Creating a Greenhouse Gas Calculator for Consumer Goods: *A Methodological Case Study of the VW Golf*

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Abstract

Consumer interest in climate change is growing, and increasingly consumers are interested in understanding how their behaviors impact the environment. This paper proposes 6 methodologies of varying complexity that provide data on the greenhouse gas emissions associated with a single consumer item. The suggested methods, in order of increasing data requirements, are: (1) 1% of the product's cost automatically goes towards the purchase of greenhouse gas offsets, (2) the use of sector level EIO-LCA data to determine a product's emissions based on a linear relationship between cost and emissions, or a fixed relationship between product and emissions based on the average product cost, (3) a hybrid LCA method using company emissions data for direct emissions and EIO-LCA for indirect emissions, (4) the use of EIO-LCA data for the materials found in the final product, (5) adding water, electricty, and direct emissions to materials from method 4, and (6) a process-based LCA approach using GaBi software. These methods produced a range of emissions from 3 to 11 metric tons of greenhouse gas emissions. Estimates of the use-phase and end-of-life emissions were determined to be an additional 50 metric tons, with tailpipe emissions contributing 34 metric tons to this total.

1 Introduction

Currently in the United States there is no standard method to provide consumers information on the environmental impact of the goods and services they purchase. However, this information is increasingly demanded by conscious consumers, causing retailers to explore ways to provide this information to their customers. A wide range of methods exist for acquiring and presenting this information, from simple techniques criticized by some as "green-washing" to extensive life-cycle assessments of a product or process. Most require some effort at the company level to acquire, interpret, and present this information to consumers in a reliable and accurate manner. Information, even when available, is generally not presented in a way that can easily be interpreted by the consumer.

As a first step, environmental databases such as the Toxic Release Inventory (TRI) [1] contain information on toxins and hazardous air pollutants released by companies. Or, an industry-level economy-wide input-output database of environmental factors, Carnegie Mellon's Economic Input-Output Life-Cycle Assessment (EIO-LCA), provides industry-level data on emissions and energy consumption [2]. Additionally, some companies, at the forefront of environmental responsibility, have completed life-cycle assessments of their products, but few provide this information directly to the consumer. One rare example is Timberland Shoe Company, which puts an environmental label on each of their products with information on water and energy consumption [3].

A major challenge is the variation in methodology for completing a life cycle assessment, and many companies struggle to assess the environmental impact of their products. The lack of public policy and, until recently, the lack of public demand has fostered a temperament of disinterest by companies to research, interpret, and present this type of information. As more policy makers and consumers demand this information, companies will be faced with the realization that the environmental impacts of their products must be assessed. Lack of expertise, funding, and human resources may lead to inefficient and inaccurate reporting by companies faced with such a robust project.

Researchers have proposed various methods to perform rapid environmental analyses of consumer products; however, these still tend to be data and time intensive. For example, Satish Joshi has proposed a set of methodologies for product environmental assessment [4]. Each of his methods uses EIO-LCA, and his simplest proposed method, using sector wide data to represent a single product, is included as one of our options. Additionally, Sousa proposes the use of neural networks to perform approximate life cycle assessment on a proposed product design [5], by relating it to a product for which there is environmental data. This method provides product designers with environmental information prior to production, by assuming similar products will have similar impacts.

2 Problem Statement

This paper examines several methods for calculating the greenhouse gas emissions of a product, which required varying levels of information. A wide range of analytical methods were explored to determine how a company's data resources affect the analytical outcome. Such information will provide companies, and eventually consumers, with an opportunity to offset those emissions.

To test these various methods, we focused on a Volkswagen Golf automobile. This product was chosen because an excellent and comprehensive life-cycle assessment of a VW Golf was conducted in 1999 by Schweimer et al. [6]

Our aim is to help companies understand the impact of their products, and inspire companies to acquire similar data on their own products for the purpose of a more accurate presentation of the environmental impacts of consumer products. Also, to provide consumers information on their purchases. The greenhouse gases associated with a product are one example of a consumer product's environmental impact, which we consider in this paper.

In this report, data on the Golf A4 is obtained from a variety of years, but is applied to a

Golf A4 purchased in 2005. Our data is from within an 8 year time span. Due to limitations of available data, it was not possible to obtain all data from the same year, but this accurately shows the limitations of attempting to use these methods for a current product.

3 Greenhouse Gas Calculation Methodologies

In the paragraphs to follow, six methods of increasing data requirements are detailed that can be used to analyze a product's greenhouse gas emissions over its lifetime. For each method, a discussion of the background, method, findings, and uncertainty based on our Volkswagen Golf case study is included. Methods 1 through 6 focus on the product's impacts through manufacturing, and method 6 includes the use-phase and the product's end of life. Note that in some cases, data limitations allow us to calculate only CO2 rather than all CO2-equivalent emissions.

For each method, the analysis boundary and data uncertainty are analyzed. Data uncertainty is analyzed using a quantitative method described in Junila et al. [7], where the acquisition method, independence of data supplier, representativeness of the data, temporal correlation, geographical correlation, and further technological correlation are considered on a scale of 1 to 5 (1 is best).

3.1 Method 1: 1% Towards Carbon Offsets

Our first method requires only the retail price of a consumer good, and is the least data intensive method of the six to be discussed.

3.1.1 Background

Greencard [8], a credit card company based in the Netherlands, automatically offsets carbon emissions related to their customer's purchases without charging the consumer anything extra for using the card, although there is a one-time fee of 75 euros. Greencard claims that the income of their business provides the funds for the carbon offsets.

Greencard calculates, using predetermined "CO2-factors," what an appropriate offset is for a given product. These CO2-factors are determined using the Dutch input-output economic table, which contains 105 sectors [9], and local environmental data. This method is comparable to the EIO-LCA tables for the US [2], which will be discussed in more detail for Method 2.

For a household product (clothing, furniture, or CD's), the amount of CO2-equivalent emissions to be offset is 1.1 times the product's cost [8], where 1.1 is the CO2-factor. For example, if a CD costs $10, then 11kg of CO2-equivalent emissions are offset by Greencard. These factors are shown in table 1, below. Note that number of trees means how many trees have to grow for a year to offset the emission. For something considered more CO2-intensive, such as an airplane flight, the CO2-factor is 4.

On average, Greencard has determined that to offset all of a typical consumer's purchases, 1% of their payments will need to go towards carbon offsets [8]. It is unlikely the credit card company receives information on exactly what item was purchased, only the retailer's information is known;

Activity	Purchase	Average expense	CO2-factor	CO2-emission	Number of trees
Petrol	40 liters	50	2.7	135kg	6,75
Flight ticket	one way Nice	200	4.0	800kg	40
Clothing	jeans	100	1.1	110kg	5.5
Restaurant	2 people	100	0.7	70kg	3.5
Furniture	couch	400	1.1	440kg	22
CD's	1 cd	20	1.1	22kg	1.1
Hotel	2 people	80	1.0	80kg	4

Table 1: "CO2-factors" from the Greencard's website [8]

therefore the retailers may be classified by product type most commonly sold to determine the appropriate CO2-factor.

