Applying the Project Management Cost Estimating Standard to Carbon Footprinting

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Abstract

Anthropogenic emissions have a significant effect on Earth's atmosphere and contribute to changes in the global climate. These emissions and their impacts need to be tracked in order to understand their potential consequences and to be able to determine how these impacts can be eliminated or reduced by changes in methods, behaviors, and tools. A carbon footprint is the amount of carbon dioxide and other greenhouse gas emissions generated by an entity over a specific time period or lifecycle. Developing a consistent and clear approach to determining the sources and quantities of these emissions is important due to the emerging demand to account for carbon impacts. Unfortunately there are very few approaches that can accurately estimate and track carbon to determine the climate change impacts of organizations, businesses, and activities. In this paper we propose an approach to carbon footprinting in which the amount of one or more types of carbon gas emissions can be estimated. We propose that by adapting cost estimation standards to carbon footprinting practices, a standard approach can be developed, thus providing a clearer and more focused approach to carbon footprinting. In this study, we have adapted the cost estimation standard of the Project Management Body of Knowledge (PMBOK). This adaptation results in a new methodology for carbon footprint quantification that provides more clarification and robustness to carbon footprinting processes. By breaking down the whole process into three key steps, i.e., inputs, tools and techniques, and outputs, and by introducing relevant steps to take, the methodology can function as a guideline for carbon footprinting studies.

Keywords: carbon footprinting, carbon emissions, climate change, carbon dioxide, cost estimation

1. Introduction

As climate change is gaining increasing priority on the list of challenges being faced by humans, more attention is being given by decision-makers to the factors that adversely affect the planet. Although there are numerous contributors to these problems, some have significant destructive consequences and therefore require more attention and action. Gaseous carbon emissions can be regarded as one of the top challenges for current and future generations, and they will continue to increase unless firm steps are taken to develop environmentally friendly solutions for global energy systems. Indeed, according to the International Energy Agency, a record 30.6 billion metric tons of greenhouse gases were emitted in 2010, the most recent full year for which data is available (IEA, 2011).

Despite the threat posed by these emissions, there has not been any deceleration in the growth of greenhouse gas emissions. It is clear that appropriate decisions are badly needed to address these difficult emissions problems and sound approaches, procedures, and tools are needed by policymakers to be able to reverse course and put the world on a path that does not threaten both human and non-human inhabitants of the planet.

In parallel with the movement toward development of proper environmental performance measures, carbon footprinting is gaining more attention and popularity. A carbon footprint is the amount of carbon dioxide and other greenhouse gas emissions generated by an entity over a specific time period or lifecycle. At present there are only a few standard approaches (i.e. PAS2050, ISO 14021, or ISO 14044:2006) to determining the carbon emissions of a person, a product, a specific service, or an organization.

As part of any carbon footprint reduction plan, decision makers should determine how reduction goals are going to be achieved. A carbon footprint reduction plan can include a detailed action list along with information about the contribution of each element of the plan to meeting carbon emission reduction goals. In order to determine whether any carbon emission reduction plan has been successfully implemented, a vigorous performance monitoring and control process should be implemented. Results can be compared with the targets in the reduction plan to assess deviations from the plan and devise corrective actions.

As explained by Burgess and Nye (2008), the technology for carbon footprinting and carbon labeling of products is creating many opportunities to develop materials and energy-efficient products that are more environmentally friendly in terms of carbon emissions.

Sovacool and Brown (2010) conducted a comparative study of the carbon footprints of twelve metropolitan areas around the world. In their work, emissions related to various sources such as vehicles, energy used in buildings, industry, agriculture, and waste were explored. Table 1 shows the carbon emissions profile of these areas, categorized by sources of emission. Different patterns in different countries can be seen in this table. This variation in carbon emissions patterns indicates that well-developed and regionally customized emission reduction policies that target the appropriate sectors in the economy are needed. As stated by Hertwich and Peters (2009), "policy priorities hence depend on development status and country-level characteristics" (p. 6414).

Table 1. Carbon emissions profile for 12 metropolitan areas (adapted from Sovacool and Brown (2010))

Metropolitan area	Carbon emissions from energy use in buildings and industry / electricity		Carbon emissions from transport		Carbon emissions from agriculture / forestry		Carbon emissions from waste	
Beijing	87%	Primary source; processing and heating needs for industry	5%	Primary source; private automobiles	1%	Primary source; nitrogen fertilization	1%	Primary source; food waste
Jakarta	56%	Primary source; electricity	41%	Primary source; private automobiles	< 1%	Primary source; deforestation	< 1%	Primary source; landfills
London	76%	Primary source; space heating for buildings	23%	Primary source; private automobiles	< 1%	Primary source; N/A	< 1%	Primary source; N/A
Los Angeles	52%	Primary source; electricity	48%	Primary source; private automobiles	< 1%	Primary source; N/A	< 1%	Primary source; N/A
Manila	39%	Primary source; electricity	51%	Primary source; private automobiles	9%	Primary source, livestock	1%	Primary source; landfills
Mexico City	45%	Primary source; process needs for industry	35%	Primary source; private automobiles	6%	Primary source; deforestation	< 1%	Primary source; landfills
Dehli	32%	Primary source; electricity	66%	Primary source; private automobiles	2%	Primary source; livestock	< 1%	Primary source; wastewater treatment
New York	77%	Primary source; electricity and heating fuels for buildings	23%	Primary source; private automobiles	< 1%	Primary source; N/A	< 1%	Primary source; N/A
Sao Paulo	24%	Primary source; electricity	51%	Primary source; private automobiles	2%	Primary source; deforestation	23%	Primary source; landfills
Seoul	44%	Primary source; heating for industry	42%	Primary source; private automobiles	1%	Primary source; N/A	13%	Primary source; landfills
Singapore	83%	Primary source; electricity	17%	Primary source; private automobiles	-	Primary source; N/A	-	Primary source; N/A
Tokyo	67%	Primary source; commercial energy use	32%	Primary source; private automobiles	< 1%	Primary source; N/A	< 1%	Primary source; N/A

