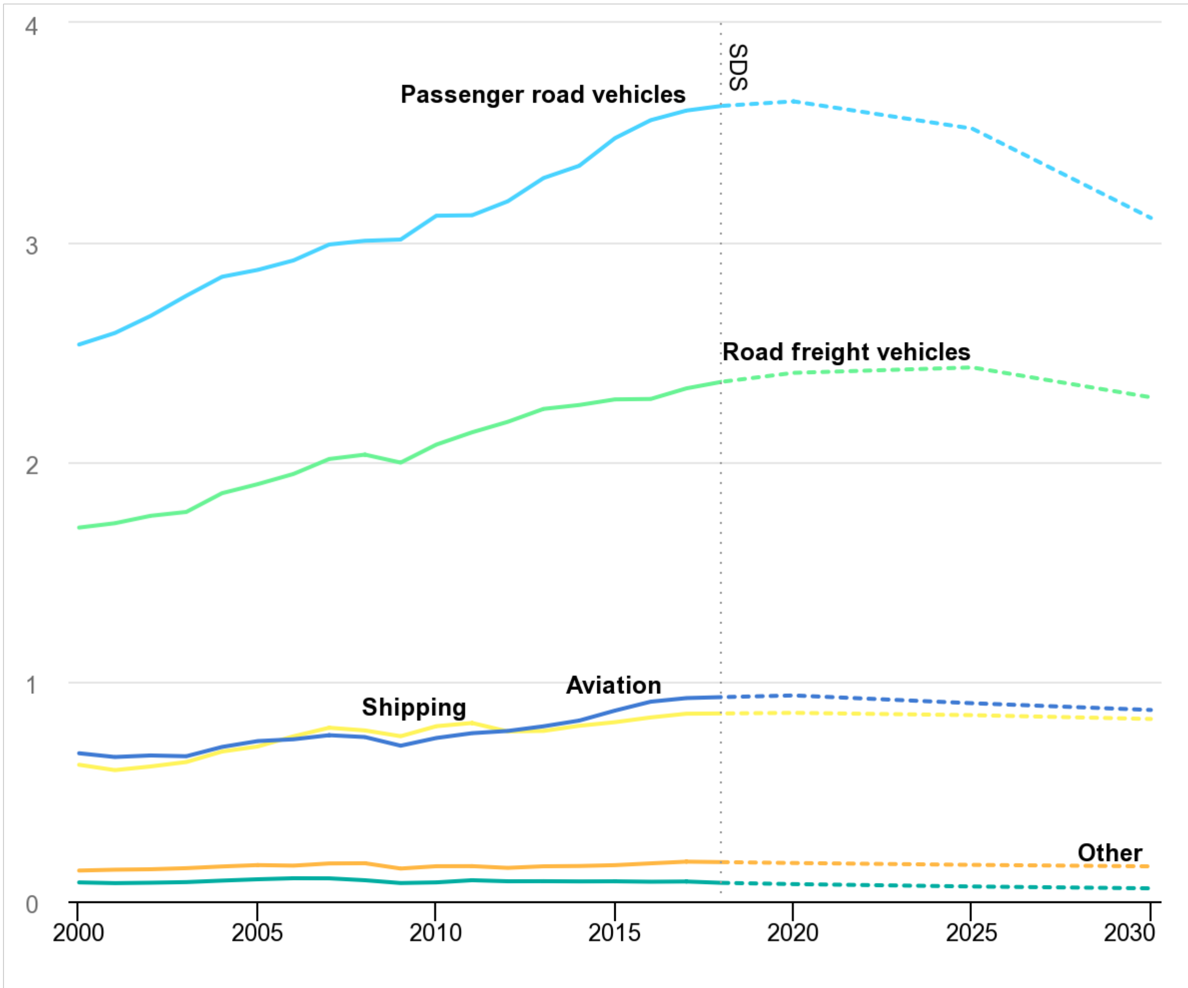

Figure 1. Transport sector Gt CO2 emissions by mode in the Sustainable Development Scenario, 2000-2030. (IEA, 2019)

1.1 State of Efficient Trucks

1.1.1 Fuel Efficiency Standards

Regulations for fuel efficiency standards for heavy-duty vehicles (HDV) began around 2014. Only 4 countries (Canada, China, Japan and United States) had them in place although these countries covered 47% of global heavy-duty vehicle sales (GFEI, 2017). By 2019, 70% of all HDV sales had fuel efficiency standards in place. This included India in 2018, the EU in 2019, further restrictions by China, Japan and United States along with developing policies from Argentina, Brazil, Chile, Mexico and South Korea by 2022 (IEA, 2020).

