

Carbon Modeling Methodology

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Preface

Observant businesses, sensing regulation on the horizon and great opportunity already close at hand, are swiftly pursuing comprehensive carbon strategy. In order to leverage carbon information to efficiently reduce costs, reach new customers, and meet regulatory requirements, however, they will have to wrestle with conflicting methodology standards, obscure reporting guidelines, and the slow, expensive consulting apparatus.

This is no way to get to a low-carbon future. For businesses to assess trade-offs and make decisions with the agility required to stay competitive, carbon information must be at the proverbial fingertips. Determining a climate impact must be as streamlined as, say, comparing prices from competing channel vendors or looking up a stock quote. It shouldn't take a team of consultants, it should take milliseconds.

Meanwhile, the climate science honeymoon has come to an end. The infamous, if decidedly overwrought, "Climategate" fiasco in late 2009 has turned public scrutiny toward the numbers behind the science of climate change. At its worst, this skepticism threatens to derail progress toward sustainable international policy. But it is also a blessing, reaffirming that because science will always be full of uncertainty, transparency and collaboration remain the only refuge against risk.

When we started building our climate software in early 2007, we knew that for climate information to begin to exert influence on business processes and consumer behavior alike, the routines that provide the information must be widely, if not universally, applicable. We designed our software to be indifferent to input quality, employing basic artificial intelligence techniques to fill gaps and rationalize inconsistencies. This means that we can process existing flows of business data and enhance them in-place with climate information to enable entirely new forms of analysis and action.

We also knew that as the market matured, it would not be enough to simply ask our clients to trust us. This is why we describe our carbon models, data sources, and aggregation methods in software whose source code is readable and expressive. All of our calculations remember and can describe exactly how they were made, providing an accountability chain that stretches all the way back to government sources.

With this kind of flexibility and reliability, businesses can go far beyond retrospective carbon accounting. Imagine the possibilities.

In the great tradition of scientific collaboration, we present this documentation of the approach taken by our climate software. We also advise the reader that it's quite easy to write one thing and do another, whether through simple human error or deliberate misinformation, and invite him or her to inspect—and improve!—the source code at the links you'll find within.

Andy Rossmeissl, co-founder
Middlebury, Vermont
28 June 2010

Table of contents

Introduction	4
1 System architecture	5
1.1 Model classes	5
1.2 Calculation approach	6
1.3 Emissions scope	6
1.4 Data sources	6
2 Emitters	7
2.1 Defining parameters	7
2.2 Execution	8
2.3 Emitter model case studies	8
2.3.1 <i>Flight emissions model</i>	8
2.3.2 <i>Automobile emissions model</i>	14
2.3.3 <i>Diet emissions model</i>	24
3 Envelopes	26
3.1 Parameterization	26
3.1.1 <i>Determining scope and context</i>	26
3.1.2 <i>Organizing emissions</i>	26
3.2 Execution	26
3.3 Case study: parameterizing the personal footprint	28
3.3.1 <i>Determining context and responsibility</i>	28
3.3.2 <i>Organizing emissions</i>	30
Data sources	36

Introduction

The field of carbon emissions modeling is in a period of rapid evolution, shaped by ongoing transformations in climate science, information technology, government regulation, and the business environment. Demand for data about the impacts of carbon-emitting activities is steadily increasing—but so too are the complexity, opacity, and inconsistency of emissions calculation methodologies, undermining advancements in the field.

At a time when carbon intelligence has an urgent role to play in stemming catastrophic climate change, a more deliberate approach to carbon modeling is warranted. Reactive attempts by authorities to establish consistent, transparent methodology standards have been only marginally successful, more so in the sphere of corporate carbon footprinting than elsewhere. As a small company developing carbon emissions models, Brighter Planet is committed to doing our part in helping transform this field.

In developing our modeling approach, we were guided by three core principles: rigor, flexibility, and transparency. We knew that our system would need to provide high quality estimates that accounted for an emitter's full and complete climate impact. We knew that the model would need to operate given huge real-world variability in the quantity and quality of data available about emissions sources. And we knew that radical openness and collaboration would be critical to maintaining trust and quality in a rapidly evolving space at the intersection of multiple fields.

Brighter Planet's proprietary carbon models and other climate data are currently delivered through a suite of web services developed over the last three years. Businesses can climate-enable their applications by integrating emission estimates and other carbon information retrieved from our servers in real time via an API. For individuals, we've developed a free online carbon profiler at brighterplanet.com that serves as an example interface to our climate software. It is to the best of our knowledge the most comprehensive individual carbon footprint tool available. As you read this paper, we invite you to experience the models interactively by creating a footprint profile or accessing the web services directly—see brighterplanet.com to get started.

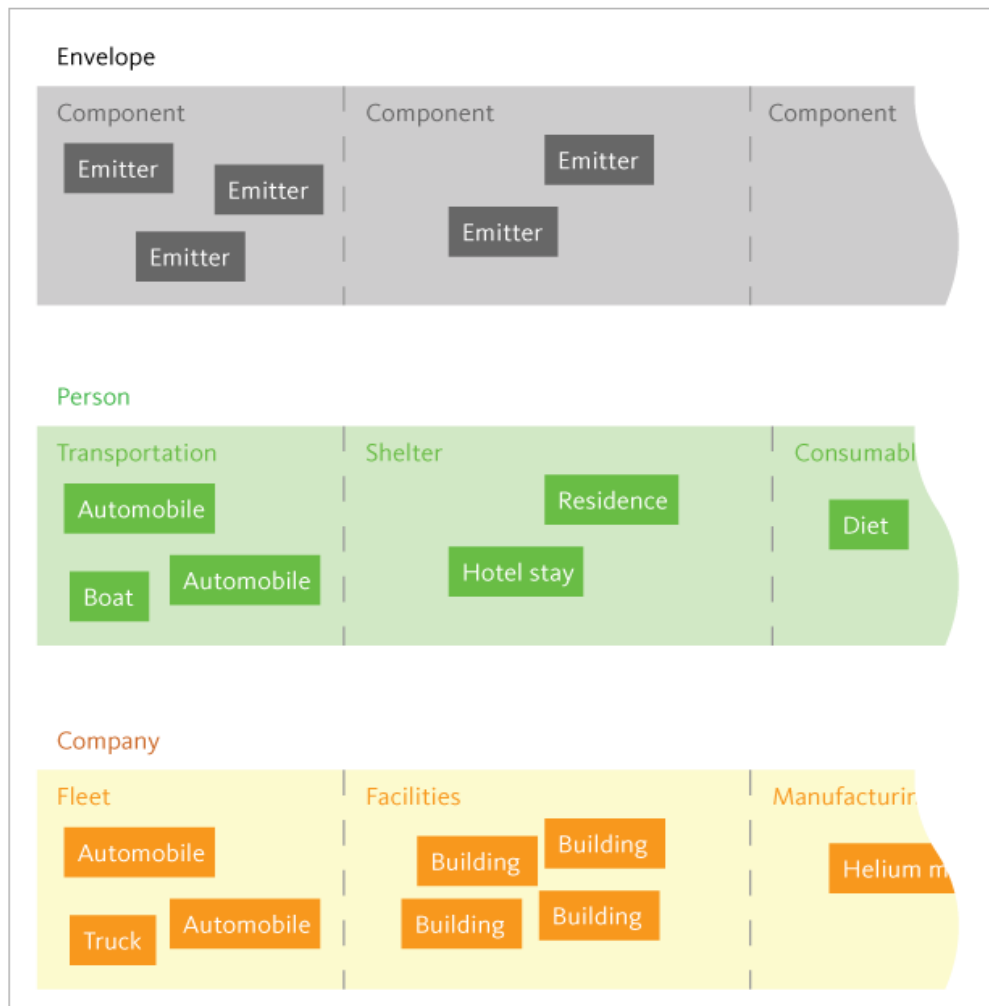
The goal of this paper is to provide insight into the approach, methodology, and data that we use to model greenhouse gas emissions, both to help fulfill our commitment to openness by documenting our own practices, and to foster a discussion about best practices in carbon modeling to help advance the field. We regularly expand and refine our carbon models, and we welcome discussion and collaboration on this project.

1 System architecture

1.1 Model classes

Brighter Planet's software provides two distinct classes of carbon models:

- Emitters are fundamental, object-oriented sources of greenhouse gas emissions such as automobiles or diets. They correspond to real-world objects, events, or processes that are familiar to clients and whose subparts, if any, are unfamiliar.
- Envelopes are complex emissions collections such as people or companies. They can contain any number of emitters, which are organized into logical groupings called components.



Envelope models are constructed and calculated differently from emitter models, and the distinction between the two model classes is important from more than a theoretical standpoint. Although connected, they are used in different contexts, and comprise distinct carbon middleware offerings delivered through separate web services. The two categories are treated separately in sections 2 and 3.

The case studies presented in this paper exemplify our construction of emitter and envelope models as they relate to an individual's carbon footprint. As implemented by our online calculator at brighterplanet.com, the personal carbon footprint calculation process can be viewed as having three phases. Initially, a user inherits a default envelope that represents the average carbon footprint, as based on our research. Users then specify information about their activities, allowing us to build a set of personalized emitters. Finally, these discrete emitter estimates are pulled back into the envelope model, replacing default values.

1.2 Calculation approach

Average-based modeling is a core aspect of our approach. From the start, uncharacterized emitters and envelopes inherit a complete average footprint, which is then refined and personalized as default values are replaced with client-specified data. This ensures that the models will function across a full range of data detail, providing an emissions estimate regardless of the scarcity or abundance of client data about the emissions source. This indifference to data quantity is matched by an indifference to data composition, as explained in section 2—the emitter models flexibly choose among a broad range of potential calculation pathways depending on the case-specific combination of client-specified characteristics, supporting wide leeway in the type of input data clients can provide.

1.3 Emissions scope

Many widely used emissions models regrettably focus exclusively on direct carbon dioxide emissions. Our analyses include the nontrivial effects of methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. We also include the effects of land use change, aircraft radiative forcing, and the indirect supply chain emissions from the production of goods and services, which often comprise the majority of emissions. As a result of this comprehensive scope, our emissions estimates are often higher than those suggested by other widely used calculators.