Current studies are shedding light on newer aspects of carbon footprinting practices. The work of Peters (2010) is worth mentioning here because he has investigated carbon footprints and embodied carbon at multiple scales. As a result of this research and the efforts of others in the field, carbon footprinting has become one of the main performance measures in the field of sustainability. Many sustainability indices and rankings use carbon footprint estimates. Examples include:

- Analysis of the sources of greenhouse gas emissions from the Intergovernmental Panel on Climate Change (IPCC)

- Rankings concerning the Global Zero Carbon Capacity Index from the Royal Institute of Chartered Surveyors (RICS)

- Statistical reports from the United Nations Statistics Division (UNSTATS)

- CO_2 emissions data from the International Energy Agency (IEA)

1.1 Definition

Although there are many environmental performance measures, our focus here is on the carbon footprint as a sustainability indicator. It is of course important to have a standard definition of carbon footprint. In fact,

researchers and institutions have offered many different definitions and there is no consensus on the definition of carbon footprint. As stipulated by Wiedmann and Minz (2008), "despite its carbon footprint's ubiquitous appearance there seems to be no clear definition of this term and there is still some confusion what it actually means and measures and what unit is to be used" (p. 2).

Table 2. Varying definitions of carbon footprint

Source	Proposed definition
(Lynas, 2008)	A carbon footprint is a measure of an individual's contribution to global warming in terms of the amount of greenhouse gases produced by an individual and is measured in units of carbon dioxide equivalent.
(Wiedmann and Minx, 2008)	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.
(Peters, 2010)	A "carbon footprint" of a functional unit is the climate impact under a specific metric that considers all relevant emission sources, sinks, and storage in both consumption and production within the specified spatial and temporal system boundary.
(EPA, 2010)	A measure of the greenhouse gases that are produced by activities of a person, a family, a school or a business that involve burning fossil fuels.

The literature on carbon footprinting is becoming richer but is still inconclusive because various definitions and scopes as well as estimation methods have been proposed. To clarify, some previously proposed definitions of the term "carbon footprint" have been listed in Table 2. Based on these definitions, differences in definitions and approaches to the problem are clear; and include but are not limited to the following:

a)   Intent: Different intentions in developing carbon footprint tools will result in different outputs. A tool that is intended solely for increasing individual awareness and a tool that is intended as a decision-support tool in a medium or large-sized company are not the same. As a result there are different levels of simplification and precision.

b)   Approach: The size of the carbon footprint may vary depending on the methodology for determining the footprint. Ackerman and Sundquist (2008) showed how different approaches taken by the U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) for estimating power plant-produced carbon dioxide emissions produce different results. They note that, "estimates that are based partly or entirely on monitoring of stack gases (reported by eGRID only) differed significantly from estimates based on fuel consumption (as reported by EIA). Differences in accounting methods appear to explain differences in estimates for emissions." (p. 5688)

Two different approaches are seen in this literature: production-based and consumption-based. The work of Druckman et al. (2008) investigates the implications of these two accounting frameworks on a national level.

c)   Types of emissions: The types of gas emissions taken into account in calculating the carbon footprint can produce different results. Wiedmann and Minz (2008) have proposed using the carbon footprint term only for carbon dioxide emissions, whereas, EPA (2010) has taken all types of greenhouse gases into account. This means that other greenhouse gases such as methane, sulfur hexafluoride, nitrous oxide, hydrofluorocarbons, and perfluorocarbons must also be included in the carbon footprint. Some studies such as the work of Becken and Patterson (2006) take not all, but only a selection of greenhouse gases into account, causing even more variations in carbon footprint estimates.

d)   Source of emissions: Many carbon accounting approaches consider only fuel combustion as the source of carbon while others account for releases of methane and other phenomena. Carbon footprint estimates can be derived with or without regard to the source of emission. The approach used is generally based on the intent or purpose for extracting carbon estimates.

e) Lifecycle: The assumed lifecycle of the product or activity is another source of differences among carbon footprint estimation methods. Narrowly-defined methods that do not count for all emissions across all product or service lifecycles can be expected to underestimate the quantity of emissions. The disposal phase of a product is an example of a lifecycle phase of most products that is ignored in most carbon footprint methods.

f) Scope: Another source of difference is the scope of calculation. It has been proposed that the scope of carbon quantification be divided into two categories: direct or scope 1 emissions (emissions from sources that are owned or controlled by the company), and indirect emissions (emissions that are a consequence of the activities of the company but occur at sources owned or controlled by another company) (Ranganathan et al., 2004). According to the World Resources Institute (WRI), indirectly-produced emissions can again be divided into scope 2 emissions (emissions from the generation of purchased electricity), and scope 3 emissions, including also all other indirect greenhouse gas emissions. The equity share and control approaches make the evaluation even more complicated. Comprehensive estimates in terms of scope are of even more importance when a product or service is provided by a supply chain. Matthews et al. (2008) have shown how underestimated carbon footprints could result if only scope 1 and 2 emissions are taken into account. The most precise results are obtained when scope 3 emissions are targeted as well. Based on this conclusion, they have even proposed taking the more rigorous step of defining a fourth "tier" or scope to address "delivery, disposal and impacts of products as a life-cycle product calculation" (p. 5842).

g) Unit of measurement: By using the term "carbon footprint", some authors refer to an area-based unit of measurement. Similar to the method of calculating "ecological footprint", however, some authors report carbon footprint estimates in measurement units such as hectare, acre, or square kilometer. Nevertheless, not all authors use area-based units. Scientists also generate reports in weight-based measurement units such as tons or even other units of measurement such as carbon dioxide equivalent per product or per currency unit.

h) Conversion factors: These factors provide the possibility of conversion from different inputs into carbon dioxide equivalents. Gas emissions resulting from greenhouse gases other than carbon dioxide can be converted into the same unit of equivalency. Conversion factors are prepared and published by some institutes such as the Australian Department of Climate Change and Energy Efficiency (publishes The National Greenhouse Accounts (NGA) Factors (DCCEE, 2011)), the New Zealand Ministry for the Environment (MFE) (see for instance, MFE, 2009), or the UK Department for Environment, Food and Rural Affairs (DEFRA) (see for instance, DEFRA, 2011).

