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2 The conundrum of calculating carbon footprints

Bjarne W. Strobel, Anders Chr. Erichsen and Quentin Gausset

Introduction

The awareness of climate change and its link with human activities is growing. This awareness is nursed by the gradual change in weather conditions experienced worldwide and an increase in the occurrence of extreme events such as heatwaves and floods. However, despite overwhelming scientific evidence that climate change is anthropogenic (IPCC 2013), there is still widespread scepticism and a wide knowledge gap between what science predicts and what people know and understand about climate change.

Mitigating the effects of climate change depends on reducing drastically the world production of carbon dioxide (CO_2) and other greenhouse gasses (GHGs). So far, the international community has been working towards limiting the increase in world average temperature to 2°C as compared to pre-industrial levels. (In the past 150 years of industrialisation, the global average temperature has increased by about 0.8°C). To reach this goal, the world community needs to reduce accumulated GHG emissions over the coming 90 years by 80 per cent (Erichsen and Arnskov 2010).

There are wide disparities in GHG emissions among countries. Average CO_2 emissions per capita in the EU is 50–100 times that of most Sub-Saharan countries (World Bank 2013). If one applies the principle of environmental justice, i.e. that each human should have the right to emit an equal amount of CO_2, then citizens from industrialised countries would have to reduce their emissions by much more than 80 per cent, while citizens from developing countries should be allowed to increase their level of emissions.

Corrective justice, or the principle of 'Common But Differentiated Responsibilities' (CBDR) was stated in the 1992 Rio Declaration and reaffirmed in the 1997 Kyoto Protocol. This principle recognises that industrial states bear a much bigger responsibility for having created the current environmental crisis and must therefore bear a much higher share in reducing their GHG emissions. Thus, early industrialised countries should reduce emissions even more drastically than other countries (Harris 1999; Rajamani 2000; Stone 2004; Cullet 2010).

In view of the fact that the international community has failed to date to reach ambitious global agreements, actors at lower levels (the EU, nations, municipalities and individuals) are increasingly filling the gap by taking important initiatives to reduce their emissions. The EU 2020 Climate and Energy Package wants to raise the share of the EU energy consumption produced from renewable resources to 20 per cent by 2020. Formal talks at the EU are underway to increase this share to 30 per cent (European Commission 2010).

Some countries have more ambitious goals. Denmark, for example, wants to be at the forefront of environmental policies, and is committed to raising its share of energy consumption produced from renewable resources to 33 per cent by 2020, and to be 'free of fossil fuel' in 2050 (Regeringen 2011). At the local level, many Danish municipalities have also developed plans to become CO_2-neutral in the near future, as demonstrated in several chapters in this book (see Hoff and Strobel 2013; and in this book: Baasch; Møllenbach and Hornbæk; Tjørring and Gausset).

The majority of the chapters in this book address social technologies to increase climate change mitigation, i.e. by reducing consumption and insulating houses, among others. But how much do these actions contribute to climate change mitigation? Will these actions be sufficient? Some studies argue that up to 72 per cent of GHG emissions are related to household consumption, with food accounting for 20 per cent of that figure (Hertwich and Peters 2009). Other studies claim that Danish households account for only 28 per cent of total energy consumption (Energistyrelsen 2012).

But how are these figures calculated? What do they include and exclude? How much can be reduced by individual behaviour change and how much is due to structural mechanisms over which individuals have very little control? Answers to these questions require tools that allow actors to measure the impact of the different options available to them and allocate differentiated responsibilities among them. GHG emissions (CO_2) calculators are the most commonly used tools for this purpose. But one can find a variety of calculators based on different principles that produce very different carbon footprints for the same household (Kenny and Gray 2009).

The greenhouse effect

The greenhouse effect consists of greenhouse gases in the atmosphere that reflect long wavelength heat radiation emitted from the Earth's surface. It reduces the amount of heat loss to the outer atmosphere and keeps the heat in the lower atmosphere near the Earth's surface. The most important GHGs in terms of climate change are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In calculations, all GHGs are converted into CO_2 equivalents in order to compare their greenhouse effect more easily. In this chapter, we discuss CO_2, or carbon emissions, as generic terms and refer more broadly to GHGs.

During the past 100 years, the CO_2 concentration in the atmosphere has increased from 280 parts per million (ppm) to over 400 ppm, a concentration that was surpassed for the first time in May 2013. Since life on Earth evolved, the climate has been changing (several ice ages and warm periods have occurred, for example) and will continue to change. However, no climate change era in the past can compare to the speed and abruptness of the present change (see Figure 2.1). The problem is that the rapid increase of GHGs in the atmosphere since the beginning of the industrial revolution, accompanied by a rapid increase of the Earth's average temperature, can seriously challenge our welfare and the way human societies are organised.