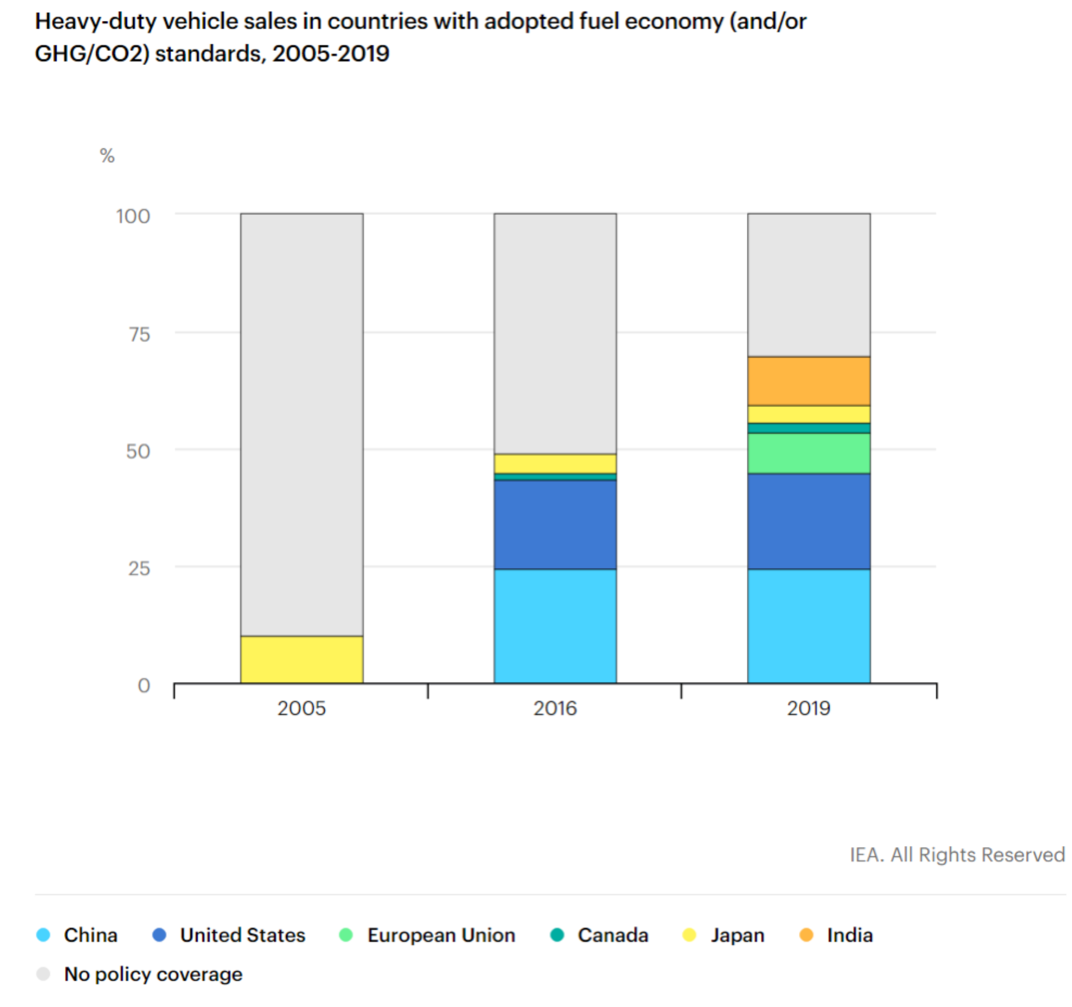

Figure 2. HDV sales with fuel efficiency regulations (IEA, 2020)

1.1.2 Technologies

Many design and technology measures are readily available to increase a truck's fuel efficiency, including low rolling resistance tires, measures to reduce aerodynamic drag and idling, more efficient diesel engines, predictive cruise control, and GPS navigation (Figure 3). Payback periods vary by technology, vehicle type, and country-specific activity patterns; the cost of most are recouped in fuel savings within three years (GFEI, 2016; Schroten et al., 2011; IEA, 2012).

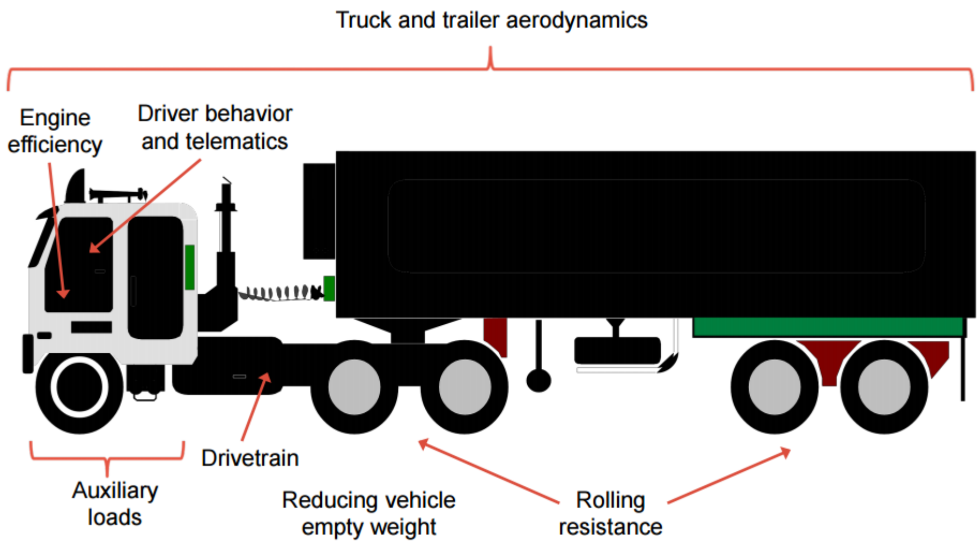

Figure 3. Areas for on-vehicle efficiency improvements (Sharpe & Muncrief, 2015)

Studies have found these technical measures have been effective in reducing fuel consumption and fuel costs for heavy duty truck operators while reducing GHG emissions. Table 1 presents fuel efficiency packages identified in the literature. The Carbon War Room Research and Development Group (2012) chose a range of proven fuel efficiency technologies based on their payback periods, efficiency improvement potentials and relative simplicity to adopt. The National Academy of Sciences (2010) selected technologies that may be implemented by 2020, although some (increasing the thermal efficiency of diesel engines and hybridization) only with the use of incentives or regulations due to cost. Schroten, et al, (2012) chose a set of measures that – according to original equipment manufacturers -- were compatible with each other. The International Council on Clean Transportation (2017) reports the technologies available for tractor-trailer combination improvements.

Table 1. Heavy-Duty Truck Fuel Efficiency Improvements from Technology Implementation (Retrofit or Factory)

Technology	Carbon War Room, 2012	Schroten, Warringa & Bles, 2012	National Academy of Science, 2010	International Energy Agency, 2012	International Council on Clean Transportation 2017
Aerodynamic	3% to 15%	5% to 9%	11.5%	12.5% to 20%	10.6%

improvements – reduce drag					
Weight reduction - material substitution		2.2%	1.25%	2% to 5%	2.5% to 15.6%
Tires and wheels - low rolling resistance	3% to 6%	9% to 12%	11%	5%	5.1%
Automatic tire inflation	N/A	1.2%	N/A	N/A	
Transmission and driveline – reduced transmission friction, automated manual transmission	2.5% to 6%	1 to 1.5	7%	4% to 6%	5.4%
Idling reduction devices	5% to 9%	N/A	Included with hybrid	N/A	
Engine efficiency	N/A	14.6% to 17.9%	20%	4% to 7%	4.5% to 9%
Hybrid w/idle reduction	N/A	N/A	10%	N/A	4.5%
Management – cruise control, route management	5% to 10%	2% to 7%	6%	2% to 5%	2.9%
Information and Communication Technologies – GPS-assisted navigation and routing, driver training	1% to 10%			N/A	
Total Package (a)	30%	43% to 62.8%	50.5%	29.5% to 48%	33% to 46.55%

Note: Ranges in efficiency estimates reflect the fact that these technologies will vary in effectiveness depending on make and model of truck, urban or highway travel, duty cycle (the proportion of time the technology is implemented), and other factors.
N/A: Technology not included by author(s).

