Carbon emissions intensity ratio: an indicator for an improved carbon labelling scheme

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Abstract
This letter proposes a new carbon labelling scheme to improve the visibility of products’ life cycle carbon emissions (sometimes defined as carbon footprint). This approach starts by normalizing carbon emissions data on a common scale of ‘carbon emissions intensity’, and a new indicator ‘carbon emissions intensity ratio’ is generated based upon its ratio to the annual national greenhouse gas emission per gross domestic product. Five ranges (extremely low, low, medium, high and extremely high) are used to represent the level of carbon emissions intensity ratio by a simple diagram with colour gradation. Case examples are presented, in which the carbon emissions intensity ratios of various selected products, both distinct and related, are calculated and compared. The limitations of this approach are then discussed, laying a foundation for further work.

Keywords: carbon emissions, carbon labelling, carbon emissions intensity, carbon emissions intensity ratio, carbon footprint labelling

1. Introduction

With the issue of global climate change assuming a higher profile in the socio-political context, greater attention is being paid to the greenhouse gas emissions produced by goods and services, directly and indirectly during their lifecycle (Wiedmann and Minx 2007, Iribarren et al 2010). Business management, in the UK and elsewhere, has been encouraged, and in some instances required, to measure and report carbon emissions to incentivize and monitor emissions reductions (e.g., DEFRA 2009). For manufactured goods environmental interventions, such as emissions reductions, need to be implemented mainly through product design and innovation (Deutz et al 2010, Song and Lee 2010). Moreover, with the concept of ‘green’ consumerism emerging gradually into the market, consumer preference may be also influenced by information provided through carbon labelling of products (Vanclay et al 2011). The UK government launched the carbon labelling program in 2007 and now more than 1100 products have been carbon labelled (Tesco 2011). Recent investigation shows that some UK customers can be persuaded to buy a product with low carbon emissions; given the relevant information 59% of people surveyed had selected at least one carbon labelled product during the past three years (Tan 2009, Tesco 2011).

The carbon emissions embodied in a product are usually presented to consumers in the form of a carbon label on product packaging. Emissions information is typically presented either in numerical form (e.g., tonnes of CO2 emitted per product unit) or with claims of emissions reduction (Upham et al 2011). A typical carbon reduction label has been developed by the Carbon Trust. The label presents the life cycle carbon emissions of the product per functional unit (i.e., packet, or serving), which the Carbon Trust define as the carbon footprint (www.carbontrustcertification.com; accessed 31/10/2011). The carbon label is seen as an effective means of communication to raise consumers’ awareness of climate...
change, and thus to help change their lifestyles and purchasing behaviours (Carbon Trust 2008, Tan 2009). However, based upon the responses from focus groups and surveys of responses to carbon labelling, it is clear that the public find it quite difficult to imagine a given quantity of CO₂ emission and its potential environmental impact (Upham et al 2011, Gadema and Ogletorpe 2011). In this context, the authors consider that the current system of carbon labelling does not communicate a sufficiently meaningful message to the consumer.

This letter proposes a dimensionless system of carbon emissions labelling, which, by facilitating comparison between products, would increase the ability of green consumers to implement their concerns in the market place. The carbon emissions data is normalized to a common scale of carbon emissions intensity (CEI), and a new indicator carbon emissions intensity ratio is generated based the ratio of CEI to the annual national greenhouse gas emission per gross domestic product. The value of the dimensionless carbon emissions intensity ratio (CRIE) of a product can be evaluated on a simple scale with five ranges of values from ‘extremely low’ to ‘extremely high’. The performance of a given product can be presented on its packaging by a simple diagram with colour gradation. It is hoped that this study could lead to an improvement in the clarity of current carbon labelling schemes and thus encourage consumers to select low carbon products, as well as increasing the potential for reduction in carbon emissions.