1.4 Data sources

We rely on third-party data to support our emissions models. The vast majority are publicly available from authoritative government, academic, or industry sources. A complete catalog of data sources is provided at the end of this document.

2 Emitters

Emitters are fundamental, object-oriented sources of greenhouse gas emissions; we maintain a set of unique models for numerous emitter types. The outputs calculated by these models can stand alone as footprint estimates for the emitter in question, or can be pulled into an envelope to model emissions for a complex entity as described in section 3.

Our goal in developing emitter models is to support diverse input options while making every input optional. For a given emissions source, many potential calculation routines exist. An automobile's footprint could be estimated using fuel expenditures, vehicle model and driving distance, fuel type and driving time, or any other arbitrary combination of relevant characteristics. Employing a single methodology would ease modeling, but it would sacrifice the flexibility to work with the best client data available.

Our emitter models accept any arbitrary combination of relevant characteristics as input, use a rudimentary artificial intelligence system to determine the optimal calculation pathway based on the given set of inputs, and supplement client data with dynamic averages where needed to derive a final emissions value. This makes the models flexible and resilient, allowing their implementation across diverse applications that vary in data quantity, quality, and delivery pattern.

2.1 Defining parameters

We begin the development of each emitter model by identifying a list of relevant client-supplied variables, or characteristics, that could be used to estimate the emitter's footprint. Given this set of characteristics, we then ensure viable calculation pathways for every potential subset, which often requires supplementing client-specified values with averages based on our own research. Finally, we prioritize the methods according to their accuracy. Clients can restrict the set of calculation pathways to ensure their calculations conform to specific protocols.

Because many of our data sources release new and amended data frequently and unpredictably, we use a data-management system to ensure that calculations always use the most up-to-date data possible. Our system automatically downloads and parses the latest data from source locations on a nightly basis. These direct data links between our emissions model and the EPA, BTS, EIA, and other government servers ensures that we have access to the latest data the same day it becomes publicly available.

These data are often inconsistently formatted or difficult to parse, and sometimes contain errors or proprietary numerical codes that interfere with analysis. Our import scripts automatically parse, normalize, and correct the data using custom dictionaries and errata. The source code for the import routines is available for inspection and collaboration at data.brighterplanet.com, along with the cleaned datasets in a variety of formats.

2.2 Execution

Because all characteristics are optional, the default emitter represents the average emitter of its type. When a set of characteristics is specified by the client, the model identifies the optimal calculation methodology, supplements the client data with averages from our database, and returns an emissions estimate. The more complete the set of characteristics the client has defined, the more accurate the estimate. Since the calculation routine varies according to inputs, custom methodology documentation is generated for each iteration of the model to inform clients of the calculations used in each instance.

2.3 Emitter model case studies

The following case studies illustrate the emitter models for flights, automobiles, and diets. For details and source code for our other emitter models, including bus and train trips, residences, and pets, see carbon.brighterplanet.com.

2.3.1 Flight emissions model

The flight emitter models individual greenhouse gas emissions from air travel. Given any combination of characteristics that describe a flight, it returns the emissions from that flight for a single passenger. Flights can be characterized by origin airport, destination airport, distance, distance class, airline, aircraft, aircraft class, seat class, load factor, number of layovers, number of seats, round-trip vs. one-way, domestic vs. international, and jet vs. turboprop.

Cohort

Many flight calculations make use of the 2008 BTS T-100 Segment (All Carriers) database,¹ a collection of data about every commercial flight that originated or terminated in the U.S. in 2008. To use this data, a “cohort” comprising all the segments that match the information provided about the flight’s origin, destination, airline, aircraft, propulsion type, and domesticity (whether or not it is domestic) is selected from the database. The passenger-weighted average of any characteristic for those segments is then calculated using equation (1):

$$\text{Characteristic} = \frac{\sum_{\text{Cohort Segments}} (\text{Characteristic} \times \text{Passengers Carried})}{\sum_{\text{Cohort Segments}} (\text{Passengers Carried})}$$

Emissions

Flight emissions are calculated using equation (2):

$$\text{Emissions} = \frac{\text{Total Fuel}}{\text{Passengers}} \times \text{Seat Class Multiplier} \times (1 - \text{Freight Share}) \times \text{EF} \times \text{RFI}$$

¹ BTS (2009)

Seat class multipliers are calculated across all airlines and aircraft using seat pitch and width data from SeatExpert² and SeatGuru.³ For every unique airline-aircraft configuration, weighted average seat area is calculated across all seat classes, and then class-specific seat areas are divided by this average to determine multipliers. These aircraft-specific multipliers for each seat class are then averaged across the industry, weighted by the annual volume of passengers that travel on each aircraft configuration, to determine final multipliers.⁴ If seat class is not provided, the multiplier defaults to 1.

Freight share is calculated from the cohort using equation (1). If no information that allows a cohort to be selected has been provided, the default freight share is calculated from a cohort comprised of every segment in the 2008 T-100 database using equation (1).

The emissions factor (EF) is taken from the EIA.⁵ All flights are assumed to use jet fuel.⁶

A radiative forcing index (RFI) of 2 is used to account for the effects of high-altitude fuel combustion.⁷

Total Fuel

Total fuel is calculated using equation (3):

$$\text{Total Fuel} = \text{Fuel per Segment} \times \text{Segments} \times \text{Trips}$$

If trips (1 for one-way, 2 for a round-trip flight) is not provided a default of 1.941 is used.⁸

Fuel per Segment is calculated using equation (4):

$$\text{Fuel per Segment} = b + (m_1 \times d_s) + (m_2 \times d_s^2) + (m_3 \times d_s^3)$$

The segment distance (d_s) is calculated using equation (5):

$$d_s = \frac{\text{Distance}}{\text{Segments}} \times \text{Route Inefficiency Factor} \times \text{Dogleg Factor}^{(\text{Segments} - 1)}$$

The route inefficiency factor (1.07) accounts for the fact that circling before landing and other factors make actual flights longer than the great circle distance between origin and destination.⁹

The dogleg factor (1.25) accounts for the fact that most layovers are not directly on-route, and so flights with layovers travel farther than the direct distance between origin and destination.¹⁰

² SeatExpert (no date)

³ SeatGuru (no date)

⁴ Passenger-weighted averaging is performed using 2008 T-100 data.

⁵ EIA (no date)

⁶ Most emitters use top-down calculated emissions factors. For example, see the Emissions Factor section of 2.3.2

⁷ See 3.3.1.4

⁸ BTS (2006) Table 7

⁹ Kettunen et al. (2005)

¹⁰ It is assumed that on average each layover adds 25% of the direct origin-destination distance

If the number of segments is not provided, a default of 1.67 is used.¹¹

Distance

Distance is calculated using one of the following methods:

Method 1 – from origin and destination airports

Distance is calculated by looking up the latitude and longitude of the airports and computing the great circle distance between them using the Haversine formula. This method has priority over a client-provided distance.

Method 2 – from distance class

Distance is looked up from the distance class.¹²

Method 3 – from cohort

Distance is calculated from the cohort using equation (1).

Method 4 – default

Distance is calculated from a cohort comprised of all segments in the 2008 T-100 database using equation (1).

Fuel Use Coefficients

The coefficients b , m_1 , m_2 , and m_3 are calculated using one of the following methods:

Method 1 – from aircraft

The fuel use coefficients are calculated by fitting a third-order polynomial equation to the EEA fuel consumption data for the aircraft.¹³

Method 2 – from aircraft class

The fuel use coefficients are calculated by fitting a third-order polynomial equation to the EEA fuel consumption data for each aircraft in the aircraft class and then averaging the values for each coefficient.¹⁴

Method 3 – default

The fuel use coefficients are calculated by fitting a third-order polynomial equation to the EEA fuel consumption data for every aircraft and then averaging the values for each coefficient using equation (6):¹⁵

$$\text{Coefficient} = \frac{\sum_{\text{All Aircraft}} (\text{Coefficient} \times \text{Passengers Carried})}{\sum_{\text{All Aircraft}} (\text{Passengers Carried})}$$

¹¹ Calculated from Federal Highway Administration (2001)

¹² Distance classes are defined by Brighter Planet

¹³ European Environmental Agency (2009) Part B.1.A.3.a annex

¹⁴ *ibid.*

¹⁵ *ibid.*

Passengers carried for each aircraft is calculated from the 2008 T-100 database by summing the passengers for every segment performed by that aircraft.

Passengers

The number of passengers is calculated using equation (7):

$$\text{Passengers} = \text{Seats} \times \text{Load Factor}$$

If load factor (the fraction of available seats that are occupied) is not provided, it is calculated from the cohort using equation (1). If no information that allows a cohort to be selected has been provided, the default load factor is calculated from a cohort comprised of all segments in the 2008 T-100 database using equation (1).

Seats

The number of seats is calculated using one of the following methods:

Method 1 – from aircraft

This method has priority over a client-provided number of seats.

Method 2 – from cohort

The number of seats is calculated from the cohort using equation (1).