In using these factors, care should be taken to ensure that oversimplification does not occur and that proper regionally specific factors are used. Varying assumptions and standards used in measuring carbon and energy content have resulted in varying conversion factors.

i) Others: Other sources of difference can be the inclusion or exclusion of some geographically specific, process specific, resource specific or other types of emissions.

Varying characteristics of carbon footprint estimation methods in the literature cover such a broad range of options that a combinatorial approach can be used for model selection purposes. For this purpose an example of these diagrams is provided in Figure 1, which shows various variations caused by diverse sources of difference between carbon footprint estimation methods.

Providing a precise definition for the term "carbon footprint" is essential, especially when projects aiming at reduction of carbon dioxide and other specific gas emissions are undertaken. This clarification will help prevent any ambiguity regarding the scope of results and responsibilities for projects. However, the aim of this paper is not to provide this clarification but to highlight the importance of process documentation and complying with methodological standards throughout the process.

For the purpose of this paper, the PMBOK standard (PMI, 2010), a well-established standard for the project management profession, has been chosen as the estimating standard for carbon footprinting because it is well suited for evaluating the processes associated with various products, services or activities. In addition, the PMBOK standard is an internationally and generally recognized standard, and the practitioners of project management have a consensus opinion about its validity and relevance.

Later in this paper we will explain why the PMBOK standard has been chosen for adoption in this research. In the meantime, the definition of "estimate" from the Project Management Institute (PMI)'s point of view is worth mentioning: "Estimate is a quantitative assessment of the likely amount or outcome which is usually applied project costs, resources, efforts and durations and is usually preceded by a modifier (i.e. preliminary, conceptual, feasibility, order-of-magnitude, definitive). It should always include some indication of accuracy (e.g. x percent)"

(PMI, 2010, p. 426). According to PMI, "estimates are a prediction that is based on the information known in a given point in time" (p. 168). This definition will be used as the basis for the carbon footprinting approach described in this paper.
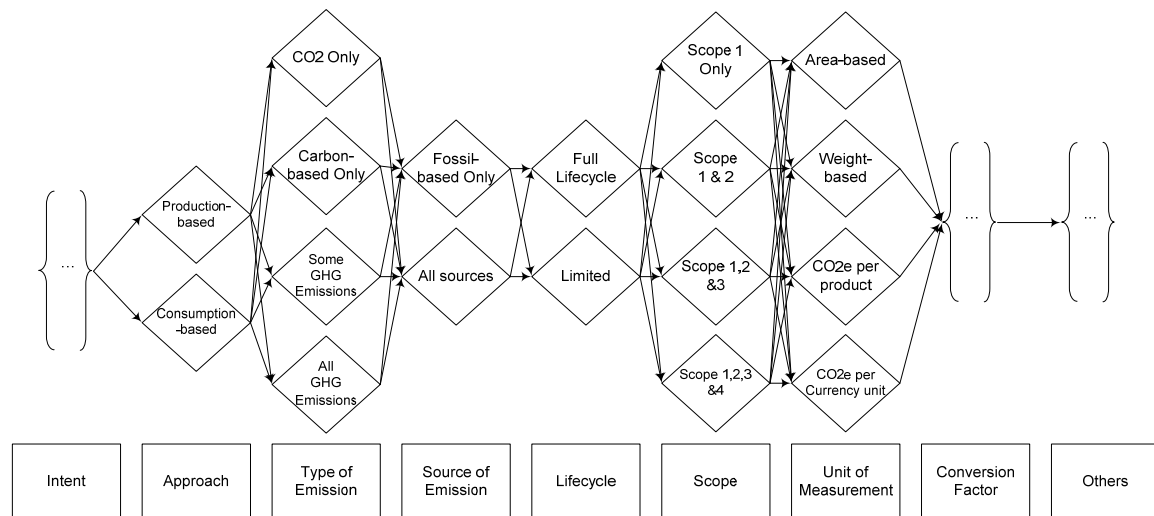

Figure 1. Combinatory variations of carbon footprint definitions and approaches

1.2 Carbon Footprinting Methods

The term "carbon footprint calculation" is frequently used as a general term to describe efforts that are undertaken to quantify the amount of one or more gases emitted for a given product or service, however, in cases where estimates are projected into the future, we suggest that a better description would be "carbon footprint estimation". The term "carbon footprint calculation" gives the impression that the process is a matter of pure measurement, computation, or reckoning types of activities. In cases where carbon estimates are to be projected into future periods, the term "carbon footprint estimation" seems more appropriate because it is concerned about appraisal and assessing types of practices which are influenced by judgmental reviews. Additionally, due to the complexities involved in forecasting, providing either an approximate quantification or a range of values in the form of a confidence interval makes more practical sense than expecting quantified values as the result of computation methods. Altogether, the term "carbon footprint quantification" seems more appropriate in general terms.

