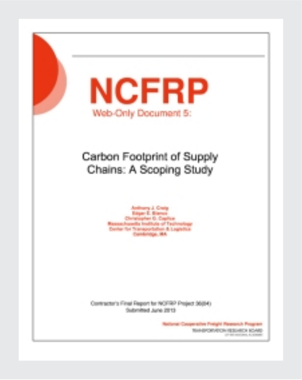

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Carbon Footprint of Supply Chains: A Scoping Study

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Dr. Christopher G. Caplice, CTL Executive Director, was the Project Director and Principal Investigator. The other authors of this report are Dr. Anthony J. Craig, CTL Postdoctoral Associate, and Dr. Edgar E. Blanco, CTL Research Director.

ABSTRACT

This report presents the results of a study to define a standardized approach to measuring the carbon footprint of the transportation component of supply chains, evaluate existing methodologies, and prepare a work plan for a decision tool to measure the carbon footprint. Existing methodologies were reviewed and used to create a standard definition of the carbon footprint of the transportation component of the supply chain. The proposed definition focuses on direct transportation activities, considers the six primary greenhouse gases, and uses a well-to-wheel emissions scope. A list of criteria to evaluate current methodologies were developed based on concepts from accounting, supply chain management, and life cycle assessment. The criteria of breadth, depth, and precision define how relevant a measure is to decision-making, while the criteria of comparability and verifiability assess its suitability for external reporting. Using the Analytic Hierarchy Process, the criteria were used to evaluate existing programs and methodologies. Participants in a workshop identified the relative importance of each criterion, and these weightings were used to evaluate the methodologies. The results of this exercise were used to identify strengths and weaknesses of current approaches, and inform the design of the decision tool.

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SUMMARY

Freight emissions are expected to grow by 30% by 2050 due to increases in demand and the shift to less efficient modes of transportation. In the United States, freight currently represents 28% of transportation energy use, or 8% of overall energy use. Improved logistics is one method for reducing freight emissions, but making informed logistics decisions requires improved tools for measuring emissions from transportation in the supply chain.

A large number of tools are currently available to estimate the emissions from transportation, using a variety of approaches. These approaches can be grouped into four general categories: models and simulation; surveys; Life Cycle Assessment methods; and econometric methods. The diversity of approaches reflects the needs of the many different stakeholders interested in the issue. In order to provide a common basis for calculating the carbon footprint of transportation in the supply chain, a standard definition was proposed based on a review of existing programs and methods. This definition involves a focus on energy consumed by transportation vehicles used to move goods between locations, adopts a well-to-wheel view for considering the emissions required to produce that energy, and includes the six greenhouse gases referred to as the Kyoto gases. This definition is consistent with emerging standards in Europe, captures the upstream portion of the fuel cycle necessary to compare alternative fuels and vehicles, and focuses on transportation rather than supporting logistics activities.

Drawing on existing research in supply chain management, LCA, and accounting, a set of five criteria for evaluating existing carbon measurement tools were developed.

1. Breadth—the scope of activities included in the measurement
2. Depth—the range of direct and indirect emissions included in the measurement
3. Precision—the level of detail provided by the measurement
4. Comparability—the degree with which measurements can be compared across time and organizations
5. Verifiability—the degree of assurance in the results and methodology

The first three criteria together capture how relevant a measure is for decision-making. The final two criteria provide a measure of how well suited the tool is for external reporting, captured by the ability to compare the results with other organizations and to accurately and faithfully represent the actual performance. Together these five criteria cover the major characteristics of a tool needed for both internal and external use. Higher degrees of performance across these categories increase the relevance of the results to making decisions; the ability to incorporate the results into benchmarking and information sharing; and the trustworthiness of claims based on the results.

The current tools were evaluated using the Analytic Hierarchy Process (AHP), a quantitative method for making complex decisions. The process relies on humans estimating the magnitude of difference between choices by making simple comparisons. The AHP process is well suited to group decision making, where consensus must be reached between many group members.

In a workshop held at MIT a group of 16 stakeholders used the AHP process to evaluate the importance of the five evaluation criteria. The results indicated strong preference for comparability as the most important criterion, with a relative weighting of 39%. Of the remaining criteria, breadth and verifiability were judged to be next most important, with weightings of 19% and 18% respectively. Precision and depth were judged to be least important, with relative weightings of 13% and 11%.

The existing tools were evaluated within each of the five criteria using a set of standards. These evaluations were combined with the relative weightings of each criterion to produce an overall score for each tool. The scores demonstrate how different approaches to the design of tools can produce results that score similarly. Tools that can produce highly comparable results with consistent system boundaries and methods scored well, despite the lack of breadth offered by programs primarily tailored for single modes. Other high scoring tools provide consistent methodologies across all four primary modes of transportation, but lack the ability to provide more precise ratings at the specific carrier or shipment level.

Based on the evaluations of existing tools, a direction for future tools was identified. The primary requirements of a future tool are to provide a consistent set of well-to-wheel emissions factors across all four major modes, use a consistent system boundary, and produce performance indicators that measure both total emissions and relative emissions. This could be based on transparent, open data and methods that make use of average levels of performance or it could collect data from specific carriers and routes. The latter approach would provide more precision in the results, but at a cost of some transparency and verifiability.

Design elements for a future tool were presented based on three-tier architecture. The primary role of the control tier is to define how data is input to the tool and what results are returned to the user. In direct input the user enters the necessary information directly without requiring support from the logic provided by the tool. The model tier is responsible for the actual calculation of the emissions within the tool. It must support the inputs from the control tier, interface with the data tier, and handle the logic of emissions calculation. The data tier must contain all the data needed to perform the actual calculations. This primarily consists of emissions factors at multiple levels of detail.

Two possible development plans for a future tool were presented. A basic tool would require little more than a form for data entry linked to data tables of emissions factors and locations. The advanced tool would expand on the capabilities of the basic tool through a more advanced user interface, actual route calculations, and a dynamic set of emissions factors that could be updated based on data provided by users. Timelines for development of both tools was presented with a breakdown of time by task.

1 INTRODUCTION

The transportation sector is a significant contributor to global greenhouse gas emissions and energy usage. Transportation as a whole accounts for 19% of global energy use[1]. In the U.S., with the largest transportation footprint, the sector represents 28% of total greenhouse gas emissions. The International Energy Agency (IEA) predicts emissions from transportation to grow by 50% by 2030 and by 100% by 2050 from 2007 levels[2]. The Energy Information Administration (EIA) predicts similar high growth in energy consumption, rising by 39% by 2030 and 92% by 2050 from 2006 levels[3]. Within the transportation sector, freight is expected to experience the fastest growth. Freight accounted for 27% of transportation energy use globally in 2006[4]. In the United States it represented 28% of transportation energy use, or 8% of overall energy use. Freight is expected to grow by 30% by 2050, compared with 20% for the sector as a whole. This growth is not a new development, as emissions from transportation have been increasing for the past 30 years. From 1973 to 1992 emissions and energy use from freight transport grew faster than any other sector in an analysis of 10 industrialized countries[5].

The growth in emissions from freight has occurred despite improvement in the efficiency of vehicles, primarily due to increased demand and a shift to less efficient modes. The IEA projections call for a 50% increase in truck freight demand by 2050[6]. Maritime shipping has seen a 15% decrease in emissions intensity over the last 20 years, but this has been more than offset by a doubling in the amount of goods shipped[7]. The IMO projects that by 2050 maritime traffic will grow by between 150% and 300% from 2007 levels, driven primarily by a 400% to 800% increase in container traffic[8].

The growth in demand has been coupled with a shift to less efficient modes of transport. Between 1980 and 2009 total freight ton[i]-miles in the United States increased by 26%. Trucking increased its modal share from 18% to 31% during that time, primarily at the expense of domestic water transportation. This continues a long-term trend seen across countries, where overall freight activity and share of trucking are coupled with GDP growth[9].

Given the projected growth in demand for freight transportation, a number of strategies for reducing emissions must be considered. Possible approaches can be grouped into three categories: improved technological efficiency, improved operational efficiency, and shifting to more efficient modes.[10] The Pew Center on Global Climate Change identified a possible 7-10% reduction in freight emissions achievable by 2030 in the United States being the result of improved logistics[11].

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[i] Throughout this document, the use of the word ton shall be used to reference a short ton (2,000 lbs.).

In order to achieve these improvements firms involved in freight transportation need tools to measure the impacts of freight activity. Many firms measure their carbon emission at an organization level, but the methods used for organizational reporting are often inadequate to the needs of supply chains that span organizational boundaries. A number of programs have emerged to deal with these inadequacies, but as of yet no consistent, standardized approach has emerged.

OBJECTIVES

The objectives of this project are to (1) define a standardized, conceptual approach to assessing global greenhouse gas emissions of the transportation component of supply chains; (2) critique the current methods and data used to quantify greenhouse gas (GHG) emissions of the transportation component of supply chains; and (3) prepare a detailed work plan listing the specific tasks necessary to develop a decision tool to help estimate the carbon footprint of the transportation component of supply chains and to assess potential supply chain modifications to reduce these impacts.

APPROACH

To meet the objectives of this project four primary tasks were identified:

1. A state of the art practice review
2. Identify the qualities of an effective tool
3. Evaluate existing programs and techniques
4. Develop a work plan for a decision tool

In the first part of this research we identified a list of supply chain carbon footprint measurement programs and methodologies. The list was based on previous research work at the MIT Center for Transportation & Logistics (CTL) that had identified more than 60 programs and tools, and supplemented with additional programs identified through literature review; contacts within industry, academia, government, and non-profits; and feedback from the panel. After compiling a comprehensive list of programs CTL analyzed them to develop a definition of the transportation component of the supply chain and the associated carbon footprint measurements. The results of this task are described in Chapter 2.

The objective of the second phase was to identify the qualities of an effective tool for measuring the GHG emission profiles of the transportation component of major supply chains. CTL identified current performance measurement frameworks drawn from supply chain performance measurement, management accounting, and environmental reporting. Using these frameworks CTL developed a list of criteria based on analysis of the similarities and differences of the performance frameworks. The results of this task are discussed in Chapter 3.

The objective of the third phase was to evaluate the programs identified in the first task using the qualities identified in the second task. The programs were evaluated using the Analytic Hierarchy Process (AHP) to help vet, rank, and prioritize the criteria at a workshop held at MIT. The results of this evaluation were a quantitative evaluation used to identify the strengths and weaknesses of existing programs according to criteria prioritized by the stakeholders at the workshop. The results of this task are covered in Chapter 4.

The objective of the fourth phase was to prepare a detailed work plan to develop a decision tool for estimating the carbon footprint of the transportation component of the supply chain based on the results of Tasks 1-3. CTL has developed the requirements for a decision tool based on the concept of three-tier software architecture. This includes a description of the proposed three-tier architecture with illustrative examples linking the architecture with carbon footprint calculations. A work plan was developed describing the requirements for each tier broken down in to discrete tasks, and potential timeframes for two possible development paths were created. The results of this task are presented in Chapter 5.

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2 REVIEW OF CURRENT PROGRAMS

A review of current methodologies for measuring GHG emissions should begin with the guidelines developed by the Intergovernmental Panel on Climate Change (IPCC). These guidelines serve as a basis for nations to estimate their GHG emissions, and the structure and methods developed by the IPCC have been adopted by many of the programs that have followed. After reviewing the IPCC Guidelines, a survey of other approaches is performed, a framework for considering the carbon footprint of transportation in the supply chain is presented, and a working definition is developed that builds on emerging standards in Europe.

BACKGROUND

The United Nations Framework Convention on Climate Change (UNFCCC) is an environmental treaty signed in 1992 with the objective to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[12]" Though the treaty does not require any legally binding limits on emissions, countries are committed to providing an inventory of national greenhouse gas emissions and sinks on an annual basis.

The parties to the UNFCCC prepare national inventory reports using the methods developed by the IPCC, an intergovernmental body responsible for providing scientific information regarding climate change. These methods were used in the Kyoto Protocol, a 1997 addition to the UNFCCC that set legally binding emissions reduction targets. In addition to publishing methodologies for measuring GHG emissions, the IPCC provides regular assessment reports reviewing the state of climate science.

Though the United States signed the Kyoto Protocol, it was not ratified. The U.S. is thus not subject to any legally binding commitments to reduce greenhouse gas emissions. The Environmental Protection Agency (EPA) does prepare an annual assessment of U.S. sources and sinks of greenhouse gases in accordance with obligations as a party to the UNFCCC[13].

IPCC GUIDELINES

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories[14] (IPCC Guidelines) provide the most recent methodologies for estimating national greenhouse gas emissions. The IPCC Guidelines are based on the original 1996 IPCC Guidelines, along with the supporting Good Practice Guides.

GREENHOUSE GASES

The gases covered in the Guidelines are the direct greenhouse gases, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), the indirect greenhouse gases carbon monoxide (CO), oxides of nitrogen (NO_x) non- methane volatile organic compounds (NMVOCs), halocarbons (HFCs, PFCs) sulfur hexafluoride (SF_6), and sulfur dioxide (SO_2). Other gases (i.e. chlorofluorocarbons (CFCs), hydrochlorofluorocarbon 22 (HCFC-22), the halons, methyl chloroform and carbon tetrachloride) are not included because they are covered under the Montreal Protocol for ozone depletion. CO_2, CH_4, and N_2O are identified as the main GHGs.

Greenhouse gases trap heat, making the planet warmer. Since different gases may have different direct and indirect effects on the atmosphere the IPCC developed the concept of Global Warming Potential (GWP) to compare the gases to one another. The GWP of a greenhouse gas is defined as the ratio of the average amount of radiative forcing caused by the gas over a given time period to the same amount of a reference gas, with CO_2 used as the reference[15]. This allows the amount of warming produced by quantity of a greenhouse gas to be expressed in terms of carbon dioxide equivalents (CO_2e) using the following expression:

$$\text{g } CO_2 \text{ Eq} = (\text{g of gas}) \times (\text{GWP})$$

The IPCC defines the GWP of gases in the regular assessment reports. Though the values may change over time as the understanding of climate science improves, the inventories prepared for the UNFCC continue to use the values defined in the IPCC Second Assessment Report (SAR) to remain consistent with previous inventories. Table 1 shows a comparison of the 100-year GWPs for several gases compared to the Third Assessment Report (TAR) and Fourth Assessment Report (AR4)[16].

Gas	SAR	TAR	AR4	Change from SAR	
				TAR	AR4
CO_2	1	1	1	NC	NC
CH_4	21	23	25	2	4
N_2O	310	296	298	(14)	(12)
HFC-23	11,700	12,000	14,800	300	3,100
HFC-32	650	550	675	(100)	25
HFC-125	2,800	3,400	3,500	600	700
HFC-134a	1,300	1,300	1,430	NC	130
HFC-143a	3,800	4,300	4,470	500	670
HFC-152a	140	120	124	(20)	(16)
HFC-227ea	2,900	3,500	3,220	600	320
HFC-236fa	6,300	9,400	9,810	3,100	3,510
HFC-4310mee	1,300	1,500	1,640	200	340
CF_4	6,500	5,700	7,390	(800)	890
C_2F_6	9,200	11,900	12,200	2,700	3,000
C_4F_{10}	7,000	8,600	8,860	1,600	1,860
C_6F_{14}	7,400	9,000	9,300	1,600	1,900
SF_6	23,900	22,200	22,800	(1,700)	(1,100)

Table 1: Comparison of 100-Year GWPs

CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 have relatively long atmospheric lives and tend to be evenly distributed. These gases are used to quantify the annual greenhouse gas emissions for the UNFCCC. The other gases vary regionally, making quantification of their impact difficult. For this reason there is no GWP attributed to those gases, and they are not used in measuring the annual national emissions[17].

TRANSPORTATION EMISSIONS

The IPCC Guidelines identify five main categories of emissions: Energy; Industrial Processes and Product Use; Agriculture, Forestry, and Other Land Use; Waste, and Other. Emissions from transportation are covered within the Fuel Combustion Activities section of the Energy category.

The IPCC Guidelines provide three tiers of methods for estimating emissions within the Energy sector. The Tier 1 method is fuel-based, using total fuel combustion and average emissions factors. Emissions factors for all greenhouse gases are provided for a variety of fuel types. The Tier 2 method uses a similar approach to Tier 1, but uses country-specific emissions factors in place of the Tier 1 defaults. This allows countries to derive emissions factors that are more appropriate to the specific combustion technologies and fuels used in that country. The Tier 3 method uses detailed emissions models or measurements and data. They can provide better estimates for non-CO_2 greenhouse gases, but at the cost of more detailed information and effort.

The IPCC Guidelines identify mobile sources as producing three direct greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The combustion of fuel produces relatively little carbon in non-CO_2 gases. Almost all the carbon in fuel is oxidized during combustion and is generally independent of the combustion technology, so the Tier 1 approach is recommended for estimating CO_2. Emissions of CH_4 and N_2O are highly dependent on the technology used, and therefore a Tier 2 or Tier 3 approach is recommended for these gases.

The recommended approach for measuring emissions is to use collect data and apply the methodologies separately for the different types of mobile sources. The IPCC Guidelines provide methods for five different sources: road, railways, water borne navigation, civil aviation, and off-road. The methods for the four main transportation modes are reviewed below, and serve as a starting point for understanding how emissions from transportation are estimated.

ROAD

Emissions from road transport are best estimated using fuel consumption for CO_2 and vehicle distance traveled for CH_4 and N_2O.

The Tier 1 approach to estimating emissions from CO_2 is shown in Equation (1), and requires only the quantity sold of each fuel and an emissions factor for that fuel.

$$\text{Emission} = \sum_{a} \left[\text{Fuel}_a \times \text{EF}_a \right] \tag{1}$$

Where:

$\text{Emission} = \text{Emissions of } CO_2$

$\text{Fuel}_a = \text{fuel sold}$

$\text{EF}_a = \text{emission factor equal to carbon content of the fuel multiplied by } 44/12$

$a = \text{type of fuel}$

A similar approach for is used for Tier 1 estimates of CH_4 and N_2O. When country specific emissions factors are available the Tier 2 approach makes the minor change of defining separate emissions factors based on fuel, vehicle type, and emission control technology, but otherwise using the same equation format. This requires more detail in the data collection, as rather than total fuel consumed data must be collected on fuel consumed by each type of vehicle and emissions control technology.

The Tier 3 approach estimates CH_4 and N_2O using distance travelled plus emissions produced during cold start of the vehicle. It requires a more detailed breakdown of the data, requiring distance traveled and emissions factors by fuel type, vehicle, type, emission control technology, and operating conditions. This is shown in Equation (2).

$$\text{Emission} = \sum_{a,b,c,d} \left[\text{Distance}_{a,b,c,d} \times \text{EF}_{a,b,c,d} \right] + \sum_{a,b,c,d} C_{a,b,c,d} \tag{2}$$

Where:

$\text{Emission} = \text{emission of } CH_4 \text{ or } N_2O$

$\text{EF}_{a,b,c,d} = \text{emission factor}$

$\text{Distance}_{a,b,c,d} = \text{distance travelled during thermally stabilized engine operation phase for a given mobile source activity}$

$C_{a,b,c,d} = \text{emissions during warm-up phase}$

$a = \text{fuel type}$

$b = \text{vehicle type}$

$c = \text{emission control technology}$

$d = \text{operating conditions}$

When data cannot be separated by road type this can be ignored. In addition, the IPCC Guidelines require reporting CO_2 produced from combustion of biofuels separately to prevent double counting of emissions that were considered in the Agriculture, Forestry, and Other Land Use sector.

In addition to the recommended procedures for estimating emissions, the Guidelines also specify a method for validating fuel consumption data using Equation (3). Fuel consumption is estimated based on activity data—the distance travelled by vehicles of each type and their average fuel consumption. The validation is considered good practice as many countries and municipalities collect this type of data, and it can serve as a check on the reported fuel consumption numbers.

$$\text{Estimated Fuel} = \sum_{i,j,t}\left[\text{Vehicles}_{i,j,t} \times \text{Distance}_{i,j,t} \times \text{Consumption}_{i,j,t}\right] \tag{3}$$

Where:

Estimated Fuel = total estimated fuel use estimated from distance travelled data

$\text{Vehicles}_{i,j,t}$ = number of vehicles of type i using fuel j on road type t

$\text{Distance}_{i,j,t}$ = annual distance travelled per vehicle of type i using fuel j on road type t

$\text{Consumption}_{i,j,t}$ = average fuel consumption by vehicles of type i using fuel j on road type t

i = vehicle type

j = fuel type

t = type of road

RAILWAYS

The methods for emissions from locomotives work in much the same way as for road vehicles. The Tier 1 and Tier 2 methods use fuel consumption data to estimate total emissions, with the Tier 2 method substituting specific emissions factors depending on locomotive type rather than default fuel emissions factors. The Tier 3 method for estimating CH_4 and N_2O uses activity data based on the number of locomotives of a given type, their annual hours of use, average rated power, typical load factors, and emissions factors specific to that type of locomotive and journey.

WATER-BORNE NAVIGATION

Emissions from water-borne navigation, from recreational craft to large ocean-going cargo ships, are estimated using either a Tier 1 or Tier 2 approach. In the Tier 1 methodology only total fuel consumed of each type is used, and emissions are calculated using the default fuel emissions factors. In the Tier 2 approach countries develop their own country-specific emissions factors, and emissions are calculated separately for each combination of fuel and type of water-borne navigation.

There is no Tier 3 methodology provided for water-borne navigation, but activity data can be used to estimate fuel consumption numbers. Average fuel consumption and engine power data is provided for a number of ship types. When activity data is used it is recommended to check the accuracy of the results using historical shipping data. Recommended approaches for checking activity data include comparing the estimates of emissions against historical averages per tonne[ii]-km or passenger-km for different ship types.

[ii] Throughout this document, the use of the word tonne shall be used to reference a metric ton (1,000 kgs).

Though emissions from international shipping are not accounted for in developing national inventories, the methods defined for water-borne navigation are applicable to estimating the emissions of international shipping.

CIVIL AVIATION

Sources of emissions for civil aviation are all civil commercial airplanes, including general aviation such as agricultural aircraft, private jets, and helicopters. Three tiers of methods are defined, with two possible approaches to the Tier 3 methodology. The Tier 1 methodology again uses only fuel consumption data and average emission factors to estimate emissions, and is suitable for aircraft using aviation gasoline or when operational data for jet fueled vehicles are not available. The Tier 2 methodology expands on the Tier 1 approach by calculating emissions separately for the cruise phase of a flight and the landing/take-off (LTO) phase. This requires knowing the number of LTOs and separating fuel consumed during this phase from the cruise phase, but allows for using emissions factors that capture differences in emissions during these phases.

Tier 3 methods are more complex, based on actual flight movement data. There are two possible approaches, one that uses origin-destination (OD) data and one that uses full flight trajectory information. The OD approach accounts for different flight distances, which changes the relative impact of the LTO phase compared to the cruise phase. The full flight trajectory model uses aircraft and engine specific performance information over the entire flight, requiring sophisticated modeling approaches.

As is the case for water-borne navigation, emissions from international aviation are not included in national inventories. The methods defined by the IPCC are applicable to international aviation, but parties to the UNFCCC are expected to separate out emissions from domestic and international flights.

OVERVIEW

For each mode the IPCC recommends a fuel-based approach to measuring emissions. This approach is recommended due to the fairly consistent estimates of the amount of greenhouse gases produced by combustion of each type of fuel and the availability of data related to fuel consumption. Fuel-based approaches are most reliable for CO_2, and CO_2 is the primary greenhouse gas from transportation, representing an estimated 97% of emissions from road[18] and 98% from marine transportation[19].

The IPCC Guidelines provide the basic methodology and understanding for estimating emissions at the national level. They provide the scientific background and understanding of how emissions sources can be categorized and the emissions calculated. The approach of the IPCC has influenced many of the tools and programs aimed at businesses, but falls short of being a complete guide for calculating the emissions of transportation in the supply chain. Two major issues are the exclusion of transportation related emissions that occur in non-mobile sources and the reliance on fuel data.

First, the IPCC Guidelines are established with national inventories in mind, and there is a focus on separating emissions sources and avoiding double counting. This creates difficulty where transportation occurs at the intersection of different sectors. Two primary examples of this are electric vehicles and biofuels. When vehicles use electricity for power, such as with electric railway locomotives, the emissions from the electricity generation are assessed at the power plant under the stationary combustion sector. The Guidelines provide no methods for estimating emissions from the operation of electric locomotives separately.

For biofuels the IPCC Guidelines recommend accounting for the CO_2 produced during combustion separately, as these emissions must be reconciled with the CO_2 sequestered from the atmosphere in the biogenic material used to produce the fuels. Since those emissions are accounted for in the agricultural section it requires separate accounting to make sure the total net emissions are correctly counted. In both of these cases the approaches fall short of the needs of organizations interested in accounting for emissions from transportation, where the focus is on accounting for all the emissions that can be attributed to the transportation activity, regardless of boundaries or sectors.