(a) Range of all technologies is shown if authors did not provide total package efficiency. The combined fuel efficiency benefit of different truck technologies is not additive because as incremental improvements are added, each percentage applies to an already reduced fuel consumption (IEA, 2012; NAS, 2010).

For example, the Carbon War Room indicated that the adoption of five technologies by tractor-trailer type trucks in the United States could reduce fuel use by 30% at a cost of about $30,000 (Tables 1 and 2). These measures could prevent the emission of 624 million tons of CO_2 by 2022 under predicted industry growth rates, with average fuel savings of $26,400 per truck (in 2010 USD based on fuel price of $4/gallon). Adoption of a single physical technology resulted in emission reductions in the range of 1% to 15% (Carbon War Room, 2012).

Table 2. Cost of Sample Fuel Efficiency Packages

Technology	Carbon War Room (2012)	Schroten, Warringa & Bles (2012)	National Academy of Science (2010)	International Energy Agency (2012)	International Council on Clean Transportation 2017
Aerodynamics - fairings, skirts	$300; $10,000 for system	$4,612 to $4,694	$12,000	$6,000 to $6,700	$2,000
Weight reduction -material substitution	N/A	$1,600 to $2,283	$13,500	$2,000 to $5,000	$11,176
Tires and wheels - decrease rolling resistance	(a)	$1,038 to $1,300	$3,600	$1,800 to $3,000	$895
Automatic tire inflation on trailer and tractor	N/A	$3,728 to $11,790	N/A	N/A	
Transmission and driveline – reduced transmission friction, automated manual	(a)	$208	$5,800	$4,500 to $6,000	$1,500

transmission					
Idling reduction devices – auxiliary power unit (APU)	$10,000 to $15,000 (electric APU)	(included in hybrid)	(included in hybrid)	N/A	
Engine efficiency – improved diesel engine	N/A	$11,271	$23,000	$3,000 to $8,000	$9,136
Hybrid w/idle reduction	N/A	$21,137 to $24,000	$25,000	N/A	$13,000
Management – cruise control, route management	$800 to $3,000; $1,500 for system	$1,153 to $1,400	$1,700	$1,900	$640
Information Communication and Technology – GPS-assisted navigation and routing, driver training	$1,000			N/A	
Total Package (nominal)	USD$30,000	EUR$44,784 to $45,430	USD$84,600	USD$24,900	USD$14,171 to $38,347
Total Package (USD$2014)	$30,900	$59,306 to $60,161	$92,214	$25,647	$13,687 to $37,036

(a) Assumes improved technology will cost less than their conventional counterparts.
N/A: Technology not included by author(s)

In addition to the studies in Tables 1 and 2, Ogburn & Ramroth (2007) provide a combination of technologies -- aerodynamic improvements, wide-base tires and anti-idling device -- reducing fuel use by 22% at a cost of $35,806 (2014 $USD). In China, the cost for better aerodynamics, tires and wheels was estimated at $10,000 (2010 USD) (Punte et al 2010); $10,900 in 2014 USD. In the United States an investment of $2,400 (2014 $USD) for engine efficiency would result in fuel savings of 3% (Transport & Environment, 2018).

	Technology	TIAX Payback Period (years)							
		Service	Urban Delivery	Municipal Utility	Regional Delivery	Long Haul	Construction	Bus	Coach
Aerodynamics	Aft box taper		2						
	Boat tail				2	1			
	Box skirts		3						
	Cab side extension or cab/box gap fairings		5						
	Full gap fairing				3	1			
	Full skirts				4	2			
	Roof deflector		2						
	Streamlining	0.4							2
Lightweighting	Material substitution	8	8	14	5	2	6	8	35
Tires and Wheels	Automatic tire inflation on vehicle/tractor				29	11	33		3
	Automatic tire inflation on trailer				2	1			
	Low rolling resistance tires	0.05		1				1	1
	Low rolling resistance wide-base single tires		1		0.2	0.1	0.2		
Transmission and Driveline	Aggressive shift logic and early lockup	0.3		1					
	Increased transmission gears	3		4					
	Transmission friction reduction	1		1	1	0.3	1	1	1
Engine Efficiency	Improved diesel engine	4	3	2	2	1	2	1	3
Hybridization	Dual-mode hybrid	13			4	5			
	Parallel hybrid		5				3		14
	Parallel hydraulic hybrid			6					
	Series hybrid							2	
Management	Predictive cruise control				0.3	0.1			0.3
	Route management					2			
	Training and feedback					0.5			

Figure 4. Fuel efficiency investment payback periods (Schroten et al., 2012)

1.1.3 Efficient Trucks and Climate Change

The global road freight sector is diverse, with variations from region to region including regulations, fuel costs, road quality, dominant freight transportation methods, truck makes and models, and the options available for financing efficiency investments.

In the United States alone, trucks deliver 70% of all freight tonnage, hauled by 26 million trucks in the year 2010 of which 3.5 million vehicles were registered as Class 8 vehicles which refers to vehicles of 33,001 lbs (14,969 kg) and over. These Class 8 trucks account for over 75% of the fuel consumed by the United States road freight sector while producing nearly 20% of the sector's total emissions. With over 100,000 of such vehicles sold in country per year and with tractor-trailers remaining on the road for an average of 19 years, there is clearly a market opportunity for fuel efficiency in new trucks or through retrofitting of existing trucks (Carbon War Room, 2012).

1.2 Adoption Path

1.2.1 Current Adoption

The current modal share of efficient trucks is the percentage of total freight tonne kilometers done through efficient trucks. Adoption projections are gathered from as many credible sources as possible. Sources include reports from the ICCT and several IEA reports. The current adoption of efficient trucks is estimated by calculating the average based on these sources. Current modal share can be seen in Table 1.1.