Various methods have been proposed for the purpose of carbon footprint quantification efforts. As we discussed in the definitions section of this paper, carbon footprint quantification methods have been developed based on different assumptions and considerations. A variety of institutes have introduced and offered their tools for carbon emission quantification and analysis. Many web-based tools are also available to the public for this purpose.

If they are designed and developed appropriately, carbon footprinting methods can be regarded as decision support systems on an individual or group level. For instance, Larsen and Hertwich (2010) have shown how carbon footprinting can provide invaluable insight for municipal decision makers in adjusting their urban policies.

It is instructive to mention the work of Bottrill (2007) as well as the work of Padgett et al. (2008) as helpful comparative studies on carbon footprinting tools. The work of Bottrill (2007) entails the review of twenty-three carbon footprinting tools for investigating their carbon accuracy and effectiveness. He has concluded that many carbon footprinting tools hardly provide users with accurate results or the possibility of continuous monitoring of carbon emissions. Padgett et al. (2008) conducted a study to identify similarities and differences among some US-based carbon dioxide emission "calculators". These "calculators" are listed in Table 3. They drew a similar conclusion and reported that the results obtained from many carbon footprinting tools vary to a large extent. They emphasized the need for providing much more transparency and consistency in carbon "calculators" to bring about improved and consistent results when the same input data is fed into these tools. An example of

varying results based on the same set of data is shown in Table 4.

Kenny and Gray (2009) reached a similar conclusion by undertaking a comparative analysis of six different carbon footprinting models. Another study that produced conflicting results based on different carbon footprinting sources is the work of Johnson (2008), in which the carbon footprint of electric and LPG forklifts were estimated and compared. Johnson concluded that, in many cases, non-transparent definitions are the cause of discrepancies among carbon footprint results.

2. Methodology

Although there is some controversy about definitions and the methods used for carbon footprinting, it is clear that carbon footprinting is a technique being used to determine a reasonably sound determination of carbon gas emissions produced for a given product, service or activity. In this sense, carbon footprinting can be viewed as the process by which an approximation of the gas emissions is derived. Depending on whether carbon footprint estimates are going to be projected into future periods of time, the use of the term "carbon footprint estimation" may seem more appropriate for this process, but no matter what term is being used, we recommend adapting estimation standards to benefit from their well-established standard requirements. This adaption would provide the opportunity for stakeholders to examine their carbon footprinting practices to make sure established norms and requirements have been well-satisfied throughout their endeavors.

As mentioned before, in this paper, the PMBOK standard has been chosen for this purpose. The section of the PMBOK in which the estimation standard has been elaborated is the "Estimate Costs" module. Similar to other modules contained in the PMBOK, the "Estimate Costs" has been structured to introduce norms and guidelines into three main areas of concern: inputs, tools and techniques, and outputs. Different elements of these areas of concern with some modifications to match our purpose are shown in Figure 2. Also, a demonstration of the flow of data along with decomposed data processing units is shown in the form of a data flow diagram in Figure 3 (modified from the original flow diagram to match our purpose).

In the following sections, we explore the different elements in Figure 2 and 3 and explain how carbon footprint estimates are dependent upon these elements. We base our approach to the detailed process description proposed by the Project Management Institute (PMI, 2010).

2.1 Inputs

(1) Scope Baseline: The Scope Baseline is the result of a process that creates work breakdown structures (WBS). In carbon footprinting, WBS will define the exact scope of work and inclusions based on which scope-related assumptions, exclusions and practice boundaries can be determined. An attempt should be made to clarify whether carbon footprint estimates will include only those activities directly contributing to carbon production or also include indirect carbon producing-activities. WBS's are beneficial tools that can be used for scope clarification. Figure 4 and 5 illustrate two examples of WBS's that can be used for providing more clarification about the scope and elements included in carbon footprinting.

Table 3. Carbon dioxide calculators examined in study (adapted from Padgett et al. (2008))

American Forests	http://www.americanforests.org/resources/ccc/
Be Green	http://www.begreennow.com/
Bonneville Env. Foundation	https://www.greentagsusa.org/GreenTags/calculator_intro.cfm
CarbonCounter.org	http://www.carboncounter.org/
Chuck Wright	http://www.chuck-wright.com/calculators/carbon.html
Clear Water	http://www.clearwater.org/carbon.html
The Conservation Fund	http://www.conservationfund.org/gozero
EPA	http://www.epa.gov/climatechange/emissions/ind_calculator.html
SafeClimate	http://www.safeclimate.net/calculator/
TerraPass	http://www.terrapass.com/

Table 4. Comparison of values for personal air travel and CO_2 emissions (adapted from Padgett et al. (2008))

	Flight conversion (lbs CO2/mile)	CO2 emitted for 830 miles flown (lbs/year)
American Forests	0.44	365
Be Green	0.42	352
BEF	1.36 [a]	1129
CarbonCounter.org	0.87 [a]	720
Chuck Wright	0.51	426
Clear Water	0.62	517
The Conservation Fund EPA	0.43	360
SafeClimate	0.64	528
TerraPass	0.45	373
Range	0.94	777
Modified Range V [b]	0.21	176
Mean	0.64	530
Median	0.51	426
Standard deviation	0.154	255

a Include the effects of additional greenhouse gases and/or contrails

b Modified Range V is the difference in flight values from calculators that do not account for the effects of additional greenhouse gases and/or contrails.

One of the advantages of developing WBS upon which carbon footprint estimates can be built is that the role of each element illustrated in the structure can be specified independently so that carbon footprint statistics are not generated in aggregation but separately for each contributing element.

(2) Enterprise Environmental Factors (EEF): The enterprise environmental factors are external factors that impose any kind of influence on carbon footprints. Examples of EEF can include:

Market conditions: As explained by PMI, "market conditions describe what products, services, and results are available in the market, from whom, and under what terms and conditions" (p. 171). We can take different fuel types and grades as an example of how different market conditions can have different implications for quantification of the carbon footprint.