Second, the reliance on fuel data makes it difficult to calculate emissions at a disaggregated level. Shippers may wish to know the emissions related to shipments that are handled for them by carriers, but since shippers do not own the vehicles or purchase the fuel the necessary data may be unavailable. Further, if carriers do not track fuel purchases at a detailed level it may be impossible to calculate emissions at an individual shipment level. The IPCC focus on total emissions within a national boundary on an annual timeframe is inconsistent with needs of transportation stakeholders who wish to know emissions at a more refined level of detail.

This difficulty has led to several approaches to estimating emissions based on activity data that are more appropriate for estimating emissions from transportation. Similar to the activity data methods supplied by the IPCC Guidelines in Tier 3 approaches, these approaches attempt to estimate fuel consumption and emissions based on standard activity data such as vehicle distance travelled or shipment weight and distance. Given the different needs and data availability of the various stakeholders this has led to a number of different approaches.

OTHER APPROACHES

Many of the programs and approaches reviewed in this work provide the capability to estimate emissions given fuel consumption data, and the approaches are consistent with the guidelines laid out by the IPCC. Where approaches show more diversity is in the estimate of emissions where fuel consumption data is not available. These approaches can be grouped into four general approaches: models and simulation; surveys; Life Cycle Assessment methods; and econometric methods.

MODELS AND SIMULATION

These approaches generally use mathematical or computer models to estimate the fuel consumption and emissions of a vehicle engine under different operating conditions. The power of many of the tools in this category allow for calculation of very detailed results. Sophisticated computer models such as the EPA's MOVES[20] model can consider many different operating characteristics. In some cases the models can provide estimated fuel consumption in very small time increments, allowing modeling of the full range of vehicle operations.

The large number of parameters and the technical sophistication of some models make them ideally suited for scenario analysis. By varying the input parameters, possible future scenarios can be tested and used to create emissions estimates. These approaches generally come at the cost of complexity, requiring detailed knowledge of not just the vehicle used, but the actual operating conditions. If these details are not known the results of any model may not reflect actual operations.

Programs may make use of these models to produce more simplified tools. The Network for Transport and Environment[21] (NTM) methodology represents one example of this approach. Under the NTM methodology the ARTEMIS tool is used to model emissions for a set of vehicle types under different load factors and driving conditions. This allows users to estimate emissions knowing only the size of the vehicle, weight of the load, and the type of roadway used. By adopting a set of standardized operating models the tool can be used to produce a set of emissions factors that capture the major drivers of emissions without requiring large amounts of input data.

SURVEY DATA

Survey approaches collect data from actual transport operators in order to provide emissions factors. Several of the most popular programs, including the GHG Protocol[22], Business for Social Responsibility (BSR) Clean Cargo Working Group[23] (CCWG), and the EPA's SmartWay[24] program, employ this approach. The emission factors for road transport supplied by the U.K. Department for Environment, Food, and Rural Affairs[25] (Defra) used in the GHG Protocol use surveys of carriers to estimate fuel efficiency and average loading factors by equipment type. These two pieces of data are then combined to calculate an emissions factor in kg of CO_2 per tonne-km for each equipment type.

The EPA SmartWay program uses a similar procedure to collect data on fuel consumption and miles driven by trucking carriers operating in the US. The data is used to create an emission factor for that carrier in terms of CO_2 per mile. Carriers are ranked in one of five tiers based on their score, and the ranking for all carriers is made available. Shippers are able to use the carrier's tier-specific emissions factors to estimate the emissions of the shipments handled by those carriers.

The BSR CCWG employs a similar approach, providing a standard methodology and format to collect data from ocean carriers. In 2011 the survey captured data for more than 2,000 vessels[26]. The data is used to develop a set of performance metrics expressed in grams of CO_2 per twenty-foot equivalent unit (TEU)-km. These metrics are captured for 24 different trade lanes, as well as an overall system average.

Survey approaches capture data from actual vehicle operators, and the results reflect actual operations in practice. As in the case of SmartWay and the CCWG, surveys can be used to capture data from individual carriers, allowing their performance to be compared with one another. This practice does create the possibility of fraudulent or error-prone inputs, as surveys often rely on self-reported data. Care must be taken that the information collected is consistent and truthful across carriers in order to make the results useful.

LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is a quantitative method for assessing the environmental impact of a product or service over its entire life cycle, referred to as a cradle-to-grave approach. Two main methods of performing LCA exist. The standard method defined by the International Standards Organization[27], sometimes referred to as a process-based method, traces all inputs and outputs to the environment for each process in the product's life cycle. The Economic Input-Output[28] (EIO) LCA method uses high-level economic input-output data and public environmental data to estimate the environmental impact of each dollar of economic activity spent in an industry sector.

LCA methods go beyond most carbon calculators by including not just direct emission from fuel combustion, but also indirect emissions over the entire life cycle. This includes the emissions related to the upstream production of the fuel, as well as other life cycle impacts such as vehicle production and disposal, maintenance, and infrastructure.

Several popular tools make use of LCA methodologies to calculate the environmental impact, including greenhouse gas emissions, of transportation. Ecoinvent is a comprehensive database of LCA information, referred to as a Life Cycle Inventory (LCI) database. This database includes a wide variety of emissions factors for different transportation modes and vehicle types. These emissions factors allow for the calculation of emissions from freight using activity data per km or per tonne-km.

Researchers at Carnegie Mellon University have developed an EIO-LCA tool[29] that can calculate environmental impact from a number of transportation modes, including truck, water, air, rail, and pipeline. The calculator uses activity data inputs in dollar values to calculate greenhouse gas emissions, and provides a breakdown of the industry sectors that contribute the most to the production of emissions.

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation[30] (GREET) model developed by Argonne National Lab uses an LCA approach to model the full fuel cycle for a number of different fuel pathways. This data is used to produce a calculator that can use either fuel-based or activity-based inputs to calculate emissions. The fleet calculator is capable of handling vehicle that use Gasoline, Ethanol E-85, Diesel, Diesel HEV, Biodiesel B20, Biodiesel B100, Electricity, CNG, LGN, H2 Gas, H2 Liquid, and LPG. Activity data can be entered based on the number of vehicles, miles driven, and MPG efficiency. Default values are supplied for a number of vehicle types.

The primary advantage of LCA is the ability to consider environmental impacts over the full life cycle. This allows for the comparison of alternative fuels, such as ethanol or electricity, where activities upstream in the fuel cycle are important contributors to overall emissions. The incorporation of infrastructure, maintenance, vehicle production, and end-of-life scenarios in some LCAs provides a more complete picture of the true environmental impact of transportation.

LCA methods are generally time-consuming to develop, due to the requirements of tracing all inputs and outputs of the system over a full cradle-to-grave life cycle. The high cost and time required to perform the analysis means that the results are not always easily updateable. LCA studies are often based on an “average” scenario, or on one specific study, and then extended to more general use. This can lead to problems if the data used in the original study is not representative for other scenarios.

ECONOMETRIC

Econometric models rely on statistical or mathematical analysis of data to estimate emissions. They have proved popular in the academic literature, as many of the methods allow for long time series comparisons to estimate efficiency by mode and nation. The coupling of the emissions data with other economic data also allows for analysis of the role of global trade and economic activity on emissions level. By developing models that relate emissions to economic indicators these methods can be used to forecast future transportation related emission based on projected economic growth.

One of the most popular programs for measuring corporate emissions, The GHG Protocol, makes use of an econometric method for developing emissions factors. The GHG Protocol Mobile Source Tool provides two sources for the emissions factors, one from Defra for the U.K. and one from the EPA for use in the United States. The EPA factors were created for the EPA's now-discontinued Climate Leaders[31] program, and employ a top down methodology to calculate emissions factors by mode. Total emissions by mode are estimated from data provided by the EPA's national greenhouse gas inventory.[32] The total emissions are then divided by the estimated ton-miles carried by the mode using data from the Federal Highway Administration[33]. This produces an emissions factor in terms of kg of CO_2 per ton-mile for each of the major freight modes: road, rail, water, and air.

While econometric models offer consistent methods that can be applied across time and nations, the results tend to be aggregated at high levels. They do not generally allow decomposition below regional or national levels. As in the case of the EPA Climate Leaders program adopted by the GHG Protocol, they can serve as a source of emissions factors for use in company or shipment level calculations, but involve the use of average emissions factors aggregated at high levels.

SUMMARY

Based on a review of current programs and methods, there is not a single preferred approach to estimating carbon emissions from transportation. The choice of different approaches represents a range of levels of detail in the output and required information of the input. The diversity of approaches may represent a signal regarding the diversity of stakeholders interested in the topic, including academic practitioners, government agencies, NGOs, trade groups, shippers, carriers, and logistics providers.

Simulation models are capable of providing detailed estimates of emissions and analyzing potential changes, but require detailed system knowledge to model specific operations. Surveys capture data on actual operations and can be used to compare the results of different carriers, but rely on self-reported data of historical operations. LCA can be used to provide a cradle-to-grave analysis that measures the true impact of different transportation systems, but they are costly and time consuming to perform. Econometric models make use of readily available data and allow for comparisons across time and nations, but are typically highly aggregated and do not provide detailed analysis of operations.

Given the wide variety of approaches employed in practice, it is necessary to first understand the role of transportation in the supply chain before proposing a definition. In the next section, we review the role of transportation in the supply chain and how these decisions are typically modeled. This decision model is then used to develop a framework for defining the carbon footprint of transportation in the supply chain.

TRANSPORTATION IN THE SUPPLY CHAIN

Transportation services play a central role in seamless supply chain operations, moving inbound materials from supply sites to manufacturing facilities, repositioning inventory among different plants and distribution centers, and delivering finished products to customers[34]. When making choices about which mode or carrier to use, shippers must balance cost constraints with customer service, transit time, and market characteristics to make the best transportation choice for the supply chain. To include the greenhouse gas emissions of transportation in this choice, shippers need access to information regarding emissions in a way that fits the decision process.

In typical transportation science modeling, the transportation decision is modeled using a network approach. For policy makers this typically involves a model of the physical network consisting of two types of nodes. The first type includes junctions and crossings, while the second includes access-nodes such as terminals, stations, and crossings. The links between the nodes consist of the physical means of travel, such as roads, railways, and waterways[35]. This physical network can be extended with the concept of the super-network and hyper-network. A super-network aggregates together multiple physical networks, and links between nodes can be replaced with abstract links that represent different routing choices along the physical network. A hyper-network expands this to include other decisions such as the mode choice, by representing the use of different modes with different abstract links[36].

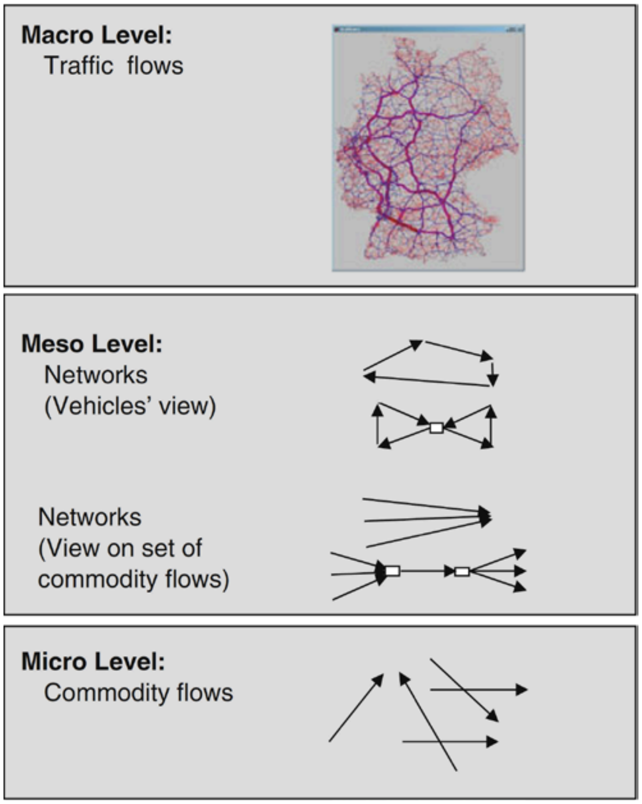
These transportation-focused models often neglect important logistics elements, such as shipment size, consolidation points, and transshipment locations[37]. Logistics networks employ a logical model of the network, with nodes representing facilities and links representing different transportation services between the nodes, not necessarily corresponding to the physical network. In some case additional links in the network can be added to represent logistics activities such as warehousing, transferring at terminals and ports, or handling operations. Beuthe et al.[38] refer to this as a virtual network, and propose a method where a virtual network is created by expanding the geographic/physical network to include virtual links between nodes that represent not just the different modes and means of transportation, but all the associated loading, unloading, transshipment, and transiting.

This concept of the virtual network can be applied to transportation models for the calculation of greenhouse gas emissions as well. In standard transportation modeling, each link would have an associated cost, and the planning problems would involve solving the network flow with a minimum level of cost. The concept can be expanded by having each link also include an associated cost in terms of GHG emissions (or replacing the financial cost with the carbon cost if a single objective method was employed). A number of examples of using network models to calculate GHG emissions and other environmental impacts can be found in the literature[39,40,41]. The emissions from any shipment would simply be the carbon cost associated with traversing that link in the virtual network. The amount of flow on a link could be the number of vehicles or the tons of cargo moved, and the cost of the link calculated using an emissions factor, in terms of GHGs per mile or ton-mile, derived from any of the available methods. From a carbon standpoint, the challenge becomes deciding how to create the appropriate virtual links in the network to model the available transportation choices and their associated emissions.

CONSTRUCTING THE VIRTUAL NETWORK

The number of possible virtual links in the network is in practice too great to model. Each virtual link represents the choice of sending a shipment of a certain size on a certain route using different choices of mode, carrier, equipment, fuel, service level, and handling. The needs and information available to different stakeholders in the transportation decision complicate this. Liedtke and Friedrich[42] refer to this as the micro-macro gap in their review of freight modeling approaches, and it is illustrated in Figure 1.

At the micro level, shippers deal with planning individual shipments along the logical network. At the macro level, policy makers are concerned with aggregate levels of flow along the physical network. In between are the carriers, who must handle routing the shipments along with physical network, but must coordinate their activities between different shippers, services, and intermediate handling activities. While each stakeholder takes a network approach to the transportation decision, the view of the network is quite different.



Source: Transportation, 39(6), 2012, 1335-1351, Generation of logistics networks in freight transportation models, Gernot Liedtke and Hanno Friedrich, Figure 1, Copyright Springer Science +Business Media, LLC. 2012, with kind permission from Springer Science+Business Media B.V.

Figure 1: Micro-Macro Gap in Freight Modeling[42]

Consider the view of a standard intermodal shipment, consisting of an origin drayage movement, a rail line haul, and a destination drayage movement. In the virtual network used by the shipper, this consists of a single virtual link from origin to destination, representing the total cost, time, emissions, and service level offered by the intermodal operator. This is shown in Figure 2.

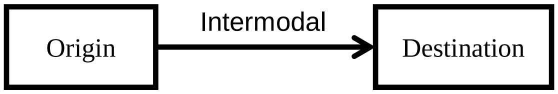


Figure 2: Logical Network Representation

This can be contrasted with how that same link may be modeled in a network for the carrier. In this case each of the links represents a specific route in the physical network over roads and railways and additional nodes are added to represent the terminals. This is shown in Figure 3.

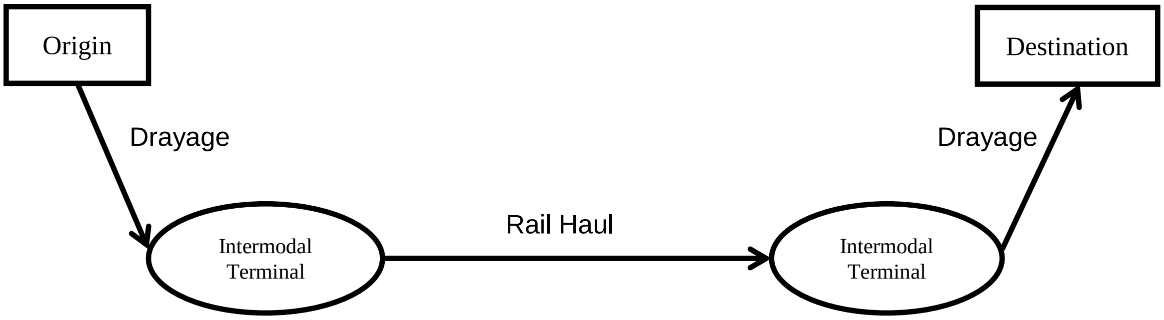


Figure 3: Network Operator View

If the network were expanded to include not just transportation, but logistics activities as well, the operations at the terminals could be further modeled using additional links. This is shown in Figure 4.

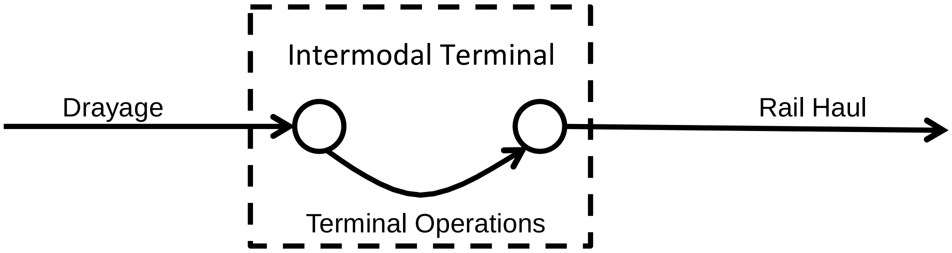


Figure 4: Terminal Operations in the Logistics Network

Each choice of different route, equipment, service level, and mode by various carriers could result in the creation of a virtual link in the shipper's network model. This process could potentially create a large number of links between a single origin and destination, as shown in Figure 5.

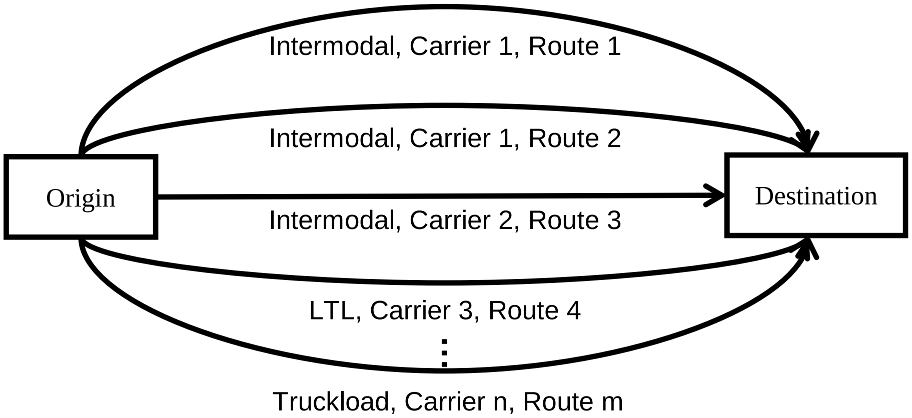


Figure 5: Virtual Network

Creating a model that fits the needs of stakeholders at all levels of the decision-making process can begin by working at the micro level. In order for shippers to make decisions regarding which modes and carriers they wish to use to move their goods, they must solve the network problem at the micro level. Once the flow of goods is determined at this level the network operators then determine actual routings of the goods. Finally, the aggregation of these individual routing decisions provides the macro level view for planners and policy makers.

To determine the network at the micro level requires a decision about which virtual links need to be created in the logistics network. Due to the large number of possible links, careful consideration must be given to deciding how to construct these links. Each of the approaches to estimating emissions discussed in the previous section are capable of generating virtual links for the network, but differences in methods affect the number, type, and emissions of the links. More detailed methods may allow a larger number of links, reflecting the increased detail and options capable of being modeled by the more detailed approach. To compare how well the different approaches meet the needs of users, a method of categorizing the links is needed, and drawing upon the idea of traceability in carbon footprints can do this.

TRACEABILITY

The carbon footprint of transportation in the supply chain represents a credence attribute. Economists define this as an attribute that cannot be determined from a product even after the product has been bought and used[43]. Since no type of testing or other after-the-fact approach can determine the carbon footprint, an identity preservation system is required to trace the attribute through the supply chain[44]. No single approach to traceability is adequate for every system, and the characteristics of a good traceability system cannot be defined without considering the system's objectives. However, the traceability system itself can be described by three dimensions: breadth, depth, and precision. Breadth refers to the information recorded by the system. Depth is how far backwards or forwards the system tracks. Precision is the degree of assurance the system can track a particular characteristic. In traceability systems the characteristics of the attribute determine the minimum breadth, depth, and precision required to preserve a record of the attribute throughout the supply chain[45]. Together, these attributes describe the measurement of a carbon footprint[46].

BREADTH

The first characteristic of the carbon footprint is its breadth—what is included in the measurement. At the most basic level this covers which gases should be included in the measurement. Though CO_2 is the primary greenhouse gas related to transportation, CH_4 and N_2O can also contribute to the total carbon footprint.

The breadth of the measurement also determines which activities should be included. The IPCC Guidelines recommend using different methods for different transportation modes. Many tools focus on only a limited set of transportation modes. Transportation includes many additional logistics activities, such as port and terminal operations; warehousing, break bulk facilities, and cross-docking; refrigeration; equipment repositioning; and infrastructure development. The breadth of the system defines which modes are included, and whether the emissions from other activities are included in the definition of transportation.

DEPTH

The standard for LCA, the accepted methodology for measuring carbon footprints, is a cradle-to-grave approach, where all inputs are traced back to their origin as raw materials and then followed until end of life. Most tools estimate the emissions from electricity generation and fuel combustion based solely on the emissions released during fuel consumption. This ignores the other steps in the supply chain required to prepare fuel for use, such as extraction, refining, and transportation. LCA normally takes these considerations into account, such that burning a gallon of gasoline involves emissions not just from the carbon content of the gallon of fuel, but also from its production. The full life cycle approach also includes activities such as production, disposal, and maintenance of the vehicles used for transportation. The depth of the system determines whether only the direct emissions of fuel are included in the carbon footprint, or whether a life cycle approach is extended to fuel production and other aspects of transportation.

PRECISION

The final dimension that defines the carbon footprint is the precision at which the measurement is performed. This includes determining when to draw a distinction between different modes of transportation, how to allocate for shared transportation, and the appropriate use of secondary data. It may be obvious that road and rail must be considered differently, but whether a distinction must be drawn between TL, LTL, parcel delivery, heavy hauling, tankers, and other forms of road transportation must be determined.

The precision must also specify the appropriate use of secondary data. The determination of appropriate secondary data sources is an important one given the difficulty in directly monitoring emissions. When direct emissions monitoring is not available, measurable data such as gallons of fuel consumed or vehicle miles traveled must be converted into carbon emissions through the use of emissions factors. The choice of factors affects the precision of the carbon footprint. Emissions factors may be calculated at a number of different levels of detail, and the appropriate level of precision must be determined.

DEFINING THE CARBON FOOTPRINT OF TRANSPORTATION IN THE SUPPLY CHAIN

Developing a definition of the transportation component of the supply chain requires defining the breadth and depth of emissions included. The breadth specifies the activities and types of greenhouse gases to include, while the depth specifies how far back the emissions should be traced. The focus on organizational boundaries developed by the IPCC and adopted by corporate level programs, such as The Greenhouse Gas Protocol, Carbon Disclosure Project[47] (CDP), or the Global Reporting Initiative[48] (GRI), is inappropriate for supply chains. Supply chains, and their transportation component, can span multiple organizations and impact a number of stakeholders.

The recent adoption of the EN 16258[49] standard for quantifying greenhouse gas emissions from transportation in Europe provides a guideline for establishing a definition of transportation in the supply chain. Given the global nature of supply chains and the challenges for multi-national corporations to meet multiple standards, the standards set by EN 16258 should be carefully considered.

SCOPE OF THE SUPPLY CHAIN

The boundaries specified by the EN 16258 standard state that the calculation should take into account:

- all vehicles used to perform the transport service, including those operated by subcontractors;
- all fuel consumption from each energy carrier used by each vehicle;
- all loaded and empty trips made by each vehicle.

This covers all processes related to the operation of transportation vehicles, including all onboard propulsion and ancillary services. It does not include:

- direct emissions of GHG at the vehicle level, resulting from leakage (of refrigerant gas or natural gas for example) and not from combustion;
- additional impacts of combustion of aviation fuel in high atmosphere, like contrails, cirrus, etc.;
- processes consisting of short-term assistance to the vehicle for security or movement reasons, with other devices like tugboats for towing vessels in harbors, aircraft tractors for planes in airports, etc.;
- processes implemented by external handling or transhipment devices (for freight), or by external movement devices (for passengers, like elevators and moving walkways), for the movement or transhipments of freight or the movement of passengers. In express delivery services and other transport services organized in networks, handling operations that take place inside platforms, and consisting of loading and unloading of parcels or pallets, belong to this category of processes;
- processes at the administrative (overhead) level of the organizations involved in the transport services. These processes can be operation of buildings, staff commuting and business trips, computer systems, etc.;
- processes for the construction, maintenance, and scrapping of vehicles;
- processes of construction, service, maintenance, and dismantling of transport infrastructures used by vehicles;
- non-operational energy processes, like the production or construction of extraction equipment, of transport and distribution systems, of refinery systems, of enrichment systems, of power production plants, etc. so as their reuse, recycle and scrap.