To convert 1% of the purchase price to CO2 emissions, we require a carbon trade price. However, there is no set purchase price for carbon offsets. In November of 2006, offsets could be purchased for between $4.50 and $30 per metric ton of CO2 [10]. The wide range of offset prices reflect varying emissions offset methods. On the less expensive end are reforestation and efficiency research offsets. On the more expensive end, an offset purchase goes towards funding research into renewable energies [10]. For this analysis we will use an average value of $17/ton.

3.1.2 Method

This method has only three steps, making it the simplest of our possible models:

1. Determine the product's retail cost in a given year
2. Multiply the retail cost by 1%
3. Obtain the conversion from dollars to kilograms of CO2 in that year

3.1.3 Results

The retail price of a 2005 Golf A4 ranged from $17,000 to $25,000 [11]. Therefore, offsetting the purchase of an Audi A4 in 2005 would cost an average of $210.

Based on the values provided in the background section of this method, for converting from a dollar value to a value of CO2 emissions, the vehicle's lifetime emissions are $210 divided by $17 per metric ton, which equals 12 metric tons of CO2-equivalent emissions.

3.1.4 Discussion

The main advantages of this method are its simplicity and use of publicly available data, meaning that any consumer can assess the emissions related to their purchases.

Unfortunately, this method does have many fundamental problems, particularly in its inability to distinguish between various product types or companies. Environmental impact is determined solely on sales price, and does not vary from industry to industry. This method provides no incentive for a company to modify their behavior or product design to reduce environmental impact, only to reduce cost. Finally, the conversion from retail price to metric tons of CO2 is highly variable depending on the offsetting method and market price.

Additionally, this method cannot provide a consistent value for the amount of CO2 emissions attributable to a given product, because the cost of carbon varies with demand and availability of offset options. This method will give a changing value of CO2 intensity for a product as the exchange rate varies, even if the product's supply chain and manufacturing remain constant.

The advantages of this model are in the simplicity of implementation. Any consumer or company can offset their product's impact by adding 1% to its cost. This simplicity means that companies are not hassled to collect or provide data, saving them cost and time.

Also, the average of 1% may work for a consumer, who purchases many different products throughout the year. But for a company, which produces only a couple types of products, the 1% is likely to be a misrepresentation. Our more detailed models may be able to provide a more accurate value.

3.1.5 Uncertainty

Qualitative indicator scores are used to assess the quality of the data used for each method (see table 2). This method requires three data points: the product's retail price, the market price of CO2 offsets, and the average 1% value from greencard. The retail price was found in an article on the 2005 Golf, which was impartial, and based on an expected sale price in the US. The CO2 offset cost was determined from an impartial and current survey of various websites offering offsets to consumers. The average 1% carbon offset price is based on input-output data and environmental data from the Netherlands, whereas we are looking at a product manufactured in Germany and purchased in the US. Additionally, their conclusion is based on the average of all purchases made by consumers in the Netherlands, rather than one automobile purchase in the US. Therefore, Greencard's measurement of a 1% average cost for offsets is the primary source of this method's uncertainty, because the geographical correlation and technological correlation are poor.

Data	Acquisition Method	Independence of Supplier	Representativeness	Temporal Correlation	Geographical Correlation	Technological Correlation
1%	3	2	1	3	4	5
Offset Price	1	1	1	1	1	1
Retail Price	3	1	1	1	1	1

Table 2: Uncertainty of 1% Method (*average data uncertainty is 1.8*)

3.2 Method 2: Using Input Output Data from EIOLCA

Similar to the previous method, Method 2 is based on publicly available data: a producer price value for the product and information from a database called EIO-LCA [2].

3.2.1 Background

One common method to estimate an environmental footprint of a consumer, based on different types of consumption, was originally developed by Wackernagel and Rees [12], and has been dubbed the "Ecological Footprint." This footprint is defined as, "The land area that would be needed to meet the consumption of a population and to absorb all their waste." Within the model, consumption is divided into 5 categories: food, housing, transportation, consumer goods, and services. Data is collected from a variety of sources such as production and trade accounts, state of the environment reports, and agricultural, fuel use and emissions statistics. "The footprint is then calculated by compiling a matrix in which a land area is allocated to each consumption category. In order to calculate the per-capita ecological footprint, all land areas are added up, and then divided by the population, giving a result in hectares per capita" [13]. The model, however, lacks the ability to input a wide range of products, and generally asks difficult questions, such as: estimate the amount of food purchased that is grown locally. Another drawback to this method is the theoretical nature of the estimation of land required to absorb CO2 in biomass. The theory states that some area of biomass is able to "sink" the effects of CO2 production, due to many factors, including biodiversity, this is difficult to verify empirically. Although this method provides motivation to reduce greenhouse gas emissions, a more accurate methods is needed. A more robust model developed by Jones [14] is discussed below, and is the basis for Method 2.

3.2.2 Method

Method 2 is based on the "Consumer Footprint Calculator" developed by Jones [14], which estimates environmental impact using data from the Economic Input-Output Lifecycle Assessment (hereafter referred to as EIO-LCA) software created by the Green Design Initiative at Carnegie Mellon University [2]. The software "traces out the various economic transactions, resource requirements and environmental emissions required for a particular product or service. It captures all the various manufacturing, transportation, mining and related requirements to produce a product or service" [15]. The software divides the entire economy into 491 distinct sectors based on the North American Industry Classification System (NAICS). This economic data is paired with data on environmental stressors from a variety of sources, including the Unites States Department of Commerce, and Environmental Protection Agency [16], to estimate an economy wide environmental impact (energy use, air pollutants, toxic releases, etc.), which is without boundary.

The industry data from EIO-LCA is then linked to 1,500 products and services listed in the Consumer Expenditures Survey (CES), published by the Bureau of Labor Statistics [17]. Because EIO-LCA data is from 1997, and CES data is current (2006), we determined the inflation for each item in CES using the Producer Price Index published by the Bureau of Labor Statistics, which measures the average change over time in the selling prices received by domestic producers for their output [18].

Data from this model can be utilized in 2 ways:

1. Average Cost per Unit: Inputting the average cost per unit of a consumer good or service into the model can produce average environmental impact data for that product. The result is a fair approximation of environmental impact of one unit of product or service. The drawback is that a producer may have additional information that shows their environmental impact is lower than the average unit, even though the cost is at, or above, the average for the industry.

2. Actual Cost per Unit: Inputting the actual cost per unit of a consumer good or service into the model will output the environmental impact of that product. The limitation of the model is that it is based on a linear relationship of impact versus price. This means the impact of a $10 product would be double that of a $5 product. For many industries, this may be a reasonable approximation. For instance a dry cleaning service will have a generally linear increase in environmental impact with an increase in cost. However, the drawback falls in categories where an increase in price does not necessarily represent an increase in environmental impact. The automobile industry is an example of this, where a $40,000 car will not necessarily have twice the impact of a $20,000 car. This may be justified if all the value-added went towards additional material possessing and manufacturing. It may be unjustified if additional price is due to more environmentally benign processes such as engineering research.