2. Overview of carbon labelling studies

The cornerstone of carbon labelling is the assessment of product carbon emissions following the principles of life cycle assessment (LCA). A number of standards and protocols have been, and are still being, developed for this purpose. The ISO, the International Organization for Standardization, for example, has devised carbon emissions measurement standards. These include ISO 14067, which will elaborate the requirements for the quantification and communication of the product carbon emissions (Gaussin et al 2011, Dias and Arrofa 2012). Additionally, the British Standards Institution (BSI) published the Publicly Available Specification (PAS) 2050 in 2008. The latter attempts to standardize methods for assessing the life cycle greenhouse gas (GHG) emissions for various goods and services, as well as specify the detailed requirements of the assessment (BSI 2008, Sinden 2009, Iribarren et al 2010). In addition, the Greenhouse Gas Protocol Initiative was developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) as guidance to help organizations report their GHG emissions, (WRI/WBCSD 2004, 2011).

There are concerns over the volume of data required for a viable LCA, alongside the availability and accessibility of that data (Tan 2009, Wang and Gupta 2011), which would apply to any form of carbon labelling derived from that approach. However, whilst these issues are acknowledged, the use of carbon labelling as a guide to consumers is actively encouraged and the contribution of this letter is to address the presentation of information to the consumer. There is very little literature on carbon labelling and consumers’ responses to it (Upham et al 2011). Upham et al (2011) have discussed the public perceptions of carbon labelling of grocery products. They found that the emission value, without further explanation, does not significantly influence product selection. Similarly Gadema and Ogletorpe (2011), have surveyed the purchasing habits and perceptions related to various carbon labelled food products. Although the surveyed consumers displayed a high preference motivation (72%) for carbon labelled products, a high proportion (89%) were confused by carbon labels resulting from different interpretation or comprehension.

Clearly more work is required to develop a system of carbon labelling with widespread appeal to the public. Accomplishing this would in turn increase the incentive for manufactures to reduce the impact of their products. One problem with the current practice of carbon labelling is that it is typically provided on a specific functional unit (Cagiao et al 2011). Thus comparison of emissions levels between different packet/portion sizes requires calculation. Carbon Trust (2008) suggested that normalized values of carbon emissions would be easier to interpret than absolute. DEFRA (2009) recommend that companies to report emissions intensity rather than absolute emissions in order to aid comparison. Intensity can be based on either a production unit (e.g., tonnes of CO₂ per tonne of product produced) or economic unit (e.g., tonnes of CO₂ per thousand pound’s worth of product produced). Each method has its advantages and disadvantages (DEFRA 2009). For example, providing financial based emissions intensities aids comparison between products. Conversely, fluctuations in price create problems for comparison over time, which is important for a firm seeking to show how their emissions performance has improved. Our method, as outlined below, seeks to avoid this issue by providing a baseline derived from national greenhouse emissions intensity. The latter has been suggested as a macro-indicator to reflect the changes in emissions caused by fluctuations in economic activity, as well as to inform policy making on CO₂ emissions reduction (Fan et al 2007, Wang et al 2012). The required inputs, gross domestic product and national greenhouse emissions levels (albeit estimated rather than measured) are readily available from the World Bank (www.worldbank.org, 7/1/2012).

A second issue with current labelling practice is the style of presentation of the information. There is some evidence that consumers would make more use of carbon emissions information if it were presented in a different format. Vanclay et al (2011) have examined customers’ response to carbon labelled products over a three month period. Thirty seven products were labelled with green, yellow and black footprints to represent their corresponding carbon emissions level, as below average, near average and above average, respectively. It was noted that customers’ purchasing behaviour changed slightly, with reduction of 6% in the case of the black labelled products, and an increase of 4% in green labelled products.

The approach used by this study emphasizes the ease with which the consumer can apply the information. Thus the
indicator developed is dimensionless to aid comprehension by the public and comparability of values between products. Furthermore, it is presented in a simple, visually appealing manner. Nonetheless, the calculations behind the proposed indicator, whilst mathematically straightforward, are more complex than a typical consumer is likely to want to comprehend. This underlying complexity is true of LCA itself, but the proposed methodology has the advantage of producing a dimensionless number, which is widely comparable and can be presented as a simple graphic. This letter outlines and demonstrates the mechanics of the process for policy makers/companies, as well as presenting sample labels.