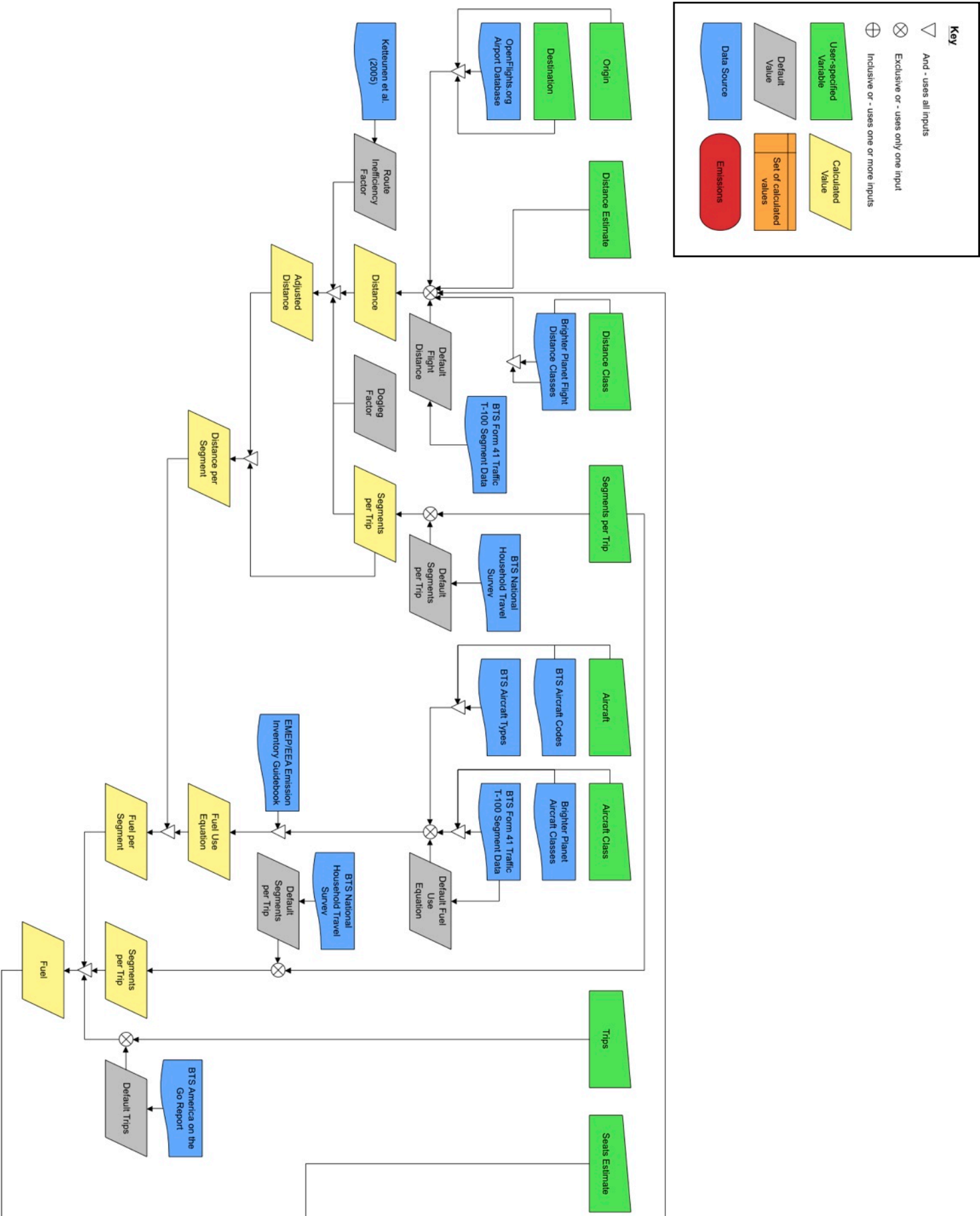
Method 3 – from aircraft class

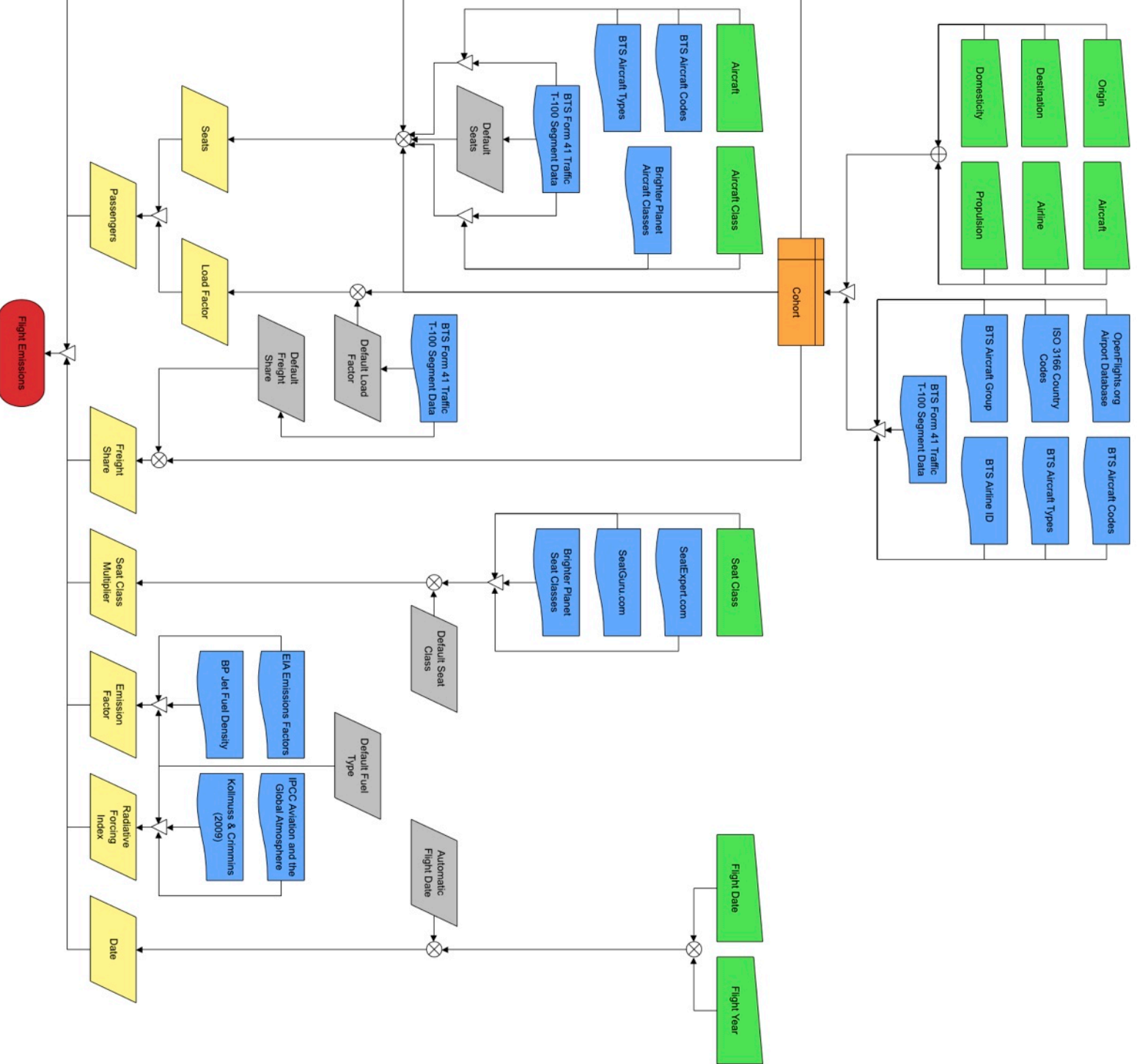
The number of seats is calculated from a cohort comprised of all segments performed by aircraft belonging to the aircraft class using equation (1).

Method 4 – default

The number of seats is calculated from a cohort comprised of all segments in the 2008 T-100 database using equation (1)

Flight emitter diagram: key data sources and calculation pathways





2.3.2 Automobile emissions model

The automobiles emitter models annual greenhouse gas emissions from a car or light-duty truck. Given any combination of characteristics that describe an automobile, it returns the total emissions for that automobile over the course of a year. Automobiles can be characterized by make, model year, model, variant, size class, fuel type, fuel efficiency, hybridity, daily driving time, weekly distance driven, annual distance driven, and portion of driving that takes place on highway vs city streets.

Emissions

Automobile emissions are calculated using equation (8):

$$\text{Emissions} = \text{Fuel Used} \times \text{Emissions Factor}$$

Fuel Used

If fuel use is not provided, it is estimated from the distance driven and fuel economy using equation (9):

$$\text{Fuel Used} = \frac{\text{Distance}}{\text{Fuel Economy}}$$

Distance

If distance driven is not provided, it is calculated using one of the following methods:

Method 1 – from driving time

Distance driven is estimated from driving time using equation (10):

$$\text{Distance} = \text{Driving Time} \times \text{Speed}$$

Speed is calculated using equation (11):

$$\text{Speed} = \frac{1}{\frac{\text{City Portion}}{\text{City Speed}} + \frac{\text{Highway Portion}}{\text{Highway Speed}}}$$

City Portion is the fraction of the total distance that is driven in the city. A default of 43% is used unless an alternate value is provided.¹⁶

Highway Portion = 1 – City Portion

City Speed = 19.9 miles per hour¹⁷

Highway Speed = 57.1 miles per hour¹⁸

¹⁶ EPA Light Duty Automotive Technology and Fuel Economy Trends: 1975-2008, p. A-10

¹⁷ The average speed for city driving used in the EPA 5-cycle fuel economy test – see EPA Final Technical Support Document Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates, p. 50

¹⁸ The average speed for highway driving used in the EPA 5-cycle fuel economy test – ibid.

Method 2 – from automobile size class

The annual distance traveled is estimated based on the automobile size class (e.g. midsize car). First, automobile type (car or light truck) is inferred from the size class. Then average annual distance is calculated using equation (12):

$$\text{Distance} = \left[\sum_{\text{Gasoline}} (\overline{\text{VMT}}_y \times \text{Portion}_y) \right] \times \% \text{ Gasoline} + \left[\sum_{\text{Diesel}} (\overline{\text{VMT}}_y \times \text{Portion}_y) \right] \times \% \text{ Diesel}$$

$\overline{\text{VMT}}_y$ is the average vehicle-miles traveled in 2010 for each model year of the fuel and vehicle type (e.g. 9,456 miles for model year 2000 gasoline cars)¹⁹

Portion_y is the portion of 2010 automobiles of the fuel and vehicle type that come from each model year (e.g. 5.47% of all diesel light-duty trucks used in 2010 were made in 2001)²⁰

% Gasoline is the portion of 2010 automobiles of the vehicle type that ran on gasoline (e.g. 99.5% of all cars used in 2010 ran on gasoline).

% Diesel is the portion of 2010 automobiles of the vehicle type that ran on diesel (e.g. 4.16% of all light-duty trucks used in 2010 ran on diesel).

To calculate the number of gasoline and diesel cars and light-duty trucks, car and light-duty truck gasoline and diesel consumption in 2000 through 2007 is taken from the EPA GHGI.²¹ U.S. transportation gasoline and diesel consumption in 2000 through 2008 is taken from the EIA MER.²² Projected U.S. transportation gasoline and diesel consumption in 2005 through 2010 is taken from the EIA AEO.²³ The AEO data is scaled to match the MER data in overlapping years. The GHGI data and MER data are compared to determine the portion of total gasoline and diesel consumption due to cars and light-duty trucks. This portion is applied to the scaled AEO data to determine final car and light-duty truck gasoline and diesel consumption in 2000 through 2010.