3.2.3 Results

Implementing this method for the purchase of a Volkswagen Golf automobile requires data on producer prices for automobiles. The 2005 producer price for a Volkswagen Golf sold in the U.S. was $17,010 (averaged over 4 Golf trim options) [19]. The 'Consumer Footprint Calculator' maps the consumer purchase of an automobile to the sector in EIO-LCA called 'Automobile and light truck manufacturing' (IO Sector 336110). The actual production cost of a Volkswagen Golf is converted to a 1997 value for input into the EIO-LCA model and reveals the production of 10.6 MT C02-equivalent greenhouse gases. The largest contributor to the production of greenhouse gases is, by far, electrical power generation, followed by the automobile manufacturing process itself, wholesale trade, natural gas distribution, and iron and steel production.

This method is also applied to the average producer price for an automobile, which in 2005 was $23,680 [20] (assuming an average wholesale to retail ratio of 80% [14]. Similarly this is scaled to a 1997 value, revealing the production of 13.3 metric tons of C02-equivalent greenhouse gases.

3.2.4 Discussion

The actual cost of a Volkswagen Golf is significantly less than the average automobile cost. Due to the linearity of the EIO-LCA model, the actual cost presents a lower greenhouse gas emission than the average. This is expected, and to a limited extent, may be true. If one assumes that a more expensive automobile includes more options and development effort, and thus more raw materials, human labor, and overhead. It may take more electricity to process, fabricate, and assemble. However, the actual relation between price variation within the automobile sector and greenhouse gas emissions needs further examination. Another major limitation of the method is that it cannot accurately differentiate between two products from the same sector. In this case 2 cars, priced identically, but made in different factories would have the same greenhouse gas emissions. It does, however, provide an adequate estimation of greenhouse gases for automobiles, and if evaluated at the overall industry level, presents an accurate estimation of greenhouse gases for the automobile industry as a whole. This would make it a great candidate for comparisons to other methods of transportation.

3.2.5 Uncertainty

This method has two data sources for each result: EIO-LCA, and the automobile's retail price. The data from EIO-LCA is based on economic survey information from 1997. Current economic and environmental data would ensure the results are of higher accuracy; and environmental data not reported by each company would improve independence. Accurate prices for current models of Volkswagen Golf are available, but need to be converted to 1997 values in order to utilize the data in EIO-LCA. Low scores in Table 3 for both independence of supplier, and representativeness could be improved by verifying producer price, and average price of a Volkswagen Golf from a larger variety of data sources. Additional data sources are limited, but only minor variability in this data is expected. Finally, low scores for geographical correlation are due to the assumption that manufacturing has taken place in the United States. In the case of the Volkswagen Golf, it is more likely manufactured in Germany, and a German factory may have more oversight and environmental policy guidelines to follow; therefore greenhouse gas emission may vary significantly. This uncertainty assessment is summarized in Table 3.

Data	Acquisition Method	Independence of Supplier	Represent-ativeness	Temporal Correlation	Geographical Correlation	Technological Correlation
Producer Price	2	3	5	1	1	1
Average Price	3	4	5	1	1	1
EIOLCA	3	2	1	3	4	4

Table 3: Uncertainty of EIO-LCA Method (*average data uncertainty is 2.5*)

3.3 Method 3: Company Data Hybrid Model 1

3.3.1 Background

Another option for determining the carbon-offset cost of particular consumer products is to use data provided directly by corporations on their CO2 emissions. This information is usually their direct emissions, and can be used with EIO-LCA to include indirect emissions [2].

This approach amounts to a hybrid LCA approach that combines both process-based emissions data (developed by companies or their third party consultants, as discussed in method 6) and input-output based emissions data. There are useful precedents for such a hybrid approach; Suh et al. [21]

provide a valuable overview of studies that have combined both IO and process-based methods. They categorize these hybrid studies into three primary categories: tiered, input-output based, and integrated. In the tiered approach, lower-order downstream activities are covered by process-models, while higher-order upstream activities are dealt with using input-output models. The input-output-based method relies more heavily on IO tables where it is possible to further disaggregate sector categories. The third model is the integrated LCA, which more directly combines data from both process and IO data; this will be used in method 5.

3.3.2 Method

Direct emissions data, often provided by the company, is required. Where possible, the source of this emissions data, possibly from a process-based LCA (method 6), should be documented in order to avoid double counting.

There are several possible sources of data on company emissions of greenhouse gases, which are outlined below.

- Company Reports, Websites, and Products: Companies may list their emissions in a Corporate Social Responsibility (CSR) or Sustainable Development Report. Others, such as Timberland, have even started putting it on their products. CSR Reports are also available at a single site through the Global Reporting Initiative, which has developed a set of standards and guidelines for companies to report on their progress towards more sustainable production and maintains a database of these reports [22]
- Carbon Disclosure Project (CDP): The CDP is a major initiative to collect information on the emissions of companies around the world, and is driven by investor concerns about the risks associated with climate change. It has the support of organizations representing 31 trillion dollars in assets, and collected data from 940 companies (including 72% of the FT500) in its 2006 survey [23].
- Carbon Registries: Other potential sources of information are more regional carbon registry projects, such as the one here in California. Based on publicly available reports, it appears to have very limited participation, but is a potential source of information [24].
- Chicago Climate Exchange: Companies engaged in trading emissions may have to disclose the amount of their baseline and annual emissions [25].

Because the companies' direct emissions are not generally provided per product, but rather for the company as a whole. To be useful in this analysis, they must be scaled to our functional unit of one product. There are two ways to make this conversion:

1. The total company emissions in a given time period can simply be divided by the total number of cars produced by the company in that same time period. This does not take into account differences in carbon footprints between cars, but focuses on the carbon footprint of the corporation that is making the car.

2. A second method is to use revenue as a proxy measure of the carbon intensity of a particular product. Thus a more expensive item is assumed to have a proportionately larger carbon footprint. To complete such a calculation, total company revenue is divided into the amount of revenue earned from the sale of one product. This fraction is then multiplied by the total company emissions to estimate the direct carbon footprint of one product. This value is then divided by the volume of that product produced.

Direct emissions data is then supplemented with data from EIO-LCA. Using a method like that outlined in method 2 of this paper, where a producer value for the product is input to EIO-LCA, a vector of contributing sectors to that product's CO2-equivalent emissions is obtained. By replacing the EIO-LCA given contribution from automobile manufacturing with the direct emissions known about a company, a new personalized EIO-LCA sector is created.