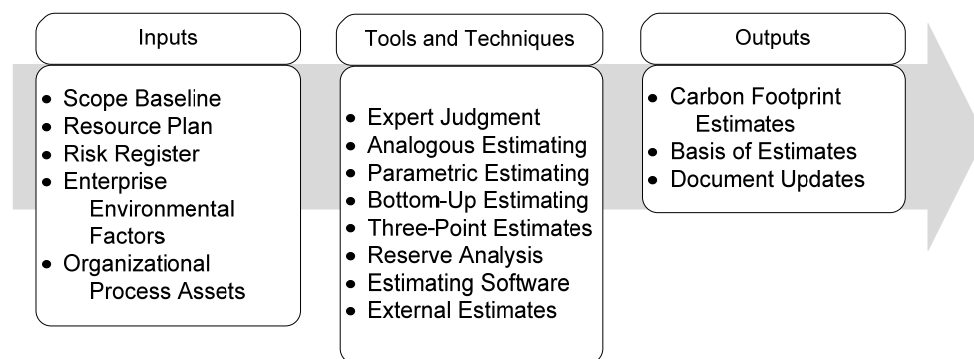| Inputs	Tools and Techniques	Outputs
• Scope Baseline • Resource Plan • Risk Register • Enterprise Environmental Factors • Organizational Process Assets	• Expert Judgment • Analogous Estimating • Parametric Estimating • Bottom-Up Estimating • Three-Point Estimates • Reserve Analysis • Estimating Software • External Estimates	• Carbon Footprint Estimates • Basis of Estimates • Document Updates

Figure 2. Estimate Carbon Footprint: Inputs, Tools and Techniques, Outputs (adapted with minor modifications from PMI (2010))
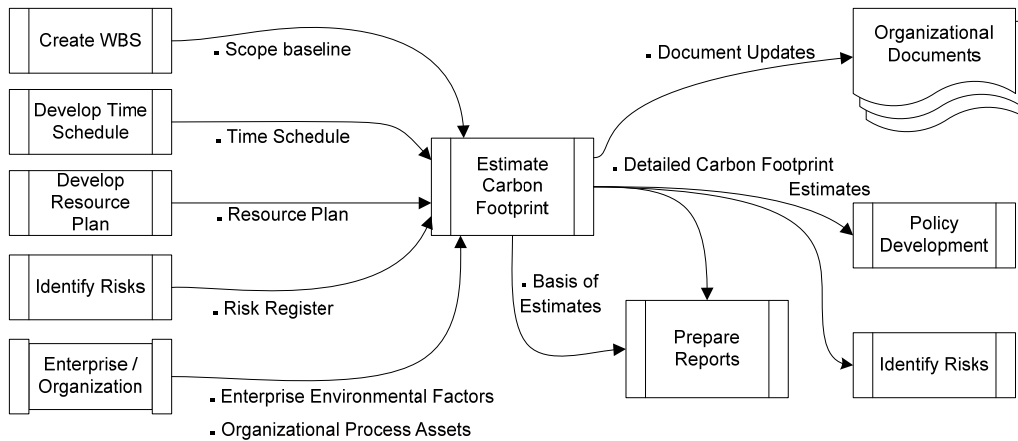
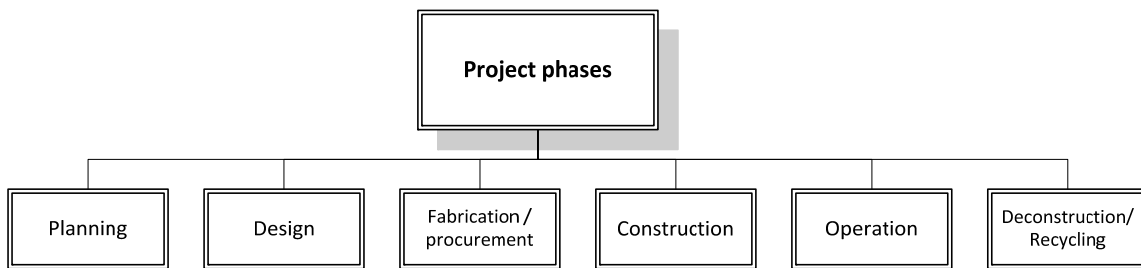Figure 3. Estimate Carbon Footprint Data Flow Diagram (Adapted with minor modifications from PMI (2010))

Figure 4. Lifecycle stages - An example of WBS clarifying inclusions and exclusions in carbon footprint estimation for a project
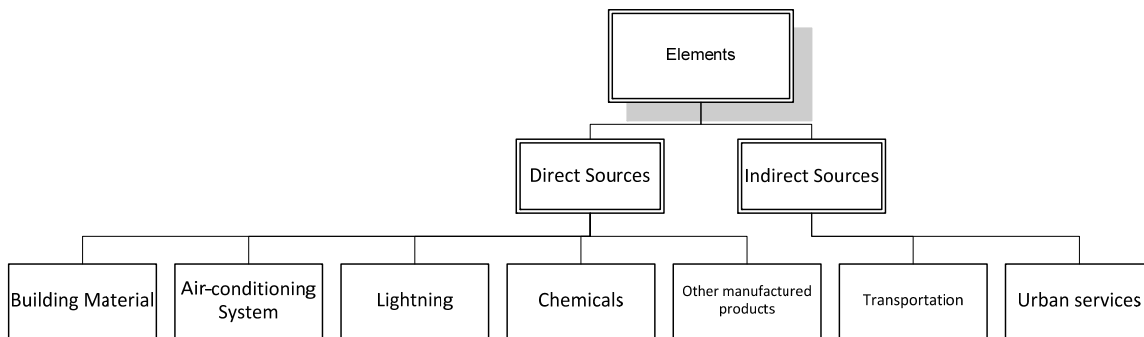
Figure 5. Elements - An example of WBS clarifying inclusions and exclusions in carbon footprint estimation for a building project

- Published carbon dioxide equivalent conversion factors: As mentioned before, the purpose of carbon dioxide conversion factors is to provide help in converting various data sources such as utility bills, fuel consumption, and driving mileage into carbon dioxide equivalent emissions by applying appropriate conversion factors.