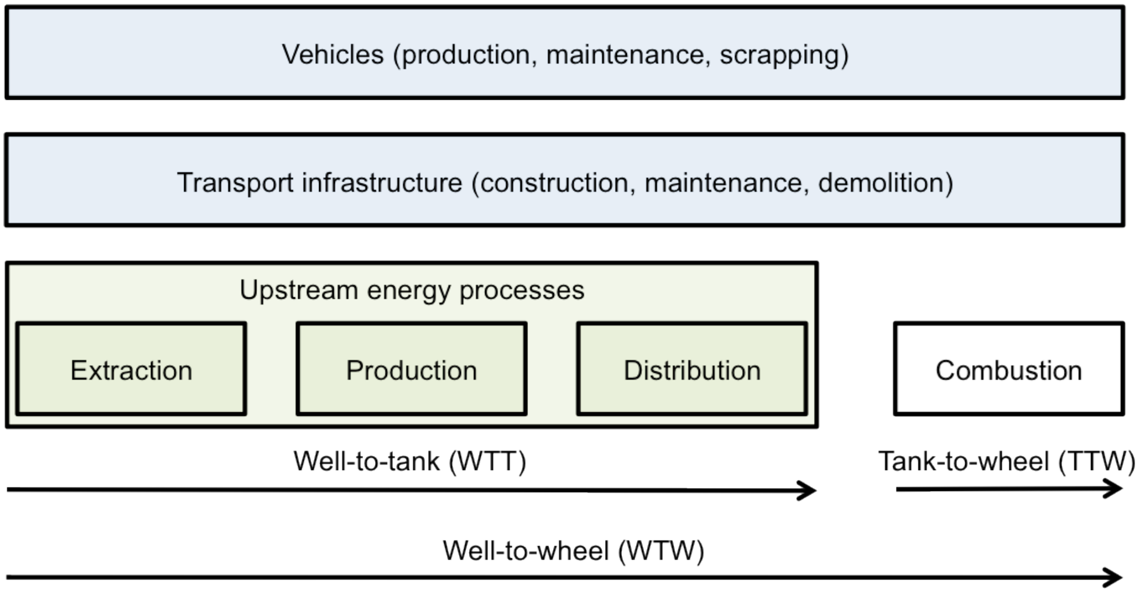
The processes included are related to the transportation service, and are not limited by organizational boundaries.

LIFE CYCLE PHASES

The EN 16258 standard states that the energy operational processes shall include:

- for fuels: extraction or cultivation of primary energy, refining, transformation, transport and distribution of energy at all steps of the production of the fuel used;
- for electricity: extraction and transport of primary energy, transformation, power generation, losses in electricity grids.

The inclusion of both the direct emissions from fuel combustion and from upstream processes is generally defined as well-to-wheel (WTW) emissions. Considering only the direct emissions, as done in the IPCC Guidelines, represents a tank-to-wheel (TTW) scope. A full LCA scope would generally include not only the WTW emissions of the energy system, but also the full life cycle emissions from the vehicle and associated infrastructure. This is shown in Figure 6.



Source: Auvinen, H., Makela, K., Lischke, A., Burmeister, A., de Ree, D. and Ton, J., 2012. Existing methods and tools for calculation of carbon footprint of transport and logistics. Deliverable 2.1, the COFRET project (Carbon Footprint of Freight Transport).

Figure 6: Life Cycle Phases of Transport [50]

GREENHOUSE GASES

The EN 16258 Standard specifies that calculation of GHG emissions shall include all the following six gases: CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6. All other gases are excluded. This is consistent with the gases reported for the Kyoto Protocol and as part of national inventories.

OUTPUT

The EN 16258 standard defines four outputs that should be produced, two related to energy and two related to GHG emissions:

- well-to-wheel energy consumption;
- well-to-wheel GHG emissions;
- tank-to-wheel energy consumption;
- tank-to-wheel GHG emissions.

COMPARISON TO CURRENT PROGRAMS

The EN 16528 standards are consistent with the majority of assessed programs in terms of the scope of transportation in the supply chain. Most of the current tools focused on transportation limit the scope to only emissions generated by the vehicles involved in transportation. LCA approaches may extend this boundary to include infrastructure, vehicle production, and associated handling equipment, but this outside of the normal scope of transportation considered by most tools.

The explicit inclusion of empty miles is not consistent across tools. In many cases, such as when total fuel use is calculated, any empty miles moved by the vehicle will be included through the fuel consumed during the movement. For activity based approaches the empty miles can be included either implicitly through inclusion within the emissions factors or explicitly through inclusion of the empty miles activity.

Inclusion of upstream energy processes is also not consistent across tools. While some tools do include these emissions, the majority do not. The difficulty in deriving a standard set of emissions factors that cover WTW emissions may be partially responsible. TTW emissions factors are fairly consistent across most sources, showing relatively small amounts of uncertainty. WTW emissions factors require greater effort to derive, and involve a number of assumptions. This increases the uncertainty of such emissions factors, and a consistent set of such factors have not been widely adopted as of yet.

Current tools also vary in the greenhouse gases they include. Many tools consider only CO_2, while others include N_2O and CH_4. These are generally the only direct greenhouse gases emitted during combustion of standard transportation fuels, but the inclusion of upstream emissions involves other potential greenhouse gases. Despite wide use, the term carbon footprint seems to have no clear definition[51]. Based on a review of its use in literature, Wiedmann and Minx proposed the following definition: "The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." This definition includes only the emissions from carbon dioxide, but is applied to the full life cycle of a product. Wiedmann and Minx proposed the use of "climate footprint" as a term for measures that include all greenhouse gases. This is in contrast to most definitions, which include all greenhouse gas emissions. Wright et al.[52] identified confusion surrounding this term, as the influence of a number of gases on global climate is still debated. They noted that stricter definitions simply specify the six Kyoto Protocol gases, but in their own definition include only CO_2 and CH_4.

Most tools provide only total GHG emissions as an output. For tools that include WTW emissions, it is not uncommon for both WTW and TTW emissions to be reported. Some tools may also include total energy in the output, but for most tools focused on GHG emissions this is not included.

RECOMMENDATION

Based on the review of current programs, the emerging EN 16258 standard in Europe, and output of similar research projects such as COFRET; we recommend adopting a scope consistent with that of the EN16258 standard. This involves a focus on energy consumed by transportation vehicles used to move goods between locations, adopts a well-to-wheel view for considering the emissions required to produce that energy, and includes the six Kyoto gases. This provides a standardized scope for companies that operating both in the U.S. and Europe, and captures the most relevant aspects of transportation in the supply chain. The decision to include TTW emissions or energy consumption in reported emissions is a separate issue. A tool that calculates emissions may produce a number of outputs, including those required by the EN 16258 standard. However, this should be considered a question of implementation and tied to the use of the tool.

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3 QUALITIES OF AN EFFECTIVE TOOL

In the previous chapter current methods for measuring emissions were reviewed and a definition of the carbon footprint of transportation in the supply chain was presented. In order to critique current methods a set of qualities that can be used to evaluate tools must be developed. This chapter explores how a number of different frameworks can be used to develop those criteria.

GREENHOUSE GAS PROGRAMS, METHODS, AND TOOLS

In discussing the transition from network models of transportation planning to tools designed to calculate greenhouse gas emissions, it is helpful to first begin with a discussion of how to classify different tools. Baldo et al.[53] classified current carbon footprint measurement methodologies into three different main groups:

- *General guidelines, such as ISO standards, that represent the normative standard references for CO_2 calculation.*
- *Specific guidelines, such as PAS 2050, that contain ad hoc indication on GHG calculation and monitoring.*
- *Calculation tools that are aimed at calculating CO_2 emissions of specific activities.*

The COFRET[54] project, in performing a review of transportation carbon footprint methodologies, categorized items within four categories:

- *Carbon footprint **methodologies** cover actual standards, standard-like guidelines, guidebooks and schemes that provide the framework for how to calculate and report carbon footprint of transport and logistics along the supply chain or some part of it.*
- *Carbon footprint **calculation tools** encompass all tools, instruments, software, algorithms and other applications, whether public, commercial or company specific, that are used to carry out and facilitate the calculations of carbon footprint of transport and logistics along the supply chain or some part of it.*
- ***Emission factor databases** are considered as collections of greenhouse gas emission data, either public or commercial, that are needed in order to calculate carbon footprint of transport and logistics along the supply chain or some part of it. Examples of emission factors in such databases are vehicle emissions, emissions from fuel production and emissions per transport unit.*
- ***Other activities** cover all items other than methodologies, calculation tools and databases that contribute to the topic of carbon footprint of transport and logistics along the supply chain. Examples of such activities include research projects, awareness raising initiatives and different types of communication forums and channels.*

Both of these definitions include the idea of a difference between high-level standards that provide only guidance regarding calculating emissions and actual tools used for calculating emissions from specific activities. We consider existing greenhouse gas accounting tools to fit into a hierarchy of three different levels: Programs, Methodologies, and Tools. This hierarchy is shown in Figure 7.

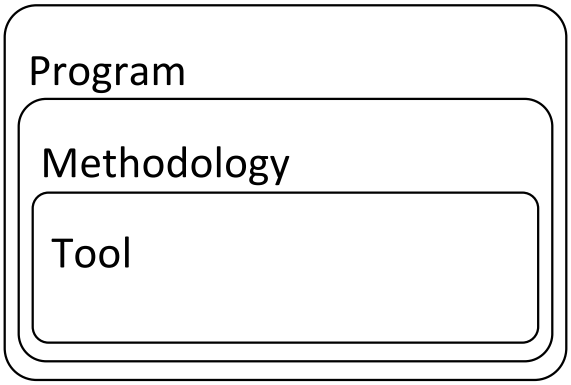


Figure 7: Classification of GHG Accounting Types

Programs represent the highest level of the hierarchy, and consist of guidelines describing what activities should be accounted, which gases to track, as well as how they should be reported. A program need not specify the actual method used to perform the calculations, but may provide one or more approved methods.

The methodology represents the next level in the hierarchy, and specifies the process by which emissions should be calculated. A single program might have a number of appropriate methodologies that could be used, and conversely a single methodology could be appropriate to use in a number of different programs.

A tool represents the lowest level of the hierarchy, and at its core represents a specific implementation of a methodology. A tool provides the ability to produce an actual quantifiable value for greenhouse gas emissions by linking a methodology with data sources.

Items categorized by COFRET as emission factor databases can be considered a version of a tool, since a tool requires a methodology and an emission factor to produce output. An emission factor implicitly requires a specific methodology, since a factor given in CO_2 per mile requires activity data in miles to produce a carbon footprint value.

This hierarchy can be demonstrated through an example drawn from the GHG Protocol. The GHG Protocol publishes “A Corporate Accounting and Reporting Standard”[55] that fits the definition of a program. These standards describe what emissions should be accounted for using three emissions scopes, specify which greenhouse gases are included, and describe how a company determines what activities fit within the program boundary. The standards do not describe how specifically the emissions should be calculated.

The GHG Protocol does provide a number of tools that can be used to do this, including a cross-sector tool designed to calculate the emissions from mobile sources. The tool allows for the use of two primary methodologies: one based on total fuel use and the other based on activity data. Within these methodologies there are several choices of emissions factor data that can be used. In order to calculate greenhouse gas emissions the user is thus required to first choose the methodology and next choose which emissions factors to use.

A view of this hierarchy is shown in Figure 8. The accounting standards represent the program, and define what emissions are to be accounted for. Two possible methodologies are available, representing the choice of either fuel or activity data to calculate emissions. Finally, in order to use the tool the specific emissions factors appropriate for that methodology must be chosen in order to produce the actual output.

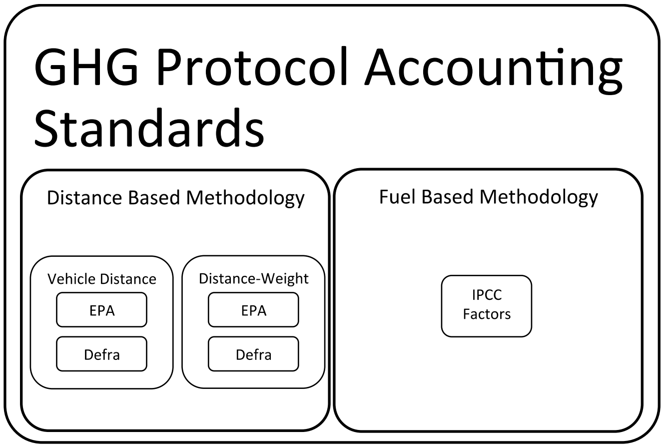


Figure 8: View of GHG Protocol Hierarchy

METHODOLOGIES

While a number of programs exist, there are two primary methods for quantifying greenhouse gas emissions from transportation: fuel-based methodologies and activity-based methods. Fuel-based methodologies use fuel consumption data to estimate emissions based on the content of the fuel and assumptions regarding its combustion. The fuel-based methodology is listed as the methodology of first choice for the GHG Protocol, as well as serving as the primary methodology for use in the IPCC national emissions inventories.

While fuel based methodologies are the preferred approach to calculating emissions inventories, they are by nature backwards looking, and not appropriate for use in the planning and decision making process. They rely on accounting for actual fuel consumed, but this information is not known for future transportation operations. Fuel-based methods also require knowledge about actual fuel consumption, data that may not be available to many shippers.

Activity-based approaches provide a methodology that, while not as accurate for historical emissions of CO_2 as fuel based approaches, is also suitable for planning situations. In activity-based methods some measure of activity, such as vehicle miles traveled or ton-miles moved, are multiplied by an emission factor to estimate total emissions. The emission factors can be calculated in a number of ways, including simulations, surveys, LCA, and econometric analysis. Shippers may prefer activity-based approaches, as they can be used to estimate emissions from more widely available data, such as shipment distances and weight, rather than fuel consumption.

PERFORMANCE FRAMEWORKS

In order to define the criteria that should be used to evaluate methodologies, three different performance frameworks are considered. First, an accounting framework is used to assess how well it provides information, both internally and externally. Second, a supply chain framework is used to understand how well suited it is to measuring the performance of a supply chain. Third, an environmental framework is used to understand how effective it is as a method of measuring and reporting environmental impacts.

ACCOUNTING

The use of activity-based methods allows for use as both a planning tool and a tool for accounting of historical emissions. The question of whether such a method is better than the fuel-based methodology is dependent on the intended use of the tool. Zimmerman[56] identifies three main areas where the information generated by accounting systems is used. First, the information is collected and processed into external reports that provide information to outside organizations such as regulators. These systems are primarily concerned with producing information in a manner that meets the requirements of the external consumers of the information.

The second and third areas of information use are both internal, where information is used for two primary purposes—decision-making and control. For decision-making, the goal of the system is to provide managers with information that is relevant to the decision at hand, allowing them to make the current decision. The control function is related to performance measurement—by providing information related to specific targets or measures the accounting system is used to incentivize managers in the correct manner. As an example, a manager may have a target to reduce total emissions from transportation by 10%. By calculating total emissions from transportation and providing feedback the accounting system is used to incentivize the manager to reduce emissions. This may be separate from the information needed for decision-making, which might include data such as the estimated emissions to send a specific shipment by several different choices of mode or carrier.

When evaluating the performance of any tool it must be done with the intended use in mind. Some tools may fulfill multiple roles, or fill different roles for different users. Consider the EPA SmartWay 2.0 tool. This tool provides a method for carriers to calculate emissions using a fuel-based methodology[57]. In addition, the tool captures certain activity data. Together this data is used to provide each carrier with a score, give in both CO_2 per mile and CO_2 per ton-mile[58]. Carriers are separated based on different services they provide, such as truckload, less-than-truckload, drayage, intermodal, and rail. The EPA then groups the carriers into different performance bins and makes the average scores of the carriers in those bins publicly available. In this use the tool provides a methodology for external reporting, as the tool provides guidelines that each carrier must follow, and the information is then used to provide reports to shippers.

The tool also provides the capability for shippers to calculate their emissions based on an activity-based methodology that tracks the amount of shipping done by each carrier. The tool calculates the total emissions for the shipper, as well as an overall performance score, based on how the shipper makes use of higher or lower ranked carriers. This serves to influence the decision making of the shippers, as the availability of the carrier scores allows them to prioritize carriers with low emission during the procurement process. Finally, the shippers are awarded a score based on the scores of the carriers they use, and this is also made publicly available. Figure 9 shows how the tool fills various roles for the shippers and carriers.

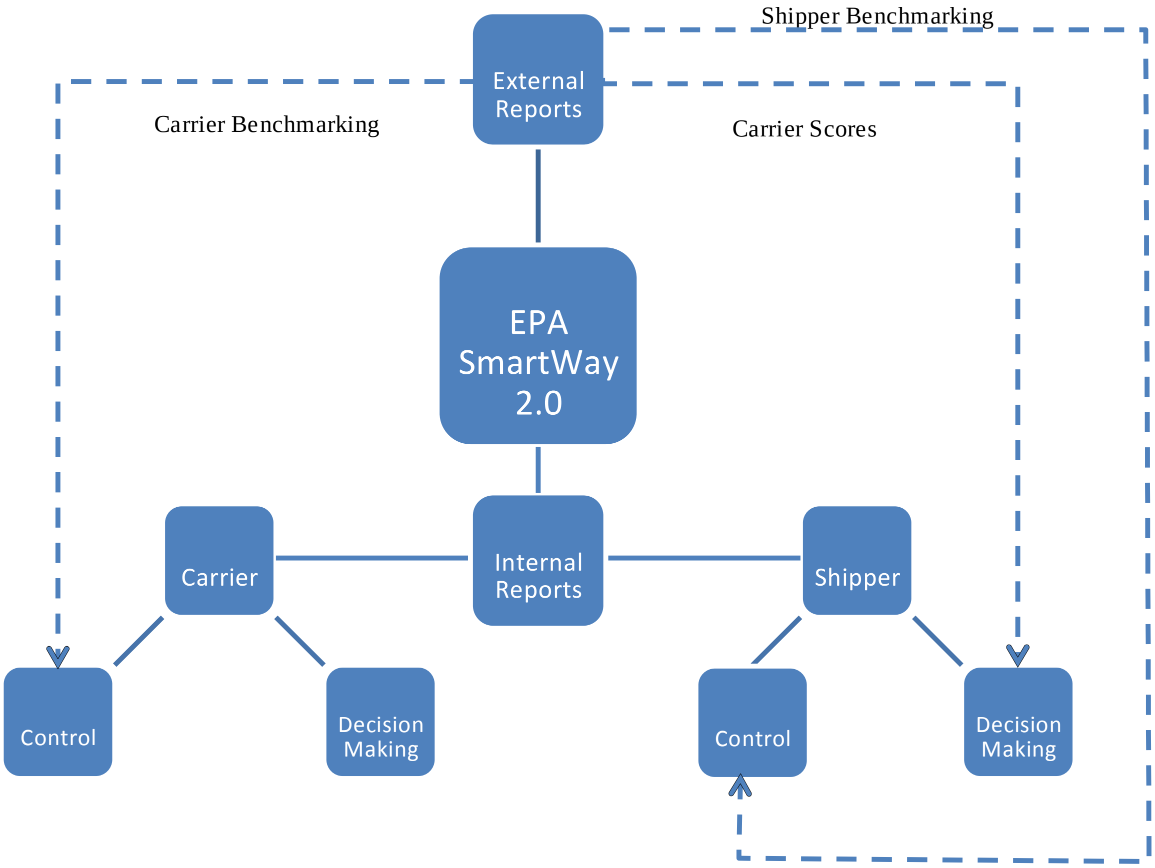


Figure 9: SmartWay Tool Uses

Working in this manner the tool is used for all three roles, though not necessarily for all users. For carriers the tool acts as both an external reporting tool and an internal control tool. The external reporting function sets reporting guidelines and scores that are shared externally to the shipper, as well as other carriers. The tool can also fulfill the internal control function, by allowing carriers to measure their performance. However, the tool does not provide the capability to help carriers make better decisions—the actual strategies that can be used to reduce emissions and improve their score are not included in the tool. This can be contrasted with the way the tool works for shippers. In this case the tool is designed to improve decision-making by helping shippers choose better-ranked carriers, allowing the shipper to improve their performance. This is provided in addition to the internal control and external reporting uses that work in a similar manner as it does for the carriers.

SUPPLY CHAIN

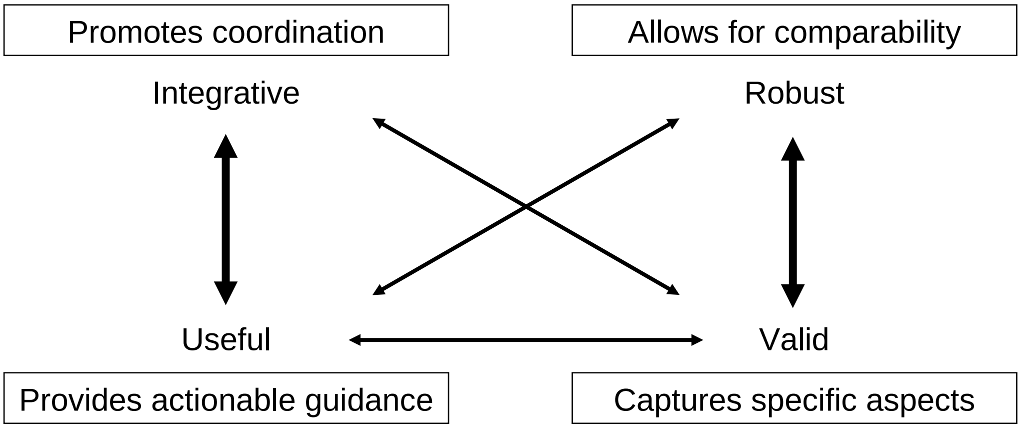
Traditional supply chain models have predominantly utilized two different performance measures: cost and a combination of cost and customer responsiveness (which includes many customer oriented aspects such as time, reliability, and quality). Such measurements are generally inadequate, as they are not inclusive, ignore interactions among important supply chain characteristics, and ignore critical aspects of organizational strategic goals[59]. Further, such measurements fail to capture any aspects of environmental performance[60].

Most organizations focus on metrics within their organization[61], but supply chain level capabilities are even more essential when supply chains incorporate social and environmental goals, as sustainability goals require even closer interactions between all firms involved[62]. In making decisions for the supply chain, environmental performance must be included with non-environmental performance requirements such as cost, quality, time, and flexibility so that alternatives that best support the environmental performance also make business sense[63].

Bringing together both environmental and non-environmental performance requires a performance measurement system that provides information necessary for decision-making[64]. A performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action[65]. A performance management system brings together individual performance metrics to measure system level performance[66].

A number of individual metrics can be developed that are appropriate to measuring the environmental performance of a supply chain[67]. The carbon footprint is an environmental common denominator that runs across all processes and operations. These common denominators identify specific information that can be gathered across the supply chain to provide a measure of environmental performance for the supply chain as a whole, and within distinct functional areas[68].

Whether the carbon footprint is a metric that measures performance across the supply chain or within a functional area is dependent on how it is defined. Metrics can be evaluated in a number of categories, but designing metrics that excel in each category is not practically possible. Instead firms must choose metrics that tradeoff between certain criteria. Two of the primary trade-offs are between integrative and useful metrics, and between robust and valid metrics[69].



Source: Caplice, C. and Y. Sheffi (1994). "A review and evaluation of logistics metrics." The International Journal of Logistics Management 5(2): Page 17. Copyright, Emerald Group Publishing. Permission has been granted for this image to appear here (http://www.trb.org/Main/Blurbs/169329.aspx). Emerald does not grant permission for this image to be further copied/distributed or hosted elsewhere without the express permission from Emeral Group Publishing Limited.

Figure 10: Tradeoffs Between Criteria[69]

Integrative metrics promote coordination across functions, while useful metrics are easily understood and provide managers with direct guidance. Providing managers with actionable guidance requires a level of specificity that makes promoting coordination across functions difficult. In this sense measuring the carbon footprint of transportation is a useful metric, since it provides guidance on one specific aspect, but not across functions. As such it must be incorporated as one metric in an entire performance measurement system that covers both environmental and non-environmental aspects across the functions of the supply chain.

The other primary trade-off is between a robust metric that allows for comparability and a valid metric that captures specific aspects. This represents a similar situation as the internal and external uses of accounting information. A valid metric provides help with making a specific decision, but is less suitable to external uses where it might be compared with similar metrics for other organizations.

MEASURING ENVIRONMENTAL IMPACT

Life Cycle Assessment provides a general framework for measuring the environmental burden of a product or function. Its general structure allows for application to a wide variety of systems, but also allows considerable freedom in implementation. Differences in implementation can be separated between issues of methods, whether process-based or EIO-LCA, and purpose, whether attributional or consequential. This freedom makes for difficulty in comparison between any two separate LCAs.