Car and light-duty truck vehicle miles in 2000 through 2007 are taken from the EPA GHGI.²⁴ Car and light-duty truck vehicle miles in 2000 through 2006 is taken from the FHWA Highway Statistics.²⁵ Car and light-duty truck fuel economy in 2000 through 2006 is calculated by dividing FHWA vehicle-miles by the fuel consumption determined above. Projected car and light-duty truck fuel economy is taken from the EIA AEO.²⁶ The AEO data is scaled to match the MER data in overlapping years. Car and light-duty truck vehicle miles in 2010 are calculated by multiplying the scaled AEO data by the fuel consumption determined above. These vehicle miles are then scaled to match the GHGI vehicle miles, giving final vehicle miles in 2000 through 2010.

¹⁹ 2007 data is assumed to be representative for 2010 – EPA GHGI, table A-83

²⁰ 2007 data is assumed to be representative for 2010 – EPA GHGI, table A-82

²¹ EPA GHGI, table A-76

²² EIA MER, table 3.7c

²³ EIA AEO, supplemental table 46

²⁴ EPA GHGI, table A-78

²⁵ FHWA Highway Statistics, table VM-1

²⁶ EIA AEO, table 7

The number of cars and light-duty trucks in 2000 through 2006 is taken from the FHWA Highway Statistics.²⁷ FHWA vehicle miles are divided by FHWA number of vehicles to determine miles per vehicle in 2000 through 2006. The average miles per vehicle in 2000 through 2006 is used in 2007 through 2010. The final number of gasoline and diesel cars and light-duty trucks is determined by dividing final vehicle miles determined above by average miles per vehicle.

Method 3 – from automobile fuel type

The annual distance traveled is estimated based on the fuel type (gasoline or diesel) using equation (13):

$$\text{Distance} = \left[\sum_{\text{Cars}} (\overline{\text{VMT}}_y \times \text{Portion}_y) \right] \times \% \text{ Cars} + \left[\sum_{\text{Trucks}} (\overline{\text{VMT}}_y \times \text{Portion}_y) \right] \times \% \text{ Trucks}$$

$\overline{\text{VMT}}_y$ is the average vehicle-miles traveled in 2010 for each model year of the fuel and vehicle type (e.g. 9,456 miles for model year 2000 gasoline cars)²⁸

Portion_y is the portion of 2010 automobiles of the fuel and vehicle type that come from each model year (e.g. 5.47% of all diesel light-duty trucks used in 2010 were made in 2001)²⁹

% Cars is the portion of 2010 automobiles of the fuel type that were cars (e.g. 59.5% of all gasoline automobiles used in 2010 were cars)

% Trucks is the portion of 2010 automobiles of the fuel type that were light-duty trucks (e.g. 85.8% of all diesel automobiles used in 2010 were light-duty trucks)

Method 4 – default

Annual distance traveled is calculated using equation (14):

$$\text{Distance} = \sum_{\text{All Types}} \left(\sum_{\text{Each Type}} (\overline{\text{VMT}}_y \times \text{Portion}_y) \times \% \text{ Type} \right)$$

$\overline{\text{VMT}}_y$ is the average vehicle-miles traveled in 2010 for each model year of the fuel and vehicle type (e.g. 9,456 miles for model year 2000 gasoline cars)³⁰

Portion_y is the portion of 2010 automobiles of the fuel and vehicle type that come from each model year (e.g. 5.47% of all diesel light-duty trucks used in 2010 were made in 2001)³¹

% Type is the portion of 2010 automobiles that were of a particular vehicle and fuel type (e.g. 58.3% of all automobiles used in 2010 were gasoline cars)

Fuel Economy

²⁷ FHWA Highway Statistics, table VM-1

²⁸ 2007 data is assumed to be representative for 2010 – EPA GHGI, table A-83

²⁹ 2007 data is assumed to be representative for 2010 – EPA GHGI, table A-82

³⁰ 2007 data is assumed to be representative for 2010 – EPA GHGI, table A-83

³¹ 2007 data is assumed to be representative for 2010 – EPA GHGI, table A-82

If fuel economy is not provided, it is calculated using one of the following methods:

Method 1 – from automobile make, model year, model, and variant
Fuel economy is calculated using equation (15):

$$\text{Fuel Economy} = \frac{1}{\frac{\text{City Portion}}{\text{Adjusted City Fuel Economy}} + \frac{\text{Highway Portion}}{\text{Adjusted Highway Fuel Economy}}}$$

City Portion is the fraction of the total distance that is driven in the city. A default of 43% is used unless an alternate value is provided.³²

Highway Portion = 1 – City Portion

Adjusted city and highway fuel economy are calculated using equations (16) and (17):³³

$$\text{Adjusted City Fuel Economy} = \frac{1}{0.003259 + \frac{1.1805}{\text{Unadjusted City Fuel Economy}}}$$

$$\text{Adjusted Highway Fuel Economy} = \frac{1}{0.001376 + \frac{1.3466}{\text{Unadjusted Highway Fuel Economy}}}$$

Unadjusted city and highway fuel economy are looked up from the EPA FEG based on the using the automobile make, model year, model, and variant (e.g. Honda 2010 Accord 4-door 6-cylinder 5-speed automatic).

Method 2 – from nominal fuel economy
Fuel economy is calculated using equation (18):

$$\text{Fuel Economy} = \text{Hybridity Multiplier} \times \text{Nominal Fuel Economy}$$

Nominal Fuel Economy

Nominal fuel economy is calculated using one of the following methods:

Method 1 – from automobile make, model year, and model

The possible variants are looked up from the EPA FEG using the automobile make, model year, and model (e.g. Honda 2010 Accord).³⁴ The variants' unadjusted city and highway fuel economies are averaged, and then adjusted using equations (16) and (17). Nominal fuel economy is then calculated from the adjusted fuel economies using equation (15).

³² EPA Light Duty Automotive Technology and Fuel Economy Trends: 1975-2008, p. A-10

³³ EPA Light Duty Automotive Technology and Fuel Economy Trends: 1975-2008, p. A-9-10

³⁴ EPA FEG, various years

Method 2 – from automobile make and model year

The fuel economy for the make and model year (e.g. Honda 2010) is looked up from CAFE data and used as the nominal fuel economy.³⁵

Method 3 – from automobile size class

The nominal fuel economy for the automobile size class (e.g. midsize car) is calculated using data from the EPA Fuel Economy Trends report.³⁶ First, the report city and highway fuel economies for each model year of the size class are back-converted to the original lab values using equations (19)-17:

For model years 1975-1985 (equations (19) and (20)):

$$\text{Lab City Fuel Economy} = \frac{\text{Report City Fuel Economy}}{0.9}$$

$$\text{Lab Highway Fuel Economy} = \frac{\text{Report Highway Fuel Economy}}{0.78}$$

For model years 1986-2004 (equations (21) and (22)):

$$FE_{cl} = \frac{FE_{cr}}{0.9} - \left(\left(\frac{FE_{cr}}{0.9} - \frac{1.1805}{\frac{1}{FE_{cr}} - 0.003259} \right) \times \frac{(\text{Model Year} - 1985)}{20} \right)$$

FE_{cl} = Lab City Fuel Economy

FE_{cr} = Report City Fuel Economy

$$FE_{hl} = \frac{FE_{hr}}{0.78} - \left(\left(\frac{FE_{hr}}{0.78} - \frac{1.3466}{\frac{1}{FE_{hr}} - 0.001376} \right) \times \frac{(\text{Model Year} - 1985)}{20} \right)$$

FE_{hl} = Lab Highway Fuel Economy

FE_{hr} = Report Highway Fuel Economy

For model years 2005-2010 (equation (23) and (24)):

$$\text{Lab City Fuel Economy} = \frac{1.1805}{\frac{1}{\text{Report City Fuel Economy}} - 0.003259}$$

³⁵ NHTSA, personal communication

³⁶ EPA Light Duty Automotive Technology and Fuel Economy Trends: 1975-2008, Appendix E

$$\text{Lab Highway Fuel Economy} = \frac{1.3466}{\frac{1}{\text{Report Highway Fuel Economy}} - 0.001376}$$

Next, the lab city and highway fuel economies for the size class are adjusted using equations (16) and (17).

Then, the weighted average city and highway fuel economies for the size class are calculated using equation (25):

$$\overline{\text{Fuel Economy}} = \frac{1}{\sum_{\text{All Model Years}} \left(\frac{\text{VMT}\%}{\text{Adjusted Fuel Economy}} \right)}$$

VMT% is the percent of all automobile vehicle-miles traveled in 2010 that are attributed to automobiles of a particular model year of the size class.³⁷

Finally, nominal fuel economy for the size class is calculated from the adjusted fuel economies using equation (15).

Method 4 – from automobile model year

The nominal fuel economy for the automobile model year (e.g. 2008) is calculated from CAFE data³⁸ using equation (26):

$$\text{Nominal Fuel Economy} = \frac{\sum_{\text{Each Make}} (\text{CAFE Fuel Economy} \times \text{Vehicles Sold})}{\sum \text{Vehicles Sold}}$$

Method 5 – from automobile make

The nominal fuel economy for the automobile make (e.g. Honda) is calculated from CAFE data³⁹ using equation (27):

$$\text{Nominal Fuel Economy} = \frac{\sum_{\text{Each Model Year}} \text{CAFE Fuel Economy} \times \text{Vehicles Sold}}{\sum \text{Vehicles Sold}}$$

Method 6 - default

The nominal fuel economy is calculated using the same procedure as for size class fuel economy, but using the Fuel Economy Trends report values for the fuel economies of all automobiles.⁴⁰

Hybridity Multiplier

³⁷ 2007 data is assumed to be representative for 2005-2010 – EPA GHGI, table A-84

³⁸ CAFE fuel economy and vehicles sold from NHTSA, personal communication

³⁹ ibid.