3. Methodology

A carbon footprint derived from the LCA is generally determined by functional unit. That is the carbon emissions relate to a specific scenario, e.g. per pack, per serving, per pint etc (Carbon Trust 2010). The starting point of the methodology presented in this letter is to normalize the carbon footprint into a common scale. We suggest using an indicator defined as ‘carbon emissions intensity’ (CEI), which can be understood as carbon emissions per unit of economic output (DEFRA 2009). It can be calculated as follows:

\[
\text{Carbon emissions intensity (CEI)} = \frac{CE_i}{R_i(j)}
\]

where \(CE_i\) is the carbon emissions of the \(i\)th product (kilogramme per functional unit), which is derived from a LCA; \(R_i(j)\) is the retail price of the \(i\)th product at the \(j\)th year, using British pounds per functional unit.

However, the CEI is highly dependent upon the retail price, fluctuations of which would disguise temporal variations in carbon emissions levels (DEFRA 2009). Thus, in successive years the product’s retail price would need to be adjusted to allow for inflation. This is not a trivial matter, but the UK government, for example, provides guidance on the derivation of official measures of inflation, as well as tracking the calculated values (Office of National Statistics: www.ons.gov.uk/ accessed 8/1/2012).

The second stage of our methodology is to devise a baseline to build a dimensionless indicator and frame of reference. The baseline is the national carbon emissions per unit of gross domestic product (GDP), defined as National Carbon Emissions Intensity (NCEI) (Fan et al 2007, Wang et al 2012). This is defined as follows:

\[
\text{NCEI}(j) = \frac{GHG(j)}{GDP(j)}
\]

where \(NCEI(j)\) is the National Carbon Emissions Intensity for the country of production in a designated year \((j)\); \(GHG(j)\) is the national greenhouse gas emissions (direct emissions) at the \(j\)th year and \(GDP(j)\) is the national gross domestic product at the \(j\)th year. We note that NCEI is based on estimated emissions for a given year, rather than life cycle emissions for a product. This is appropriate as we are establishing a emissions intensity baseline in time, to facilitate comparison of product emissions intensity over time, as well as between products at a given time.

From equations (1) and (2), we can set up a dimensionless indicator based upon the ratio of CEI and NCEI, which can be defined as ‘carbon emissions intensity ratio’ (CEIR) and expressed as follows:

\[
\text{CEIR}_j = \frac{CEI_j}{NCEI(j)} = \frac{CE_i}{R_i(j)} \frac{GHG(j)}{GDP(j)}
\]

By definition, the value for NCEI for the designated baseline year would remain constant for the calculation of CEIR for successive years. Thus any change in CEIR over time would be accounted for primarily by changes in carbon emissions per product unit for the given product.

It is assumed that CEIRs are normally distributed with mean value \(\mu\) and standard deviation \(\pm \sigma\). This assumption may be compromised if, for example, products for which data are available are preferentially from higher emissions categories. However, this potential problem would decrease over time, as labelling became more widely adopted. Based on this assumption, we suggest dividing the carbon emissions intensity ratio into five ranges, designated as extremely low, low, medium, high and extremely high, respectively (see figure 1).

Both \(\mu\) and \(\sigma\) are calculated based on equation (3), in order to determine the range boundaries. Thus, the mean of carbon emissions intensity ratio \(\mu\) can be expressed as follows:

\[
\mu = \frac{\sum_{i=1}^{n} \text{CEIR}_i}{n}
\]

where \(n\) indicates the sample number of the measured products.

\(\sigma\) is the standard deviation of carbon emissions intensity ratio, which reflects how much variation is from the mean, and can be measured by the following equation.

\[
\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\text{CEIR}_i - \mu)^2}.
\]
Figure 2. Level of carbon emissions intensity ratio.

For example, if certain product’s CEIR approaches the mean, within the standard deviation range ±σ/2, it is suggested that the measured product could be labelled as ‘medium’.

In order to help customers perceive this dimensionless indicator intuitively, we have developed a diagram to present the ratio in a visual way, and thus to improve the carbon label scheme. The prototype for the diagram is the UK’s Health and Safety Executive’s representation of the concept of ‘tolerability of risk’ (HSE 1988). However, we suggest dividing the ‘inverted triangle’ into five ranges of carbon emissions intensity ratio. The ranges are highlighted using a background colour that gradually changes from red to green, as the CEIR decreases from extremely high to extremely low (see figure 2).