Table 1.1 Current Global Modal Share and Adoption of Efficient Trucks in million tonne-kilometers

	Percent (%)	Million TKM
Global Current Adoption	1.61%	2,160,374

1.2.2 Trends to Accelerate Adoption

1.2.2.1 Legislation

Existing legislation is becoming more stringent and coverage is expanding(IEA, 2020). The secondary market for used HDVs is an opportunity to improve truck fuel efficiency. To increase the adoption of fuel efficiency measures governments in various parts of the world, including China, United States and the European Union, are actively introducing new or more stringent fuel efficiency standards and/or considering emission ceilings for heavy-duty vehicles and the potential inclusion of road-based freight in emission trading schemes. Several institutions and non-profits are also driving the uptake of such measures through a number of broad-range or measure-specific programs and demonstration projects.. Many countries are participating in voluntary green freight programs that provide fleet efficiency improvements and contribute to development of future efficiency standards (Global Fuel Economy Initiative, 2016; Muncrief, 2014).

1.2.2.2 Fuel Prices

Rising fuel prices will encourage private owners to invest in fuel efficiency measure to save money.

1.2.3 Barriers to Adoption

1.2.3.1 Market Fragmentation

Market fragmentation and access to capital: In many countries the trucking industry is highly fragmented, with a large number of owner-operators (less than five trucks) and with multiple stakeholders involved in trucking transactions. In an industry with often small margins, the high upfront capital costs and the limited access to capital provide little incentive to upgrade. This is especially true in developing countries and for those driving leased fleets. In addition, many lending institutions have been reported to not take fuel efficiency into account when providing loans for the purchase of trucks.

1.2.3.2 Burden of fuel cost

Depending on who pays (the carrier or the shipper) for the fuel cost of bringing a load from one destination to the other, the owner of the truck who would pay for the upgrade, may or may not see a benefit from its investments.

1.2.3.3 Electrification and Alternative Fuels

In the long term, electric trucks are the ultimate goal with already some progress towards achieving it but there are still range and infrastructure challenges. There has been some inroads into alternative fuels as well. As these technologies are adopted, fuel efficiency technologies from design such as aerodynamics will be adopted but engine fuel efficiency technologies will be abandoned (IEA, 2020)

1.2.4 Adoption Potential

Uncertainty in fuel prices and decreasing prices in fuel efficiency technology coupled with increased legislation make the adoption potential very high. Several sources (ICCT, 2018a; IEA, 2016, 2020) forecast complete or almost complete adoption by 2035 and before the transition to electric or alternative fuels.

1.3 ADVANTAGES AND DISADVANTAGES OF EFFICIENT TRUCKS

1.3.1 Similar Solutions

Solutions that are similar to or can replace efficient trucks are all other modes that can move freight. These modes include inefficient trucks and rail, air and ocean shipping where available. All of these modes (except for inefficient trucks) are current Drawdown Solutions (with added technologies). Due to local and regional differences the replaced technology is defined as inefficient trucks at the typical efficiency of 2014.

1.3.2 Arguments for Adoption

Increasing legislation, fuel price uncertainty, decreasing fuel efficiency technology costs and incentives and willingness to make used HDVs more sustainable all point to strong increased adoption.

1.3.3 Additional Benefits and Burdens

Additional benefits of efficient trucks include less air pollution.

Additional burdens to increased truck fuel efficiency is a lack of motivation to transition to electric or alternative fuels and more importantly a shift to rail which is a much lower emitting mode for freight transportation.

2 METHODOLOGY

2.1 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[2]) is what constituted the results.

The functional unit[3] of the analysis is freight million tonne-kilometers (tkm); and the implementation unit[4] the number of modified trucks. The agency level used for the analysis is the business or enterprise, as it this level that will make the decisions (although the business level can be an individual).

The Total Addressable Market (TAM) covers all demand for the function provided by the solution. For efficient trucks, the TAM is global demand for freight including conventional and emerging solutions.

The Project Drawdown Scenarios, (PDS), estimate an annual increase of freight moved by efficient trucks as the total number of tkm grows..

---

[2] 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.

[3] The functional unit is the unit measuring the society function provided by the technology, in this case – mobility.

[4] The implementation unit is the unit measuring installation of the technology. As the focus is on encouraging travelers to use existing systems, which are expected to provide an indication of value to public authorities as well as increased financial security, this would lead to improvements in service levels to match demand which in turn would lead to increased ridership resulting in a virtuous cycle.

The conventional technology in this model is inefficient trucks of typical efficiency of 2014.

As mentioned previously, the functional unit of the analysis is freight million tonne-kilometers and the implementation unit the number of efficient trucks.

2.2 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.

2.2.1 Total Addressable Market

The Total Addressable Market (TAM) covers all demand for the function provided by the solution. For the Efficient Trucks solution, TAM is world freight million tonne-kilometers made by all freight modes. Global TAM was projected mainly using data obtained from (Airbus, 2016; Boeing, 2015; ICAO, 2015; IEA, 2016; The International Council on Clean Transportation, 2012).

2.2.2 Adoption Projections

Adoption projections are gathered from as many credible sources as possible. Sources include (EC, 2019; ICCT, 2012; IEA, 2016, 2020; OECD/ITF, 2021).

2.2.3 Variable Inputs

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

2.2.3.1 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.

There is no conventional first cost as solution first costs represent the additional costs to making a conventional truck more efficient which include those listed in the Technologies section. Solution first costs are collected from (ICCT, 2017, 2018b, 2019; NACFE, 2018).

The conventional and solution lifetime capacity data come from (ATRI, 2020; Cullen, 2015; ICCT, 2017, 2019; Sustainable Freight, 2015).

The conventional and solution average annual use come from (ATRI, 2020; EC, 2019; ICCT, 2017, 2019; IEA, 2016; Sharpe & Muncrief, 2015).

2.2.3.2 Emissions Reduction Variables

The conventional fuel consumed per functional unit data is from (ATRI, 2020; ICCT, 2017, 2018b, 2019; Kodjak et al., 2015; North American Council for Freight Efficiency, 2015; Sharpe & Muncrief, 2015) some of which have multiple data points for many countries.

The solution fuel efficiency factor data is collected from (ICCT, 2017, 2018b, 2019; NACFE, 2018) some of which have multiple data points for many countries.

2.2.3.3 Additional Variables

Average utilization rate (by weight) is from (ICCT, 2017; Sharpe & Muncrief, 2015).

Average long haul truck capacity data come from (EC, 2019; ICCT, 2017, 2018b, 2019).

Average truck lifetime data is collected from (ATRI, 2020; Cullen, 2015; ICCT, 2017, 2019; Sustainable Freight, 2015).