3.3.3 Results

The total direct emissions calculated by Volkswagen was 1.32 million tons of CO2 in 2004 [26]. Note that this is CO2, not CO2-equivalent emissions. Our first per car estimate simply divided this number by the number of cars produced by Volkswagen in 2004, which was 5,093,000 [27]. The resulting estimate of direct emissions per car is 0.3 metric tons of CO2 per Golf car.

Our second estimate multiplied the percentage of VW's revenue from Golf cars, which was 18%, by VW's total emissions, which was then divided by the total number of Golf cars produced. The resulting estimate of direct emissions per car was 0.3 metric tons of carbon dioxide per Golf car.

These direct emissions results were then combined with the EIO-LCA data, found as in Method 2; except this time only CO2 values are taken from EIO-LCA to be compatible with the company data. EIO-LCA reports total emissions of 9 metric tons of CO2 from the sector "automobile and light truck manufacturing", with 0.21 tons of this coming from the same sector (direct emissions). Replacing EIO-LCA's direct value with the one calculated for VW, we obtain a value of 9 metric tons of CO2.

3.3.4 Discussion

This model also has both its strengths and weaknesses. It depends on trusting that the company has calculated its direct emissions accurately, and because it is unknown exactly how VW calculated its direct emissions, there may be some overlap between the EIO-LCA and VW's direct estimates.

VW explains its carbon emissions estimate as including "emissions from the combustion of energy sources such as natural gas or coal, which arise directly at Group plants, for example in heat treatment installations in the hardening shops or the boiler plants for generating heat. In the absence of a standard international method for calculating indirect CO2 emissions, i.e. emissions which arise elsewhere from the generation of purchased electricity and district heating, we have decided not to report such emissions for the time being." This method quickly provides VW with an estimate of their indirect emissions.

This method improves on Method 2, because EIO-LCA data provides an estimate of the direct and indirect manufacturing costs for ANY automobile manufacturer in the US, but the method described in this section provides direct manufacturing costs specifically for VW, which can then be combined with indirect costs to provide a more relevant assessment.

An important issue to consider when using company data is its reliability and accuracy. Almost all of these estimates are self-reported (or assessed by third-parties paid for by the firms being audited), therefore there is a potential for either under or over-reporting, depending on the company's perception of its various incentives and risks. Therefore other factors and variables may be useful in determining both the veracity of the estimates and the overall commitment and capacity of the firm to reducing its emissions. One potential source of this type of information is CERES' recently published "Climate Change Governance Ratings," which rates 100 major contributors of greenhouse gases on their board oversight, management execution, public disclosure, emissions accounting, emissions management and strategic opportunities related to climate change policies [28]. These ratings could potentially be used as a complementary variable to actual emissions level, or as a substitute for when no data is available.

A similar data set that could be used to assess data validity is the company's participation in the EPA's Climate Leaders Program. To participate in the program, companies have to submit specific goals for reducing their emissions. While this program is non-binding, developing a method to evaluate the scope and seriousness of these goals could be an interesting exercise [29].

3.3.5 Uncertainty

Table 4 shows the three sources of data for this method, which are the VW Annual Report, Sustainability Report, and EIOLCA. The primary sources of uncertainty in these data sources are the lack of independence of the Sustainability Report, as it provides unverified information; the acquisition method of the EIO-LCA, as it uses data based on assumptions, and the poor geographic and technological correlations of the EIOLCA data. The strengths of this method are the primary data from the Reports that correlate well with the process we are interested in and the mostly independent EIOLCA data.

Data	Acquisition Method	Independence of Supplier	Represent-ativeness	Temporal Correlation	Geographical Correlation	Technological Correlation
Sustainability Report	1	5	1	1	2	2
Annual Report	1	2	1	1	2	2
EIO-LCA	3	2	1	3	4	4

Table 4: Uncertainty of Hybrid 1 Method (*average data uncertainty is 2.1*

3.4 Method 4: Materials in Final Product

3.4.1 Background

Another method for determining the carbon footprint of a consumer product is to determine the footprint of each raw material found in the final product. This does not include any materials consumed during manufacturing. It also ignores manufacturing and transportation. This information can be used to analyze how material choices affect the product's footprint, and provide a basis for suggesting cleaner alternatives.

Previous researchers considered similar approaches. Jonsson studies tools and methods for environmental assessment of building products using six different approaches, material-based LCA being one of them [30]. For the purpose of external decision making support and internal development, she analyzed six approaches for LCA of building products using floorings as an example and then compared the results to assess the relative accuracy of the methods employed. As a more recent example, Fujitsu laboratories explored the possibility of constructing a database of product materials based on LCA information to supplement information such as electric power consumption in the production line [31]. One of the significant results of this study is that CO2 emissions during a product's life cycle were reduced by 15% when a bio-based polymer, made from corn crops, was used in the housing of notebook PC's instead of plastics from fossil resources. McCullar et al. also considered using material LCA to evaluate the environmental impact of computing products [32].

3.4.2 Method

This model is based solely on the material that appears in the final product. The approach for this model is:

1. Determine the product's material break up.

2. Determine the producer price per kg for each of the input materials in 1997. We assume a conversion factor of 50%, to convert from retail to producer price.

3. Input these producer price/kg values for all materials into the EIO-LCA database to determine the metric tons of CO2 and CO2-equivalent emissions for each material.

4. Sum up the values to calculate the total emissions per car

3.4.3 Results

Without access to company data, materials found in the final product are determined from a previous LCA study of the VW Golf [6]. There are 16 main materials found in the final product: steel, iron, industrial fibres, mineral fillers, fuel oil, lubricating oil, aluminium alloys, rubber, reinforcements(for tires), glass, copper cable, titanium, chromium, fibreglass insulation, nylon insulation, and automobile paints. Steel is the largest by mass, contributing 60%.

Inputting the producer price value in 1997 dollars to EIO-LCA results in a total of 3.7 metric tons of CO2-equivalent emissions (3.6 metric tons of CO2).

3.4.4 Discussion

It is important to note that this method ignores the additional greenhouse gas emissions from manufacturing, transportation, and materials consumption. It ignores the fact that for most products, more raw material enters the manufacturing phase than what comes out in the finished product. For example, in automobile manufacturing a large block of steel goes in, and is machined down to something smaller for the finished product. Additionally, in processes such as semiconductor manufacturing, materials are used for processing that do not appear in the final product. These limitations cause the result to be a low estimate.

The advantage of this method is that it enables us to distinguish between different products in the same sector, and such a model can be useful in incorporating cleaner material choices.

3.4.5 Uncertainty

There is significant uncertainty associated with this approach, because of the large number of assumptions required to determine material weight and material cost in 1997. Also, EIO-LCA doesn't provide emission data for 'cleaner alternatives' such as recycled raw materials, organic cotton, or renewable sources of energy. Additional sources of uncertainty are due to the temporal variability of the data, which has been accounted for only by including an average inflation value, an inexact measure of the increase in the economic activity from 1997. Finally the model assumes that the place of production is a plant in United States, which is inaccurate for a VW Golf manufactured in Germany.