4. Case examples

In this section, two case examples are presented to demonstrate the application of the above methodology. The first example uses a wide range of product types to establish a baseline figure for the UK for the purposes of this exercise. The baseline is then applied to calculate CEIR for the included products. The second example demonstrates that the methodology can discriminate between the emissions intensity of similar products, in this case milk with differing fat contents.

4.1. Example one: establishing the baseline and comparing carbon labelling of different product categories

For the purposes of this example we are using the 60 products with carbon emissions data derived from an input–output model developed by Small World Consulting Ltd, in collaboration with Lancaster University (Berners-Lee 2010). The products can be divided into four categories in terms of their applications, ranging from heavy industrial products, light industrial products, groceries to ‘other commercial products’. The emissions data were converted to the carbon emissions intensity in units of kilogrammes CO\textsubscript{2} per pound Sterling (£) of output based on the retail price.

As the economic output values of these products are based on 2009 retail prices, the year 2009 is set as the baseline year. Thus, the national emissions intensity for the UK can be calculated as follows:

\[ \text{NCEI}(2009) = \frac{\text{GHG}(2009)}{\text{GDP}(2009)} \]

where GHG(2009) is the direct national greenhouse gas emissions of UK at 2009, estimated to be 566 300 million kilogrammes of carbon dioxide equivalent (DECC 2011); GDP (2009) is the national gross domestic product of UK at 2009, given as 2173 154 million US dollars by the World Bank (2010). As the yearly average currency exchange rate from US dollars to pounds Sterling is about 0.63 (HM Revenue & Customs 2011), the GDP value at year 2009 can be transformed into £1369 087.02 million pounds Sterling. Thus, the UK baseline value NCEI(2009) can be calculated as 0.41 kg of carbon emissions per pound Sterling.

Using equation (3), the carbon emission intensity ratio of the 60 selected products can now be calculated, as shown in table 1, with \( \mu \) computed as 2.28, and \( \sigma \) as 1.97, based on equations (4) and (5). In this example, therefore, the ‘extremely low’ region lies between 0 and 0.31, ‘low’ between 0.31 and 1.29, ‘medium’ between 1.29 and 3.27, ‘high’ between 3.27 and 4.25, and ‘extremely high’ above 4.25 (see figure 3).

It is apparent that the CEIR of the selected products is related to the energy embodied in them. The heavy industrial products (including metal ores and fossil fuels) have CEIR values in the medium to extremely high ranges. Other petroleum based products (e.g., fertilizers and man-made fibres) also have high CEIR values. Light industrial, and food products typically have medium to low CEIR values (see figure 4–6). The ‘grocery’ category covers not only food and beverages, but also some house-hold products, such as furniture, domestic appliances, cutlery etc. Figure 7 shows their different CEIRs; most fall into the low region.

Thus, the calculated CEIRs provide a convenient, dimensionless, value by which to compare the emissions intensity of widely different products. Furthermore, these initial values, based on 2009 price figures, would provide...
Table 1. Carbon emissions intensity ratio of different products (derived from carbon emissions data in Berners-Lee 2010).