The commercial/industry discount rate is based on data from (EC, 2015; ICCT, 2017, 2018b; Steinbach & Staniaszek, 2015; Stutzman et al., 2017).

2.3 Total Addressable Market

The Total Addressable Market (TAM) is the total freight transportation, in tonne-km, provided to the world market by all modes. Data were obtained from the International Energy Administration (2016), International Council on Clean Transportation (2012a), International Civil Aviation Organization (2015), and Boeing (2014) and Airbus (2015) companies. The TAM is projected to increase from 118,854,241 million tonne-kms in 2014 to 363,475,800 million tonne-kms in 2050. Our calculations indicate that the truck industry provides about 17% of that (with the marine shipping industry providing the vast majority at 73%). The values shown represent the average from all the sources (Table 2.1).

Table 2.1 Global TAM, in million tonne-kms

Drawdown Region	2015	2030	2045	2050
World	120,148,998	183,264,518	302,475,349	363,475,800

2.4 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.

2.4.1 Reference Case / Current Adoption

For most Project Drawdown solutions, the REF scenario assumes that the 2014 adoption of the solution is "frozen" for the study period. It uses the percentage of adoption in the base-year as the fixed percentage of TAM projecting forward which is 1.61%.

2.4.2 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. Two methods were used to calculate these estimates with assumptions made from multiple sources for each source. The first method estimates new heavy trucks sold in each country from 2014 to 2050 and the year in which national mandatory fuel efficiency regulations are (projected to be) effective and therefore assumed to include a fuel efficiency package. The second method used estimates of heavy duty truck activity (freight tonne-km) 2014 to 2050 and the portion of those that include fuel efficiency technologies from multiple sources.

2.4.2.1 Plausible Scenario

This scenario assumes that fuel efficiency regulations are put into place by the announced schedules for the countries listed above and that most other countries are very slow to impose regulations.

2.4.2.2 Drawdown Scenario

In this scenario, the countries that have announced regulations meet the schedules and many manufacturers only produce efficient trucks making inroads into countries without regulations or earlier than announced.

2.4.2.3 Maximum Scenario

This scenario assumes that many manufacturers and countries meet the regulations faster, by 2030 and that many other countries follow suit. In this scenario, all freight moved by truck is done by efficient trucks in the country and in the year and following years of the regulation.

2.5 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 influence walkable cities is the city. Therefore, the impacts on the perspective of the city are analyzed.

2.5.1 Climate Inputs

This section addresses the environmental inputs of the model. These can be either direct emissions, through fuel combustion or the electricity grid, or indirect, through the construction of the vehicles.

2.5.1.1 Direct Emissions

Direct emissions can come from fuel combustion or from electricity consumption. Certain assumptions regarding the technologies are made to calculate them. All conventional technology vehicles are ICE heavy duty vehicles, therefore conventional has only fuel-combustion related emissions.

For inefficient trucks, the input required is the average liters of fuel required per million tonne-km.

To calculate the reduction obtained by the solution technology, one estimates how much fuel would be saved (%) by switching an inefficient truck million tonne-km to an efficient truck million tonne-km.

2.5.1.2 Indirect Emissions

Indirect emissions from vehicle manufacturing must also be taken into account. However, the manufacturing of an inefficient truck and efficient truck are not very dissimilar and no data was found on the differences..

Table 2.2 Climate Inputs

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Fuel Consumed per Functional Unit - CONVENTIONAL	*Liter/ million tonne-km*	32,007-53,517	34,127	13	4
Fuel Efficiency Factor SOLUTION	*Fuel % saved*	32.1%-46.7%	39.4%	8	4

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[5].

2.5.2 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.

2.5.2.1 First Cost

There is no conventional first cost as solution first costs represent the additional costs to making a conventional truck more efficient which include those listed in the Technologies section.

2.5.2.2 Operational Cost Factors

The fixed expense of insurance is assumed to be the same for the conventional and the solution and is therefore excluded.

The variable operating costs of maintenance are assumed to be the same for inefficient and efficient trucks and are also excluded.

[5] 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.

The variable operating cost of fuel is different for the conventional and solution as the solution is consumes less fuel.

2.5.2.3 Learning Rate Factor

The learning rate for the first cost for the solution was estimated to be 10% based on two sources.

Table 2.3 Financial Inputs for Conventional and Solution Technologies

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Fuel Cost (Conventional)	*US$2014/million tonne-km*		43,491	13	4
Fuel Cost (Solution)	*US$2014/million tonne-km*		26,361	13	4

2.5.3 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.

2.5.3.1 Replacement Factors

The Conventional and Solution Implementation unit is only relevant for a million tonne-kms per Truck. The conventional and solution average annual use and the lifetime capacity are therefore the same.

2.5.3.2 Technical Factors

Other variables were used in the calculations for the climate, financial and replacement factors. They are listed below.

2.5.3.2.1 Average Annual Use

It is assumed that the technologies are applied to the standard truck at an additional cost, and that they last as long as the truck, hence when the truck is replaced, the technologies need to be applied to the new truck as before. Hence the annual usage (and capacity) of the technologies is the same as the annual usage (and capacity) of the truck.

2.5.3.2.2 Discount Rate

In some cases in the literature it is specifically indicated that a distinct discount rate is appropriate when applied to investment decisions made at a Commercial / Industrial level. The Commercial / Industrial level discount rate is directly related to decision-making at a Commercial / Industrial level and likely varies greatly across different regions of the world. Taking the numbers found in the literature above comprises a conservative case. Without distortions this discount rate would be equivalent to the interest rate afforded by alternative investments available to larger commercial / industrial entities such as multinational corporations or corporate utility enterprises. Discount rates reported in the literature that are used for policy decisions are not necessarily equivalent to Commercial / Industrial level financial investment decisions, but oftentimes are not distinguished and may be conflated.

Table 2.4 Technical Inputs

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Lifetime Capacity (Conventional and Solution)	Million tonne-kms/Truck	5.49-13.19	9.59	13	5
Average Annual Use (Conventional and Solution)	Million tonne-kms/Truck	0.26-0.86	0.56	13	6
Average Utilization Rate (by Weight)	Percent	23.2%-34.8%	29.0%	4	2
Average Long Haul Truck Capacity	Tonnes	14.68-27.84	21.26	7	4
Average Truck Lifetime	Years	6.52-15.07	10.80	12	5
Discount Rate	Percent	5.7%-12.1%	8.90%	10	5

2.6 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. Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below.