⁴⁰ EPA Light Duty Automotive Technology and Fuel Economy Trends: 1975-2008, Appendix E

If hybridity is not provided, hybridity multiplier defaults to one. Otherwise, the multiplier is calculated using equation (28):

$$\text{Multiplier} = \frac{1}{\frac{\text{City Portion}}{\text{City Multiplier}} + \frac{\text{Highway Portion}}{\text{Highway Multiplier}}}$$

City Portion is the fraction of the total distance that is driven in the city. A default of 43% is used unless an alternate value is provided.⁴¹

$$\text{Highway Portion} = 1 - \text{City Portion}$$

The city and highway multipliers are calculated using equation (29):

$$\text{Multiplier}_{\text{urbanity}} = \frac{(\text{Adjusted Fuel Economy})_{\text{urbanity, hybridity}}}{(\text{Adjusted Fuel Economy})_{\text{urbanity, all vehicles}}}$$

The adjusted fuel economy for all 2010 automobile variants is taken from the EPA FEG. If the automobile size class is provided, only vehicles of that size class are used in the calculation. For example, to calculate a city multiplier for a hybrid midsize car, the average city fuel economy of 2010 hybrid midsize cars is divided by the average city fuel economy of all 2010 midsize cars.

Emissions Factor

The emissions factor is determined based on the fuel type. If the fuel type is not provided but the automobile make, model year, model, and variant are provided (e.g. Honda 2010 Accord 4-door 6-cylinder 5-speed automatic), the vehicle's fuel type is looked up from the EPA FEG. Otherwise a default emissions factor is used.

Emissions factors for gasoline and diesel are calculated using equation (30):

$$\text{EF}_{\text{fuel}} = \frac{\text{Fuel Emissions}}{\text{Fuel Consumption}}$$

Fuel Consumption

To calculate fuel consumption, car and light-duty truck gasoline and diesel consumption in 2000 through 2007 is taken from the EPA GHGI.⁴² U.S. transportation gasoline and diesel consumption in 2000 through 2008 is taken from the EIA MER.⁴³ Projected U.S. transportation gasoline and diesel consumption in 2005 through 2010 is taken from the EIA AEO.⁴⁴ The AEO data is scaled to match the MER data in overlapping years. The GHGI data and MER data are compared to determine the portion of total gasoline and diesel consumption due to cars and light-duty trucks. This portion is applied to the

⁴¹ EPA Light Duty Automotive Technology and Fuel Economy Trends: 1975-2008, p. A-10

⁴² EPA GHGI, table A-76

⁴³ EIA MER, table 3.7c

⁴⁴ EIA AEO, supplemental table 46

scaled AEO data to determine final car and light-duty truck gasoline and diesel consumption in 2000 through 2010.

Fuel Emissions

Fuel-specific emissions for cars and light-duty trucks are taken directly from the EPA GHGI. Air conditioning emissions are split between gasoline and diesel vehicles using equations (31) and (32):

$$\text{Gasoline AC Emissions} = \text{Total AC Emissions} \times \frac{\text{Gasoline Vehicle Miles}}{\text{Diesel Vehicle Miles}}$$

$$\text{Diesel AC Emissions} = \text{Total AC Emissions} - \text{Gasoline AC Emissions}$$

To calculate vehicle miles, car and light-duty truck vehicle miles in 2000 through 2007 are taken from the EPA GHGI.⁴⁵ Car and light-duty truck vehicle miles in 2000 through 2006 is taken from the FHWA Highway Statistics.⁴⁶ Car and light-duty truck fuel economy in 2000 through 2006 is calculated by dividing FHWA vehicle-miles by the fuel consumption determined above. Projected car and light-duty truck fuel economy is taken from the EIA AEO.⁴⁷ The AEO data is scaled to match the MER data in overlapping years. Car and light-duty truck vehicle miles in 2010 are calculated by multiplying the scaled AEO data by the fuel consumption determined above. These vehicle miles are then scaled to match the GHGI vehicle miles, giving final vehicle miles in 2000 through 2010.

Emissions factors for blends of ethanol and gasoline or biodiesel and diesel are calculated using equation (33):

$$EF_{\text{blend}} = EF_{\text{gasoline or diesel}} \times (1 - \text{Blend Fraction})$$

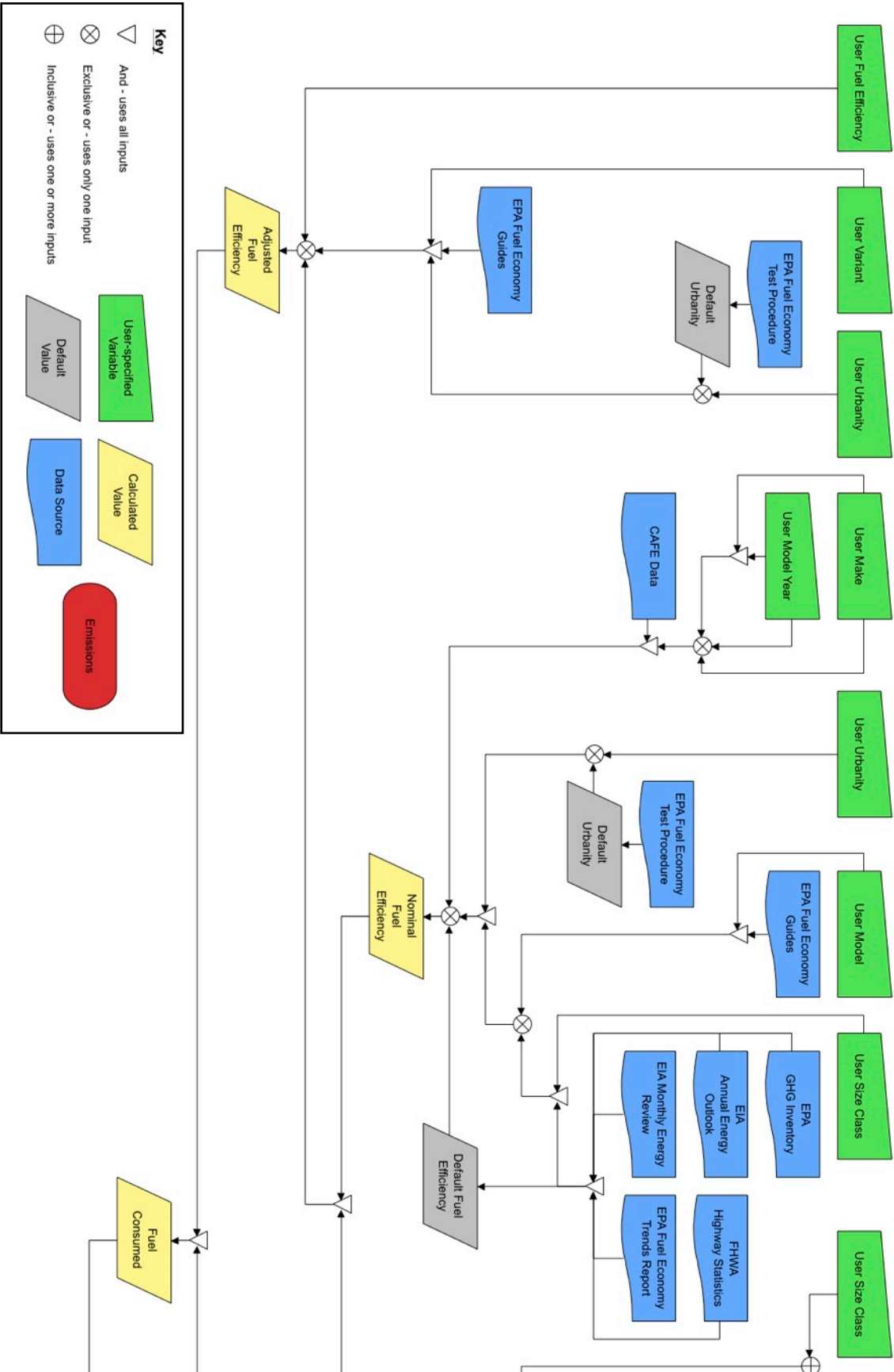
The default emissions factor is calculated using the same procedure as for gasoline and diesel, but using combined gasoline and diesel consumption and emissions data.