Data	Acquisition Method	Independence of Supplier	Represent-ativeness	Temporal Correlation	Geographical Correlation	Technological Correlation
Materials in Product	1	3	1	1	3	1
Material Price	4	3	1	1	2	3
EIO-LCA	3	2	1	3	4	4

Table 5: Uncertainty of Material Based Method (*average data uncertainty is 2.3*)

3.5 Method 5: Company Data Hybrid Model 2

The goal of this method is to add some measure of manufacturing impact to the materials impact data from Method 4, using only data that might be readily available to a company: electricity use, water use, and direct emissions.

3.5.1 Background

Using easily obtained company data, such as water use, energy use, direct factory emissions, and final materials, a hybrid LCA is performed to determine the company's impact. Because of this method's data limitations, we expect the calculated emissions to be lower than models 1 through 4.

Suh et al. [21] describe several methodological issues associated with hybrid LCA's, including the important issue of double counting. This problem is particularly evident in the tiered approach, and is mitigated somewhat by the IO-based and integrated models. Another issue, which is common to all LCA's, is boundary definition. One approach to confront this challenge described by Suh et al. is structural path analysis, which aims to show where most of the impacts lie at a broader scale and define the boundaries for more detailed process-based analysis. Another important issue is that input-output approaches do not automatically take into account use and end of life stages of a product, and must be supplemented with additional IO or process-based analysis. Also, of course there are the dual problems of data availability and reliability, and the selection of the method will often be dictated by these factors.

3.5.2 Method

In Model 4, materials found in a VW Golf were assessed. This method adds to that assessment the carbon footprint of water and electricity consumption during the manufacturing process, which is determined by inputting a dollar value to EIO-LCA. Company level data is attributed to a product in the simplest way possible: all products are considered equal (i.e. total company data is divided by all products sold). This method also includes direct emissions calculated by the factory, as was used in method 3, but neglects any materials other than water, which were consumed during manufacturing and transportation.

3.5.3 Results

In 2005, Volkswagen used 15.91 million Megawatt-hours of electricity. The 1997 the average price of electricity in the US in 1997 was 4.53 cents/kWh. VW's cost of energy in 1997 dollars therefore was $720 million. Inputting this into EIOLCA in the "power generation and supply" sector, we estimate that the total global warming emissions from VW's energy use was 7.6 million tons of CO2-equivalent. Dividing this amount by the total number of cars produced by VW, we calculate that an individual Golf car has a carbon footprint of 1.5 metric tons of CO2 from electricity.

The amount of water used per car was estimated by Schweimer et al. [6]to be 3.22 gallons per car. The estimated price of water in 1997 was $1.30 per 1000 gallons [33], which was multiplied by the amount of water used in production. This amount, 11 cents per car, was then input into EIOLCA's "water, sewage, and other systems" sector. The resulting estimate was .0000790 metric tons of CO2-equivalent per car due to the water use in vehicle assembly.

Combining electricity and water emissions values with 0.3 metric tons of CO2 direct emissions (method 3) and a finished product material emissions value of 3.6 metric tons of CO2(method 4), this hybrid model concludes that the VW Golf is responsible for 5.3 metric tons of CO2 prior to use.

3.5.4 Discussion

The main limitation of this method is its drawing of boundaries. For some manufacturing processes, where water and energy use comprise most of the factories' impact this could be a reasonable estimate (although low). But for others, where materials not seen in the final product are consumed to create the product, this method ignores a large part of the product's total impact. Therefore, it should be used carefully. Alternatively, if all consumed materials are known, these could be added to achieve a more complete result.

This method also relies on EIO-LCA data to represent processes and industries in countries other than the U.S. The energy supply varies from country to country and assuming a U.S. energy mix elsewhere could be problematic for this method.

Finally, estimating the per car emissions from total emissions of the company has many challenges. By dividing the total emissions by the number of cars produced, the overall carbon footprint of the company is taken into account. It does not take into account the fact that some cars require much less energy and materials to build. However, using revenue as a proxy measure of the carbon intensity of a car model is one method to take such differences into account, but it is not clear that the relationship between carbon and revenue is linear. Nevertheless, it may be a good first-degree approximation.

3.5.5 Uncertainty

The uncertainty associated with this model can be attributed mainly to our dependance on data from the company. On the other hand, the independence of EIO-LCA contribute to the robustness of this approach. The geographical correlation is also not high as the manufacturing plant is in Germany. The use of EIO-LCA affects the temporal correlation because its results are based on 1997 data.

Data	Acquisition Method	Independence of Supplier	Represent-ativeness	Temporal Correlation	Geographical Correlation	Technological Correlation
Energy Data	1	5	1	1	2	1
Water Data	3	3	3	3	3	3
EIO-LCA	3	2	1	3	4	4

Table 6: Uncertainty of Hybrid 2 Method (*average data uncertainty is 2.6*)

3.6 Method 6: Process Based LCA

3.6.1 Background

The most data intensive calculation method is the process-based LCA, a more traditional method of calculating a carbon offset for a product. This process-based model approach is based on the standard recommendations of the Society of Environmental Toxicology and Chemistry (SETAC) [34]. This LCA approach attempts to trace out the major stages and processes involved over the entire life cycle of a product from raw material extraction to ultimate disposal. LCA systematically considers and quantifies the consumption of resources and the environmental impacts of a product or process. However, it is not easy to specify every possible relationship, or to include all materials use and environmental emissions. This limitation means that process-based methods focus only on the most important process materials [35], which is often a subjective assessment based on data that is not yet collected.

There are many versions of process-based LCA software because this is the most traditional method. These include GaBi, SimaPro, TEAM, Rockvile, MD, Ecomanager, and Prairie Village. Hendrickson et al. [36] identifies the many disadvantages of process-based LCA methods when compared to using input output methods. The critical problems with process-based LCA are that its analysis is expensive and time consuming because inputs and environmental burdens have to be either empirically gathered or obtained from literature, and a narrow focus on the most important processes may ignore important effects and lead to incorrect decisions. The advantage of process-based LCA is that it can be quite specific to a particular product.

3.6.2 Method

The GaBi LCA software was used by Schweimer et al. in 1999 to analyze emissions related to the Golf A4 [6]. GaBi was developed by the Institut fuer Kunststoffpruefung und Kunststoffkunde (IKP) at the University of Stuttgart, Germany [37], and is representative of a suite of software tools based largely on the process-based model [38].

To complete their LCA, the authors took the majority of materials production data from the GaBi database and incorporated it into a separate, special database. Interestingly, data processing was actually completed with the TEAM software code, because its compiling speed is quicker and it performs an exceptionally comprehensive consistency check [6]. Their model includes material suppliers, production, energy & transport suppliers, waste for re-use and disposal, and end of life.

Ideally, we would conduct our own process-based analysis using a demo version of GaBi 4; however, the demo version and our access to detailed emissions and use data are too limited. Therefore, we accept the results of Schweimer et al. [6] as the process-based results. Our inability to complete this analysis is a testament to the incredible data requirements necessary for a process based LCA.