- Published emission coefficients for different processes: the purpose of emission coefficients is to provide help in estimating emissions generated as the result of different processes.

- Published fuel combustion efficiency factors: Fuel combustion efficiency factors are measures of useful energy extracted from the combustion process of a fuel source. For example, an engine with a fuel combustion efficiency of 50% converts 50% of the fuel's energy content into useful motive force. Fuel combustion efficiency factors are published by energy device manufacturers or fuel suppliers.

(3) Organizational Process Assets: According to PMI, Organizational Process Assets are "all process related assets {that} … include formal and informal plans, policies, procedures and guidelines. The process assets also

include the organization's knowledge bases, such as lesson's learned and historical information" (PMI, 2010, p. 32). Carbon footprint reduction plans can be regarded as one of the major success factors in any emissions reduction project. The role of organizational process-oriented assets to achieve successful results should be included in the quantification process or estimate of carbon footprints. Organizational policies, procedures, templates, lessons learned and any other relevant information from previously executed projects would benefit any current carbon footprinting practice. Examples of some organizational process assets that might be helpful in the process of carbon footprinting include:

- Organizational standards (such as quality management, documentation and testing standards)

- Organizational policies (such as reporting policies, ethics and public policies, occupational safety and health policies)

- Organizational procedures, guidelines and templates (Organizational performance measurement indices, scorecards, estimating templates)

- Corporate Knowledge base which includes current and historical databases of the corporate's methods, product and service information, and organizational resources.

2.2 Tools and Techniques

The concept of carbon footprint has the potential to draw the attention of the public as well as that of decision makers to the effects of different products and services on the environment. For this reason, the term carbon footprint is being used and promoted. Earlier carbon footprint methods found in the literature have used either the bottom-up or top-down approach to addressing the problem. In the bottom-up approach, the whole scope is broken down into sufficiently detailed components. Estimated or quantified carbon footprints are determined for each of these components and the results are ultimately rolled-up to determine the overall carbon footprint. The opposite approach, the top-down approach, uses input-output analyses to identify lower-level patterns. Both of these approaches have been used in the work of Becken and Patterson (2006) in which the authors have derived estimates of the influence of the tourism sector on New Zealand's national carbon dioxide emissions.

Similar to what the PMBOK standard has suggested for cost estimating, other methods that can be used in cases where carbon footprints cannot be measured and need to be estimated are as follows:

(1)   Expert Judgment: The PMBOK standard states that expert judgment can contribute to a large extent to the quality of estimates by providing knowledge of the environment and historical project information based on past experience. This statement is also applicable to carbon footprint estimating efforts. The reliability of carbon footprint estimates will be under question unless the whole estimating process is designed and implemented under the auspices of experts. Identification of all influential variables that affect the quality of carbon estimates, such as resource usage, energy consumption rates, and waste rates, is probably the most crucial task of experts involved in the process.

(2)   Analogous Estimating: As the name of this method implies, analogical inferences can be derived in situations in which some similarities between carbon footprint cases are recognizable. For instance, in carbon footprint studies in which a product is chosen as the representative of a category of products and carbon footprint estimates are derived only for the chosen product, the analogous approach has been taken. In this case, the measured emissions produced by the designated product might be used as carbon footprint estimate for its peer products.

(3)   Parametric Estimating: PMBOK has proposed the use of this method when some statistical relationship among historical data (such as cost, budget, and duration) and other variables (such as square footage of construction) exists. If we consider the carbon footprint of an activity as a parameter, the same definition can be applied for the case of carbon footprint estimates. Many instances of the use of this method can be found in the literature of carbon footprinting. Examples include carbon footprint per capita or per household, carbon footprint per kilowatt-hour of electrical energy generated, and carbon footprint per kilometer flight.

(4)   Three-Point Estimates: Three-Point Estimation is a technique used for estimation based on historical information in which three scenarios, i.e. best case scenario (optimistic), the worst case scenario (pessimistic), and the most likely, are assumed. Proper estimate values are derived corresponding to each scenario. As we will explain in the "outputs" section of the methodology, clarification about the targeted degree of certainty in carbon footprint estimates is necessary and important. In this sense, different types of estimate such as preliminary, conceptual, order-of-magnitude or definitive can be developed and used. Taking risk factors into account, three-point (optimistic, pessimistic and most-likely) estimates can also be used in carbon footprinting efforts depending on the level of certainty that may be required.

(5)   Reserve Analysis: In anticipation of and preparation for uncertainty, surplus "contingency allowances" of carbon footprint estimates can be established. Contingency in estimates works as an allowance to cover unforeseen circumstances. Estimates in different levels of uncertainty (i.e., preliminary, conceptual, order-of-magnitude or definitive) might need different amounts of contingency to be set aside. Usually the contingency is expressed as a percentage of the estimated values.

(6)   Estimating Software: Several carbon estimation, footprint assessment software applications, and web-based tools such as SafeClimate, TerraPass, Berkeley carbon footprint, Nature Conservatory, and ClimateCrisis have been developed which can be utilized to facilitate carbon footprint estimates. For this purpose, some organizations even establish their own customized tools that are more meaningful and relevant to their needs. These tools are gaining more popularity in carbon footprint practices due to their improved capabilities and ease of use.