The high cost and time of performing process-based LCAs poses difficulties for products with complex supply chains spanning many organizations. A survey of LCA practitioners identified data collection as the most time consuming and costly aspect of performing an LCA[70]. Collecting data across organizational boundaries presents issues with proprietary and confidential information, data accuracy, and a lack of representative data.[71,72]

EIO-LCA provides an approach that requires less detailed process data. By including all upstream activity within the economy the data is more complete, and there is no need to draw system boundaries. The data is generally compiled from publicly available sources, allowing for greater transparency than process-based LCAs that use proprietary data. Finally, the EIO approach allows a much cheaper and faster method of providing results. In cases where only an approximate result is needed an EIO LCA can provide a very rapid and inexpensive answer[73].

The assumptions and methods of EIO analysis do have drawbacks for determining the environmental burdens of a specific product. Though EIO tables may contain hundreds of sectors, this still requires significant aggregation of different products and processes. Some sectors may be too heterogeneous to produce correct results[74]. The information in the Input-Output tables only captures the effects of production and therefore the use and disposal phases are not included[75]. Many countries lack the sectoral environmental data needed for analysis, meaning that imports must be assumed to be homogeneous with domestic products[76]. Finally, the nature of Input-Output analysis assumes proportionality between monetary and production flows[77]. That is, if a product doubles in cost then the environmental burden doubles as well. Though necessary for the computational results this may not reflect the reality of the production process.

LCAs generally fall into two categories based on their purpose. An attributional LCA is focused on looking back on a product and determining what emissions can be attributed to it. A consequential LCA is focused on the environmental effects of what will happen due to a decrease or increase demands for goods and services[78]. The two types of LCAs are suitable for different purposes and require different types of data. An attributional LCA is appropriate for making specific environmental claims regarding a product, and typically makes use of average data for the product. The consequential category is more suited to performing scenario analysis. It uses marginal data for the product, as it requires making assumptions about economic factors related to changes in product consumption or production[79].

The distinction between the attributional and consequential approach reflects similar issues to those of the accounting and supply chain performance measurement frameworks. The differing approaches between attributional and consequential methods represent the core difference in perspective between decision-making and control. The attributional approach is designed to be a backward looking accounting of environmental impact, suitable for measuring performance. The consequential approach is designed for decision-making, taking a forward-looking view.

IDENTIFYING CRITERIA

These ideas can be used to develop a framework for evaluating tools designed to measure the carbon footprint of transportation in the supply chain. Tools can be classified based on their ability to fulfill each of the three functions of an accounting system: external reporting, internal control, and decision-making. Evaluation of a tool must consider its intended use, and tools may perform better for some uses than others.

Measuring the carbon footprint of transportation is just one metric that captures a specific aspect of performance, and can be integrated into a larger system to measure overall performance. A metric must trade-off between being suitable for general use or to making a specific decision. This trade-off must be considered in how the metric will be used, and the method for measuring it.

The concepts of breadth, depth, and precision can be used to classify how different GHG programs measure the carbon footprint of transportation. Breadth and depth together provide a description of the scope of the program, defining what is included in the program, from the different activities to the range of the fuel cycle. This is illustrated in Figure 11.

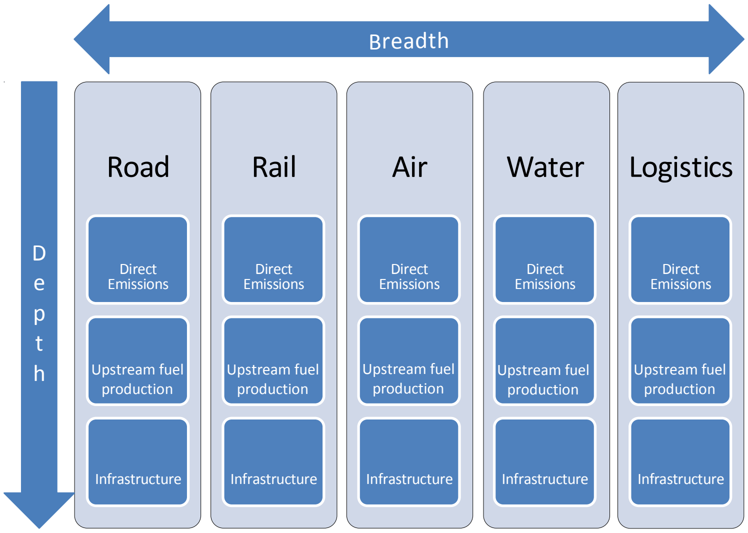


Figure 11: Breadth and Depth

Rather than identify what is included in the program, the precision determines the level of detail the program provides. Depending on the level of aggregation in data sources or the approach for generating emissions, programs may provide more or less precision in their estimates of GHG emissions. Some programs may provide only rough estimates by mode, while others allow calculations based on specific shipment level details. As the scope of the decision narrows, from mode to equipment type to carrier to individual shipment, more precision is required in the calculation to differentiate between options. This is shown in Figure 12.

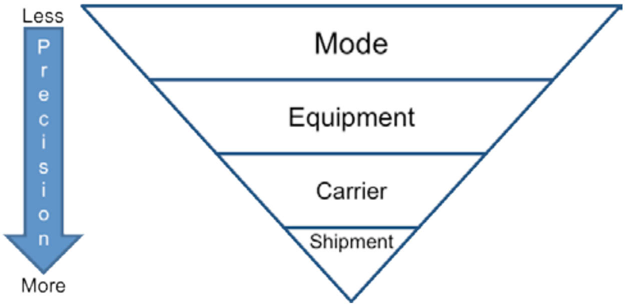


Figure 12: Precision

Based on the concept of traceability, the carbon footprint of any shipment can be defined in terms of the breadth, depth, and precision of the measurement. The breadth and depth together consider the scope of emissions included in the measurement. They define what modes and logistics activities should be considered in the network, which greenhouse gases to measure, and which portions of the full life cycle of the transportation process should be included. The precision of the measurement defines at what level of precision a distinction can be drawn between calculating the carbon footprint of two separate shipments. Together the breadth, depth, and precision cover how relevant a measurement is for making a specific decision. The scope of the supply chain must include enough breadth and depth to capture the relevant emissions, while the measurement must be precise enough to allow differentiation between the options.

BREADTH, DEPTH, AND PRECISION IN PRACTICE

The approaches of two popular GHG calculators provide an illustration of how the breadth, depth, and precision can vary between different programs, and how this impacts the ability to calculate emissions. The GHG Protocol is the most widely used tool for corporate level GHG accounting, and offers a tool for the calculation of emissions from mobile sources. NTM is a calculator more narrowly focused on transportation in Europe. Both sources provide calculators for greenhouse gas emissions from transportation, but use different methods for the calculation.

NTM

The NTM methodology uses a bottom-up methodology to calculate emission factors for road[80]. Figure 13 depicts the decision flow used by NTM to calculate emissions. By standardizing the road types, fuel, energy content and emission factors, and abatement equipment, NTM is able to provide emissions factors on a vehicle-distance traveled basis for 10 vehicle types at any load utilization between 0 and 100%. Thus, NTM operates at a vehicle and load level of precision. The calculator is also able to provide an emissions factor on a per tonne-km basis, which is done by making use of an assumed load factor, which represents less precision than the vehicle distance traveled factor.

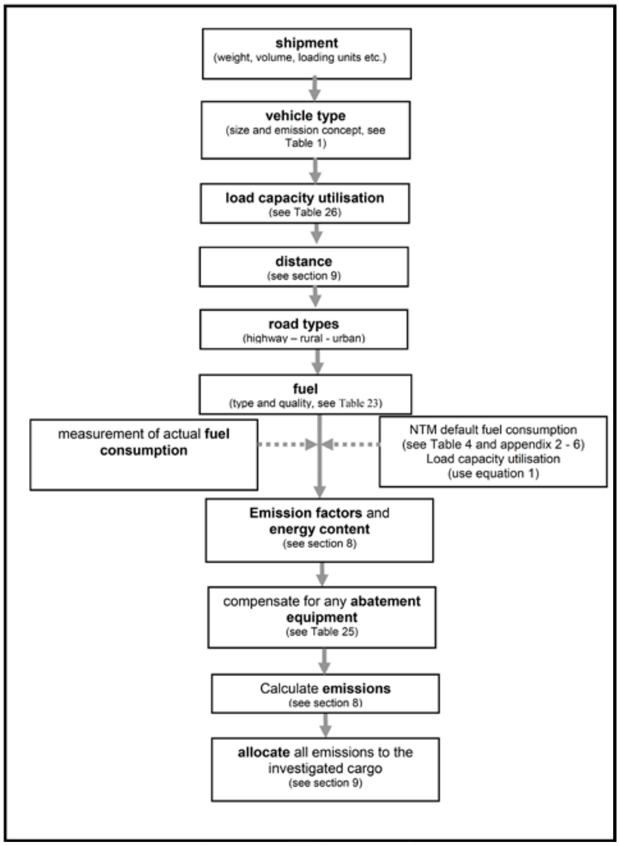


Figure 13: NTM Methodology[80]

NTM considers only emissions from transportation, and not additional logistics activities. The calculator does include CH_4 and N_2O in addition to CO_2. These decisions define the breadth of the system chosen by NTM. Finally, NTM does not include the emissions from the upstream production of fuel, nor from any life cycle impacts of the vehicle and infrastructure. Thus the depth of the system is limited to only the direct emissions from the combustion of fuel.

THE GHG PROTOCOL

The GHG Protocol provides a calculator for the emissions from transportation called "GHG emissions from transport or mobile sources"[81]. The tool allows for calculation of emissions using both a fuel-based and activity-based methodology. The activity-based methodology gets emissions factors from two sources, the EPA Climate Leaders[82] program for the US and Defra[83] for the UK. The EPA Climate Leaders program uses a top down methodology to estimate freight emissions per ton-mile. The process uses total emissions from the transportation sector, separated between road, rail, air, and water modes, taken from the EPA divided by activity data, in ton-miles by mode, from the Federal Highway Administration[84] (FHWA) to calculate an emissions factor in kg CO_2/ton-mile for each of the four modes. In addition, the US factors include a vehicle distance factor based on estimated miles per gallon. However, factors are provided for only a limited selection of vehicle classes (light duty, heavy duty rigid, and heavy duty articulated).

The Defra emissions factors are calculated using a survey methodology, which captures average vehicle fuel consumption and load factors for a number of different vehicle types. Emissions factors are provided per tonne-km for a number of different types of road vehicles and watercraft, as well as for rail and air. Emission factors are also provided by vehicle distance and load factor, allowing for calculation at any load factor for a number of different vehicle types. Thus, even within a single program a number of different levels of precision are available depending on the source of the data.

In contrast to the NTM program, the GHG Protocol also provides tools capable of measuring the emissions from other logistics activities. Tools are provided that can measure the emission from electricity and other fuel combustion used in buildings and for operating equipment. Thus, from a breadth standpoint the GHG Protocol is capable of measuring transportation related logistics activities in addition to the direct emissions from transportation, but requires multiple tools to accomplish this. The mobile calculator provides a similar breadth to NTM in terms of greenhouse gases included, as factors for CH_4 and N_2O are provided in addition to CO_2. The GHG Protocol uses the same level of depth as NTM, as emissions are based only on direct emissions from fuel combustion, and other portions of the fuel cycle are not included.

A comparison of these two programs shows how the concepts of breadth, depth, and precision relate to the capabilities of the programs. The GHG Protocol offers the ability for greater breadth of activity due to the inclusion of calculators capable of measuring non-transport logistics activities, while the NTM program provides more precision in the ability to measure emissions due to the high level of aggregation provide by the GHG Protocol, particularly for the US emission factors.

OTHER CHARACTERISTICS

While breadth, depth, and precision cover the relevant aspects needed to decide if a tool is capable of making a specific decision they do not cover all the aspects of a good tool. In addition to decision-making a tool must also be capable of providing information externally for reporting purposes, and internally for measuring performance. This is especially true in the context of a supply chain, where effectively communicating performance between firms and functional units is necessary to effectively manage the supply chain as a whole.

In order to identify characteristics of a tool that go beyond making individual decisions, it is helpful to identify the principles around which many tools designed for external reports have been organized. The CDP[85], GRI[86], and Greenhouse Gas Protocol[87] were all created with the idea of measuring the environmental performance of many different firms in a standardized way. The principles each of them has been designed around are shown in Table 2.

Carbon Disclosure Project	Global Reporting Initiative	Greenhouse Gas Protocol
Relevance	Relevance	Relevance
Faithful Representation	Reliability	Completeness
Comparability	Clarity	Consistency
Timeliness	Comparability	Transparency
Understandability	Timeliness	Accuracy
Verifiability	Verifiability	

Table 2: Comparison of Principles

The high degree of similarity around their principles is immediately obvious. All three programs have been designed around the core principles of financial accounting. The Federal Accounting Standards Board (FASB) set forward a set of principles to be used as a conceptual framework for financial accounting[88]. This principle-based view of financial accounting came about in response to criticism of the traditional rules-based approach due to several recent accounting scandals[89].

The FASB standards were developed and harmonized with the International Accounting Standards Board (IASB)[90] to converge the standards. These standards identified two fundamental qualitative characteristics: relevance and faithful representation. In addition, they identified four enhancing characteristics: comparability, verifiability, timeliness and understandability. These characteristics were explicitly adopted for use by the CDP.

According to the IASB:

> *"comparability* is *the quality of information that enables users to identify similarities in and differences between two sets of information. Consistency refers to the use of the same policies and procedures, either from period to period within an entity or in a single period across entities. Comparability greatly enhances the value of information to investors and is therefore the objective of this requirement; consistency is the means."*

while verifiability:

> *"is the characteristic of information that helps to assure users that it has been faithfully represented. Verifiable information is characterized by supporting evidence that provides a clear and sufficient trail from monitored data to the information presented in disclosures. "*

Together comparability and verifiability provide the final two criteria for evaluating tools. Comparability ensures that the results of a tool are comparable to those of other users, an especially important consideration in the context of a supply chain. Verifiability provides increased trust in the results of the tool, providing reassurance that the results can be used as part of an overall performance measurement system.

SUMMARY

In all three performance frameworks a common distinction between internal and external uses are present. The accounting framework makes this distinction between managerial accounting and financial reporting; the supply chain literature in the tradeoff between useful and robust metrics; and in the LCA literature on the distinction between consequential and attributional studies. Thus, any evaluation of current tools must recognize this distinction.

Based on our review of performance frameworks we propose the following five criteria for evaluating carbon footprint tools:

1. Breadth—the scope of activities included in the measurement
2. Depth—the range of direct and indirect emissions included in the measurement
3. Precision—the level of detail provided by the measurement
4. Comparability—the degree with which measurements can be compared across time and organizations
5. Verifiability—the degree of assurance in the results and methodology

The first three criteria together capture how relevant a measure is for decision-making. This is generally captured by the idea of relevance from the accounting standards. The other two criteria provide a measure of how well suited the tool is for external use—can the results of the tool be compared with other organizations and trusted to accurately and faithfully represent the actual performance.

A tool is useful internally if it can provide relevant information to help make decisions. The exact information needed may vary depending on the decision being made, and a tool's relevance is determined by whether it is sufficient for that decision. As the breadth, depth, and precision of a tool increases the range of decisions for which it is relevant increases.

The results of the tool should show a high level of comparability. This is useful for internal benchmarking, where a firm compares its year-on-year performance to itself, and externally, where a firm compares its performance to competitors. Further, in a supply chain context where information is shared between firms, the results of the tool must represent a common language between the firms. This is reflected in the degree of comparability between the results of different firms.

Finally, due to the credence nature of carbon footprints, the output of a tool cannot be directly verified. Instead, verification can come only indirectly through examining this inputs and methods of the tool. Tools that provide more transparent methods or external verification increase the verifiability of the results, making the results more trustworthy to external viewers.

Together these five criteria cover the major characteristics of a tool needed for both internal and external use. Higher degrees of performance across these categories increase the relevance of the results to making decisions; the ability to incorporate the results into benchmarking and information sharing; and the trustworthiness of claims based on the results.

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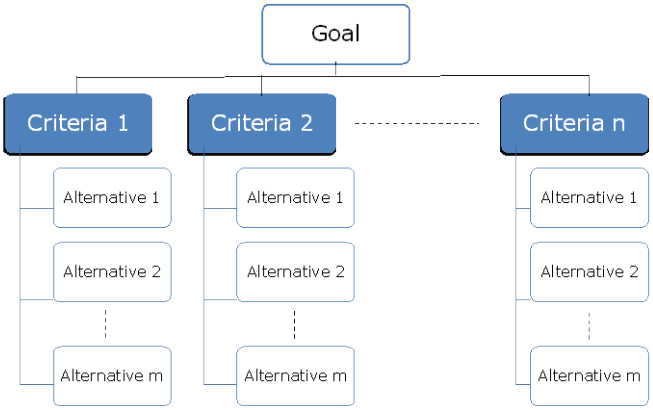
4 EVALUATION OF CURRENT PROGRAMS

Given the five criteria identified as relevant to evaluating current programs identified in the previous chapter, a method to actually perform the evaluation is needed. In this chapter the Analytic Hierarchy Process is presented as a suitable method for performing this evaluation. The process is applied to current programs, and the results are discussed.

ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process[91] (AHP) is a quantitative method for making complex decisions. The process relies on estimating the magnitude of difference between choices by making simple comparisons. Through the AHP the simple comparisons are used to first evaluate the relative weight of each criteria, and then to evaluate each of the alternatives according to the criteria. The result is a set of relative “weights” for each of the criteria and a quantitative score for each alternative that represents the preferences of the participants.

The process works by defining a goal in terms of a hierarchy of criteria (and possibly sub criteria), and then evaluating each of the alternatives within those criteria. This is shown in Figure 14.



Source: NTM—ENVIRONMENTAL DATA FOR INTERNATIONAL CARGO TRANSPORT, ROAD TRANSPORT EUROPE, Version 2010-06-17, Page 9.

Figure 14: Goal, Criteria, and Alternatives in AHP

In the first step, pairwise comparisons are made between the different criteria. For each pair of criteria, a comparison is made to determine which criteria is more important and how much more important it is. From these comparisons the AHP process identifies the relative importance of each criterion.

Once the relative importance of the criteria is identified, the alternatives are evaluated. Within each criterion the various alternatives can be compared with one another in a similar manner to the first step. These comparisons are used to generate a score for each alternative within a specific criterion. After completing this process for all the criteria the total score for each alternative is calculated by weighting the score within each criterion by the relative importance of that criterion. This produces an overall evaluation of each alternative with respect to the goal. The AHP process is well suited to group decision making, where consensus must be reached between many group members. By structuring the decision in the form of a hierarchy and then focusing attention on individual components, AHP amplifies a group's decision-making capabilities. It does not require numeric guesses to quantify results; instead it accommodates subjective judgments by using a ratio scale[92]. Given the many different types of stakeholders interested in the carbon footprint of transportation, as well as the large number of programs to be evaluated, AHP is well suited to the problem.

APPLICATION OF AHP

In order to evaluate current tools for measuring the carbon footprint of transportation in the supply chain, a workshop featuring many different stakeholders was held at MIT on October 25th, 2012. The workshop featured 16 participants in the AHP exercise, drawn from a number of different industries. This included carriers (road, drayage, rail, ocean), shippers (high tech, retail, apparel, chemicals, beverages), 3PLs, and other stakeholders (government, NGO, research, equipment manufacturers). All participants had some previous familiarity with carbon footprint tools for transportation, and ranged in experience from lead engineers to vice presidents.

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment moderately favor one element over another
5	Essential or strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

Source: Reprinted from European Journal of Operational Research, Vol. 48 (1), Thomas Saaty, "How to make a decision: The analytic hierarchy process", Page 15, 1990 with permission from Elsevier.

Table 3: The Fundamental Scale[92]

At the workshop the five criteria were presented to the participants and discussed in the context of current programs and views on transportation. After presentation of the criteria, the participants in the workshop provided their individual input on the relative importance of each of the criteria. This was done through a series of pairwise comparisons between each criterion. Each participant was asked to determine which of the two criteria was more important, and to judge the relative magnitude of that relationship based on the scale shown in Table 3. This was repeated for each of the 10 possible pairs of criteria.

After the responses were collected from the 16 participants, the results were averaged to produce a consensus judgment for the group as a whole. The results of this analysis are shown in Table 4. The criteria determined to be more important is shown in bold and underlined. The relative intensity of the importance of the chosen criteria is shown in the intensity column.

Criteria A	Criteria B	Intensity
Breadth	**Comparability**	1.75
Breadth	Depth	1.55
Breadth	Precision	1.50
Breadth	**Verifiability**	1.11
Comparability	Depth	4.04
Comparability	Precision	3.40
Comparability	Verifiability	1.95
Depth	**Precision**	1.01
Depth	**Verifiability**	1.64
Precision	**Verifiability**	1.05

Table 4: Criteria Preference

The pairwise comparisons show a clear preference for comparability as a criterion, as it was judged more important than each of the other four criteria. It also recorded the strongest intensity of importance, with it being considered between moderately and strongly more important than depth and precision.

Verifiability and breadth showed the next highest importance. Verifiability was rated as more important than each of the criteria, except comparability. The relative strength of the importance was not overly strong with scores ranging from 1.05-1.95. Breadth was judged more important than depth and precision, but less so than verifiability and comparability. However, the average strength of preference for breadth was slightly higher than for verifiability.

A particularly useful aspect of AHP is the ability to turn the pairwise comparisons into a quantitative evaluation of their importance. Applying the AHP process to the participant's ratings produced a relative weight for the importance of each criterion. These weights are shown in Figure 15.

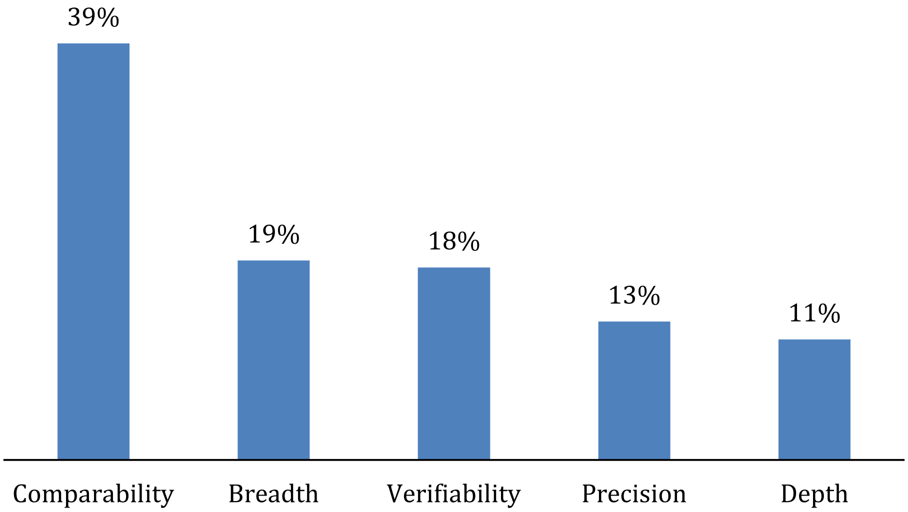


Figure 15: Relative Importance of Criteria

The quantitative results indicate the strong preference for comparability as the most important criterion, with a relative weighting of 39%. Of the remaining criteria, breadth and verifiability were judged to be next most important, with weightings of 19% and 18% respectively. The slightly higher weighting for breadth represents the higher average intensity of preference compared to precision and depth, as well as the lower intensity of preference for comparability in comparison. This explains why breadth is judged to be overall slightly more important than verifiability, even though verifiability was judged more important in the pairwise comparison. Precision and depth were judged to be least important, with relative weightings of 13% and 11%.

In addition to the relative weightings of the criteria, a measure of the inconsistency of the ratings was calculated. The average scores of the group produced an inconsistency rating of .00921, indicating a very consistent set of beliefs. In general applications of AHP an inconsistency ratio of less than 0.1 is considered to be consistent. With the relative weightings of the criteria determined, it is now possible to evaluate current programs by comparing their performance within each criterion.

EVALUATING ALTERNATIVES

There are two primary methods for evaluating the different alternatives within each criterion: relative measurement and absolute measurement[93]. Relative measurement works in a similar manner to the procedure for criteria weighting, with each alternative being pairwise compared with the others and assigned a relative intensity of preference under each criterion. The results of the pairwise comparisons are then used to generate scores for each alternative within that criterion.

In absolute measurement the alternatives are not compared with each other, instead they are compared against a set of absolute standards that are established for each criterion. The standards themselves are compared with each other under each criterion in order to develop the relative scores achieved by meeting each standard. This allows for creation of standards that use concepts such as high, medium, and low or A, B, C, D, and F letter grades.