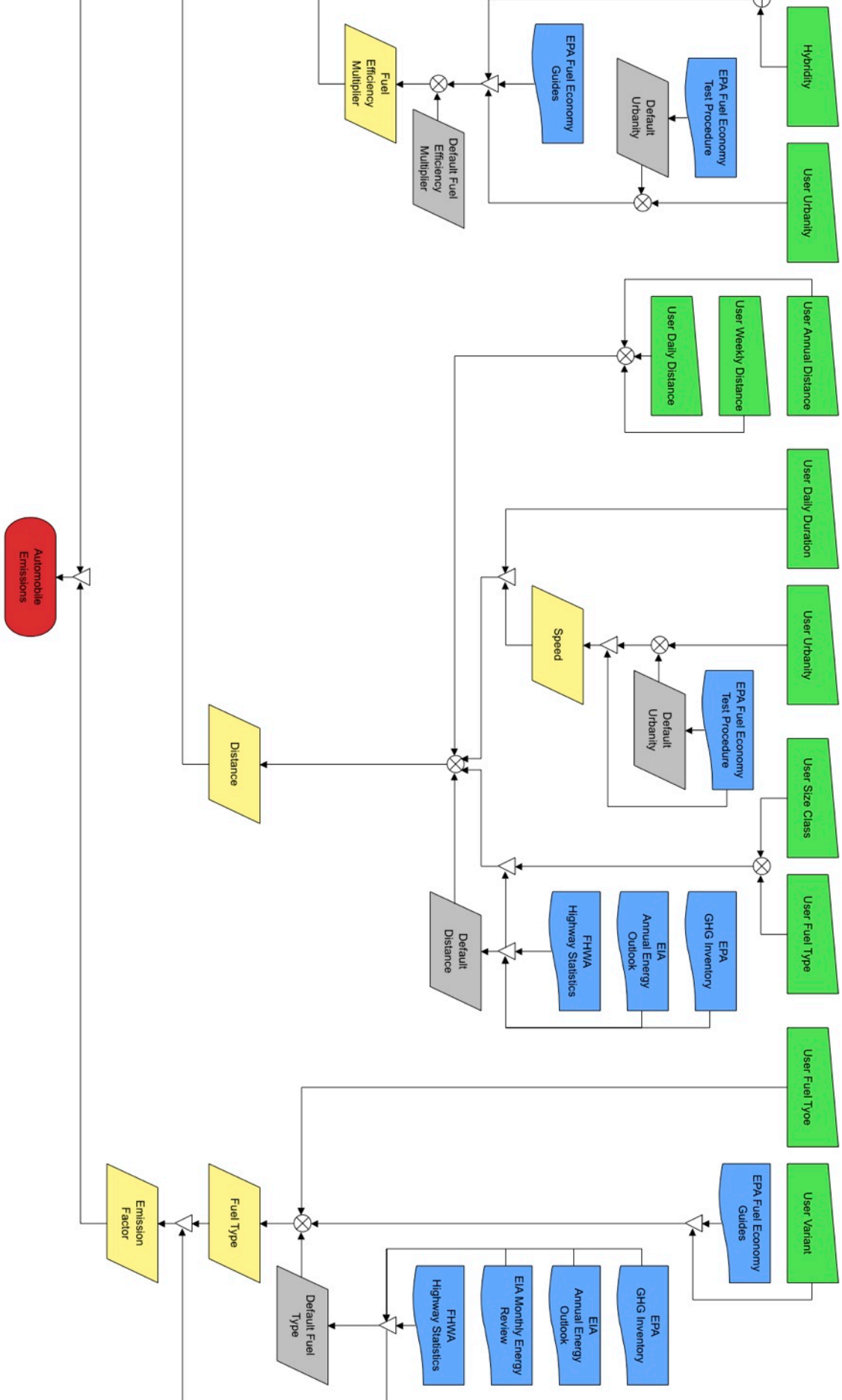
⁴⁵ EPA GHGI, table A-78

⁴⁶ FHWA Highway Statistics, table VM-1

⁴⁷ EIA AEO, table 7

Automobile emitter diagram: key data sources and calculation pathways





2.3.3 Diet emissions model

The diet emitter models annual individual greenhouse gas emissions from food. Given any combination of characteristics that describe a diet, it returns the emissions associated with producing and delivering the food that makes up that diet over the course of a year. Diets can be characterized by size, diet class, and food group balance (diet composition by food type).

Embodied food emissions are calculated by multiplying consumption by emissions intensity using equation (34):

$$\text{Emissions} = \text{Daily Calories} \times \text{Emissions Factor}$$

If daily calories is not provided, a default of 2,150 is used.⁴⁸

The emissions factor is calculated using one of the following methods:

Method 1 – from food group balance

If the portion of the diet made up by each food group (e.g. red meat) is provided, the emissions factor is calculated using equation (35):

$$\text{Emissions Factor} = \sum_{\text{Food Groups}} (\text{Portion} \times \text{Emissions Intensity})$$

Emissions intensity is calculated using equation (36):

$$\text{Emissions Intensity} = \frac{\text{Food Group Emissions}}{\text{Food Group Calories}} \times \text{Multiplier}$$

Food group emissions are calculated based on the results of an environmental economic input-output model⁴⁹ that identifies total annual U.S. embodied food emissions by sector. These emissions are re-categorized into the nine food groups by combining or dividing sectors identified in the model. In cases where emissions from a given sector are divided into two or more food groups, they are allocated in proportion to the caloric importance of those food groups in the average American's diet, as reported in the U.S. Department of Agriculture (USDA) Food Availability Data System (FADS).⁵⁰ Emissions from food served in restaurants are also distributed in this way across all food groups.

Food group calories are taken from the FADS.⁵¹

A multiplier is applied to account for the fact that the loss-adjusted food supply data shows more calories per person than people report eating in surveys. The multiplier is calculated using equation (37):

⁴⁸ USDA NHANES

⁴⁹ Weber/Matthews

⁵⁰ USDA ERS FADS

⁵¹ USDA ERS FADS

$$\text{Multiplier} = \frac{\text{Availability Calories per Person}}{\text{Consumed Calories per Person}}$$

Available calories per person are taken from the FADS.⁵² Consumed calories per person are taken from the USDA National Health and Nutrition Examination Survey.⁵³

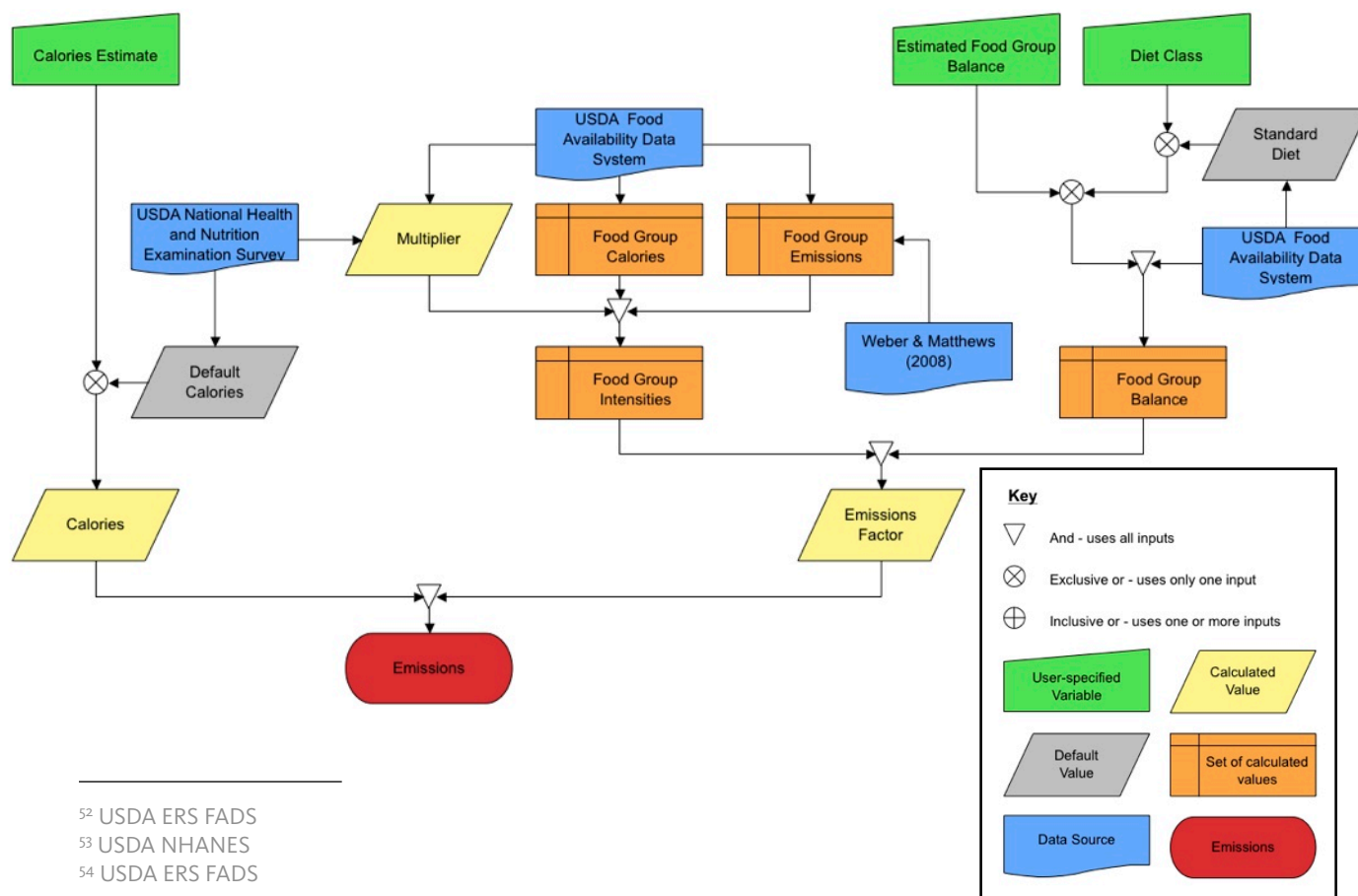
Method 2 – from diet class

If the diet class (e.g. vegetarian) is provided, the portion of the diet made up by each food group is determined based on the FADS.⁵⁴ For a “standard” diet, an average blend of food as identified in the FADS is used. For a “vegetarian” diet, meat- and fish-based calories from this standard blend are redistributed among the other categories, proportionally according the existing calories in these groups. For a “vegan” diet, this same process is used to reallocate all meat, fish, eggs, and dairy calories. The emissions factor is then calculated from the food group portions using equations (35), (36), and (37).

Method 3 – default

The emissions factor is calculated using method 2 and a standard diet.

Diet emitter diagram: key data sources and calculation



⁵² USDA ERS FADS

⁵³ USDA NHANES

⁵⁴ USDA ERS FADS

3 Envelopes

Envelope modeling happens in two stages. During parameterization, a default envelope is calculated that represents the average emissions profile for an entity of that type. For example, the envelope for an individual would initially resolve to the average emissions for an American. Then during execution, this envelope is personalized by replacing average components with client-specific values for individual emissions sources.

3.1 Parameterization

Envelope parameterization is broken into two phases. During scope and context determination, the average emissions of the envelope type is determined. During emissions organization, those emissions are categorized into a set of emissions categories or “components,” each with a default average value, that together comprise the complete emissions envelope.

3.1.1 Determining scope and context

The scope of an envelope is the set of emissions for which the envelope bears responsibility. For example, the scope of an individual envelope would be all the emissions for which that individual bears responsibility. The context of an envelope is the group to which that envelope belongs. For example, the context of an individual envelope might be U.S. residents. Finally, the average emissions for an envelope, the emissions for which an archetypal entity is responsible, are determined by dividing the context's total scoped emissions – the emissions for which all members of the context are responsible – by the context's population. In our example, the average emissions for the individual envelope would be calculated by dividing the total emissions for which all U.S. residents are responsible by the U.S. population.

3.1.2 Organizing emissions

The envelope's emissions quota is then disaggregated into a hierarchy of meaningful categories called components. Each component could represent, for example, a real-world activity division or lifecycle phase. Considering again the example of a person, top-level components could include transportation and shelter. An important advantage of this top-down approach, dividing the quota into components rather than constructing the envelope's footprint piecewise, is that it ensures total coverage of all emissions in the context's inventory.

3.2 Execution

During execution of the envelope model, client-supplied data is incorporated to derive a custom estimate. Calculation accepts three inputs:

- A timeframe during which the emissions occurred or will occur,
- a set of notations indicating which footprint components should be disabled, and
- a collection of described emitters

Typical calculations will involve of a timeframe of the current 12-month calendar year, but the system is timeframe-agnostic: emissions estimates can be calculated for any time range.