If the concentration of CO_2 reaches 450 ppm, as will soon be the case, this would be 50 per cent more than the highest concentration found in pre-industrial times and would lead to an increase in the global average temperature of approximately 2 degrees (IPCC 2013). This temperature increase would affect continental areas much more than oceans. Thus, although the average temperature for the entire planet will rise by 2 degrees, the temperature rise of the ocean surfaces (covering approximately 70 per cent of the Earth's surface) is expected to be +0.1 to +0.3 degrees and the average temperature rise over the continents is expected to be +5 to +6 degrees (IPCC 2013).

Moreover, the continental temperatures will not be evenly distributed. Some regions, especially near the equator, might see very little change, while the temperature is expected to increase by 8–10 degrees in the Polar Regions (IPCC 2013). In large areas, the temperature increase will be barely detectable, while in

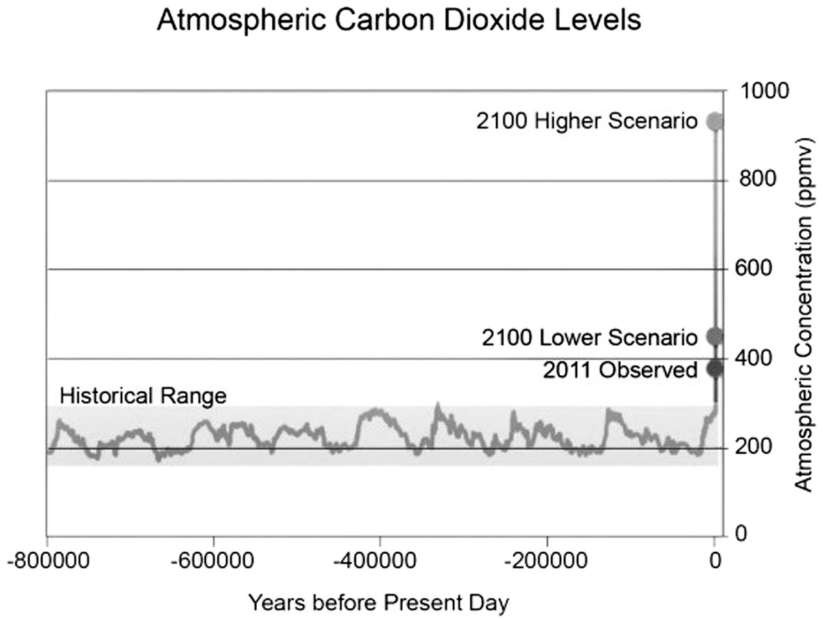

Figure 2.1 Atmospheric CO_2 concentration in the past 800,000 years

Source: US Global Change Research Program 2014, based on data from Tans 2008 and Lüthi *et al.* 2008 other parts of the Earth it will be noticeable and will have dramatic consequences. Most scenarios predict that the concentration of CO_2 will not stabilise at 450 ppm and will reach between 550 and 900 ppm by the year 2100, which would lead to a global average temperature increase estimated to be between 2.5 and 5 degrees (IPCC 2013).

It can be difficult for individuals to notice such changes on a yearly basis since the weather we observe locally this year (or that we remember from the past few years) might be in contradiction to the weather experienced in other locations or observed globally. For example, arctic air from the Barents Sea cooled Europe in 2012–2013 by approximately a one-degree colder winter average, while at the same time Greenland experienced a very warm winter and record glacier and sea ice melting. It is therefore very difficult for individuals experiencing local climate variations to get a global picture of global warming. Variations such as these can create scepticism about scientific predictions, which can become an important obstacle to behaviour change.

Since GHG emissions circulate the global atmosphere within a few weeks, we all share the impact of emissions regardless of their source. Local actions have a global impact: we all have a shared responsibility to change behaviour so as not to harm other people. Carbon footprint calculators that measure the 'load' imposed upon nature by a given population can help people understand how their actions and consumption habits impact the global climate and help them adopt greener behaviour.

However, the variety of existing calculators may confuse people and increase their scepticism. Because they rely on different principles, various calculators produce different estimated emissions and conclusions about what needs to be done to become CO_2-neutral. For example, based upon the different results of various calculators, is the average CO_2 imbalance produced by a Danish citizen 6 tons, 11 tons or 19 tons per year? Is the average carbon footprint of one kilogram (kg) of pork meat 4 kg, 28 kg or 50 kg CO_2? It all depends on the underlying principles of each calculator and on the criteria taken into consideration when making the calculation, which will be discussed in more detail later in this chapter.

Scopes

Calculating the CO_2 emitted while an individual conducts daily life is a complex matter: the energy we consume involves a large amount of actors at different levels and each actor directly controls only part of the energy invested. The three scopes (sources of emission) in the consumption of energy and emissions of CO_2 are: 1) Direct emissions, 2) indirect emissions from electricity and heat and 3) activity associated with indirect emissions (GHG Protocol 2001), as illustrated in Figure 2.2.