For the evaluation of existing programs an absolute measurement approach was used. This approach has two primary advantages over relative measurement. First, it allows for the evaluation of a large number of alternatives. In a relative measurement scheme the number of comparisons required increases as additional alternatives are added. For the five criteria evaluated during the workshop each participant made a total of 10 comparisons. If five alternatives were to be compared using a relative measurement it would require 10 comparisons to be made for each of the five criteria, a total of 50 comparisons. The total number of comparisons can increase quickly—it would require 225 comparisons to handle 10 alternatives and more than 24,750 comparisons for 100 alternatives. Under absolute measurement, each alternative need only be compared to the standards for each criterion, requiring significantly less total comparisons.

Second, relative measurements are sensitive to the addition of new alternatives, even if those alternatives are copies of existing alternatives. This can include rank reversal—where the addition on a new alternative may cause two existing alternatives to switch their order in the ranking. This phenomenon does not occur with absolute measurements, so if new alternatives are added to the process it will not cause a change in the preference order of the previously existing alternatives.

In order to perform the absolute measurement, a series of standards were established to rank alternatives as achieving high, medium, or low performance in each criterion. The standards for high, medium, and low within each criterion were based on the review of the current programs and discussion during the workshop held at MIT.

In addition, the relative importance of achieving each rank in each criterion was developed based on the guidelines given in Table 3. For each criterion, a score of low was given the baseline value of one, and the medium and high scores were evaluated based on their relative preference to the low standard. For internal consistency, the relative preference of the high standard to medium was assumed to be simply the ratio of their relative weights in comparison to the low standard. For example, the preference for high to medium in the case of breadth is defined as 1.14, reflecting the ratio of 8:7. The standards and relative weights used for each of the five criteria are shown in Table 5.

Criteria	Measure	Description	Weight
Breadth	High	Includes all modes plus logistics activities	8
	Medium	All four main modes (road/air/water/rail)	7
	Low	Single mode	1
Comparability	High	Standardized boundaries and output measures	8
	Medium	Single standardized data and methodology	5
	Low	Multiple methodology and data options	1
Depth	High	Full Life Cycle Assessment	6
	Medium	Well to Wheel analysis	5
	Low	Direct emissions only	1
Precision	High	Shipment level reporting	7
	Medium	Carrier level reporting	5
	Low	National/Industry Average	1
Verifiability	High	External audit/verification required	5
	Medium	Methodology and data are publicly available	2
	Low	No verification/non-standardized data	1

Table 5: Absolute Criteria Measures

The weights were determined based on discussion with participants of the October 25th workshop and the estimated value of meeting higher standards. The use of different weights for scores of high, medium, and low in each criterion allows for differences in the value of achieving higher scores in different criteria to be captured in the final evaluation. An increase from low to medium in verifiability is only slightly preferred, as the benefits are judged to be of relatively small value. In contrast, an increase from low to medium in breadth is of strong importance due to the value in having all four modes considered in the tool.

Using the weights given in Table 5, the AHP methodology was used to develop a score, within each criterion, for achieving a given level of the standard. The scores were normalized by setting a score of 1.00 for achieving the high standard within each criterion. These scores are shown in Table 6, and reflect the values that will be used to evaluate existing programs.

Criteria	Measure	Score
Breadth	High	1.00
	Medium	0.88
	Low	0.13
Comparability	High	1.00
	Medium	0.63
	Low	0.13
Depth	High	1.00
	Medium	0.83
	Low	0.17
Precision	High	1.00
	Medium	0.71
	Low	0.14
Verifiability	High	1.00
	Medium	0.40
	Low	0.20

Table 6: Scores of Criteria Measures

The relatively high importance attached to achieving a medium level of breadth reflects the need for a tool capable of handling each of the main transportation modes. The addition of other logistics activities increases the breadth to capture associated activities, but these are generally considered to have a minor impact on emissions when compared to the actual transportation. This explains the only slightly greater score for achieving a rating of high.

For comparability, the use of a standardized set of methods and data ensures that comparisons between different organizations are based on the same methods. This was judged to be strongly more important than a tool having multiple options. The addition of guidelines on setting standardized boundaries for what emissions should be included, as well as providing some measure of standardization in the output of a relative efficiency score, provide additional benefit.

The majority of emissions from most transportation fuels are produced during direct combustion, and even a low level of depth might capture most of the relevant emissions. When alternative fuels and electric vehicles are considered; however, a WTW approach is more suited to capturing the relevant emissions. For this reason a score of medium for depth was judged to be strongly more important. Adding additional life cycle impacts such as infrastructure or vehicle production add only marginal benefit, and thus a score of high was not judged significantly more important that a score of medium.

The importance of precision was based on discussion with participants during the workshop. The participants expressed a preference for tools that were capable of providing differentiation between different carriers, but that shipment level reporting was not significantly more important. For this reason a score of medium, reflecting a carrier-specific level of precision, was judged to be moderately more important than a tool that used average values, while a shipment-level precision was only slightly more important.

Verifiability represents the most difficult criteria to judge. Most tools rely on the user to input accurate and true data, and only through some manner of external verification can this be checked. Such verification is often costly and time consuming, but some programs, such as the CDP, GHG Protocol, and carbon label standards require this level of verifiability. This high level of verifiability was judged moderately more important than a low level, reflecting the difficulties that such verification presents. Verifiability may also be increased by transparency in methods and data sources, and this transparency level of transparency is considered slightly more important than a low level of verifiability.

EVALUATING CURRENT PROGRAMS

With the relative weights of the criteria and the scoring within criteria set, the existing programs can now be evaluated. Each program is evaluated using the AHP method through a three-step process. First, the program is evaluated against the standards in Table 5 to determine the rating of high, medium, or low in each of the five criteria. Second, the relative weighting of the criteria shown in Figure 15 were multiplied by the scores associated with each ranking shown in Table 6 to get the weighted score for each criterion. Third, the overall score is calculated by adding together the weighted scores for each of the five criteria. This process is shown in Figure 16.

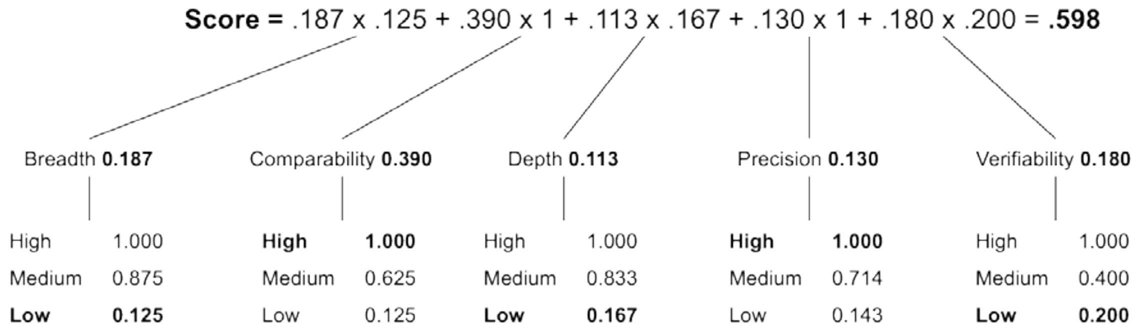


Figure 16: Evaluating an Existing Program

All scores are based on a maximum score of 1.0, with a theoretical tool achieving ratings of high in each category achieving a perfect score. Similarities in the design of many tools allow them to be grouped into a limited number of "types" of tools. The range of scores, even within a given type, demonstrates how different approaches to the design of tools can produce different results depending on the implementation. Similarly, tools that take different approaches may earn similar scores, as strengths in one area are balanced by weakness in another. After applying this methodology to current tools, four major types of tools can be identified.

The first type of tool focuses on producing highly comparable results for a single mode, achieving scores in the range of 0.56-0.60. Examples of this type of methods include the EPA SmartWay program and the BSR CCWG. The consistent system boundary and methods required by participants in these programs, as well as the standardized scoring of carriers, produce results comparable across companies. This comparability is supported by high levels of precision allowed by the carrier-level data supplied by SmartWay and carrier-route-level data produced by the BSR CCWG. These advantages were offset by the lack of breadth offered by programs tailored primarily for single modes (though SmartWay does provide scores for railways in addition to trucking).

The second type of tool offers consistent methodologies for all four primary modes, but lack the ability to provide carrier-specific default values or a relative output value such as CO_2 per tonne-mile or TEU-km. Tools of this type achieve scores of 0.52-0.59. The use of standardized emissions factors lead to higher verifiability, due to the transparency in their use. This comes at the cost of higher levels of precision, since the results are not based on company or shipment specific data. EcoTransIT[94] and the NTM calculator[95] are examples of tools that use this type of approach.

The third type of tool provides methods for all modes, but offer a lower level of comparability. Tools of this type achieve scores in the range of 0.32-0.44. Examples of this type of tool include the IPCC Guidelines and the GHG Protocol. They provide methods for all the major modes, but only provide average emissions factors that use a tank-to-wheel level of depth. The lack of consistent activity-data based methods and emissions factors limit the ability for different organizations to produce consistent results with the tools.

The fourth type of tool is focused on a single mode, but lacks the balanced performance across criteria of higher scoring tools. Tools of this type achieve scores in the range of 0.29-0.45. The EPA MOVES and the GREET tool represent examples of this type. The EPA MOVES tool is capable of producing very detailed emissions calculations, but is focused only on road vehicles and TTW emissions. The large number of factors that can be considered in the model also makes the results less comparable across organizations, as different assumptions regarding inputs can lead to different results. The GREET model is also focused on road vehicles. It uses a WTW depth for a number of different fuel types, but makes use of average vehicle efficiency numbers that lack the precision of other approaches.

COMPARABILITY WITHIN AND BETWEEN TOOLS

The participants of the workshop expressed a desire for tools that provided a common boundary, allowed for tracking at the carrier level, and provided results that could be used to benchmark across different firms. The widespread support of SmartWay and the CCWG by industry participants, as well as the high scores achieved under this evaluation, provide guidance for the direction of future tools. By incorporating these features and with the participation of industry in the development of these tools the EPA and BSR have produced some of the most successful tools to date.

However, the preference for comparability expressed in this evaluation was based on comparability *within* a tool. Specifically, the focus was on how the results of the tool could be compared across different organizations or time periods. The focus was not on comparability *between* tools. That focus would be on how comparable the results from different tools are to one another. This is important given the high scores of tools focused on single modes, creating a need for multiple tools each focused on different industries.

The issues with comparing between tools can be illustrating by examining the methods used by two of the top scoring tools: the BSR CCWG tool focused on ocean carriers and the EPA SmartWay tool focused primarily on truck carriers. Both tools use a survey approach to assess the performance of individual carriers, but methodological differences between the tools create issues in direct comparison of the results.

The EPA SmartWay tool asks carriers to provide information on total fuel consumption, total number of miles traveled, the number of revenue miles charged to the customer, and data regarding average payload. The carrier receives a score in terms of CO_2 per mile and CO_2 per ton-mile by taking the total CO_2, calculated using the fuel data provided, and dividing it by the total number of revenue miles or the total ton-miles, calculated by multiplying the revenue miles by the average payload. The SmartWay program divides carriers into five bins based on their scores, and the publicly reported score for each carrier is the midpoint value for all carriers in the bin.

This score is made available to shippers, who can then use the score to estimate their emissions from shipments hauled by each carrier. The shipper enters the total miles or ton-miles of shipments hauled by that carrier, and these are multiplied by the carrier's score to estimate total emissions. Because the carrier's score is based on revenue miles rather than total miles, the contribution of empty and out-of-route miles to overall efficiency are accounted for in the estimated emissions. Further, the use of average payload means the ton-miles score represents the actual average utilization. By knowing just the distance between origin and destination, and the weight of the shipment if using a ton-miles score, the shipper is able to get an estimate for emissions that reflect the carrier's actual average operating performance.

This is in contrast to the BSR CCWG methodology. Ocean carriers are asked to provide data on total fuel consumption, total distance sailed, nominal ship capacity in TEUs, and number of reefer plugs. In a similar manner to the SmartWay approach, the total CO_2 is calculated from fuel data, and this is divided by the total TEU-km, calculated by multiplying the nominal capacity by the total distance sailed, to calculate a performance metric in terms of CO_2 per TEU-km. This can also be calculated for specific trade lanes and for reefer containers.

By using nominal TEU capacity the emissions per TEU-km are underestimated, as vessels are not at 100% utilization at all times. The use of total distance sailed also creates complications for shippers who wish to use the performance metrics to estimate the CO_2 of ocean shipments. In order to accurately calculate emissions, the shipper must know the actual sailing distance between the origin and destination, but this is dependent on any intermediate ports that may have been visited. The extra sailing distance is essentially out-of-route distance for a shipper trying to move goods directly between the origin and destination, and this will not be accounted for if the shipper uses the direct sailing distance between origin and destination.

The differences between the two methodologies mean that the results are not directly comparable with one another. Using nominal capacity as opposed to actual utilization will tend to underestimate emissions for an ocean shipment in comparison to trucking. The shipper must also account for out-of-route distance introduced by intermediate ports when estimating emissions from ocean shipments, further underestimating emissions if this is not accounted for.

The lack of comparable standards between modes may not necessarily impact the preference for multiple tools, as the relative carbon efficiency of each mode is generally consistent. However, the challenge for future development is to create a tool that offers the level of comparability offered by mode-specific tools, while also providing a consistent basis for comparison between modes. As of yet no similar tool has been created for the airfreight industry, and shippers may not want to manage using multiple tools. Given the global scope of most supply chains, future tools should be capable of providing multi-modal calculations while delivering the benefits of current mode-specific tools.

FUTURE TOOL DEVELOPMENT

A tool that provided a consistent set of well-to-wheel emissions factors across all four major modes would achieve a score of medium for both breadth and depth. If the tool was part of an overall program that required a consistent system boundary and guidance for which transportation activities are to be included, and provided a set of performance indicators that measured both total emissions (effectiveness) and relative emissions (efficiency), a score of high could also be achieved for comparability. The tool could be based on transparent, open data and methods that make use of average levels of performance for different fuels, vehicles, and mode types. This tool would receive a score of low for precision and medium for verifiability, for an overall score of 0.74.

Alternatively, the tool could follow a similar path to the SmartWay and CCWG tools and collect data from specific carriers and routes. This could be used to achieve a score of medium (for carrier specific emissions factors) or high (for route level emissions factors) in the breadth criterion. This would come at the cost of some level of transparency due to the private nature of the information supplied by the carriers. This would reduce the verifiability score to low. A tool based on this design would achieve a score of 0.78 for providing carrier-level emissions factors or a score of 0.81 for route-specific emissions factors. In the next chapter we discuss developing a work plan for a tool that would be capable of providing these capabilities.

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5 DEVELOPING A DECISION TOOL

In this chapter the proposed three-tier architecture for the decision tool is presented along with the specific elements it requires. Next, a number of example scenarios for calculation are provided to illustrate some of the issues that must be considered when designing the tool. Finally, a work plan that describes the discrete tasks that must be performed to build the tool is developed and timelines to complete development for two possible versions of the tool are given.

DECISION TOOL

The proposed tool presented in this chapter is designed as a decision tool to support measuring and incorporating greenhouse gas emissions in the supply chain decision process. It is assumed that the users of such a tool will primarily be the shippers, carriers, and logistics providers that make transportation decisions, and the tool is designed as a way to provide information for both historical accounting of emissions and future decisions. Explicit consideration is given to the fact that different users may have access to different types of information at different levels of detail.

The focus on decision support means the tool as presented is flexible and designed to estimate emissions under a wide array of scenarios. As such, it may not be suitable for some uses currently employed by existing tools. The focus on flexibility and a supply chain view of emissions makes the tool less well suited to regulatory approaches or those specifically designed for corporate level reporting.

Tools such as EMFAC and the EPA MOVES tool can be used to estimate greenhouse gas emissions related to transportation, and for some situations the use of these tools is required. At their core these tools employ conceptually similar approach to the proposed decision tool, taking a set of input activity data and using that to produce emissions estimates. Include the emissions factors from those tools and allowing for the input of the same data, the tool could conceivably produce the same results.

Similarly, some approaches to calculate emissions are focused on preventing double counting of emissions. Double counting may occur in situations where both the shipper and carrier measure and report emissions for the same shipment. From a supply chain perspective this behavior is not necessarily problematic, and may in fact be beneficial as it incentivizes both firms to work to reduce the emissions from transportation. Some programs, such as those designed for corporate reporting or when emissions reductions are used to claim carbon credits, may explicitly wish to avoid double counting.

The approach outlined in this chapter does not provide any specific mechanism to guarantee compliance with regulatory approaches or to avoid double counting. Rather, it is assumed that such mechanisms can be handled by the appropriate choices of emissions factors, input data, and use of the tool. A decision support tool for supply chains may not be the ideal tool for use in specific programs, and thus the decision of whether the tool should support such approaches is a question for the implementation of the design, and is left outside the scope of this report.

THREE-TIER APPROACH

Three-tier software architecture divides software in to three layers to allow developers to modify and change the tiers independently[96]. The tiers consist of a control tier that provides the interaction for the user; a model tier that provides the functionality and detailed processing; and a data tier that stores and retrieves information. These tiers may also be referred to as the presentation, logic, and database tiers. By separating the functions across three tiers, each individual tier can be modified and improved without requiring changes to the others.

CONTROL TIER

The control tier provides the interface and control for the user. The primary role of the control tier is to define how data is input to the tool and what results are returned to the user. Based on capabilities of current tools and the proposed network model framework for calculation, two methods of data input are proposed: direct input and network building. In direct input the user enters the necessary information directly without requiring support from the logic provided by the tool. In a network builder mode, the user locates the nodes of the network and describes the flow of goods on the links between the nodes, but the tool provides the capabilities of calculating the distances and routes between nodes. This is necessary for situations where the user may have only limited information related to the actual transportation, or for estimating future flows and what-if scenarios.

MODEL TIER

The model tier is responsible for the actual calculation of the emissions within the tool. It must support the types of measurements required for the control tier as well as interfacing with the data tier. The model tier may need to be capable of modeling each node and link in a supply chain, from the transportation of goods through multiple types of modes to the facilities needed to support that movement such as ports, terminals, airports, and warehouses. It must support the ability to link each of these types of nodes via transportation links and calculate emissions from each link using data pulled from the data tier. In some cases this may require the ability to calculate distances between two given locations in a network.

DATA TIER

The data tier must contain all the data needed to perform the actual calculations. The data tier must support emissions factors and data for each of the aspects of supply chain and do so at multiple levels of detail to support the types of decisions specified in the control tier — from high level strategic planning to low level operational decisions such as carrier assignment. In addition to the emissions factors, the data must store the necessary information for the model tier to calculate distances, including the ability to locate points and calculate a route between them.

ELEMENTS

Together the specifications for each tier describe the workings of the tool. Within a given tier, a number of functions may be performed, and the separate functions are referred as elements. A representation of the various elements identified for inclusion in the tool is shown in Figure 17. More detail on the specific purpose and requirement of each element is given in the following sections.

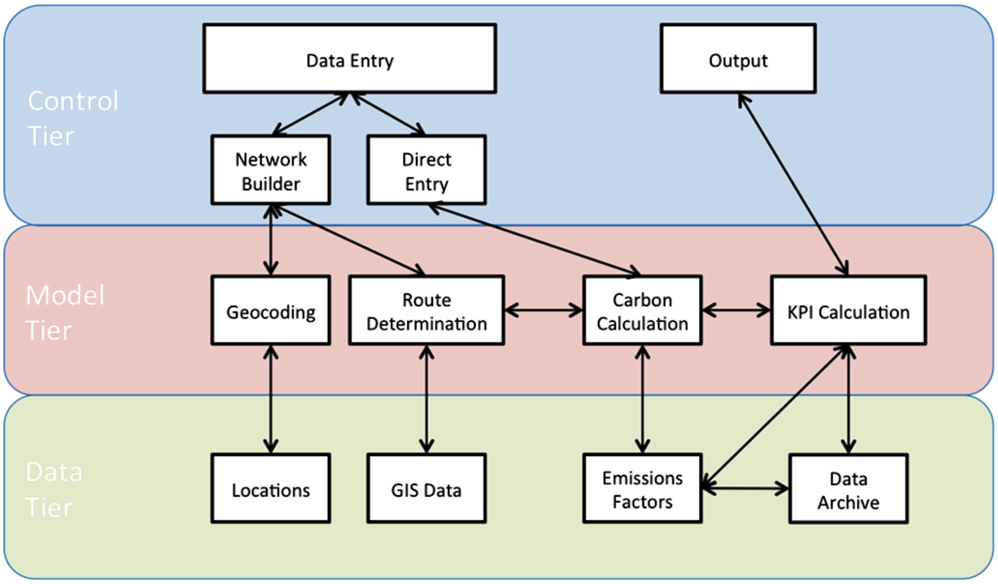


Figure 17: Proposed Three-Tier Architecture

CONTROL ELEMENTS

There are two primary elements of the control layer: data entry and output of results. Together these elements control how the user interfaces with the tool, both inputting data and viewing the results.

DATA ENTRY

The data entry element determines what information the user is required to provide in order for the tool to calculate emissions and how that information is entered. Two primary methods are possible for entering data. The first is direct entry of the relevant information by the user. The second allows the user to construct the network using nodes and links.

Direct Entry

The primary input method for most current carbon footprint tools is manual entry via web interface or through a Microsoft Excel spreadsheet. The GHG Protocol and SmartWay, two of the most popular and widely used tools, both rely on Excel spreadsheets. Both tools provide columns specifying the necessary information, and users enter data in the rows for each entry. A screenshot of version 2.3 of the GHG Protocol Mobile Combustion[97] tool is shown in Figure 18.

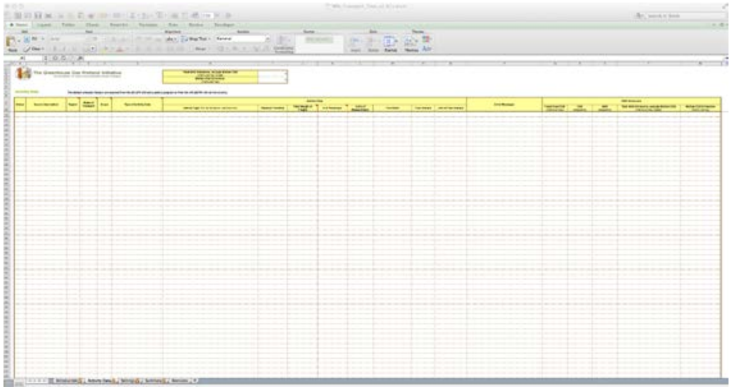


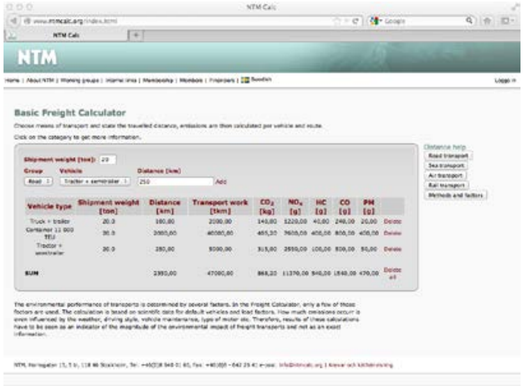
Figure 18: GHG Protocol Tool Screenshot

In this tool, each row allows the user to enter a separate source of activity data. Users select the mode of transportation, the type of activity data (fuel use, vehicle distance, or weight and distance), emissions factor, and enter the relevant data. The GHG emissions associated with each row are then calculated.

The SmartWay[98] program provides similar capabilities through multiple tools designed for shippers, carriers, drayage, rail, and multi-modal operators. Though implemented in Excel, the tool uses Visual Basic code to provide forms for data entry. Users list the carriers they do business with, and then enter activity data for each carrier. Activity data is typically based on total ton-miles and miles by carrier, though default values related to payload, density, and loaded percentage may be used to estimate that data when it is not available. Emissions are calculated for each carrier, and summed to present a total. A screenshot of the activity data entry screen is shown in Figure 19.

Figure 19: SmartWay Shipper Tool Activity Data Entry Screen

Other popular tools employ a web-based interface that allows for similar types of data entry. The NTM[99] basic freight calculator allows users to build up a list of movements by entering distance, weight, mode, and vehicle information. Emissions are calculated for each entry, as well as the total for all movements. A screenshot of this web interface is shown in Figure 20.



Basic Freight Calculator

Choose means of transport and state the travelled distance, emissions are then calculated per vehicle and route.

Click on the category to get more information.

Shipment weight [ton]: 20

Group: Road

Vehicle: Tractor + semitrailer

Distance [km]: 250

Vehicle type	Shipment weight [ton]	Distance [km]	Transport work [tkm]	CO_2 [kg]	NO_x [g]	HC [g]	CO [g]	PM [g]	
Truck + trailer	20.0	100,00	2000,00	140,00	1220,00	40,00	240,00	20,00	Delete
Container 11 000 TEU	20.0	2000,00	40000,00	413,20	7600,00	400,00	800,00	400,00	Delete
Tractor + semitrailer	20.0	250,00	5000,00	315,00	2550,00	100,00	500,00	50,00	Delete
SUM		2350,00	47000,00	868,20	11370,00	540,00	1540,00	470,00	Delete all

The environmental performance of transports is determined by several factors. In the Freight Calculator, only a few of those factors are used. The calculation is based on scientific data for default vehicles and load factors. How much emissions occur is even influenced by the weather, driving style, vehicle maintenance, type of motor etc. Therefore, results of these calculations have to be seen as an indicator of the magnitude of the environmental impact of freight transports and not as an exact information.