3.6.3 Results

Schweimer et al. [6] conclude that prior to the use phase and end of life, 4.4 metric tons of CO2 can be attributed to the VW Golf. Unfortunately, their results are only CO2 rather than all CO2-equivalent emissions.

3.6.4 Discussion

This method has both its strengths and weaknesses. One advantage is that the process-based method is very popular so there are many available software options. However, these systems often require expert knowledge to operate. Moreover, the analysis is expensive and time consuming because inputs and environmental burdens have to be either empirically gathered or obtained from literature. And, a narrow focus on processes perceived to be most important may ignore important effects and lead to incorrect decisions. In addition, the Gabi software results are based on previous LCA's, which may be limited by poor data quality or data from inappropriate areas [36].

3.6.5 Uncertainty

If the GaBi software does not contain any required process data, it must be externally determined or provided by the supplier. For this, measurements or assumptions are needed; thus, the score for Acquisition method in Table 7 is average. Additionally, data available from GaBi may not be reliable because the methods and source of the original LCA study that produced the data is unknown, making the representativeness rather low. One private company, which developed their own process-based LCA method, has updated the GaBi database frequently, affecting its impartiality. However, GaBi software attempts to use data from similar geographical areas, when data is available. The GaBi LCA analysis used data from a 1999 study [6] which explains the lower temporal score.

Data	Acquisition Method	Independence of Supplier	Represent-ativeness	Temporal Correlation	Geographical Correlation	Technological Correlation
GaBi	3	3	2	3	3	2

Table 7: Uncertainty of Process LCA Method (*average data uncertainty is 2.7*)

3.7 Use Phase and End of Life

3.7.1 Background

The models discussed thus far have not included a product's impacts after it is purchased by the consumer. In fact, these methods do not include the environmental costs of getting the product to the consumer either. Including these stages of the product's life-cycle is crucial to completing a full analysis of the product. However, for a retailer interested in providing offsets for the customer, is it appropriate to offset the future? A consumer, on the other hand, may want use phase impacts and end of life options information to choose between products. This is similar to the strategy adopted by Energy Star, which makes no mention of the product's footprint before use, but assesses the energy efficiency of the product during operation [39].

3.7.2 Method

For the use phase, data on how much energy the product itself consumes (such as a computer plugged into the wall), and how much energy is required to keep it functional (such as washing a shirt) is required. Additionally, we will have to make some assumptions about the average use and functional life of the product. Finally, EIO-LCA data may be used for purchases during the product's lifetime, such as electricity, water, or replacement parts.

An end-of-life analysis requires information on the possible options for a given product, the likelihood each option will be chosen by the consumer, and the impact of each option. The analysis may be done in multiple ways, to provide insight on how each option has an impact, or the most likely option may be chosen. Unfortunately, EIO-LCA does not have information specifically on the recycling industry. For paper manufacturers, for example, pulp mills that accept raw materials or recycled materials are all in one category [2].

3.7.3 Results

During the use phase of an automobile, we must consider consumption, service, and end of life impacts. Based on the analysis conducted by Schweimer et al. [6], the average Golf A4 from 1999 has a lifetime of 150,000 kilometers over 10 years. Schweimer states that the spark plugs, oil filters, air filter, wiper blades, engine oil, coolant, brake fluid, and windshield cleaning fluid are replaced yearly; the battery and tires are replaced 3 times over the 10 years. This maintenance schedule is likely that recommended by Volkswagen, but we feel this is more than most people actually do. So, Schweimer's assumptions will be considered a high estimate. As a low estimate, we assume that the spark plugs, oil filters, air filter, wiper blades, engine oil, coolant, brake fluid, and windshield cleaning fluid are replaced 3 times over the lifetime of the car (every 50,000 km).

Fuel Production and Distribution As already stated, the car's lifetime is assumed to be 150,000 km, and the gas mileage for the 2005 Golf A4 is on average 26 miles per gallon [40]. Data from EIO-LCA will be used, so only the wholesale or producer price of gasoline in 1997 is necessary. According to the California Energy Commission [41], the average refinery sold gasoline for $0.75 per gallon in 1997. EIO-LCA contains two possible industry sectors for computing impacts: "Petroleum Refineries" and "Pipeline Transportation", which will give us a range of results. The purchase of fuel is then found to release somewhere between 6 to 10 metric tons of CO2-equivalent emissions, or 4 to 5 metric tons of CO2 emissions.

Fuel Consumption - Tailpipe Emissions The emissions from actually driving the Golf A4 must also be considered. According to the US department of energy, 19.564 pounds of CO2 are emitted per gallon of motor gasoline [42]. The vehicle's lifetime of 150,000km (93,206 miles) and mileage of 26 miles per gallon, results in a total emissions of 32 metric tons of CO2. Additionally, the US EPA states that on average, CO2 tailpipe emissions account for 95% of total global warming gas emissions from the tailpipe [43]. Using this rule of thumb, the total global warming gas emissions during operation are 34 metric tons of CO2-equivalent emissions.

Service Schweimer et al. [6] estimate conservatively that the car's spark plugs, oil filters, air filter, wiper blades, engine oil, coolant, brake fluid, and windshield cleaning fluid are replaced every 15,000 km. We feel an appropriate non-conservative, or low, estimate is that they are replaced every 50,000 km. For either estimate, the battery and tires are replaced every 50,000 km. EIO-LCA data is used to approximate the impact of purchasing each of these items; therefore, the producer price for each is required. The producer price of service items in 1997 is determined from the purchase price today (2006), which is converted to a producer price (rule of thumb is 50% of retail), and back-dated using an average inflation rate of 1.25 from 1997 to 2006 [44]. This value is then plugged into the appropriate sector of EIO-LCA. The goal of our various assessments is to be reasonably fast and straightforward, so the 50% rule of thumb should provide a reasonable estimate to within an order of magnitude. The retail price in 2006 is determined by searching froogle.com and taking an average of the retail prices shown. This method results in a high-end estimate of 1.6 metric tons of CO2-equivalent emissions (1.4 metric tons of only CO2), and a low-end estimate of 0.7 metric tons of CO2-equivalent emissions (0.6 metric tons of only CO2).

Schweimer et al. also mention car washes as part of the vehicle's service life [6]. They assume the vehicle undergoes 180 washes over its lifetime. EIO-LCA contains an industry sector that is appropriate for this analysis: "car washes." Operating costs for the car wash are stated to be 53% of retail [45], and the average national carwash price is $9.75 [46]. Therefore, in 1997 prices (again using a 1.25 inflation rate) the wholesale price of a car wash is $4. This results in a total of 0.3 metric tons of CO2 equivalent emissions, or 0.25 metric tons of CO2.