| Products                        | Product category | Carbon emissions intensity ratio | Carbon impact level |
|--------------------------------|------------------|----------------------------------|--------------------|
| Cement, lime and plaster       | Heavy industrial | 9.85                             | Extremely high     |
| Ceramic products               | Heavy industrial | 1.12                             | Medium             |
| Clay products                  | Heavy industrial | 2.29                             | Medium             |
| Coal                           | Heavy industrial | 8.68                             | Extremely high     |
| Concrete                       | Heavy industrial | 3.20                             | Medium             |
| Glass and glass products       | Heavy industrial | 2.29                             | Medium             |
| Inorganic chemicals            | Heavy industrial | 2.92                             | Medium             |
| Iron and steel                 | Heavy industrial | 6.41                             | Extremely high     |
| Metal castings                 | Heavy industrial | 6.98                             | Extremely high     |
| Metal ores                     | Heavy industrial | 2.41                             | Medium             |
| Non-ferrous metals             | Heavy industrial | 4.39                             | Extremely high     |
| Oil and gas                    | Heavy industrial | 1.90                             | Medium             |
| Organic chemicals              | Heavy industrial | 3.63                             | High               |
| Petroleum products and coke    | Heavy industrial | 1.56                             | Medium             |
| Stone, clay and minerals       | Heavy industrial | 2.59                             | Medium             |
| Agricultural machinery         | Light industrial | 1.68                             | Medium             |
| Clothing                       | Light industrial | 0.56                             | Low                |
| Electric motors, generators    | Light industrial | 1.56                             | Medium             |
| Footwear                       | Light industrial | 0.56                             | Low                |
| Insulated wire and cable       | Light industrial | 2.61                             | Medium             |
| Jewellery                      | Light industrial | 0.98                             | Low                |
| Knitted products               | Light industrial | 1.73                             | Medium             |
| Leather products               | Light industrial | 1.24                             | Low                |
| Machine tools                  | Light industrial | 1.43                             | Medium             |
| Made-up textiles               | Light industrial | 0.63                             | Low                |
| Man-made fibres                | Light industrial | 5.05                             | Extremely high     |
| Motor vehicles                 | Light industrial | 1.75                             | Medium             |
| Office machinery and computers | Light industrial | 0.88                             | Low                |
| Other textiles                 | Light industrial | 1.41                             | Medium             |
| Paper and paperboard products  | Light industrial | 1.73                             | Medium             |
| Plastic products               | Light industrial | 2.17                             | Medium             |
| Rubber products                | Light industrial | 2.17                             | Medium             |
| Synthetic resins               | Light industrial | 3.02                             | Medium             |
| Textile fibres                 | Light industrial | 1.51                             | Medium             |
| Wood and wood products         | Light industrial | 1.85                             | Medium             |
| Alcoholic beverages            | Groceries        | 0.63                             | Low                |
| Bread and biscuits             | Groceries        | 1.54                             | Medium             |
| Carpets and rugs               | Groceries        | 0.51                             | Low                |
| Confectionery                  | Groceries        | 0.85                             | Low                |
| Cutlery tools                  | Groceries        | 1.12                             | Low                |
| Dairy products                 | Groceries        | 2.98                             | Medium             |
| Domestic appliances            | Groceries        | 1.07                             | Low                |
| Fish                           | Groceries        | 2.07                             | Medium             |
| Furniture                      | Groceries        | 1.27                             | Low                |
| Metal boilers                  | Groceries        | 1.73                             | Medium             |
| Processed fish and fruit       | Groceries        | 1.83                             | Medium             |
| Processed meat                 | Groceries        | 2.51                             | Medium             |
| Processed oils and fats        | Groceries        | 1.83                             | Medium             |
| Receivers for TV and radio     | Groceries        | 0.56                             | Low                |
| Soap and toilet preparation    | Groceries        | 0.63                             | Low                |
| Soft drinks and mineral water  | Groceries        | 1.24                             | Low                |
| Sugar                          | Groceries        | 2.54                             | Medium             |
| Tobacco products               | Groceries        | 0.32                             | Low                |
| Transmitters for TV and radio  | Groceries        | 1.07                             | Low                |
| Fertilizers                    | Others           | 7.44                             | Extremely high     |
| Industrial dyes                | Others           | 3.46                             | High               |
| Paints, varnishes, printing ink etc | Others         | 1.37                             | Medium             |
| Pesticides                     | Others           | 2.51                             | Medium             |
| Pharmaceuticals                | Others           | 0.66                             | Low                |
| Sports products and toys       | Others           | 0.44                             | Low                |

an invaluable means of comparing emissions intensity of given products over time. The question remains as to whether the indicator is sufficiently sensitive to enable the separation of similar products on the basis of their emissions intensity, which is a closer simulation of the choices faced by consumers.
4.2. Example two: carbon labelling of similar products

Example two focuses on a range of similar products, e.g. milk, with different fat contents: whole milk (less than 4% fat), semi-skimmed (less than 2% fat) and skimmed milk (less than 0.1% fat). According to an investigation carried out by a leading supermarket in the UK, the present retail price of the above three milk products is the same, i.e. 0.49 pounds Sterling per pint. Their corresponding carbon footprints, shown in the carbon label, are 0.9 kg CO$_2$/pint, 0.8 kg CO$_2$/pint and 0.7 kg CO$_2$/pint, respectively (table 2).