Assumption 1: All cars identified as a "convectional technology" use ICE;

Assumption 2: Travel mode fuel efficiencies and fuel prices remain constant through 2050;

Assumption 3: Average urban trip lengths with cars and public transit remain constant through 2050;

Assumption 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.

2.7 INTEGRATION

The complete Project Drawdown integration documentation (will be available at 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[6]). Grid solutions are adjusted to remove the double counting as described in the Project Drawdown integration documentation.

2.8 Limitations/Further Development

The adoption scenarios in this report apply a typical fuel efficiency package to global heavy-duty truck projections 2014 to 2050. In actuality, technology efficacy varies from region to region because trucks produced in different countries vary in technical specifications and quality, and with driving distances, payloads, geography and infrastructure (Sharpe, 2015). For example, heavy duty trucks travel longer distances in the United States than in Japan, at higher speeds in the United States and Europe than in China, and idle longer in the United States than in Europe (Muncrief, 2014). Typical trucks in Asia haul freight at lower speeds and shorter distances than in North America or Europe and trucks are generally overloaded. Thus, engine efficiency and tire improvements provide more fuel efficiency improvements than aerodynamic measures (Sharpe, 2015). Nonetheless, as a simplifying assumption this study has applied the averages for technologies available for use in all heavy-duty trucks to all countries due to a lack of data on the effectiveness of fuel efficiency technology implementation for most countries (Sharpe & Muncrief, 2015; Punte, Gota & Peng, 2011; Smart Freight Center, 2014). The sensitivity of the model to assumptions regarding efficiency of the technology packages and costs are therefore examined in the Sensitivity Analysis.

The financial aspects were constructed from the company or individual truck owner's point of view, including the cost of fuel-efficiency options and fuel usage. An alternative strategy would be to model the increased production costs for manufacturers.

.

[6] Some solutions such as Electric Vehicles and High-Speed Rail increase the demand for electricity and reduce the demand for fuel.

3 Results

3.1 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	Maximum
Efficient Trucks	million tonne-kms	2,160,373.74	15,880,868.08	16,638,442.96	16,089,900.80
	(% Market)	1.6%	8.6%	9.0%	8.7%

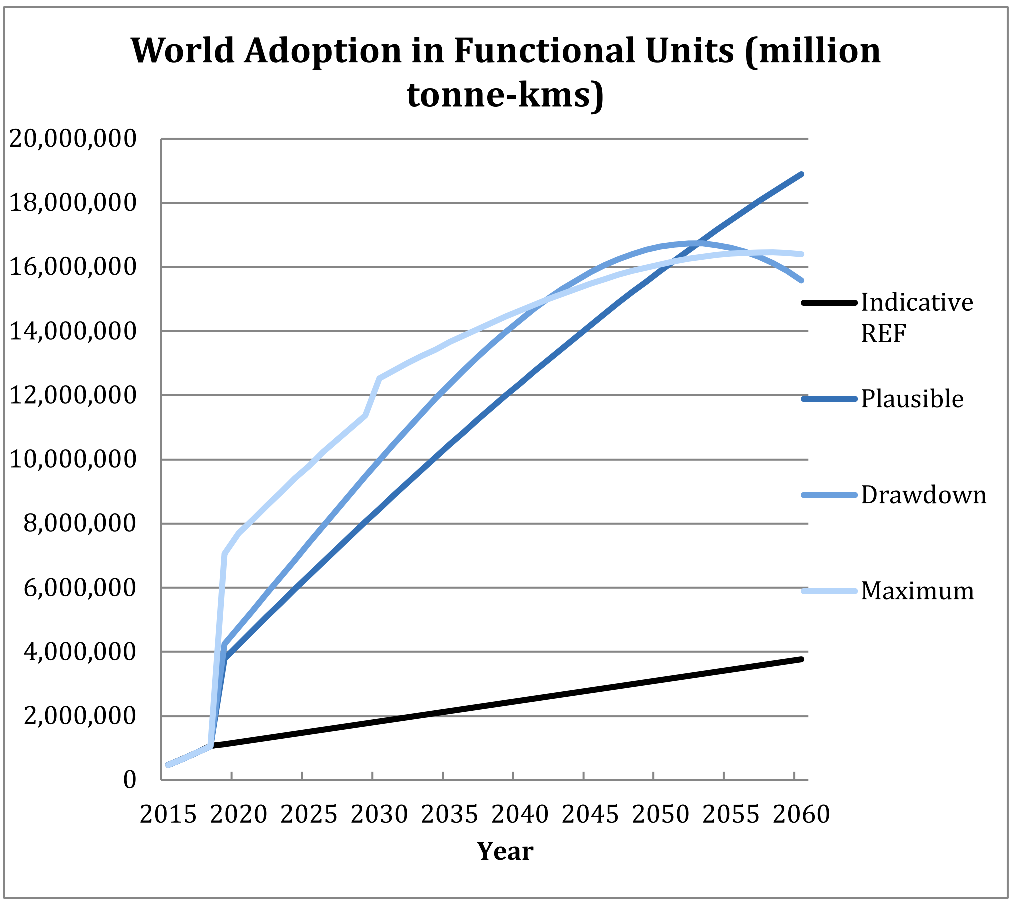

Figure 3.1 World Annual Adoption 2020-2050

3.2 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 **Error! Reference source not found.** (Section **Error! Reference source not found.**).