End of Life In 2003, an LCA of "end of life vehicles" (ELV's) was conducted by Funazaki et. al at, which determined a global warming gas emission of 5.6 during production, 24.4 during the use phase, and 3 tons at the end of life [47]. These values tend to be below those found throughout this paper, especially in the use-phase, where it appears they are considering a much more fuel efficient car, a shorter lifetime, or a vehicle without maintenance requirements. For the end of life, Funazaki et. al consider three main stages: disassembly, shredding and sorting, and releases from a controlled landfill site over 15 years. They do not consider the effects of materials recycling after disassembly and shredding. In the absence of better data, the results of Funazaki et. al will be used for the Golf end of life emissions.

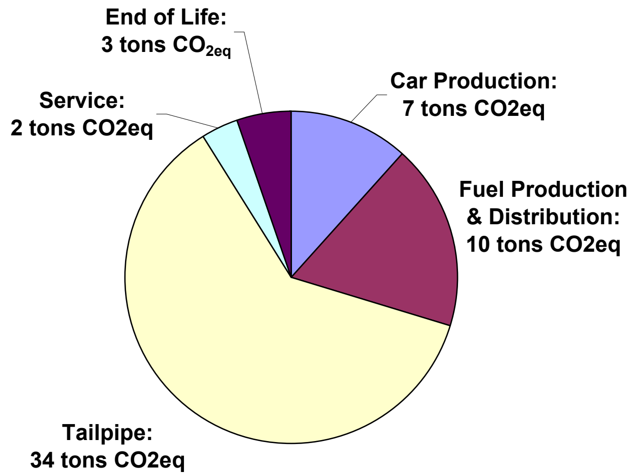

Figure 1: Emissions Breakdown

3.7.4 Discussion

In total, the use phase contributes an additional 50 metric tons of CO2-equivalent emissions. As seen in figure 1 the greatest contributor to this value is tailpipe emissions, weighing in at 34 metric tons. The smallest contributor is end-of-life, but the result is questionable because materials collection, transportation, and recycling are not considered. For figure 1 an average automobile production value from methods 1 through 6 was used: 7 metric tons of CO2-equivalent emissions.

3.7.5 Uncertainty

This assessment has a large number of assumptions: product use, functional lifetime, end of life options, and maintenance/repair costs. By being extremely transparent and balanced with our assumptions and by providing a high and low value, we aim to determine a range of product impacts that is clear to the reader. For comparing products in the future, a set of standards or method to determine functional lifetime, product use, energy sources, and end-of-life options would be beneficial.

4 Discussion Of Results

The results presented in Figure 2, showing the conclusions drawn by each method described in this paper, seem reasonable given the discussion and uncertainty already presented. It is interesting to note that they all fall within the same order of magnitude, and relatively small range of 3 to 12 metric tons of CO2-equivalent emissions. The fact that all results are within this range increases the credibility of each method and the numbers produced.

Table 8 shows the different scope of each method. This is important to understand when comparing the results of each method, and accounts for why certain methods have larger results than others.

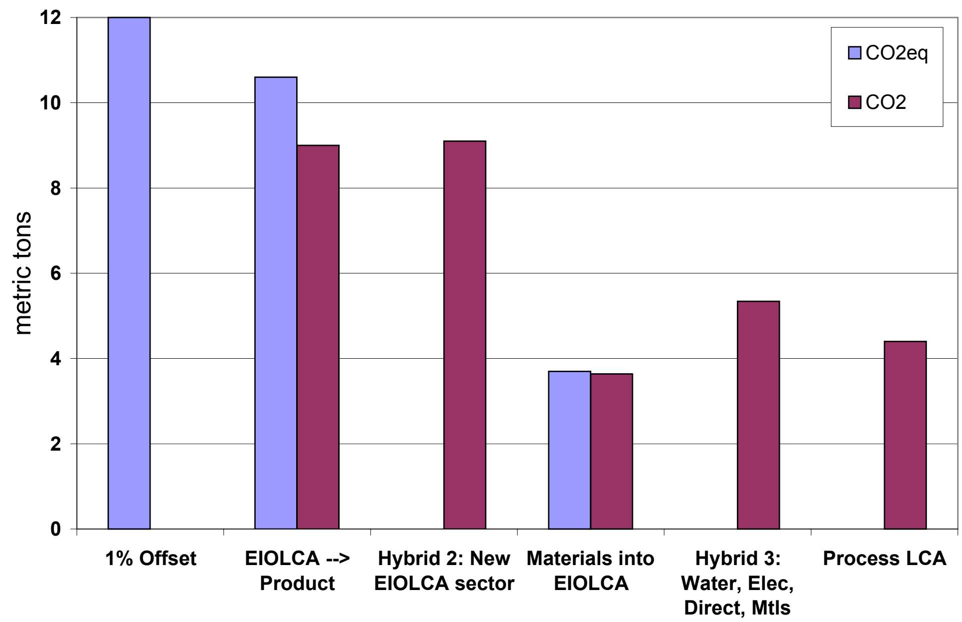

Figure 2: Comparison of Results from each Method

Method	Supply Chain	Manufacturing	Use	End of Life
1% Offset	Yes	Yes		
EIO-LCA	Yes	Yes		
Hybrid 1	Yes	Yes		
Materials	Partial			
Hybrid 2	Partial	Yes		
Process LCA	Partial	Yes		
Use Phase and End of Life			Yes	Yes

Table 8: Boundaries of Each Method

The pure EIO-LCA method and 1% method (Methods 1 & 2) produce the highest CO2-equivalent emissions, and this is expected based on the fact that both include all of the direct and indirect effects of the manufacturing process and its supply chain. Despite the shortcomings discussed earlier on EIO-LCA's linear price to emissions correlation, its inclusion of direct and indirect effects would be expected to be the most complete.

Hybrid Method 1 (Method 3) value is also relatively high, due to the use of EIO-LCA to determine all indirect emissions. The fact that VW's direct emissions estimate is similar to EIO-LCA's direct emissions estimate reflects well on this method; although it may be surprising to some people that Volkswagen's estimate is greater than the average US automobile manufacturing emissions estimate provided by EIO-LCA.

The last three methods have lower results than EIO-LCA predictions, based on the fact that they draw boundaries that limit the scope of the method. This is expected; since contributions to the total emissions footprint of a product are not included, the result should be lower.

Figure 3 shows the comparison of results found by methods 1-6 with the results of the previous process-based LCA by Schweimer et al. [6]. The conclusions are similar, with the main discrepancies being in Oil Production and Materials emissions. The results of our materials analysis is lower than the previous Golf LCA, because we only considered materials found in the final product. This ignores the fact that more material enters manufacturing than leaves it in the finished product, and that other materials are consumed during manufacturing, such as tool wear during a drilling process and chemicals consumed during silicon wafer processing. Additionally, our value for oil production related emissions is likely higher than the previous LCA, because we used EIO-LCA to estimate its emissions.