(7)   External Estimates: Another source of obtaining carbon estimates may also be external resources or estimates derived by third-parties. External resources are those estimators who are not part of the organization that is interested in having carbon estimates. For instance, a manufacturer might decide not to employ carbon footprint estimating techniques for all sub-systems involved in a product but to rely on carbon footprint estimates provided to them by the sub-suppliers of some sub-systems.

2.3 Outputs

(1)   Carbon Footprint Estimates / Quantities: The key output of any carbon footprinting practice is the approximate amount of gas emissions produced as a result of certain activities. The final quantified or estimated results will be more accurate if approximations are developed for the lowest level of elements in the scope breakdown structure. Detailed carbon footprint assessments are ultimately used for preparing reports, identifying risks, or for policy development purposes (see Figure 3). Well-extracted carbon footprint data provides the necessary foundation for entities –i.e., individuals, organizations, businesses, and communities – to plan for and develop proper environmental policies. Carbon footprint data is an instrumental way, especially for organizations, to engage their staff, organizational partners, local communities and customers about their carbon footprint, and to drive behavior change to produce better carbon footprint management practices.

(2) Basis of Estimates: As discussed in the PMBOK, "the amount and type of additional details supporting the … estimate vary by application area. Regardless of the level of detail, the supporting documentation should provide a clear and complete understanding of how the … estimate was derived." (PMI, 2010, p. 174) Parties involved in carbon footprint practices can minimize ambiguities by documenting the basis of carbon estimates or calculations that encompasses at least the following pieces of information about their use of carbon footprint measures:

•   Documentation of method statement: Method statement details all key processes, tools and techniques, or methods employed for the purpose of extracting carbon footprint data.

•   Documentation of all background assumptions such as types of emissions, sources of emissions, and lifecycle.

•   Documentation of any specific constraints faced or imposed by circumstances.

•   Documentation of the degree of accuracy: The degree of accuracy in carbon footprint analysis can be considered as the degree to which we expect the result of carbon footprint analysis conforms to the correct value. The degree of accuracy relates to the quality of estimation or calculation so that higher accuracy levels imply that data is expected to be nearer the true values. In cases where carbon footprints are estimated, accuracy is conventionally expressed as a + (positive) or – (minus) percentage range around the point estimate, e.g. $100 \pm 20\%$. As the level of detail in estimates increases, the expected degree of accuracy of the estimate is also inclined to rise, as shown by a tighter +/- range.

•   Documentation of confidence level of end results. In some carbon footprinting practices the quantities of carbon footprint can be measured or determined with absolute certainty. In other cases, carbon footprints need to be estimated. Because estimating is a type of prediction, documenting the targeted degree of accuracy of estimates is of prime importance. According to Druckman et al. (2008) and Marland (2008), the need for determining carbon footprints with a reasonable degree of confidence is important. Few studies of carbon footprinting have addressed the need to specify how confident users should be that a given estimate is accurate (Marland, 2008).

(3) Document Updates: In the end, all related organizational data repositories and databases are updated and historical records are collected. Estimates refinement and update to incorporate additional details, as they

become available, are of paramount necessity and importance to make sure carbon analysis remain accurate and valid.

3. Case Study

For applying the proposed methodology, we chose a carbon footprinting study, titled "The residential energy and carbon footprints of the 100 largest US metropolitan areas" (Brown & Logan, 2008). In this case-study we have implemented some of the proposed steps of the proposed methodology. The methodology is likely to be most useful if it is used when a carbon footprinting study is still underway, but applying it on a completed study can also show strengths and weaknesses of the study. From this point on, we refer to this study as "the study". We explain in the following how each of the steps in the input, tools and techniques, and output sections of the methodology can be applied to a typical study such as the one mentioned above.

3.1 Inputs

(1)　Scope Baseline

The scope of work of the selected study is described in Table 1 and illustrated in Figure 6. It is not clear from the study ifindirect carbon producing-activities were taken into account. However, as shown in Figure 6, for estimating carbon footprints of residential electricity usage, carbon estimates from residential electricity "source" energy use, with the definition provided in the "assumption list" part of section 3-3, has been accounted for.

Table 5. Scope statement describing the objective and content of the study

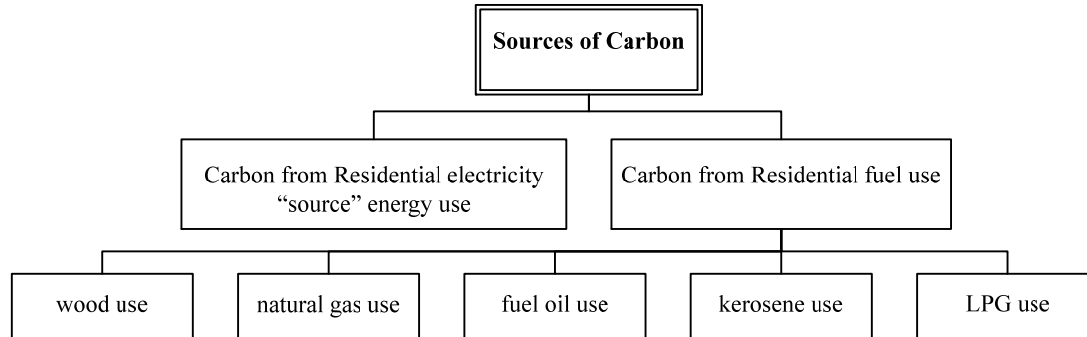| Scope Statement |
| --- |
| This study quantifies the carbon emitted in the form of carbon-dioxide by the 100 largest U.S. metropolitan areas in the years 2000 and 2005. Sources of emissions are considered as (1) the fuels used by vehicles (personal and freight) and (2) the energy used in residential buildings in the form of electricity and fuel consumed by households. |

Figure 6. The scope breakdown structure of the study decomposing its main scope elements

(2)　Time Schedule

The study estimates the carbon emitted in the form of carbon-dioxide by the 100 largest U.S. metropolitan areas in the years 2000 and 2005. It is important to note the time period for which the study was prepared, because some factors such as heat rates for electricity net generation are time-sensitive and vary year to year.