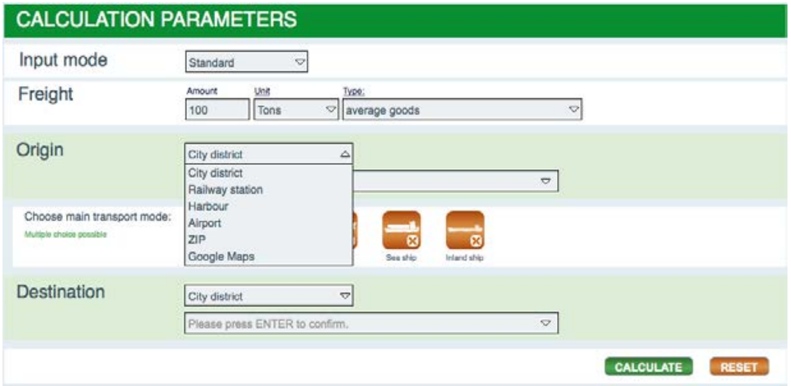
Figure 20: NTM Basic Freight Calculator Data Entry

Each of these interfaces represents a method of direct entry. The user inputs all the information necessary to calculate the emissions, and the tool performs no additional processing. This is in contrast to other forms of data entry, where the user provides location information, but the tool must determine other input needed for the calculation, such as distance.

Network Builder

This ability is referred to as a network builder approach, as the user is able to construct a network by providing origins and destinations, with the tool calculating the distance and route. This removes the need of the user to have specific knowledge of the fuel consumed or exact distance. This approach provides a useful method for users with only limited knowledge of the exact shipment routing, or for forward-looking situations where the exact information will not be known until a future time.

The EcoTransIT World[100] calculator offers a simple web interface that uses the network approach. Users are able to enter data on the amount of goods (by weight or TEU), the type of goods, the transport mode, and the shipment origin and destination. Locations may be entered in a number of ways, including by city, airport code, railway station, harbor, zip, or through a Google Maps interface. After entering the information and clicking calculate, a route between origin and destination is calculated, and, along with the mode and goods information, used to calculate emissions. The extended interface can be used to calculate more complicated trips using a transport chain. At this time only one shipment or transport chain can be calculated at a time. A screenshot of this web interface is shown in Figure 21.



Input mode: Standard

Freight: Amount 100, Unit Tons, Type: average goods

Origin: City district

Destination: City district

Please press ENTER to confirm.

Figure 21: EcoTransIT World Web Interface

The network builder approach, combined with the ability to do direct data entry when the exact details are known, provide the necessary capabilities for users to calculate emissions for transportation given a wide range of possible data types and availability. The interface of these data entry capabilities with the actual calculations is covered in the section on the model elements.

OUTPUT

The output element determines what results are returned to the user after the data has been entered and the calculations are performed. Most current tools provide only rudimentary reporting results. Often this is as limited as the total amount of CO_2e. Some tools do provide more detailed information display capabilities. The EcoTransIT World tool provides not only data on total CO_2e emissions, but also energy consumption, route visualization, distances, and modes. A screenshot of the results overview is shown in Figure 22.

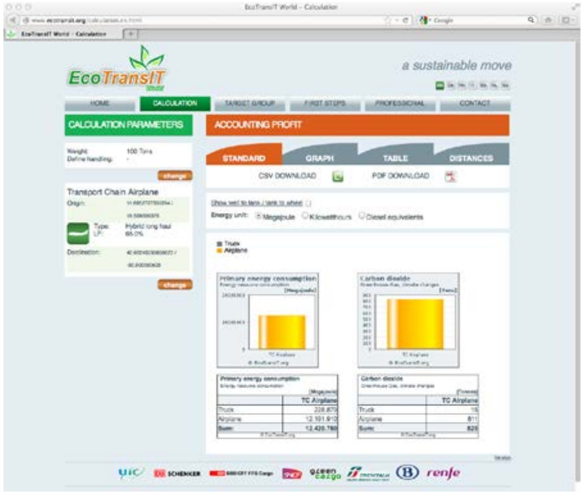


Figure 22: EcoTransIT World Results

The output element must specify what specific metrics are to be reported, the format (charts, tables, maps, etc.) for display, and any selections the user may wish to make. When calculations are performed at a high level of precision, the results may be aggregated to include not just overall totals, but also summaries broken out by factors such as mode, lanes, or even in/out of specific destinations. In addition a number of activity parameters, such as tons shipped, miles traveled, and ton-miles, can be reported and used to provide KPIs related to overall efficiency. To output these results to the user requires interaction with the model layer to aggregate results and calculate KPIs based on the data entered by the user.

MODEL ELEMENTS

The model tier is concerned with executing the logic required to support the control and data tiers. It provides the link between the two layers and is responsible for performing calculations requested by the user and returning the appropriate results. Given the proposed capabilities of the control tier, the model tier has three primary functions:

1. Providing distance calculations in the network model
2. Calculating the greenhouse gas emissions associated with shipments
3. Calculating the key performance indicators

DISTANCE CALCULATION

A strength of the network modeling approach is that it allows for the calculation of emissions when little data about the specific routing of a shipment is known. This may be particularly useful for shippers that use 3PLs to manage a large number of shipments across a variety of modes. In these situations the shipper may know little more than the origin, destination, and general mode of transportation. In the network modeling approach, the shipper can provide the origin and destination, and the model layer can determine the appropriate route and distance. This requires two steps: geocoding and route determination.

Geocoding

In the geocoding step, the origin and destination must be located given the input from the user. Depending on the interface implemented in the control layer, this could involve direct entering of locations through a Google Maps style interface, text entry, or selection from a predetermined list. Regardless of the means of data entry, the element must determine the appropriate geographic locations from the entered data, a process referred to as geocoding. Once the origin and destination have been determined in this manner, the distance can be calculated by determining a route between them.

Route Determination

After the origin and destination locations are determined, the model layer must find a route between the locations and calculate the distance. At the simplest level this can involve a great circle distance calculation between the origin and destination. This provides an approximation of the straight-line distance between two points of latitude and longitude over the Earth’s surface. This distance can be modified by applying a circuity factor based on the mode of transportation used to better estimate actual travel distance.

More complex route determinations can be made through the addition of detailed Geographic Information System (GIS) data. This data can contain information related to roads, railways, waterways, ports, terminal, interchanges, and other points that can be used to determine routes between locations. For example, the Dataloy Data Table[101] is a web service that calculates ocean-shipping distances. The service makes use of a database with 7,200 port locations and more than 69,000 waypoints to calculate distances between ports based on typical sailing routes. The results of such systems can provide more accurate representations than a typical great circle distance at the cost of increased complexity.

Geocoding and routing can be complicated procedures, and several current tools interface with specialized software in order to make use of their geocoding and routing software. The EcoTransIT World calculator works with Google Maps to provide geocoding and basic distance calculation. The GIFT model[102], developed by the University of Delaware and the Rochester Institute of Technology, interfaces with ESRI's GIS software in order to provide multi-modal routing capabilities. In cases similar to these, the model tier must handle the interface with outside software programs in order to provide these services. Regardless of the chosen level of complexity and accuracy provided by the system, the element must be able to provide some distance calculation between two points in order to support making distance-based GHG calculations from limited data.

CARBON FOOTPRINT CALCULATION

The model layer must support the three primary methods of GHG emissions calculations identified in practice: fuel-based methods, distance-weight methods, and vehicle-distance methods. Based on the data entered by the user, the calculation element must determine the appropriate calculation methodology, retrieve the relevant emissions factors from the database, and perform the calculation. None of the general methods for calculation are particularly complex, and thus the calculations are straightforward given the appropriate data and emissions factors.

PERFORMANCE INDICATORS

The last element of the model layer provides for the aggregation of results from many individual GHG calculations and calculates the relevant KPIs needed by the control layer. This may involve aggregation of data from thousands of individual shipment and calculation of the KPIs at the level of precision requested by the user. In addition, the element may need to interface with the database layer to store certain KPIs in the emissions factor database. That is, in a manner similar to how results from carriers that use the EPA SmartWay tool are made available to shippers, it may be advantageous for certain results of the KPI calculation step to be stored in the database and made available for other users (or potentially the same user at a later time).

DATA LAYER

The data layer is concerned with storing information required to support the logic of the model layer. It provides the data requested by the elements of the model, but does not provide any logic of its own. Given the proposed capabilities of the model layer the data layer has three primary elements:

1. A list of locations used for geocoding points
2. GIS data that may be used to determine routes
3. Emissions factors used to calculate the carbon footprint of shipments

Optionally, the layer could also support an archive capability used to store calculation data remotely. This would allow previous calculations to be saved and accessed from multiple locations, facilitating the sharing of information. Some firms may not wish to store proprietary data on a remote server, and therefore this would be in addition to the ability to output the results to local storage.

LOCATIONS

The location data specifies the list of points and their associated geographic coordinates, typically given by latitude and longitude. This element must define what points are stored, their coordinates, and possibly a data hierarchy. The points may consist of locations such as cities, but also points relevant to supply chains such as airports, seaports, terminals, switching yards, etc. The available points determine what kinds of data users should enter, as the data must eventually be matched with a point to determine the appropriate coordinates. Establishing a type of hierarchy in the data may also be useful, as points could be categorized by their type or by features such as country, state, and city. The existence of such a hierarchy may allow the data entry elements to perform functions such as providing an easily searchable list of points for the user to choose from, potentially making the data entry steps easier and more reliable.

GIS DATA

As discussed in the section on route determination, the process can be complicated in practice, and a number of methods exist to implement this step. The type of data available in the database layer limits the choice of methods. If no data related to routing is stored in the database, then a method such as great circle distance must be used to calculate distances, while a full GIS database makes complicated multi-modal routing possible. Unfortunately, detailed data may not be available for all locations in the world, thus the data and route determination elements must be constructed such that the model layer is capable of calculating distances based on whatever results the data layer is able to provide. This element must be constructed such that data is stored in a way that detailed data can be accessed where available, but that the model layer is capable of handling situations when it is not.

EMISSIONS FACTORS

The most important data element for the actual calculation of emissions is the available emissions factors. The model layer supports three methods of calculation, and the data layer must provide emissions factors appropriate to each method. In addition the emissions factors must be available at a number of levels of precision to support the needs of different users. This could include average global data, averages specific to nations or regions, company specific emissions factors, or even detailed emissions factors appropriate for individual shipments.

A number of current tools and programs offer different approaches to emissions factors. The NTM program uses defined scenarios for road transportation to calculate emissions factors specific to different vehicle models and load factors. For example, the emissions for a given shipment can vary based on vehicle type, load utilization, road type, fuel type, and abatement equipment, in addition to distance and the specific fuel energy content and emission factor. Conceivably this approach could be used to generate a large number of emissions factors specific to the choice of vehicle, load, road, fuel, and abatement equipment.

The EPA SmartWay program provides factors in a different manner, capturing data from carriers to produce emissions factors for individual companies. These emissions factors can be specific to the company, mode, and category type. Their current database contains more than 3,000 specific emissions factors. Given the importance of the emissions factors in the calculation steps, and the large number of potential factors, this element must define how individual emissions factors are stored and the information necessary for the model layer to choose the appropriate emissions factor. The data layer must work with the model and control layers such that the information provided by the user can be used to unambiguously select the appropriate emissions factor and perform the calculation.

DATA ARCHIVE

The data archive provides the ability to save data for use at a later time. This could include storing previous year's data, allowing multiple users access to the same data, or saving work in progress to be updated later. This capability would be in addition to the ability to store work locally. The data archive could also include functionality to share results with the emissions factor database, for example by allowing carriers to have their custom emissions factors made available to shippers.

EXAMPLE SCENARIOS

Calculations based on fuel data represent the most straightforward method of emissions calculation, and are the preferred approach when the data is available. The IPCC guidelines recommend using an emissions factor based on the amount of CO_2 per unit of energy to account for differences in temperature or density, but in practice many calculators make emissions factors available based on volume. The emissions factors are derived by assuming a certain carbon content of the fuel, a heating value, and the amount of carbon oxidized during combustion. Emissions factors may further differ based on the specific country, as the IPCC recommends countries develop specific emissions factors that account for the technology and quality of the oil specific to that country. This leads to a range of possible emissions factors depending on the assumptions made.

Fuel based methods can be further distinguished by the range of fuels for which factors are provided, the depth of the emissions considered, and the greenhouse gases included in the calculation. In order to provide a comprehensive carbon calculator, a range of fuel based emissions factors must be considered that account for the necessary greenhouse gases, cover a full range of possible fuel sources, and the portion of the fuel life cycle considered.

FUEL BASED SCENARIOS

At the most basic level the calculator might provide an emissions factor for common fuels such as diesel. The EPA provides a default emission factor of 10.15 kg CO_2/gallon for diesel fuel based on 100% oxidation and assumptions regarding the heat content of the fuel, the carbon content of the fuel, and the carbon factor per gallon[103]. Using a similar process Defra provides an emission factor for the UK of 9.99841 kg CO_2/gallon[104].

If we consider a company that consumed 1000 gallons[iii] of diesel fuel, the choice of emissions factors provides two different calculation results.

$$1000 \text{ gallons} \times 10.15 \text{ kg } CO_2/\text{gallon} = 10{,}150 \text{ kg } CO_2$$

$$1000 \text{ gallons} \times 9.99841 \text{ kg } CO_2/\text{gallon} = 9{,}998.41 \text{ kg } CO_2$$

In general the range of emissions factors for the same type of fuel are fairly consistent. In a review of country specific emissions factor in Europe, the range of diesel values were within 0.3% of the IPCC default factor on average. Other fuels showed greater ranges, with bitumen and refinery gas showing the greatest difference at around 12%[105].

CH_4 AND N_2O

The default factors for CO_2 neglect two other greenhouse gases typically produced during consumption of diesel fuel for transportation— CH_4 and N_2O. In addition to emissions factors for CO_2, the EPA produces emissions factors for CH_4 and N_2O based on engine testing. These emissions factors are produced in terms of grams of CH_4 and N_2O per mile driven, based on vehicle type, emissions control technology, and fuel type. The GHG Protocol converts these into emissions factors in terms of CH_4 and N_2O per gallon based on assumptions regarding the MPG of different vehicle types.

Using a default heavy-duty articulated diesel freight truck achieving 5.9 MPG this produces emissions factors of 0.03009 g CH_4/gallon and 0.02832 g N_2O/gallon.

[iii] Throughout this document, the term gallons shall be used to reference a US Gallon (~3.79 liters).

Using the previous example of 1000 gallons of diesel fuel consumed this produces the following results.

$$1000 \text{ gallons x of } 0.03009 \text{ g } CH_4/\text{gallon} = 30.09 \text{ g } CH_4$$

$$1000 \text{ gallons x } 0.02832 \text{ g } N_2O/\text{gallon} = 28.32 \text{ g } N_2O$$

The values can be converted to carbon dioxide equivalents by multiplying each value by the global warming potential of the gases. The IPCC 4th Assessment defines the 100-year GWP of CH_4 and N_2O to be 25 and 298, respectively[106]. Applying the values to the previous calculations we have the following results.

$$30.09 \text{ x } 25 = 752.25 \text{ g } CO_2e$$

$$28.32 \text{ x } 298 = 8{,}439.36 \text{ g } CO_2e$$

Combining these with the results from the CO_2 produced by 1000 gallons of diesel we can calculate the total CO_2e produced as 10,159.2 kg. In general, the non-CO_2 gases produce relatively little contribution to the total for standard transportation fuel (less than 2%). As such, many tools exclude their calculation and focus only on CO_2. If CH_4 and N_2O are included it may be necessary to include additional activity data (such as miles traveled and emissions control technologies), or combine the assumptions regarding CO_2, N_2O, and CH_4 to create a single emissions factor. For the example of US diesel in a default heavy-duty articulated truck the factor would be 10.1592 CO_2e/gallon.

In addition to the greenhouse gases considered, the range of possible fuel types creates a need for a variety of emissions factors. Some fuels require emissions factor represented in different units, such as standard cubic feet for CNG. A comprehensive GHG calculator must supply emissions factors for a variety of different fuel types in factors that represent their typical usage. The default emissions factors used in the GHG Protocol based on factors developed by the EPA is shown in Table 7.

Fuel	Region	CO_2	CO_2 Biomass	CO_2 Unit - Numerato	CO_2 Unit - Denominator
Jet Fuel	US	9.57	0.00	kg	Gallon
Aviation Gasoline	US	8.32	0.00	kg	Gallon
Gasoline/Petrol	US	8.81	0.00	kg	Gallon
On-Road Diesel Fuel	US	10.15	0.00	kg	Gallon
Residual Fuel Oil (3s 5 and 6)	US	11.80	0.00	kg	Gallon
LPG	US	5.79	0.00	kg	Gallon
CNG	US	0.05	0.00	kg	Std Cubic Foot
LNG	US	4.46	0.00	kg	Gallon
Ethanol	US	0.00	5.56	kg	Gallon
100% Biodiesel	US	0.00	9.46	kg	Gallon
E85 Ethanol/Gasoline	US	1.32	4.73	kg	Gallon
B20 Biodiesel/Diesel	US	8.12	1.89	kg	Gallon

Table 7: Fuel Emission Factors

The inclusion of biofuels introduces a second complication—the need to separate emissions from fossil fuels from biomass. This can be seen explicitly in the factor forE85 Ethanol, where the 15% assumed to come from standard gasoline produces 1.3215 kg of CO_2, while the remaining 85% ethanol is assumed to produce 4.726 kg of CO_2. These are tracked separately because the CO_2 emissions from biomass do not represent new emissions of CO_2 to the atmosphere, but rather the release of CO_2 that had been sequestered from the atmosphere during production of the biomass.

The focus only on the direct emissions produced during combustion (tank-to-wheel) make comparisons between traditional fuels, biofuels, and electric vehicles difficult. The net contribution of biofuels to global warming is dependent on the share of biomass used in the fuel and the emissions generated producing the biomass used to make the fuel. Electric vehicles produce no tailpipe emissions, but do produce emissions during the upstream electricity generation phase. In order to provide a true comparison of the effect of different fuel sources, the use of emissions factors that consider both the direct emissions and the indirect emissions from fuel production is needed.

UPSTREAM EMISSIONS

The GREET[107] model produced by Argonne National Lab uses a Life Cycle Assessment approach to produce emissions factors for a variety of fuels that includes the upstream portion of the fuel cycle. The fleet calculator provides factors for 12 different vehicle and fuel types, and based on their modeling assumptions produces factors in terms of CO_2e per unit of fuel, shown in Table 8.

Fuel Type	kg CO_2e	Denominator
Gasoline	11.151	gallons
Diesel	12.93	gallons
Diesel HEV	12.93	gallons
B20	10.82	gallons
B100	2.96	gallons
E85	6.13	gallons
CNG	0.09	cubic feet
LNG	6.54	gallons
LPG	7.52	gallons
Electricity	0.68	kilowatt-hours
G.H2	0.04	cubic feet
L.H2	6.45	gallons

Table 8: Well-to-Wheel Emissions Factors

The use of emission factors that consider a greater level of depth in the measurement increase the total impact of transportation by including the emissions related to the production of fuel. Using the default emission factor for diesel we calculated earlier and comparing it to the WTW numbers produced by GREET provide the following results for the combustion of 1000 gallons of diesel.

$$1000 \text{ gallons x } 10.1592 \text{ } CO_2e/\text{gallon} = 10{,}159.2 \text{ kg } CO_2e$$

$$1000 \text{ gallons x } 12.9336 \text{ } CO_2e/\text{gallon} = 12{,}933.6 \text{ kg } CO_2e$$

The greater depth of the GREET number produce results that are 27% greater than in the tank-to-wheel scenario. Using the GREET factors approximately 20% of total emissions are the result of upstream production in the case of diesel. The numbers are more complex when biofuels are taken into account. The GHG Protocol factors for biodiesel, taken from the EPA, account for no non-biomass CO_2 emissions. Using those numbers for 1000 gallons of biodiesel produces results that indicate 0 kg of CO_2 and 9,460 kg of biomass CO_2. Applying the factor for B100 supplied by GREET produces at estimated 2,964 kg of CO_2e.

SUMMARY OF FUEL BASED SCENARIOS

Based on the scenarios considered, the results of a fuel-based calculation can differ significantly based on the breadth, depth, and precision of the emissions factors considered. Breadth includes the range of GHGs (CO_2, CH_4, N_2O) included in the emissions factor and the available types of fuels. Precision accounts for the level of detail in the factor—such as whether country-specific factors are considered or the range of assumptions built into the factor (carbon content, heating value, oxidation %, vehicle MPG efficiency, emissions control technology). Depth is primarily based on whether a WTW or TTW analysis is used, and is of particular importance when comparing non-conventional transport fuels.

The choice of emissions factors to include in any tool limits the available choices that users may make and the types of analysis that may be performed. In some cases users may not have the specific knowledge needed to determine the best emissions factors to use and simpler emissions factors that make use of standard default values may be easier to use in practice. Table 9 summarizes the results from a number of different emissions factors used in the previous discussion for consumption of 1000 gallons of fuel. The results highlight the impact that the choice of emissions factor has on the output of the tool.

Fuel	GHGs	Source	Scope	Results	Units
Diesel	CO_2	Defra	Pump-to-wheel	9,998	kg CO_2
Diesel	CO_2	EPA	Pump-to-wheel	10,150	kg CO_2
Diesel	CO_2, CH_4, N_2O	GHG Protocol (EPA)	Pump-to-wheel	10,159	kg CO_2e
Biodiesel	CO_2	GHG Protocol (EPA)	Pump-to-wheel	0	kg CO_2
Biodiesel	CO_2 (biomass)	GHG Protocol (EPA)	Pump-to-wheel	9,460	kg CO_2
Diesel	CO_2, CH_4, N_2O	GREET	Well-to-wheel	12,933	kg CO_2e
Biodiesel	CO_2, CH_4, N_2O	GREET	Well-to-wheel	2,964	kg CO_2e

Table 9: Comparison of Results for 1000 Gallons Consumed

ACTIVITY BASED METHODS

When direct fuel consumption data is not available a number of activity-based methods are available. While considered less accurate than fuel-based methods for CO_2 calculations, they offer advantages in terms of more easily acquired data and the ability to estimate future emissions from predicted transportation demand. Activity-based methods generally work by estimating the fuel consumed during transportation based on vehicle characteristics, or combining fuel consumption data with activity data to calculate average efficiency numbers.

Like fuel-based methods these methods will be sensitive to the choice of fuel emissions factors, but our focus here is on how the fuel consumption is estimated, rather than the emissions from the fuel itself.

VEHICLE DISTANCE BASED

The simplest approach to estimating emissions from activity data is to use the distance traveled multiplied by the average fuel consumption of the vehicle. Together these produce an estimate of the fuel consumed, which can then be used to estimate GHG emissions by choosing an appropriate factor as discussed in the fuel-based methods. A number of different approaches have been used in practice to estimate vehicle-distance emissions factors, generally varying in the level of precision they provide.

The GHG Protocol provides default emissions factors per mile for a number of vehicle types using both US and UK numbers. The emissions factors for US vehicles are based on assumed average vehicle efficiency for a variety of vehicle types (Heavy Duty, Light Duty, Passenger Cars, Motorbikes, etc.) to determine fuel consumption, and the standard factors for CO_2, CH_4, and N_2O from the EPA discussed in the fuel-based section. Numbers in the UK are based on surveys of fuel consumption in vehicle fleets. The fuel consumption data is combined with Defra's standard CO_2 factor to produce an emission factor consider only CO_2 on a per kilometer basis.

Other sources have focused more on a single mode type to provide more precise levels of emissions factors. The EPA's SmartWay program collects data from a number of different carriers. They employ a fuel-based methodology to calculate emissions from the carriers, and combine this with activity data supplied by the carriers to calculate distance based emission factors at the individual carrier level. The tool also allows the carriers to enter data not just at the company level, but also for various fleets or operating sectors within the company. This is used to create a hierarchy of emissions factors, where a user can select emission factors from a mode (truck, rail, multi-modal, logistics), a category within the mode (such as package, tl/dry van, refrigerated, and others within the truck category), and finally a specific carrier within that category. Likewise, a single company may have a number of different emissions factors, one for each category of business they reported data for.

The NTM program does not collect specific data from carriers, but rather uses the ARTEMIS simulation tool to calculate fuel consumption for a number of different

The NTM program does not collect specific data from carriers, but rather uses the ARTEMIS simulation tool to calculate fuel consumption for a number of different scenarios[108]. These scenarios account for different sizes of vehicles, % loaded, road type, and driving conditions. Using these scenarios and an associated fuel-based emissions factor a range of emissions factors can be calculated.

In each case the emissions are calculated using a straightforward multiplication of the distance and the vehicle-specific emissions factor. Table 10 shows a summary of the results of using a number of different types of factors to calculate the emissions from a 1,000 mile trip.