Table 3.2 Climate Impacts

Scenario	Maximum Annual Emissions Reduction	Total Emissions Reduction	Emissions Reduction in 2030	Emissions Reduction in 2050
	(Gt CO_2-eq/yr.)	*Gt CO_2-eq/yr. (2020-2050)*	*(Gt CO2-eq/year)*	*(Gt CO2-eq/year)*
Plausible	0.46	9.15	0.24	0.46
Drawdown	0.49	10.77	0.29	0.49
Maximum	0.47	12.07	0.39	0.47

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 CO_2-eq

Scenario	GHG Concentration Change in 2050	GHG Concentration Rate of Change in 2050
	PPM CO_2-eq (2050)	*PPM CO_2-eq change from 2049-2050*
Plausible	0.75	0.03
Drawdown	0.88	0.03
Maximum	0.96	0.03

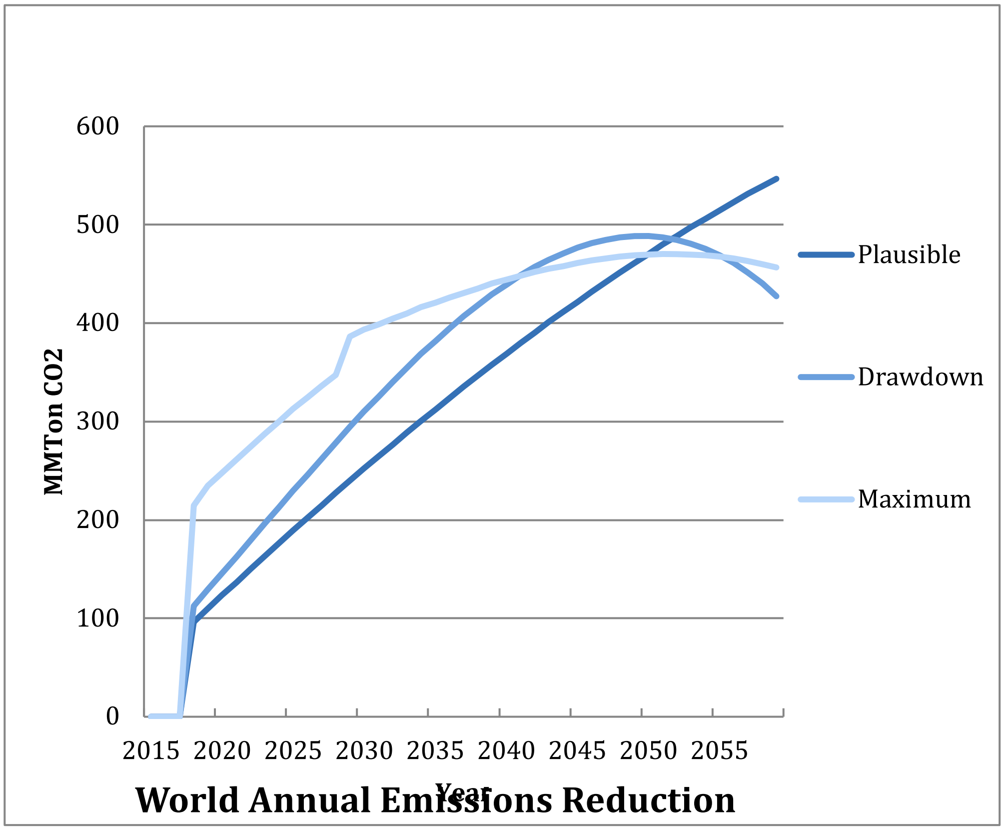

Figure 3.2 World Annual Greenhouse Gas Emissions Reduction

3.3 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 Cost 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	667.40	502.57	4,273.94	5,212.67	659.22
Drawdown	731.40	566.56	5,028.63	5,959.38	785.96
Maximum	757.47	592.63	5,602.94	6,389.69	1,007.15

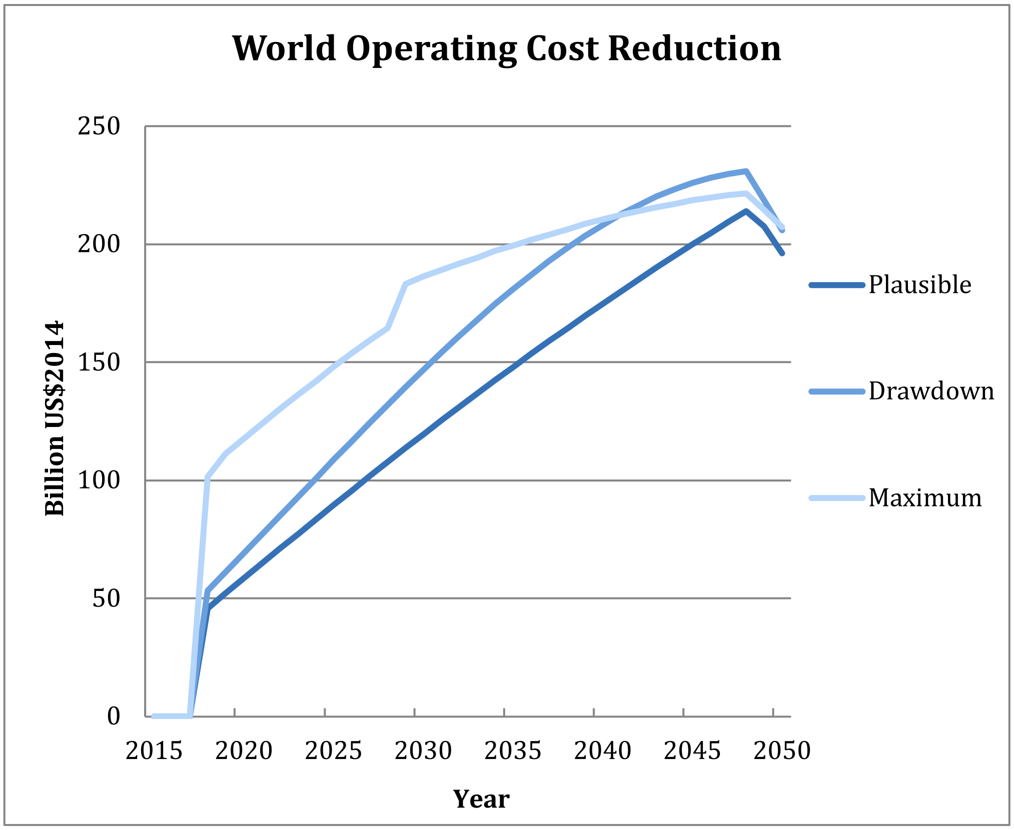

Figure 3.3 Operating Costs Over Time

4 Discussion

Efficient Trucks is a large market with a large solution to consider for Drawdown. Currently it is estimated that 9.5 Gt CO_2 eq was produced due to the transportation sector around the world in 2018 (IEA, 2018). The current estimates show that using efficient trucks can reduce CO_2 eq per year by 0.46 Gt (on average for 2020-2050 in the Plausible Scenario) resulting in 10.77 Gt CO_2 eq cumulatively from 2020-2050. Reducing emissions from freight is a huge step towards the Drawdown goal.