(3)　Resource Plan

If we assume that various household activities are the source of carbon emissions in the residential housing sector, resources will include electricity and different fuel types required for those activities. Other resources could also be included. For example, carbon footprints resulted by the use of water, as a resource for household activities, is excluded in the report.

(4)　Risk Register

The selected study has not projected any of the carbon estimates into the future. Therefore, risk studies are hardly applicable. If the purpose of the study was to estimate the residential carbon footprints of the same set of cities in the United States over a time period in the future, then factors such as severe and prolonged weather conditions, high fuel prices, or economic downturn were among risk factors to be included in the study.

Enterprise Environmental Factors

As described in section 2-1, market condition, conversion factors, or efficiency factors are examples of enterprise environmental factors. The study does not focus on any specific market condition but it makes use of some conversion and efficiency factors that are listed in Table 6. The information source of these factors has also been listed in Table 6.

Table 6. Conversion factors used in the report

Conversion factor	Source
Conversion factors to convert "site" energy to "source"	Data from the Energy Information Administration (EIA)'s Annual Energy Outlook 2002 and 2007
Carbon conversion factors	State-level electricity generation and emissions from State Electricity Profiles
Carbon content coefficients for natural gas, kerosene, fuel oil, and LPG	U.S. Environmental Protection Agency (EPA)

(5)   Organizational Process Assets

The study has not targeted any specific organization; therefore, organizational process assets are not relevant to the selected study.

3.2 Tools and Techniques

The study has been prepared based on the bottom-up approach in which the whole scope is broken down into several components, and carbon footprints are estimated for each of these components; and the results are ultimately rolled-up to determine the overall result. External estimates have also been the basis for lower-level estimates. Some of these external estimates are listed in Table 7.

3.3 Outputs

(1)   Carbon Footprint Estimates

Carbon footprint estimates have been derived using the bottom-up approach and based on the inputs listed above.

(2)   Basis of Estimates

Table 7 and Table 8 have listed some of basis of estimates provided in the study. Table 7 summarizes some input data that are used for deriving the estimates. Table 8, on the other hand, summarizes a list of assumptions that influenced the results.

(3)   Document Updates

The results generated by the report can be updated on a need-to basis if estimating records are kept properly. The application of the introduced methodology can facilitate this process by reducing the amount of effort required to deploy its steps, by providing more clarification and a better direction to its sources of data.

Table 7. Some basis of estimates along with their source of information

Number of households in each housing unit type for each county within the metro area	Census data from the US Census Bureau
Amount of electricity produced in each state	EIA State Electricity Profiles
Amount of carbon dioxide emitted from the generation of electricity	EIA State Electricity Profiles
Estimates of the total residential MWh (megawatt-hour) sold by each utility that sells electricity to any of the 100 metros	Platts Analytics
Total number of residential customers each utility serves	Platts Analytics
Annual energy consumption by each state broken down by fuel source and end use	EIA
Gross Metropolitan Product (GMP)	Bureau of Economic Affairs (BEA)

Table 8. List of assumptions used in the study

List of Assumptions
• The scope of work is limited to what has been described in the scope statement and WBS.
• The study is limited to 100 largest U.S. metropolitan areas listed in the study.
• The residential electricity "source" energy use reflects the heat rate of electricity generation and the thermal content of the electricity consumed on "site".
• The heat rate of electricity is a measure of generating station thermal efficiency commonly stated as Btu per kWh of electricity.
• Wood, as a renewable fuel, had no emissions
• The value of 3,412 Btu per KWh was assumed to be a constant thermal conversion factor for "site" electricity.

4. Conclusion

Methods or innovative practices that reinforce the design and maintenance of a healthy environment and that are consistent with ecological principles are needed more than ever before. Carbon footprinting is one of these methods. In this paper we provided a brief snapshot of definitions and methods of carbon footprinting. Because carbon gas emissions generated by different activities account for a major portion of the total emissions to the atmosphere, firm actions are required to develop policies to minimize emission-minimizing policies. Carbon footprinting is an instrumental way, especially for organizations, to engage their staff, organizational partners, local communities and customers around their carbon footprint, and to drive behavior change towards having better carbon footprint management practices. The first step toward any improvement is to determine the current performance status in order to be able to set reduction targets and plan accordingly, and, as a result carbon footprinting practices are of great importance in efforts to reduce greenhouse gas emissions. With regard to the fact that only in some carbon footprinting practices, the quantities of carbon footprints can be measured or determined with absolute certainty, we discussed that carbon footprints are must sometimes be estimated. We addressed the need for providing much more transparency and consistency in carbon estimators by adapting the cost estimation standard of the Project Management Body of Knowledge (PMBOK) that has been developed by the Project Management Institute (PMI). This adaptation resulted in a methodology for carbon footprint quantification that provides improved and consistent results. Some other advantages of this approach include:

• Facilitating the comparison of different carbon footprint studies as a result of better clarification of requirements

• Improving performance planning, monitoring and control practices in carbon emission reduction projects

• Providing the opportunity for reproducing carbon footprint results accomplished by other practitioners

• Preventing underestimation and double-counting in carbon footprint efforts

• Providing a common vocabulary for carbon footprint practitioners

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