Source	Emission Factor	Value	Units	GHGs	Total	Units
GHG Protocol	Heavy Duty Vehicle - Articulated - Diesel - Year 1960-present (US EPA)	1.722	kg CO_2e/mile	CO_2, CH_4, N_2O	1,722	kg CO_2e
GHG Protocol	HGV - Articulated - Engine Size Unknown (UK Defra)	1.560	kg CO_2/mile	CO_2	1,560	kg CO_2
GHG Protocol	HGV - Rigid - Engine Size 7.5 - 17 tonnes - 50% Weight Laden (UK Defra)	1.235	kg CO_2/mile	CO_2	1,235	kg CO_2
SmartWay	Flatbed, Carrier A[a]	1.700	kg CO_2/mile	CO_2	1,700	kg CO_2
SmartWay	TL/Dry Van, Carrier A[b]	1.750	kg CO_2/mile	CO_2	1,750	kg CO_2
SmartWay	TL/Dry Van, Carrier B*	1.550	kg CO_2/mile	CO_2	1,550	kg CO_2
NTM	Small lorry/truck, Motorway, 100% loaded	0.583**	kg CO_2/mile	CO_2	583	kg CO_2
NTM	Lorry/Truck + Semi-trailer, Motorway, 100% loaded	2.296**	kg CO_2/mile	CO_2	2,296	kg CO_2
NTM	Lorry/Truck + Semi-trailer, Urban roads, 0% loaded	1.569**	kg CO_2/mile	CO_2	1,569	kg CO_2

Table 10: Estimated Emissions for a 1000 Mile Distance

a. Specific carrier names and factors are available for download
b. Assumes default Defra factor for diesel fuel

Despite little variation between emissions factors for diesel fuel, the emissions estimated for a specific trip can vary considerably. This is true even for vehicles in the same class, as the NTM factors shown for a truck + semi-trailer range from 1.569 to 2.296 depending on the load factor and road type. The SmartWay factors show that the results can vary depending on the specific carrier and type of freight as well. This demonstrates important points about the precision of the emissions factors used. Estimations of fuel consumed can vary considerably, and therefore even if consistent fuel-based factors are used the results obtained from activity-based data are sensitive to the assumptions regarding vehicle operating conditions. Providing emissions factors at a variety of levels of detail allow users to make best estimates based on their level of knowledge of the system, improving estimated values.

WEIGHT DISTANCE BASED

Despite the ease of using vehicle-distance factors and the availability of a wide range of emissions factors, is it inappropriate when used for shared modes or when only the bare minimum of information is known about the shipment. In first case, the emissions of the vehicle as a whole are not of concern, rather the share of emissions related to a specific amount of goods are considered. In the second case, the shipper may not know the specific vehicle and distance that were used.

In these situations weight-distance methods are generally used, though in some cases a volume-distance method may be more appropriate. Emissions factors for weight-distance methods are generally expressed in terms of ton-miles of goods moved (or perhaps TEU-miles for ocean containers where volume may be more important than weight). These methods provide a quick and easy method of calculating emissions, relying only on the weight of the goods shipped, the distance, and a general knowledge of the mode of transport used. They are also useful in comparing between modes, where efficiency is measured not just in the amount of emissions produced but the total amount of goods moved.

The GHG Protocol provides emissions factors in terms of ton-miles for a variety of transportation modes, using factors derived from both the EPA and Defra. Other calculators, such as NTM or EcoTransIT, also provide similar capabilities. These factors introduce another layer of assumptions beyond those of fuel-based and vehicle-distance based methods, as now the factors must include assumption regarding the total amount of goods on the vehicle. This can lead to a wide range of emissions factors depending on the assumptions used. This is illustrated in Table 11, where emissions factors for different modes and types of transportation are compared for a shipment consisting of 10,000 short ton-miles (equivalent to a 10 ton shipment being moved 1,000 miles).

Source	Emission Factor	Value	Units	GHGs	Total (kg CO_2)
GHG Protocol	Air – Long Haul (US EPA)	1.527	kg CO_2/ton-mile	CO_2	15,270
GHG Protocol	Air – Long Haul (UK Defra)	0.346	kg CO_2/ton-mile	CO_2	3,460
GHG Protocol	Air – Domestic (US EPA)	1.527	kg CO_2/ton-mile	CO_2	15,270
GHG Protocol	Air – Domestic (UK Defra)	1.105	kg CO_2/ton-mile	CO_2	11,050
GHG Protocol	Watercraft – Shipping – Large Container Vessel (20000 tonnes deadweight) (US EPA)	0.048	kg CO_2/ton-mile	CO_2	480
GHG Protocol	Watercraft – Shipping – Large Container Vessel (20000 tonnes deadweight) (UK Defra)	0.007	kg CO_2/ton-mile	CO_2	70
GHG Protocol	Watercraft – Shipping – Small Tanker (844 tonnes deadweight) (US EPA)	0.048	kg CO_2/ton-mile	CO_2	480
GHG Protocol	Watercraft – Shipping – Small Tanker (844 tonnes deadweight) (UK Defra)	0.019	kg CO_2/ton-mile	CO_2	190
GHG Protocol	Road Vehicle – HGV – Articulated – Engine Size > 33 tonnes (US EPA)	0.297	kg CO_2/ton-mile	CO_2	2,970
GHG Protocol	Road Vehicle – HGV – Articulated – Engine Size > 33 tonnes (UK Defra)	0.049	kg CO_2/ton-mile	CO_2	490

GHG Protocol	Road Vehicle – Light Goods Vehicle – Petrol – Engine Size 1.305 – 1.74 tonnes (US EPA)	0.297	kg CO_2/ton-mile	CO_2	2,970
GHG Protocol	Road Vehicle – Light Goods Vehicle – Petrol – Engine Size 1.305 – 1.74 tonnes (UK Defra)	0.462	kg CO_2/ton-mile	CO_2	4,620
GHG Protocol	Rail (US EPA)	0.025	kg CO_2/ton-mile	CO_2	250
GHG Protocol	Rail (UK Defra)	0.016	kg CO_2/ton-mile	CO_2	160

Table 11: Results for a 10000 Short Ton-Mile Shipment

The table shows the wide variation not just between modes, where ocean shipping may be as much as 200 times more efficient than air transport, but also between sources. The EPA's numbers are based on high level, and do not distinguish between types of transport within a mode. Thus, there is no distinction between heavy-duty trucks or light-duty vehicles within road transport, or between large container ships and small tankers in watercraft. This is in contrast to the Defra numbers that are generated at a greater level of precision and show the range of values that can exist between different types of transport.

DISTANCE CALCULATION

The final step necessary to calculate emissions using activity data is a method to estimate distance traveled when the exact details are not known. The simplest method of estimating the distance between two points on the Earth is through a great circle calculation. The great circle calculation estimates the distance between two points on a sphere, measured along the surface of the sphere rather than going through it. Using latitude and longitude to mark a location's spot, and assuming the Earth is a sphere, the great circle distance provides a rough estimate of the travel distance between two points.

Actual travel distance between points varies depending on the actual route of travel (see Table 12 for an example for road and rail). This ratio of the actual distance to the great circle distance is referred to as the circuity factor, and varies depending on the mode of travel and the structure of the network. Estimates for the United States put network circuity at 1.21 for road[109], 1.45 for rail, and 1.94 for barge[110]. Calculations for ocean distances are more complicated, as vessels must navigate around land rather than over a specific route network. Circuity factors can also vary by country, further complicating distance calculation.

A number of services are available that can perform more sophisticated distance calculations. Distances between locations are estimated using models of actual road, rail, and water networks. Using these services a better distance estimate can be obtained, but does not account for any deviations due to the actual route taken. Sophisticated systems that bring together all the networks and model intermodal transfer points are capable of generating multi-modal trips. Without knowledge of the actual route; however, all of these methods must make assumption regarding the route and transfer points, and thus may not model the actual route chosen. Further, network models are not available for all global locations, so a comprehensive solution capable of calculating distances for all possible shipments is not currently available.

Origin	Destination	Mode	Method	Distance (miles)	Circuity
Los Angeles	Chicago	Road	Great Circle[111]	1,745	NA
Los Angeles	Chicago	Road	Google Maps[112]	2,029	1.16
Los Angeles	Chicago	Road	MapQuest[113]	2,031	1.16
Los Angeles	Chicago	Rail	Great Circle	1,745	NA
Los Angeles	Chicago	Rail	BNSF Calculator[114]	2,120	1.21
Los Angeles	Chicago	Rail	CSX Calculator[115]	2,218	1.27
Boston	Miami	Rail	Great Circle	1,258	NA
Boston	Miami	Rail	CSX Calculator	1,636	1.30

Table 12: Distance Comparison

The issue of distance calculation can be particularly important in ocean and airfreight, where the details of the routing may be of increased importance. In airfreight, the LTO phase can consume a significant amount of fuel. Since each flight must take off and land, regardless of the overall distance of the flight, this can cause shorter flights to emit more CO_2 per km than longer flights. This is illustrated in Table 13, showing illustrative data for a Boeing 737-400 under different flight distances[116].

		Standard flight distances (nm) [1 nm = 1.852 km]						
		125	250	500	750	1,000	1,500	2,000
Fuel (kg)	Flight total	1,603	2,268	3,613	4,960	6,303	9,187	12,168
	LTO	825	825	825	825	825	825	825
	Non-LTO	778	1,443	2,787	4,135	5,477	8,362	11,342
Emissions (kg CO2/km)		21.9	15.5	12.3	11.3	10.8	10.5	10.4

Table 13: Data for Boeing 737-400

A shipment traveling 1,000 nm by making two 500 nm flights could emit 14% more CO_2 than if it was made using a single 1,000 nm flight. Similarly, two 250 nm flights would emit 26% more CO_2 than a single 500 nm flight. The combination of higher average emissions from shorter flights and differences in aircraft type and utilization can produce drastically different emissions factors for freight. Using surveys regarding aircraft type and utilization, along with data on fuel consumption from the European Environment Agency (EEA), Defra estimated that emissions for freight on domestic flights emitted 2.41 kg CO_2/tonne-km while freight on long-haul flights emitted 0.62 kg CO_2/tonne-km.

These differences in emissions factors highlight the need for getting accurate flight data to estimate emissions from airfreight. In a hub and spoke network it is possible for a shipment to make multiple short-haul flights rather than a single long-haul flight directly from the origin to the destination. With short-haul and domestic flights emitting two or three times the amount of CO_2 as long-haul flights this can lead to significant errors in estimation in incorrect data is used.

OTHER ISSUES

In addition to the issues related to the development of appropriate emissions factors and methods there is also the question of how such methods can be combined for more complicated scenarios. There are two particular scenarios worthy of further attention. First, how should emissions from multi-modal moves be combined to produce a calculation for the movement as a whole. Second, how should the emissions from shipments carrying the goods of multiple users be allocated between the different users.

INTERMODAL

The simplest version of a multi-modal move may be a combined road-rail intermodal shipment. In an intermodal shipment the goods are picked up and delivered by truck, referred to as drayage movements. In between the drayage movements the goods are loaded on a railway to provide a rail line haul. This method combines the point-to-point service of trucking with the efficiency of rail in order to provide a single seamless movement to the shipper.

Calculating emissions from intermodal shipments requires knowledge of the distances of the drayage movements and the rail haul, as well as the relative efficiencies of the modes. When these are known the total carbon footprint of the shipment can be calculated using standard methods, treating the total journey as three separate movements. However, this may be difficult in practice. Different companies may perform the drayage movements and rail haul, and the overall movement may be coordinate by an intermodal operator[117].

Table 14 shows a comparison of the CO_2 calculated for an intermodal shipment between San Diego, CA and Bloomington, MN using three different methods. The first uses data supplied by the intermodal operator regarding drayage distances, length of the rail haul, average drayage efficiency calculated by the operator, and rail efficiency supplied by the railway. The second approach uses the average CO_2 per ton-mile for all intermodal movements performed by the operator, along with the shipment weight and great circle distance between the origin and destination to estimate emissions. The third approach uses the locations of the origin, destination, and the intermodal ramps to calculate distances (via Google maps for drayage and the CSX distance calculator for rail). This is combined with standard emissions factors from the GHG Protocol mobile calculator to estimate emissions from the drayage movements and rail haul.

Calculation Method	Estimated Travel Distance (miles)	Estimated CO_2 (tonnes)	% Difference
Intermodal Operator Data	2,721	2.48	NA
Average Intermodal Efficiency	1,524	1.90	-23%
Movement distances + average mode efficiency	2,348	1.88	-24%

Table 14: Comparison of Intermodal CO_2 Estimates

Using the intermodal operator's actual data and the full details of the shipment produces significantly higher total emissions than estimates using average efficiency or standardized factors. The average efficiency number does not account for the higher-than-average amount of drayage required for this shipment, and the resulting lower level of efficiency achieved. Using publicly available data underestimates the total distance traveled on the rail haul. The use of the shipment weight in the calculations also underestimates the emissions from rail due to failure to include the weight of the chassis required for intermodal movement. As movements involve multiple modes they become more complex, and assumptions regarding how the movement is made can affect the calculated carbon. This must be considered when creating a tool that estimates carbon for all types of shipments.

ALLOCATION

Finally, a method of allocation must be identified to separate emissions from shared modes of transport. The EN 16258 standard provides a number of methods for separating emissions from freight and passengers, as well as between shipments on the same vehicle. At its core the allocation process must calculate the emissions for the vehicle as a whole, and then assign those emissions to each of the shipments it carries. This could be done based on volume, weight, distance, value, or some combination of these.

One of the simplest scenarios that illustrates the issue is shown in Figure 23. A truck leaves the depot with 25 tons worth of goods to deliver to three customers, visited in order. After delivery to Customer 3 the truck returns empty back to the depot. During the course of the 80 mile round trip the truck burns 15 gallons of fuel and produces approximately 150 kg of CO_2. The allocation process must specify how those 150 kg should be assigned to the different customer shipments.

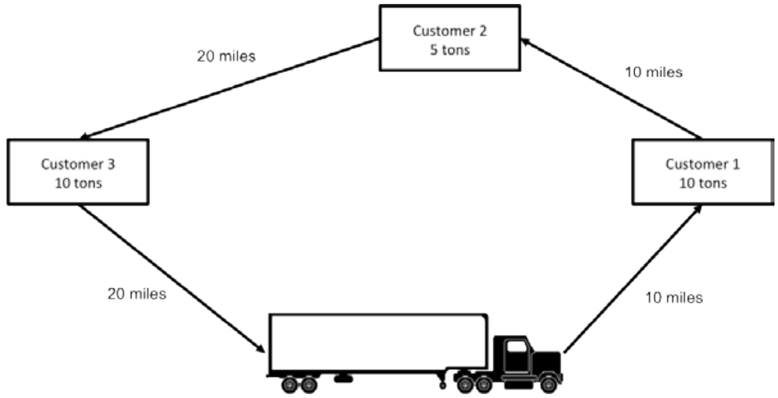


Figure 23: Delivery Scenario

A number of possible approaches could be used. The emissions could be divided equally, with each customer being charged for 50 kg CO_2. It could be allocated by weight, such that Customer 1 is charged 60 kg CO_2, Customer 2 30 kg CO_2, and Customer 3 60 kg CO_2. The emissions could be allocated by how far away each customer is, or by the combined ton-miles required to serve them.

Customer 1 is 10 miles away and received 10 tons, for 100 total ton-miles. Customer 3 is clearly 20 miles away and received 10 tons, for 200 total ton-miles. It is not clear which distance to use for Customer 2. The truck drove 20 miles to reach the customer, but only after stopping at Customer 1. Using the great circle distance the customer is perhaps 15 miles away, resulting in 75 ton-miles. That produces a total of 375 total ton-miles for the trip. Allocation on this basis would be 40 kg CO_2 to Customer 1, 30 kg CO_2 for Customer 2, and 80 kg CO_2 for Customer 3.

ALLOCATION IN COMBINED PASSENGER AND FREIGHT SERVICE

In some cases allocation must be performed to calculate emissions for freight that is moved along with passengers in the same vehicle. The EN16258 standards specifically discuss the scenario where freight is carried in the belly of a passenger plane. In these situations an allocation method must be specified that allows the emissions to be shared between the two purposes of moving passengers and moving freight.

The ISO standards for LCA call for allocation to be performed based on the underlying physical relationships between inputs and outputs, but where that cannot be established the economic value or another relationship may be used. The EN16258 standards specify the use of mass as the method of allocation between passengers and freight. Passengers, including their baggage, are assumed to have a mass of 100 kg. The number of passengers is multiplied by this number to get the total mass of passengers. The total mass of freight is then calculated and assigned a share of emissions based on the share of total mass, passengers plus freight, represented by the freight. The remaining emissions are allocated towards passenger movement.

The use of a basic physical allocation method like mass represents one type of a non-economic relationship. Economic allocation uses the value of the outputs as the means of allocation. In some cases this may be more representative of the true drivers of system behavior, and may be preferred. In the airfreight example, the total value of passenger tickets sold could be used to determine the value of the passenger travel, while the revenue from freight carried in the plane could be used to estimate the value of freight. Emissions would be allocated between passengers and freight based on their share of total revenue.

The choice of allocation method can have significant impact on calculated emissions. No allocation method can ever be considered right for all situations, so the trade-off among different choices must be considered. To provide consistency it should be clear that all emissions, including those from empty movements, must be allocated. In addition, allocations that are independent of arbitrary choices such as which customer is delivered to first should be avoided. No choice of method will necessarily satisfy all stakeholders perfectly, so a focus on consistency and transparency is recommended.

SUMMARY

The process of estimating emissions using fuel-based and activity-based data is simple in concept, but often remains complicated in practice. Assumptions regarding fuel, distance, vehicle efficiency, and utilization can introduce uncertainty into estimates. Capturing data at a level of detail needed for more precise estimates is often not possible. In the next section we present a specific set of tasks required to develop the elements of a decision support tool. As seen by the examples in this section, many of the functions of the tool can operate at different levels of sophistication, requiring a flexible tool capable of taking advantage of more detailed data when it is available.

TASK LIST

Based on the architecture defined in this chapter, there are six primary tasks composed of 11 sub-tasks that need to be completed to create a decision tool. Some of the tasks involve surveying current programs and other available technologies to identify data and best practices that can be integrated with a new tool. The example scenarios are intended to help clarify the issues involved in assessing how well those current practices can serve the needs of a new decision tool. The remaining tasks generally involve developing the back-end software support needed by the tool, at varying levels of sophistication depending on the type of tool envisioned.

TASK 1—DEFINE CALCULATION METHODOLOGIES

The review of methodologies in Chapter 2 identified two primary methodologies: fuel-based and activity-based. Activity-based methodologies generally consist of vehicle-distance and weight-distance methods, though other activity data can also be used (for example, dollar value spent for EIO-LCA methods). The first task is to define the calculation methodologies that will be used in the tool. The results from this task define the necessary emissions factors for Task 2 and the acceptable forms of data entry for Task 3.

TASK 2—COMPILE EMISSIONS FACTOR DATABASE

TASK 2.1 – COLLECT EXISTING EMISSIONS FACTORS

Based on the review of methods and proposed definition in Chapter 1, a database of emissions factors must be compiled to support the calculation methodologies. Based on the working definition of the carbon footprint of the supply chain, these emissions factors should consider a well-to-wheel system boundary. At a minimum, this includes emissions factors for a wide variety of fuel types and activity-based factors for all four main transport modes. Emissions factors in terms of energy consumed and TTW emissions scope may also be included in order to provide compatibility with requirements of EN 16258.

TASK 2.2 – DEFINE A HIERARCHY OF EMISSIONS FACTORS

As the available emissions factors define the precision with which the carbon footprint can be calculated, this task must also include a review of existing emissions factor databases to determine the appropriate range of factors within a category. This includes the appropriate regional emissions factors for fuel-based methods, with a primary focus on electricity generation. For activity-based factors this includes developing a hierarchy of data precision that might include modes, sub-modes, vehicle types, company, lane, or shipment specific factors.

TASK 3—DEVELOP A USER INTERFACE AND DATA ENTRY SYSTEM

TASK 3.1—DEFINE DIRECT DATA ENTRY METHODS

When specific data related to fuel use or distance traveled is available, users may enter this data directly. The user interface must specify the method of data entry and define the required data. The interface must connect with the emissions factor database to allow user selection of appropriate factors. The interface should support automated data input through saved data archive files created by the tool.

TASK 3.2—CREATE AN INTERFACE FOR A NETWORK VIEW

When distance and fuel are unknown, the tool should support a network view of data entry. The system allows users to enter shipment origin and destinations and automatically performs distance calculation. The system must interface with the route calculation service to provide the distances.

TASK 4—IMPLEMENT A ROUTE CALCULATION SERVICE

TASK 4.1—EVALUATE EXISTING TECHNOLOGIES

The tool must be capable of calculating the distance between two entered points. Existing routing technologies should be reviewed for their suitability based on cost, accuracy, and ease of use. The selected technology or technologies must support all four major modes (road, rail, air, and water) at the global level. At a minimum the system should support calculation of great circle distance between points.

TASK 4.2—INTEGRATE SELECTED TECHNOLOGY WITH CALCULATION TOOL

Based on the technology or technologies defined in Task 4.1, an interface to the data entry system of Task 3.2 must be implemented. The service shall take the origin, destination, and modes entered by the user and return the calculated distance between the points.

TASK 5—CREATE A PERFORMANCE DASHBOARD

TASK 5.1—IDENTIFY KEY PERFORMANCE INDICATORS

The work identified in this report has indicated total CO_2e and CO_2e per ton-mile as the primary performance indicators for the calculator. Possible secondary performance indicators include CO_2e per mile, CO_2e per ton, and CO_2e per unit of volume. Each of these performance indicators can be calculated at an individual shipment level, or aggregated at mode, company, lane, or other level. Using the programs identified in this project, the indicators identified in NCFRP Report 10, and other literature, a review should be conducted to determine the specific series of performance indicators that should be calculated by the tool and the appropriate level of aggregation for those indicators.

TASK 5.2—CREATE PERFORMANCE DASHBOARD

Based on the KPIs identified in Task 5.1 and the calculation methodologies defined in Task 1, a performance dashboard shall be created to compile the results of the calculations and display the resulting indicators to the user. Existing performance dashboards and best practices should be reviewed to determine the appropriate information and display format.

TASK 6—UPDATE AND MAINTAIN DATA ARCHIVE

TASK 6.1—CREATE ARCHIVE FORMAT

The results of the tool, both in terms of data entered and calculated results, should be saved in an appropriate data archive format. The format should allow for transfer of data between users on separate systems, or storage on a network location. The format should be readable by the tool such that the archived format can be read as input to the tool. A centralized network location should be created that can accept and store archived data.

TASK 6.2—UPDATE EMISSIONS FACTORS DATABASE

The emissions factor database shall be updateable to receive calculated results from the tool and store new emissions factors. This should allow data supplied by users of the tool to create company-specific emissions factors. These factors should be stored in a centralized repository, and the tool shall regularly update emissions factors from the repository as they become available.

TIMELINE

Given the tasks outlined for a future tool, there is significant flexibility in the time and cost required to implement the tool based on the desired level of sophistication. The GHG Protocol tool is perhaps one of the most popular tools in use, but is little more than a Microsoft Excel spreadsheet. The EPA SmartWay tool is also implemented in Excel, though with some increased functionality due to the use of macros. At the other end of the spectrum are tools like the GIFT tool that use a multi-modal, GIS based approach and represents a years long research process.

Two possible development paths and their associated development timelines are presented below. The first is a simplified tool that could be developed in several months. It would be a static tool that serves mainly to provide a consistent set of emissions factors and methods that meets the needs identified in this report. The second is a more advanced tool that provides a more dynamic, robust set of features. This tool would require professional software development, and is designed to be delivered by a web application or stand-alone software application.