Using the baseline value for NCEI(2009) of 0.41 kg per pound Sterling (see example one), the CEI, and its corresponding ratio, can be calculated for the three milk products from the equations (2) and (4), table 3.
Since milk is a dairy product, one of the 60 selected products presented in the example one, it can be deemed to be included in the normal distribution of carbon labelled products considered in example one. Hence, the levels of carbon emissions intensity ratio, defined in figure 3 are still relevant to the three milk products. Milk is a high carbon product (Berners-Lee 2010): both semi-skimmed and skimmed milk show high CEIRs, whilst whole milk’s CEIR is extremely high (see figure 8).

The CEIR, therefore, is capable of distinguishing between similar products, even, as in this case, variants of the same product. Notably, dairy products overall had a medium CEIR (see table 1). An emissions-conscious consumer, therefore, would be able to use the information provided by CEIR labelling to adjust their consumption habits.
in such a way as to obtain the nutritional benefits of dairy products whilst reducing their personal carbon footprint.

5. Discussion

No carbon emissions indicator can be more accurate or precise than the inputs from which it is derived. In this instance the inputs can be divided between those relating to the measurement of carbon emissions, and those relating to financial data. The most critical input for any carbon emissions indicator will be the LCA emissions data. As discussed, the complexities of LCA and difficulties in obtaining the required data limit the precision of calculated values. In addition, there may be biases in the types of products for which values have been calculated, which would influence the CEI. Additionally, the national emissions data used to calculate the baseline value are likely to vary significantly in methodology of collection and presentation between different countries, which will hinder international comparison of CEIR.

For financially based emissions intensities, a significant problem is posed by fluctuations in retail prices. Our methodology corrects for this, but there are uncertainties in the process, with a number of different methods available for providing a constant value to fluctuating prices. The methodology needs to be tested for sensitivity to calculations of inflation and the assumptions made on short term price fluctuations. (e.g., is average recommended retail price for the year used, or are sale prices taken into consideration or price discrepancies between different outlets.)

One potential innovation to LCA would be to combine the existing life cycle assessment approaches with other methods, such as ‘Organization Product based Life Cycle Assessment (OP-LCA), ‘Input–Output Analysis based Life Cycle Assessment (IO-LCA)’. This would allow better comparability by using the financial accounts as a unique functional unit and including all relevant products and processes (Berners-Lee 2010, Carballo-Penela and Domènec 2010). In this case, the first step of our proposed methodology (division by inflation corrected retail price) for carbon labelling could be omitted. However, the financial values used in any hybrid LCA approach would need to be corrected for variations over time.

6. Conclusions and further study

This study has introduced a normalization approach to improve carbon labelling scheme for the visibility of carbon emissions derived from a product’s life cycle. We suggest that the carbon emissions can be normalized as ‘carbon emissions intensity’ (CEI), whilst a dimensionless indicator ‘carbon emissions intensity ratio’ (CEIR) is established based upon the CEI’s ratio to the overall national carbon emissions intensity.

However, the authors recognize that there are still some limitations involved in this approach. An indicator, e.g. carbon emission intensity ratio (CEIR), cannot be better quality than the input data. The ranges for carbon emissions intensity ratio division are based on the assumption that all the products analysed are subject to the assumed normal distribution, and this may result in uncertainties of range definition. A wider range of products and specific case scenarios need to be examined to confirm the validity and sensitivity of this approach. The potential for this, however, is limited by the availability of LCA data; analysed products may not be representative of products as a whole in terms of their life cycle emissions. With regard to carbon labelling, whether the form of label suggested here, based upon the carbon emission intensity ratio, is easily understood by consumers needs to be established through questionnaires, focus groups and interviews.

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