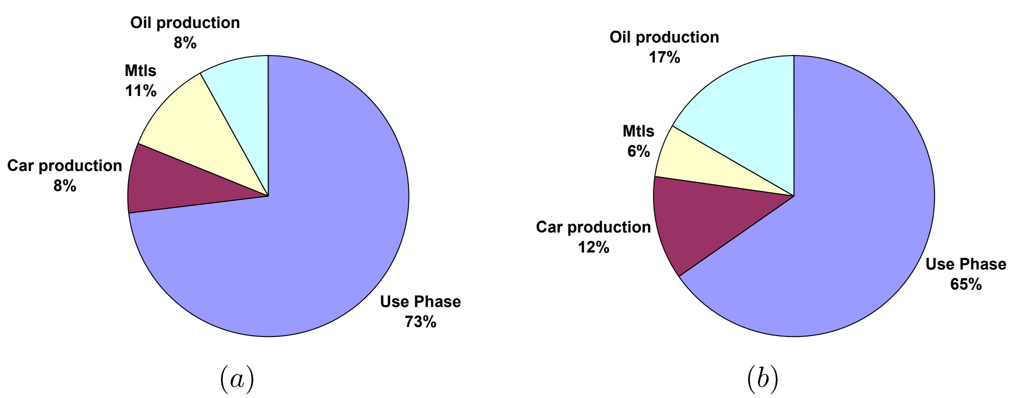

Figure 3: (a) Values found by process based analysis of a 1999 VW Golf [6], (b) Values obtained throughout this paper.

Additionally, by investigating the relative uncertainty, scope, and specificity of each method, some understanding of the drawbacks and strengths of each method for calculating emissions up through manufacturing are found. Table 9 shows the values we obtained for each method's average uncertainty, reversed so that now higher values are better quality (this is for consistency with the scope and applicability ratings). Scope is determined based on Table 8, where every "yes" in a category earns the method 2 points, and a "partial" is 1 point (use phase and end-of-life are not included); the scope value between 1-4 is converted to a scale of 1-5 for comparison with uncertainty. The specificity of each method -how exactly is it measuring the carbon footprint of a particular product- is rated using the following scheme: (0) method uses data from the wrong economy and wrong sector; (1) the wrong economy and right sector; (2) the right economy and right sector; (3) company-specific data; (4) generic product level data from company; (5) product specific data.

Method	Data Quality	Data Scope	Method Applicability	Average
1% Offset	3.2	5	0	2.7
EIO-LCA	2.5	5	1	2.8
Hybrid 1	2.9	5	2	3.3
Materials	2.7	1.25	3	2.3
Hybrid 2	2.4	3.75	2.5	2.9
Process LCA	2.3	3.75	5	3.7

Table 9: Strengths and Weaknesses of each Method (a higher score is better)

Based on this rating scheme, the process based LCA comes out as the most credible method. This follows our intuition, which would imply that the more data available specifically on the product to be analyzed, the more robust the result. The Materials method comes out the worst by this rating scheme, which is logical, because its scope and data accuracy are very limited. We actually feel that a 7th method, using both process LCA and input output data would be the best in terms of applicability and scope of method, but this requires more data resources than were available for this investigation. It should be noted that Hybrid 1 is the next best option, by this ranking scheme, and it is also one of the least data intensive methods.

To obtain a final value for the carbon-footprint of a VW Golf up through manufacturing, the values determined in Table 9 could be used to calculate a weighted average of the carbon totals from each method. The more credible the score, the higher weighted it would be. We believe this is a useful method because the overall scores, and especially the data uncertainty scores, are so low, and no one method is entirely credible. Combining each of these scores, however, improves the credibility of our final estimate. In our case, this is difficult, because methods 4, 5, and 6 provide only CO2 rather than CO2-equivalent. Therefore, we calculate two final estimates; using results from methods 1 and 2, we calculated a weighted average of 11.3 CO2 emissions per Golf car, and using results from methods 2, 3, 5 and 6, we estimated a weighted average of 8.3 CO2-equivalent emissions per Golf car. If a more robust method is developed, such as a hybrid EIOLCA-Process-based model, that uses better data and has high product specificity, such a weighted average method may not be necessary, but given the low certainty of any of one of our methods in this case, a weighted average is appropriate.

5 Conclusions & Future Work

We started this project with three goals in mind: to evaluate methods to determine the carbon footprint of a product, to incentivize companies to reduce emissions, and to provide consumers meaningful environmental information to inform their purchases. We would like to provide consumers with general carbon footprint estimates of a particular product as well as information detailed enough to differentiate between products and companies.

For emissions data up through manufacturing, our results as a whole are encouraging, because regardless of a companies' resources, they should be able to garner a value for the greenhouse gas emissions of their product that is reasonably accurate, or at the very least, consistent with other methods of analysis. They could then use this estimate as the amount of greenhouse gas emissions they should offset in order to make their purchase of the product "carbon-neutral."

However, based on our product use and end-of-life related emissions analysis, it is apparent that methods 1 through 6, which only include a product's impact through manufacturing, are incomplete from a life-cycle perspective. Future work must be conducted on the best way to package manufacturing, use-phase, and end-of-life information for the consumer. One idea is that the total life-cycle emissions expected for the product, based on average use-patterns (this would have to be standardized across industries) could be the global warming emissions value provided to consumers. It could also be provided to the consumer in a segregated manner: emissions up to purchase, emissions during use, and end-of-life options. For an automobile, use-phase emissions could be provided as emissions-per-gallon. These and other options must be explored to determine the most meaningful way to provide this information to the consumer. Eventually, environmental metrics other than greenhouse gases could be included as well.

For the purposes of calculating a carbon footprint estimate of a generic product, all of our methods appear adequate within a reasonable range; but the low quality of data currently available does not allow any of these methods to credibly differentiate between two different products within a category. For example, we cannot currently assess whether a VW Golf or an Fod Escort has a larger footprint over its entire life. These are reasons to influence the companies to provide better data.

This conclusion about our methods also limits our current ability to influence company behavior, since using the simple methods, such as Methods 1 and 2, may not lead highly polluting companies to change behavior; in these cases the average value might make them look better than they actually are. One idea for convincing companies to distinguish themselves in the eyes of the consumer would be to provide consumers with a carbon reporting grade alongside the emissions value. This would allow the consumer to know how relevant this data is to the company or product they are purchasing. In practice this could work as follow: as a basic approximation, information on all consumer products can be provided in an online database through the 1% method (Method 1) or EIO-LCA sector level data (Method 2). This information would be visible to consumers. To improve data, companies would have the opportunity to add varying degrees of information, as shown in table 10. For example, if the company provides no data, then on their product's environmental label, it would show the averaged value from EIO-LCA with a 'F' next to it.

Grade	Company Actions
A	Verified full hybrid LCA conducted at the product level
B	Verified product level data provided
C	Verified company level data provided
D	Unverified information provided
F	No information provided

Table 10: Possible Grading Schematic

By incentivizing companies to provide better data through this grading system, we will have more information available to differentiate between the carbon footprint of products and empower consumers to purchase the more climate-friendly product.

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