BASIC TOOL

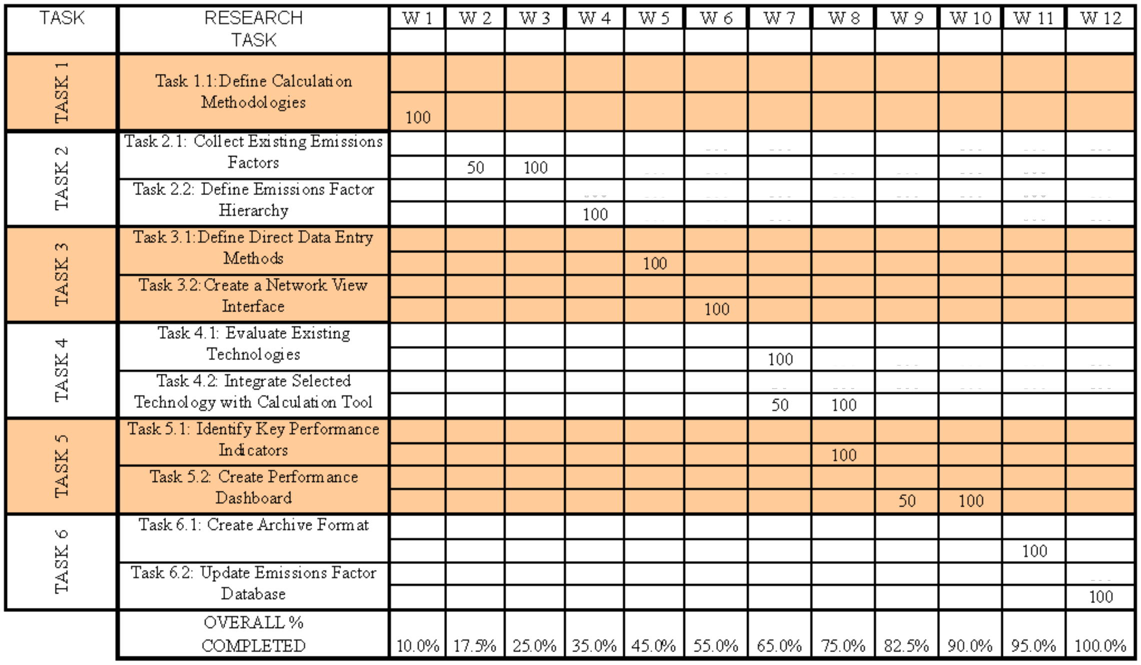
A basic tool would require little more than a form for data entry linked to data tables of emissions factors and locations. This tool could be developed in a three-month timeframe and could be developed with little professional software experience. The tool could be implemented in standard business software such as Microsoft Excel, or through a basic web interface. The tool could be made available for download, and would serve as a standalone calculation tool that does not require an interface with other programs or services.

The primary work related to this tool would be contained in Task 2 and Task 3. After defining the appropriate calculation methodologies, a consistent set of emissions factors must be developed. These emissions factors should provide a consistent system boundary for the emissions included, and may require creation of custom emissions factors by combining WTW fuel emissions factors with fuel consumption estimates from other sources. At a minimum, emissions factors for different fuel types and averages by ton-mile for each mode type should be provided.

Distance calculation would be provided through a pre-determined list of locations. This would allow users to choose origins and destinations from the list of locations, and perform basic great circle distance calculations between those points or lookup distances from a data table. This would make the tool self-contained, and remove any need for other software services or an internet connection.

The user interface would use relatively simple data entry and selections. Data entry would collect the necessary fuel and activity data, while the selections would allow user to choose the appropriate emissions factors and select locations for distance calculations. The output would be summarized in a set of standardized tables and charts. The results of the calculations would be savable to a local file. The saved files would be capable of being read by the tool to allow sharing of data without the need for reentering data.

This tool would meet the needs of a basic carbon calculator suitable for wide use, but would be limited due to the static nature of the tool. Users would be limited by the available choices of factors and locations. A proposed schedule for a three month (12 week) development plan is shown in Figure 24.



TASK	RESEARCH TASK	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12
TASK 1	Task 1.1: Define Calculation Methodologies	100											
TASK 2	Task 2.1: Collect Existing Emissions Factors		50	100									
	Task 2.2: Define Emissions Factor Hierarchy				100								
TASK 3	Task 3.1: Define Direct Data Entry Methods					100							
	Task 3.2: Create a Network View Interface						100						
TASK 4	Task 4.1: Evaluate Existing Technologies							100					
	Task 4.2: Integrate Selected Technology with Calculation Tool							50	100				
TASK 5	Task 5.1: Identify Key Performance Indicators								100				
	Task 5.2: Create Performance Dashboard									50	100		
TASK 6	Task 6.1: Create Archive Format											100	
	Task 6.2: Update Emissions Factor Database												100
	OVERALL % COMPLETED	10.0%	17.5%	25.0%	35.0%	45.0%	55.0%	65.0%	75.0%	82.5%	90.0%	95.0%	100.0%

Figure 24: Schedule for Basic Tool Development

ADVANCED TOOL

The advanced tool would expand on the capabilities of the basic tool through a more advanced user interface, actual route calculations, and a dynamic set of emissions factors that could be updated based on data provided by users. Ideally, the tool would be a web-based application to allow connection to other software services, though a standalone software application with updates delivered automatically through the internet is also a possibility. The increased capabilities necessitate the use of professional software development, and a longer one year development time is anticipated.

The primary differences between the tools are the expansion of Task 4 and Task 6, as well as a general increase in complexity and capability. Task 4 will now require implementation of actual routing through integration with road, rail, and water routing services. Great circle distance calculation would be included only for regions where no routing data was available. This requires additional time to study potential services and integrate the chosen service with the tool. Task 3.2 will also increase in complexity, as a graphical user interface and other capabilities may be needed to harness the more powerful routing capabilities.

Task 6 requires more work to allow the tool to capture data from users and use this to provide expanded emissions factors. The capabilities would be similar to those provided by the EPA SmartWay tool that allows data entered by carriers to be shared and used by shippers to calculate their own emissions. This capability requires the ability to calculate and store company specific emissions factors, make these factors available to users, and protect any sensitive information.

The longer development time for the remaining tasks represents an increase in the scope and complexity of the tool. The emissions factors database should be more comprehensive, and allow a greater level of precision through inclusion of additional factors. The user interface should include a more intuitive GUI and allow for modeling several types of what-if scenarios based on the data input. The performance dashboard should have the capability of generating more extensive metrics, reports, and analytics for output. Together these changes represented a more polished user interface, easier analysis of scenarios, and better reporting to aid in decision-making. A proposed schedule for a one year (12 month) development plan is shown in Figure 25.

TASK	RESEARCH TASK	M 1	M 2	M 3	M 4	M 5	M 6	M7	M 8	M 9	M 10	M 11	M 12
TASK 1	Task 1.1: Define Calculation Methodologies	100											
TASK 2	Task 2.1: Collect Existing Emissions Factors	25	100										
	Task 2.2: Define Emissions Factor Hierarchy			100									
TASK 3	Task 3.1: Define Direct Data Entry Methods			50	100								
	Task 3.2: Create a Network View Interface				50	100							
TASK 4	Task 4.1: Evaluate Existing Technologies						100						
	Task 4.2: Integrate Selected Technology with Calculation Tool							50	100				
TASK 5	Task 5.1: Identify Key Performance Indicators									100			
	Task 5.2: Create Performance Dashboard									50	100		
TASK 6	Task 6.1: Create Archive Format										50	100	
	Task 6.2: Update Emissions Factor Database											25	100
	OVERALL % COMPLETED	7.5%	15.0%	22.5%	32.5%	40.0%	50.0%	60.0%	70.0%	77.5%	85.0%	92.5%	100.0%

Figure 25: Schedule for Advanced Tool Development

The goal for both tools is to provide a consistent methodology, a set of WTW emissions factors across all modes, and provide output that can be easily compared with other organizations on a standardized basis. The capabilities of the advanced tool provide for better functionality than the basic tool, but also the possibility to provide better levels of precision. The advanced tool more closely aligns with the needs identified through the application of the criteria developed in Chapter 3 to current tools in Chapter 4. Tools currently exist that are capable of providing WTW emissions factors across all modes, but none that make use of carrier or shipment-level emissions factors. The combination of capturing user data to create updated emissions factors with a consistent set of emissions factors across all modes would represent an improvement on the current tools available.

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6 CONCLUSIONS

A review of current tools for measuring the carbon footprint of freight transportation has shown a lack of consistency in scope and methods. The term “carbon footprint” itself is subject to ambiguity, and the focus of many current programs on measuring emissions within an organizational boundary has limited the effectiveness of applying tools to supply chain activities that may span organizational boundaries. Based on the focus of current tools, the need for future consideration of alternative fuel vehicles, and the emerging standards in Europe, a definition that captures all six of the Kyoto greenhouse gases, employs a well-to-wheel focus on emissions, and is focused on the energy consumed in vehicles is recommended.

Through performance frameworks drawn from accounting, supply chain performance measurement, and Life Cycle Assessment a set of criteria for evaluating current tools have been proposed. These criteria recognize the needs of tools to improve decision-making internally while providing a means for external reporting and benchmarking. The criteria of depth, breadth, and precision are closely related to the internal decision-making process, as the output of a tool is relevant only if it captures the necessary scope and precision required to make a particular decision. The criteria of comparability and verifiability are drawn from principles of external reporting. Comparability is necessary if the results of the tool are to be used to compare across organizations or time periods, while verifiability helps assure that the results of the tool are a faithful representation of the claims. This latter characteristic is necessary given the difficult of directly verifying claims regarding carbon emissions.

A workshop was conducted at MIT that brought together a number of stakeholders to evaluate and verify the proposed criteria. Using the Analytic Hierarchy Process the participants in the workshop rated the importance of the different criteria. The results of this exercise were used to provide relative weights for the criteria to be used in an evaluation of current programs. A number of current programs were then rated on a high-medium-low scale for each of the five criteria, and the weightings of the criteria were used to generate a quantitative evaluation of the tools. The results of this process produced high scores for two different types of tools: tools focused on a single mode that provided consistent boundaries to capture the performance of specific carriers and tools that applied a consistent process across all modes, at the cost of a level of precision. Based on the results of this process a future tool should have the capability to provide a consistent boundary and process across all four main modes of transport, while having the ability to capture carrier-specific performance that can be used by shippers in their decision-making process.

A work plan and timeline were developed for two possible versions of a future tool. The basic tool provides a consistent set of emissions factors that capture the scope of the supply chain recommended in this work. This tool could be quickly developed, with the main focus of the work developing a consistent set of emissions factors. The more advanced tool would add more advanced capabilities and a better user interface, with the primary functional improvement of capturing user data to created updated carrier or route-specific emissions factors for use by other organizations. A series of example scenarios were provided to help clarify issues in tool development by illustrating issues related to determining emissions factors and performing calculations.

APPENDIX A LIST OF PROGRAMS AND SOURCES REVIEWED

In the process of reviewing programs for defining the carbon footprint of transportation a number of programs were excluded due to a lack of information regarding their methods. The following programs contained enough public information to effectively evaluate their defined breadth and depth.

	Breadth									Depth		
	Modes					Emissions						
Program	Road	Rail	Water	Air	Logistics	CO_2	N_2O	CH_4	Other	WTT	TTW	Other
GHG Protocol Mobile	x	x	x	x		x	x	x			x	
SmartWay 2.0	x	x				x			x		x	
Diesel Emissions Quantifier	X		x			x			x		x	
Total Energy & Emissions Analysis for Marine Systems (TEAMS) Model			x			x	x	x	x	x	x	
AAR Carbon Calculator	x	x				x					x	
EPA Moves	x					x	x	x	x			
National Mobile Inventory Model (NMIM)	x				x	x			x		x	
NONROAD 2000a Model	x	x	x	x		x			x		x	
Greenhouse Gas Emissions Model (GEM)	x					x					x	
EMissions FACtor 2007 Software (EMFAC)	x					x			x		x	
Comprehensive Modal Emissions Model (CMEM)	x					x			x		x	
System for Assessing Aviation's Global Emissions (SAGE)				x		x			x		x	
Aviation Environmental Design Tool (AEDT)				x		x			x		x	
Emissions and Dispersion Modeling System (EDMS)	x			x	x	x			x		x	
GREET Model	x					x	x	x	x	x	x	
Economic Input-Output Life Cycle Assessment (EIO-LCA) Model	x	x	x	x	x	x	x	x	x	x	x	x
NTM Calculator	x	x	x	x		x	x	x	x		x	
EnviShipping			x								x	x
Ship Emission Calculator			x			x			x		x	
Decarbonization Model	x					x					x	
Emisia	x					x	x	x	x		x	

	Breadth									Depth		
	Modes					Emissions						
Program	**Road**	**Rail**	**Water**	**Air**	**Logistics**	**CO_2**	**N_2O**	**CH_4**	**Other**	**WTT**	**TTW**	**Other**
SULTAN (**SU**stainab**L**e **T**r**AN**sport)	x					x	x	x	x	x	x	
TREMOD	x	x	x	x		x	x	x	x	x	x	
TREMOVE	x	x	x	x		x	x	x	x	x	x	
Local Authority Basic Carbon Tool	x	x				x					x?	
EcoTransIT World	x	x	x	x		x				x	x	
Clean Cargo Working Group Environmental Performance Survey for Ocean Carriers			x			x			x		x	
IPCC Guidelines for National Greenhouse Gas Inventories	x	x	x	x		x	x	x	x		x	
Ecoinvent LCA Database	x	x	x	x	x	x	x	x	x	x	x	x
Organization Environmental Footprint (OEF)	x	x	x	x	x	x	x	x	x	x	x	
Consignment-Level Carbon Reporting	x	x	x	x	x					x	x	x
ARTEMIS	x	x	x	x		x			x		x	
DHL emission calculating tool	?		x	x		x					x	
Eco Optimizer	x	x	x	x	x	x				x	x	
Carbon Intelligence	x	x	x	x	x	x					x	
Logistics Emissions Calculator (LogEC)	x	x	x	x	x	x	x	x	x	x	x	
VERSIT+	x					x			x		x	
Fleet carbon reduction tool	x					x				x	x	

Table 15: Scope of Reviewed Programs and Tools

RESEARCH ARTICLES

In addition to reviewing currently existing programs a review of scholarly literature was performed. The number of studies that include some calculation of emissions from transportation is quite large, and so the focus was on studies that introduced new methods or applications. The reviewed studies reflect a broad range of methods, from econometric studies to vehicle engine models, and applications, from estimates of global trade emissions to specific studies for individual companies. Studies reviewed, but not mentioned separately in this report include:

Cadarso, M. A., L.-A. Lopez, et al. (2010). "CO_2 emissions of international freight transport and offshoring: Measurement and allocation." Ecological Economics 69(8): 1682-1694.

- Estimates emission from international transportation in Spain. Employs an input-output model to estimate imports by region, calculates average

distance by region, and uses NTM methods to estimate emissions per tonne-km by mode.

Cristea, A., D. Hummels, et al. (2012). "Trade and the greenhouse gas emissions from international freight transport." Journal of Environmental Economics and Management.

- Uses an economic model to perform “bottom-up” estimates of transportation flows between nations. Applies emissions factors per mode to calculate emissions from international trade and estimates future trends in emissions compared to trade value.

Eyring, V., H. Kohler, et al. (2005). "Emissions from international shipping: The last 50 years." Journal of Geophysical Research 110(D17): D17305.

- Uses a bottom-up methodology to model fuel consumption based on engine power and duty cycles for 132 engine sub-groups. Combines fuel consumption model with statistical data on fleet makeup to estimate total emissions from shipping over a 50 year period.

Facanha, C. and A. Horvath (2007). "Evaluation of life-cycle air emission factors of freight transportation." Environmental science & technology 41(20): 7138-7144.

- Uses a hybrid Life Cycle Assessment approach to estimate the CO_2 emissions of different freight modes in the US.

Forkenbrock, D. J. (1999). "External costs of intercity truck freight transportation." Transportation Research Part A: Policy and Practice 33(7): 505-526.

- Estimates the external cost of GHG emissions from freight trucks. Uses average fuel consumption rates and load factors to estimate fuel consumption per ton-mile shipped, then applies an estimate external cost of GHG emissions per ton-mile.

Howitt, O. J., M. A. Carruthers, et al. (2011). "Carbon dioxide emissions from international air freight." Atmospheric Environment.

- Uses fuel uplift data to estimate emissions from airplanes departing New Zealand. This was combined with data on the total mass of air freighted import and export goods between New Zealand and other locations to get an emissions factor per ton-mile, which was then applied to estimate total emissions.

Kim, N. S. and B. Van Wee (2009). "Assessment of CO_2 emissions for truck-only and rail-based intermodal freight systems in Europe." Transportation planning and technology 32(4): 313-333.

- Uses LCA to estimate emissions from transportation, excluding infrastructure and vehicle manufacturing. Decomposes intermodal shipments to separate drayage and rail segments by estimating average drayage distance, and then compares the emissions from intermodal to a truck-only system.

Leonardi, J. and M. Baumgartner (2004). "CO_2 efficiency in road freight transportation: Status quo, measures and potential." Transportation Research Part D: Transport and Environment 9(6): 451-464.

- Surveys 50 German logistics companies to estimate CO_2 efficiency.

McKinnon, A. (2007). CO_2 Emissions from Freight Transport: An Analysis of UK Data. Logistics Research Network-2007 Conference Global Supply Chains: Developing Skills, Capabilities and Networks.

- Assembled data from a variety of sources in the UK to estimate total freight emissions. Uses both input (top-down) and output (bottom-up) methods.

McKinnon, A. and M. Piecyk (2009). "Measurement of CO_2 emissions from road freight transport: A review of UK experience." Energy policy 37(10): 3733-3742.

- Reviews methods for estimating the CO_2 emissions of road freight in the UK. Compares the results of different approaches and identifies lessons learned from the UK experience.

Ozsalih, H. (2009). A methodology for transport buying companies to estimate CO_2 emissions in transport: Application in Unilever European Logistics. Master's Thesis. Department of Technology Management. Eindhoven, Eindhoven University of Technology.

- Created a methodology for use in measuring GHG emissions from transportation used by Unilever. Uses NTM data to generate emissions factors specific to the type of vehicles used by Unilever, including an adjustment for refrigerated cargo. Specifically excludes empty miles unless paid for by Unilever.

Perez-Martinez, P. J. (2009). "The vehicle approach for freight road transport energy and environmental analysis in Spain." European Transport Research Review 1(2): 75-85.

- Uses survey data in Spain to estimate performance indicators for road freight, including CO_2 emissions.

Price, L., L. Michaelis, et al. (1998). "Sectoral trends and driving forces of global energy use and greenhouse gas emissions." Mitigation and Adaptation Strategies for Global Change 3(2): 263-319.

- Analyzes trends in global energy use and emissions using the Kaya framework.

Psaraftis, H. N. and C. A. Kontovas (2008). Ship Emissions Study, National Technical University of Athens.

- Develop a model for estimating CO_2 from specific ship types. Uses a top-down fuel-based approach to estimate emissions.

Schers, R. (2009). Determining a method for calculating CO_2 emissions in transport and the effect of emission regulations on supply chain design for a chemical company. Master’s Thesis. Department of Technology Management. Eindhoven, Eindhoven University of Technology.

- Extends the NTM methodology to calculate CO_2 emissions from transportation for a chemical company.

Schipper, L., H. Fabian, et al. (2009). Transport and carbon dioxide emissions: Forecasts, options analysis, and evaluation. Asian Development Bank.

- Describes a bottom-up approach to estimating emissions using an ASIF model that incorporates travel activity (A), mode structure (S), fuel intensity by mode (I), and emission factor (F).

Spielmann, M. and R. Scholz (2005). "Life Cycle Inventories of Transport Services: Background Data for Freight Transport." The International Journal of Life Cycle Assessment 10(1): 85-94.

- Reviews the methods for estimating environmental impact of transport services in LCA using the Ecoinvent data set.

Tarancon Moran, M. A. and P. del Rio Gonzalez (2007). "Structural factors affecting land-transport CO_2 emissions: A European comparison." Transportation Research Part D: Transport and Environment 12(4): 239-253.

- Uses an input-output methodology to estimate transport between European countries. Uses data on GHG emissions inventories from the UN to estimate CO_2 combined with economic output to estimate CO_2 efficiency.

Yang, C., D. McCollum, et al. (2009). "Meeting an 80% reduction in greenhouse gas emissions from transportation by 2050: A case study in California." Transportation Research Part D: Transport and Environment 14(3): 147-156.

- Uses the Kaya framework to decompose GHG emissions from the transportation sector in the US. The model is then used to explore scenarios that may reduce emissions in California 80% below 1990 levels by 2050.

APPENDIX B WORKSHOP MATERIALS

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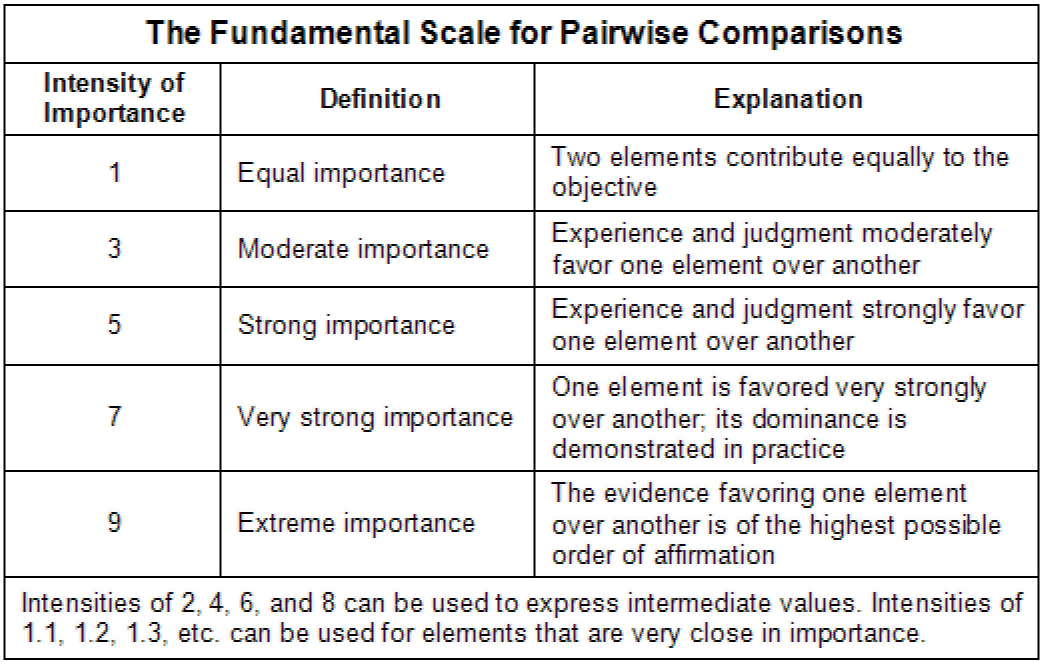
Instructions:

For each comparison between criteria you are asked to decide whether the criteria in column A or column B is more important. Place an A or B in the more important column after making your selection. Next, you must decide the relative intensity of the importance of your choice. This is a numerical score, and an explanation of the values is shown in the table below. If you believe the criteria are of equal importance place either A or B in the more important column and a value of 1 in the intensity column to indicate equal importance. Repeat this procedure for each of the 10 pairwise comparisons.



The Fundamental Scale for Pairwise Comparisons

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment moderately favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities of 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

Example:

If you believe that Comparability is moderately more important than Breadth, then in the pairwise comparison you would select B as more important with an intensity of 3. If you believe Depth should be very strongly favored over Verifiability, then you would select A as more important with an intensity of 7.

Criteria A	Criteria B	More Important	Intensity of Importance
Breadth	Comparability	B	3
Depth	Verifiability	A	7

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Name: ____

Company: ____

Industry (circle the best one):

Carrier Shipper 3PL Govt./NGO/Academic

Criteria A	Criteria B	More Important	Intensity of Importance
Breadth	Comparability		
Breadth	Depth		
Breadth	Precision		
Breadth	Verifiability		
Comparability	Depth		
Comparability	Precision		
Comparability	Verifiability		
Depth	Precision		
Depth	Verifiability		
Precision	Verifiability		

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Breadth

Low ↔ **High**

A focus on only one mode of transport.

All modes of transport and supporting logistics activities.

Comparability

Low ↔ **High**

Firms may choose different system boundaries, sources of data, or report results in non-standard ways.

All firms report in a standard format with identical system boundaries, methods, and data.

Depth

Low ↔ **High**

Only direct (Scope 1) emissions are included.

Full life cycle assessment including direct emissions, upstream fuel production, infrastructure, and capital goods.

Precision

Low ↔ **High**

Global averages or aggregate carbon emissions reporting

Shipment level reporting

Verifiability

Low ↔ **High**

No checks are performed to verify calculations and little to no data is made publicly available.

Results have been audited and verified by a neutral 3rd party and all data is publicly available for review.

APPENDIX C LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
BSR	Business for Social Responsibility
CCWG	Clean Cargo Working Group
CDP	Carbon Disclosure Project
COFRET	Carbon Footprint of Freight Transport
CH4	Methane
CO2	Carbon Dioxide
CO2e	Carbon Dioxide Equivalents
CTL	MIT Center for Transportation & Logistics
Defra	U.K. Department for Environment, Food, and Rural Affairs
EF	Emission Factor
EIA	U.S. Energy Information Administration
EIO	Economic Input Output
EPA	U.S. Environmental Protection Agency
FASB	Financial Accounting Standards Board
FHWA	Federal Highway Administration
GHG	Greenhouse Gas
GIS	Geographic Information System
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GRI	Global Reporting Initiative
GUI	Graphical User Interface
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IASB	International Accounting Standards Board
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LTO	Landing/take-off phase
N_2O	Nitrous Oxide
NTM	Network for Transport and Environment
OD	Origin-destination
PFC	Perfluorocarbons
SF_6	Sulfur hexafluoride
TTW	Tank-to-Wheel
WTT	Well-to-Tank
WTW	Well-to-Wheel