Calculation is performed on a component-by-component basis. For a given component:

- if the input designates the component as disabled, it returns zero;
- if the input collection includes relevant emitters, the component's footprint is delegated to them;
- otherwise, the archetypical value from the envelope model is used.

For future timeframes, or timeframes straddling the current date, projection heuristics are used to predict emissions. For components that describe “instantaneous” emissions like flights, future emissions are extrapolated from historical emitters described in the input. Components concerned with ongoing emissions, like those from automobiles, rely upon their emitter delegates to provide projections.

Preterite emitter projection process (example using flight component)



Preterite emitter projection scheme, exemplified using the flight component of an American individual's emissions envelope. In this example, the envelope model projects a 12-month flight footprint based on 6 months of known data: 4 months with no flights (light orange) and two months (dark orange) that contain flights that were modeled using the flight emitter model. The upper “typical emission” section displays average monthly variance in per capita US flight emissions—as indicated in the bottom “calculation methodologies” section, this variance is taken into account when projecting prehistoric and future emissions (gray) based on user deviation from the average during the known (orange) time period.

3.3 Case study: parameterizing the personal footprint

This case study describes the process used to model the carbon footprint of the average US resident. The process involves inventorying the total emissions for which the US population is responsible, dividing by population to determine each person's share, and categorizing those emissions into components according to their cause.

Identifying the full climate impact of the average U.S. resident is not a straightforward task. While calculating emissions from housing and transportation may be relatively clear-cut, few calculators go beyond this sphere to address emissions from producing the goods and services we consume, which in fact represent the majority of the average person's impact. That's because a bottom-up approach that attempts to piece together life cycle emissions from enumerated goods and services is an overwhelming undertaking that also risks double-counting or missing distant supply chain emissions.

To avoid this dilemma, a top-down approach is used, calculating the footprint of the combined U.S. population and then dividing to get the average individual's footprint. This approach treats the end consumer as ultimately responsible for all the emissions that go into producing the goods and services they consume. Using this approach, the sum of every individual's gross carbon footprint is equal to total anthropogenic emissions.

3.3.1 Determining context and responsibility

The starting point for our emissions model is the U.S. Greenhouse Gas Inventory (GHGI),⁵⁵ the authoritative annual report from the Environmental Protection Agency (EPA) on total greenhouse gas flux within the U.S.⁵⁶ As no single table in the GHGI displays emissions from all sources at the most granular level, data from multiple tables is combined in our system, and then it is verified that the sum is equal to the total emissions reported in the GHGI summary table.⁵⁷

While the GHGI comprises the backbone of the accounting process, some adjustments are necessary. The GHGI reports all emissions on U.S. soil in a given year. But what is needed is a measure of the full climate impact caused by the U.S. population that year. Greenhouse gases embodied in goods and services cross borders through international trade, landfill gas emissions have a lag effect across decades, emissions from aircraft have a greater impact at high altitudes, and fuel used by ships and aircraft departing the U.S. needs to be accounted for. These factors are corrected for in order to derive a final value for annual U.S. climate impact.

3.3.1.1 International trade

The largest adjustment made to the GHGI emissions figures accounts for carbon leakage through trade. The GHGI reports all greenhouse gas emissions in the U.S., but this does not fully correspond to the emissions U.S. residents are responsible for, because we consume goods produced in foreign countries and export domestically-produced goods to foreign consumers.

⁵⁵ EPA (2009b)

⁵⁶ This report is considered for purposes of this model to be the ultimate authority on U.S. greenhouse gas emissions, and in cases where there is disagreement between the GHGI and other data sets, the other data are scaled to bring them into accordance with the GHGI.

⁵⁷ EPA (2009b) Table 2.1

Total U.S. emissions are adjusted according to the results of an economic input-output model⁵⁸ by subtracting the emissions from producing exported goods and adding in the emissions from producing imported goods. Net percent change in U.S. emissions resulting from trade is calculated based on this model, and then total EPA-reported U.S. emissions are scaled up by that factor. Because the U.S. currently runs a substantial trade deficit, the balance of emissions embodied in trade results in a net import of emissions.

3.3.1.2 Landfill gas time lag

The GHGI reports total landfill gas emissions for a given year. But since landfilled waste takes many years to decompose and release its full load of greenhouse gases, these numbers represent current-year emissions from waste discarded in the past. To accurately reflect the climate impact of this year's activities, what is needed is a measure of future emissions from current-year waste.

Landfill gas numbers from the GHGI are zeroed out and replaced with a separate projection. The basis for this projection is the EPA Municipal Solid Waste (MSW) report,⁵⁹ which estimates U.S. solid waste generation by material type. The MSW data are then scaled by multiplying the values for each material so that the waste generation total is equal to the total reported in the BioCycles Waste in America report.⁶⁰

Next, landfill gas emission factors from the EPA's Waste Reduction Model^{61, 62} are applied to each of the scaled material types to convert kilograms of waste into CO₂e. Emissions for all material types are then summed to derive a measure of total future landfill gas emissions that will result from the waste discarded in a given year.

3.3.1.3 Bunker fuels

Substantial quantities of greenhouse gases are released in international territory by ships and aircraft that purchased fuel in the U.S. for a trip ending abroad. While the GHGI does report these emissions, they are technically beyond the scope of the inventory and so are not included in the summary tables as part of U.S. total emissions. These emissions are added into our US emissions total.

3.3.1.4 Air travel radiative forcing

The final adjustment made to the GHGI total is to apply a radiative forcing index (RFI) to all jet fuel emissions. This accounts for the fact that jet fuel combustion high in the atmosphere has a climate impact significantly greater than that of the same fuel burned at sea level. A multiplier of 2.0 is used, as recommended by the Stockholm Environmental Institute paper on Non-CO₂ emissions calculations for air travel.⁶³ This value falls within the range recommended by the Intergovernmental Panel on Climate

⁵⁸ Weber and Matthews (2007)

⁵⁹ EPA (2009c)

⁶⁰ The EPA identifies this report as the authoritative source for U.S. solid waste data; data taken from EPA (2009b) Table A-227

⁶¹ EPA (2009d)

⁶² EPA (2006b)

⁶³ Kollmuss and Crimmins (2009)

Change (IPCC) in their seminal report *Aviation and the Global Atmosphere*,⁶⁴ and is just slightly higher than the multiplier recommended by Kollmuss and Crimmins' update to the IPCC report.⁶⁵

3.3.2 Organizing emissions

Given a final value for adjusted annual U.S. emissions, the next step is to categorize those emissions by source. Emissions are broken into four major components – transportation, shelter, government, and consumables – and further divided into subcomponents such as cars or food. The average emissions for these categories serve as the default values for footprint calculator users.

In many cases this allocation process is aided by the GHGI's innate categories, which break total U.S. emissions into hundreds of line-items. But for many components the EPA categorizes emissions by their direct source instead of by their ultimate driver – an action by an individual consumer. In these cases, outside data sources are used to reallocate emissions.

As the requisite data are typically not available for the current year, data are projected forward based on the available time series using a linear trending algorithm. Some or all of a known time series may be used when identifying a trend for projection, so as to minimize the effect of outliers.

Emissions categorization follows a subtractive approach, whereby emissions associated with shelter, transportation, and government are identified, and all remaining emissions are allocated to the consumables category. This ensures that no obscure or distantly removed emissions source is overlooked – if it's included in the adjusted U.S. total, it will be included in a user's personal footprint even if it remains unidentified. The consequence of this completeness, which assures that a person's full impact is accounted for, is that emissions from unidentified sources, while included in the total, are immutable and cannot be personalized. This tradeoff is deemed worth the educational value and theoretical rigor.

Final national-level values for each component are divided by the U.S. population⁶⁶ to determine emissions per capita.

3.3.2.1 Transportation

a. Flights

Emissions from passenger air travel are calculated beginning with adjusted⁶⁷ GHGI values for emissions from jet fuel consumption by domestic flights, jet fuel and aviation gasoline consumption by general aviation, and bunker jet fuel consumption by commercial aircraft departing the U.S. These totals are then adjusted downward to take out emissions from air freight transport and government aviation.

Domestic flight jet fuel emissions reported in the EPA inventory are scaled down to remove freight transport emissions. The portion of commercial domestic jet fuel consumed by freight is determined by

⁶⁴ IPCC (1999)

⁶⁵ Sausen et al. (2005)

⁶⁶ U.S. Census Bureau (2008c)

⁶⁷ As noted in 3.3.1.4, a multiplier of 2.0 is applied to account for high-altitude effects

computing payload data from the Bureau of Transportation Statistics (BTS) T-100 Form 41 flight segment database (T-100).⁶⁸

Government aviation gasoline emissions⁶⁹ are subtracted from aviation gasoline emissions reported in the GHGI to determine aviation gasoline emissions from personal transportation.

International bunker fuels used by commercial aircraft as reported in the GHGI are scaled down to remove freight transport emissions. The portion of international bunker jet fuel consumed by freight is determined by computing payload data from T-100.⁷⁰

Finally, the adjusted values for general aviation emissions and domestic and international commercial aviation emissions are summed.

b. Automobiles

Beginning with car and light truck emissions in the GHGI, emissions from government vehicles⁷¹ are subtracted to derive the final automobile component.

c. Motorcycles

The motorcycle component corresponds exactly to the GHGI reported emissions for motorcycles.

d. Boats

The boat component corresponds exactly to the GHGI reported emissions for recreational boats.

e. Bus trips

Bus emissions are determined by subtracting government school bus emissions⁷² from the GHGI value for total bus emissions.

f. Rail trips

The GHGI reports rail emissions from diesel and electricity use, but does not differentiate between passenger and freight applications. The portion of total rail diesel fuel used by passenger rail is calculated by dividing passenger rail diesel consumption (commuter rail diesel use⁷³ plus intercity rail diesel use⁷⁴) by total rail diesel consumption (passenger rail diesel use plus freight diesel use⁷⁵). Since the American Public Transportation Association (APTA) Factbook shows freight rail as only using diesel, all electricity emissions in the GHGI are assigned to passenger rail.