With over 15,880,868 million tonne-kms done by efficient trucks in 2050, the financial benefits from switching to efficient trucks will be significant. Since the financial side was addressed from the point of view of the company or truck owner, they will have significant savings.

The financial results presented in **Error! Reference source not found.** show the NPV of the efficient trucks solution to be $659.22 billion with a net operating savings of $4,274 billion. This is an existing, cost-effective solution that has significant reductions in emissions.

Based on the results as derived, the long-haul heavy-truck industry could expect to see a considerable return on investment through the uptake of a package or even just individual measures for achieving greater truck fuel efficiency. In an industry often characterized by small profit margins and where fuel costs make up a considerable if not the largest share of operational costs, such a potential for fuel savings and therewith net cost savings should prove highly attractive considering key barriers impeding current uptake are being properly addressed.

4.1 Limitations

Making long haul trucks more efficient is an easy, existing fix to existing truck design. There is a growing interest and some projects for alternative fuels and electrification of heavy duty trucks. If these solutions are realized, the fuel efficiency savings will become obsolete. However, many design changes such as aerodynamics and lower resistance tyres will apply to alternative fuel or electric trucks as well.

5. References

Airbus. (2016). *Airbus Global Market Forecast 2016-2035*. http://www.airbus.com/presscentre/corporate-information/key-documents/?eID=maglisting_push&tx_maglisting_pi1%5BdocID%5D=109228

ATRI. (2020). *Operational Costs of Trucking*. TruckingResearch.Org. https://truckingresearch.org/atri-research/operational-costs-of-trucking/

Boeing. (2015). *Boeing Current Market Outlooks*. Boeing Commercial Airplanes. http://www.boeing.com/resources/boeingdotcom/commercial/about-our-market/assets/downloads/Boeing_Current_Market_Outlook_2015.pdf

Cullen, D. (2015, December 14). Trucking Inside Mexico [HDT Trucking Info]. *Passing Zone*. http://www.truckinginfo.com/blog/passing-zone/story/2015/12/trucking-inside-mexico.aspx

EC. (2015). *IMPACT ASSESSMENT Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A policy framework for climate and energy in the period from 2020 up to 2030*. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52014SC0015

EC. (2019). *Bodies and trailers – development of CO2 emissions determination procedure*. https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/heavy/docs/report_bodies_trailers_en.pdf

GFEI. (2017). *Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017* (Working Paper 19).

ICAO. (2015). *ICAO Air Transport Monthly Monitor—Jan 2015*. http://www.icao.int/sustainability/Documents/MonthlyMonitor-2015/MonthlyMonitor_Jan2015.pdf

ICCT. (2012). *Global Transportation Roadmap Model v1.0*. https://theicct.org/transportation-roadmap

ICCT. (2017). *Heavy-duty vehicles technology potential and cost study | International Council on Clean Transportation*. https://theicct.org/publications/heavy-duty-vehicles-technology-potential-and-cost-study

ICCT. (2018a). *Final second-phase greenhouse gas emissions standards for heavy-duty engines and vehicles in Canada | International Council on Clean Transportation*. https://theicct.org/publications/second-ghg-standards-hdv-Canada

ICCT. (2018b). *Fuel efficiency technology in European heavy-duty vehicles: Baseline and potential for the 2020–2030 timeframe | International Council on Clean Transportation*. https://theicct.org/publications/fuel-efficiency-technology-european-heavy-duty-vehicles-baseline-and-potential-2020

ICCT. (2019). *Market penetration of fuel efficiency technologies for heavy-duty vehicles in the European Union, the United States, and China | International Council on Clean Transportation*. https://theicct.org/publications/market-penetration-fuel-efficiency-technologies-heavy-duty-vehicles-european-union

IEA. (2016). *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems*. International Energy Agency. http://www.iea.org/etp/etp2016/

IEA. (2018). *Energy Technology Perspectives 2017* (p. 441).

IEA. (2019). *Transport sector CO2 emissions by mode in the Sustainable Development Scenario, 2000-2030*. IEA.

IEA. (2020). *Trucks and Buses – Analysis*. IEA. https://www.iea.org/reports/trucks-and-buses

Kodjak, D., Sharpe, B., & Delgado, O. (2015). Evolution of heavy-duty vehicle fuel efficiency policies in major markets. *Mitigation and Adaptation Strategies for Global Change*, *20*(5), 755–775.

NACFE. (2018). *Run on Less Report*. North American Council for freight Efficiency. https://nacfe.org/run-on-less-report/

North American Council for Freight Efficiency. (2015). *2015 Annual Fleet Fuel Study*. http://www.truckingefficiency.org/sites/truckingefficiency.org/files/reports/NACFE%202015%20Annual%20Fleet%20Fuel%20Study%20Report%20050115.pdf

OECD/ITF. (2021). *ITF Transport Outlook 2021*.

Schroten, A., Geert Warringa, & Mart Bles. (2012). *Marginal abatement cost curves for Heavy Duty Vehicles* (p. 42). CE Delft, Delft (Netherlands).

Sharpe, B., & Muncrief, R. (2015). *Literature Review: Real World Fuel Consumption of Heavy-Duty Vehicles in the United States, China and the European Union* [White Paper]. ICCT. http://www.theicct.org/sites/default/files/publications/ICCT_HDV_FC_lit-review_20150209.pdf

Steinbach, J., & Staniaszek, D. (2015). *Discount rates in energy system analysis Discussion Paper*. 20.

Stutzman, Weiland, Preckel, & Wetzstein. (2017). *Optimal replacement policies for an uncertain rejuvenated asset—ScienceDirect*. https://www.sciencedirect.com/science/article/abs/pii/S092552731630398X

Sustainable Freight. (2015). *Profile of Australia's Trucking Fleet: Age and Emissions*. South Australian Freight Council. www.sustainablefreight.com.au/files/557_trucking_fleet_overview.pdf

The International Council on Clean Transportation. (2012). *ICCT Roadmap Model*. The International Council on Clean Transportation. http://www.theicct.org/global-transportation-roadmap-model

Transport & Environment. (2018). *US truck fuel efficiency standards: Costs and benefits compared*.

https://www.transportenvironment.org/sites/te/files/publications/2018%2001%2010%20
US%20truck%20standards%20FINAL.pdf