⁶⁸ BTS (2009)

⁶⁹ See 3.3.2.3 b

⁷⁰ BTS (2009)

⁷¹ See 3.3.2.3 b

⁷² See 3.3.2.3 b

⁷³ APTA (2009) Table 34

⁷⁴ Oak Ridge National Laboratory (ORNL) (2009) Table A.15

⁷⁵ ORNL (2009) Tables A.12-15

g. Cruises

Total annual cruise passenger-nights departing from U.S. ports⁷⁶ is multiplied by residual fuel use per passenger night⁷⁷ to calculate cruise fuel use. As many cruises visit international destinations, this figure is then halved based on the assumption that on average cruises purchase half their fuel outside the U.S. This value is compared to the GHGI figure for total annual international shipping residual fuel consumption to determine what percentage is consumed by cruises. This percentage is then applied to the GHGI value for emissions from residual bunker fuel consumption by ships and boats to derive the final cruise footprint.

h. Ferry rides

U.S. ferry diesel consumption as reported by APTA⁷⁸ is divided by total domestic ship and boat diesel consumption as reported in the GHGI to determine the portion consumed by ferries. This fraction is then applied to the GHGI value for total emissions from domestic ship and boat diesel use to determine emissions from ferries.

3.3.2.2 Shelter

a. Residences

Estimated residential emissions map exactly to the GHGI residential sector. This category includes six major greenhouse gases released by fuel combustion, electricity use, substitution of ozone depleters, and soil fertilization by U.S. dwellings.

b. Hotels, Dormitories, and Other Lodging

Because the GHGI has no line items for these categories, the Energy Information Administration (EIA) Commercial Building Energy Consumption Survey⁷⁹ (CBECS) is referenced for energy consumption estimates. CBECS microdata is used to calculate, for the four major fuel types, the percentage of all commercial building energy consumed by hotels,⁸⁰ dormitories,⁸¹ and other lodging types.⁸² Those percentages are then applied to the GHGI emissions from commercial sector electricity, fuel oil and natural gas use to derive final emissions for the three categories of lodging. The GHGI has no line item for district heat emissions, so CBECS district heat energy use is converted into natural gas and fuel oil use based on a typical boiler conversion efficiency of 88.7% and a steam transmission energy loss 5%.⁸³

⁷⁶ U.S. Maritime Administration (2008)

⁷⁷ Calculated from Carnival and Royal Caribbean cruise lines investor reports

⁷⁸ APTA (2009) Historical Table 28

⁷⁹ EIA (2008a)

⁸⁰ Buildings identified in CBECS as hotels, motels, and inns

⁸¹ Buildings identified in CBECS as dormitories, fraternities, and sororities

⁸² Buildings identified in CBECS as monasteries, convents, orphanages, etc.

⁸³ Department of Energy Office of Energy Efficiency and Renewable Energy (2006)

3.3.2.3 Government

a. Forest

The GHGI reports carbon flux from land use, land use change, and forestry, including sequestration of carbon dioxide by plants. The forest component includes carbon sequestration from grassland remaining grassland, land converted to grassland, and forest remaining forest⁸⁴ as a negative value that neutralizes a portion of anthropogenic emissions. It also includes greenhouse gases released during forest fires as reported in the GHGI.

b. Public services

Public services emissions are estimated in a three-stage process. First, direct federal government emissions are estimated based on published government data. Then direct state and local emissions are estimated for buildings and vehicles. Finally, indirect government emissions are estimated.

Federal government emissions data come from two sources. Line items specifically identified in the GHGI as government-related are taken directly from that source – namely military jet fuel emissions and military ship and aircraft bunker fuel emissions. Coal, natural gas, aviation gasoline, gasoline, distillate fuel, residual fuel oil, LPG, and electricity used by the federal government are referenced from the EIA Annual Energy Review,⁸⁵ and emissions factors⁸⁶ are applied to determine emissions.

State and local building emissions are calculated based on CBECS microdata from the EIA by applying emissions factors⁸⁷ to the energy used by buildings identified as state or local government.

School bus gasoline consumption is taken from the Transportation Energy Databook⁸⁸ and adjusted downward so that total school and transit bus gasoline consumption equals bus gasoline consumption reported in the GHGI. School bus emissions are then calculated by dividing adjusted school bus gasoline consumption by total bus gasoline consumption as reported in the GHGI and then applying that percentage to the GHGI figure for gasoline bus emissions. This process is then repeated for diesel, and emissions are summed for both fuel types to determine school bus emissions.

Police car and ambulance emissions are calculated by averaging estimates from several sources of the number of vehicles nationally, vehicle fuel economy, and annual driving mileage and calculating total fuel consumption which is then multiplied by an emission factor⁸⁹ to determine emissions.

Fire truck emissions are calculated by combining the National Fire Protection Association's number of calls per year with U.S. Fire Administration response times, assuming fire trucks have a fuel economy comparable to semi trucks and travel at an average speed of 35 mph, calculating fuel consumed, and applying emission factors⁹⁰ to the result.

⁸⁴ Forest remaining forest accounts for the overwhelming majority of sequestration

⁸⁵ EIA (2008c) Table 1.12

⁸⁶ EIA (no date)

⁸⁷ EIA (no date)

⁸⁸ ORNL (2009) Table A.4

⁸⁹ EIA (no date)

⁹⁰ EIA (no date)

Indirect government emissions are calculated as a percentage of all emissions in the industrial sector of the GHGI. This percentage is derived by dividing all commercial sector government emissions by total commercial sector government emissions, the assumption being that government is responsible for a share of the industrial economy⁹¹ roughly equal to its share of the commercial economy.

3.3.2.4 Consumables

a. Pet

Population estimates for cats, dogs, horses, and other animals are multiplied by average body weight for each species. These values are then multiplied by an estimate of annual caloric demand per pound of body weight for each species, and then multiplied by an estimate of emission from producing a calorie of each species' typical food. These diet emissions values are summed across all species, and then emissions from veterinary services are added to derive a final pet emissions estimate.

Companion animal population estimates are sourced from the American Veterinary Medical Association.⁹² Typical dog and cat body weights are calculated by averaging breed-specific weights from online buying guides. Average estimated horse body weight is sourced from the National Research Council of the National Academies.⁹³ Caloric needs for cats⁹⁴ and dogs⁹⁵ are sourced from the National Academy of Sciences (NAS); an average of active and inactive adult dogs (or normal and overweight cats) is used, and the results were fit to a linear equation. Diet composition for cats and dogs is estimated to be 50% cereals and grains, 22.5% red meat, 22.5% poultry, and 5% oils and sugars by calorie, based on a review of the ingredients in leading brands of pet food. Horse diet composition is estimated to be 95% cereals and grains and 5% oils and sugars by calorie based on University of Minnesota Extension data;⁹⁶ a 100% feed diet was assumed. Diet emissions per calorie for the various food groups are estimated based on the methodology in 3.3.2.4 b.

Veterinary services emissions are estimated by multiplying the number of veterinary services employees in the U.S.⁹⁷ by commercial building energy use per employee. Energy use per employee is calculated for the outpatient health care sector based on CBECS microdata⁹⁸, and then emission factors⁹⁹ are applied to the various fuel types and summed to estimate emissions.

b. Diet

Estimated embodied emissions in food are sourced from the published results of an economic input-output model¹⁰⁰ that identifies greenhouse gases released by food production and transport.

⁹¹ The industrial sector of the economy consists of construction and manufacturing

⁹² American Veterinary Medical Association (2007)

⁹³ National Research Council of the National Academies (2007)

⁹⁴ NAS (2005a)

⁹⁵ NAS (2005b)

⁹⁶ University of Minnesota Extension (1995)

⁹⁷ Based on the U.S. Census

⁹⁸ Outpatient health care is the closest proxy for veterinary services

⁹⁹ EIA (no date)

¹⁰⁰ Weber and Matthews (2008)

c. Other consumables

All emissions included in our adjusted GHGI total that aren't included in one of the categories specified above are captured in this section. As explained, this ensures completeness by avoiding the overlooking of emissions from categories of goods and services that aren't examined individually.

Data sources

The following data sources, including some not cited in the body of this paper, feed into Brighter Planet's emissions models. Many are automatically updated in our system daily via programmatic import connections between our servers and the originators'.

Air Transport Association (2009). Monthly Jet Fuel Cost and Consumption Report. <http://www.airlines.org/economics/energy/MonthlyJetFuel.htm>

American Bus Association (2008). Motorcoach Census. <http://www.buses.org/research>

American Public Transportation Association (2009). 2009 Public Transportation Fact Book. <http://www.apta.com/resources/statistics/Pages/transitstats.aspx>

American School Bus Council (2008). National School Bus Fuel Data. <http://www.americanschoolbuscouncil.org/index.php?page=fuel-calculator>

American Veterinary Medical Association (2007). U.S. Pet Ownership & Demographics Sourcebook. <http://www.avma.org/reference/marketstats/sourcebook.asp>

American Veterinary Medical Association (2009). U.S. Veterinarians. <http://www.avma.org/reference/marketstats/usvets.asp>

Bureau of Transportation Statistics (2006). America on the Go Long Distance Transportation Patterns: Mode Choice. http://www.bts.gov/publications/america_on_the_go/long_distance_transportation_patterns/

Bureau of Transportation Statistics (2008a). Air Carrier Traffic Statistics. http://www.bts.gov/programs/airline_information/air_carrier_traffic_statistics/

Bureau of Transportation Statistics (2008b). Key Transportation Indicators: Amtrak Ridership. http://www.bts.gov/publications/key_transportation_indicators/february_2008/index.html

Bureau of Transportation Statistics (2007). National Transportation Statistics: Bus Profile. http://www.bts.gov/publications/national_transportation_statistics/html/table_bus_profile.html

Bureau of Transportation Statistics (2008c). National Transportation Statistics: Recreational Boating Safety, Alcohol Involvement, and Property Damage Data. http://www.bts.gov/publications/national_transportation_statistics/html/table_o2_43.html

Bureau of Transportation Statistics (2009). T-100 Form 41 Segment (All Carriers). http://www.transtats.bts.gov/Fields.asp?Table_ID=293

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To explore in more detail the models, the source code, and the datasets that underlie Brighter Planet's carbon calculations, visit our homepage at brighterplanet.com, our carbon middleware page at carbon.brighterplanet.com, and our climate data clearinghouse at data.brighterplanet.com.

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