Scope 1 applies to all direct GHG emissions resulting from the actor's own activity. In practice, this often amounts to the direct consumption of fossil fuels (such as coal, oil and gas) while heating the home, or the fuel burnt while driving

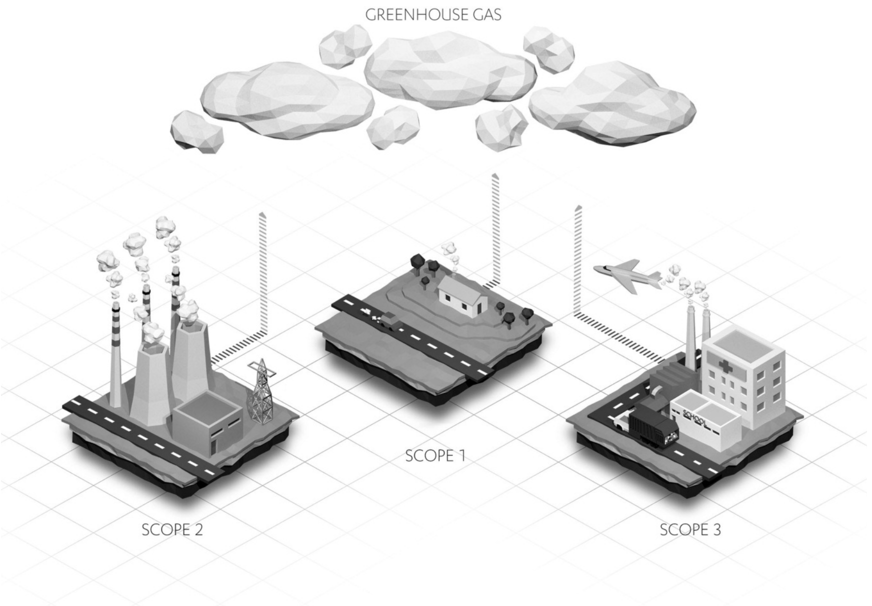

Figure 2.2 Emission of CO_2 from activities in three scopes: 1) actor's direct emissions, 2) indirect emissions from purchased electricity and heat, and 3) indirect emission from activities and products outside the actor's control

a private car. The producer of these emissions controls them: s/he can reduce his or her consumption.

Scope 2 applies to all indirect GHG emissions originating from the consumption of purchased energy such as electricity and district heating. These emissions are produced at power plants from which the consumer buys the energy. The actor controls Scope 2 emissions only indirectly. S/he cannot force the energy company to produce green energy, but can replace the supply company with a greener one.

Scope 3 applies to indirect GHG emissions coming from the public infrastructure, which surrounds the production chain, or from sub-contractors whose products are purchased to produce goods. Specific examples of public infrastructure include schools, roads and hospitals. Individual actors have little influence on Scope 3, apart from requesting from sub-contractors a minimal level of environmental friendliness, or voting for political parties that support strong environmental agendas and greener infrastructures.

Someone interested in reducing his or her carbon footprint would logically begin with Scope 1 emissions. As they are emitted directly by that person, he or she can reduce them without having to discuss the issue with anyone else. Rather, it is simply a question of burning less energy or replacing fossil fuel with renewable energy (and also driving less, reducing room temperatures in houses or switching from heating with oil to heating with renewable wood pellets, among others).

Scope 2 emissions are more difficult to control because they come from an energy company that has thousands of customers and depends on a large infrastructure that cannot be changed overnight. Nevertheless, there are a few options available, such as reducing consumption (insulating houses, reducing room temperatures) or producing one's own renewable energy (including e.g. wind energy and solar panels).

Scope 3 emissions are the most difficult to reduce because they depend on other actors (they derive from someone else's Scope 1 and 2 emissions). Yet it is often in Scope 3 emissions that one finds the largest potential for the reduction of CO_2 emissions (Huang *et al.* 2009). For example, a study of 491 sectors in the United States (US) showed that only 26 per cent of the total GHG emissions were captured by Scope 1 and 2 emissions (Matthews *et al.* 2008). It is only by addressing Scope 3 emissions that one can hope to reduce emissions by the 80 per cent required to keep global warming below +2 degrees.

Making people aware of Scope 3 emissions even though they have little control over them can help raise awareness of the challenges we face and can trigger a higher environmental consciousness. People can then lobby politicians or political parties to promote ambitious environmental goals, or they can request lower carbon footprint of the goods they consume. This can bring large-scale and long-lasting changes, even though they happen in the longer run.

Two approaches to calculating carbon footprint

The carbon footprint refers to the cumulative CO_2 emitted through the life-cycle of a product or through the total consumption of an individual or institution (Hertwich and Peters 2009; Weidema *et al.* 2008). It is not to be confused with the concept of ecological footprint that converts the burden imposed upon nature by a given population in terms of the equivalent land area necessary to sustain current levels of resource consumption and waste discharge by that population (see, for example, Wackernagel and Rees 1996, 1997). We focus here on carbon footprints and measure the load imposed on nature in CO_2e (or CO_2 equivalents), although we have chosen to write CO_2 for simplicity.

There are two broad approaches to calculating the carbon footprint. The first is a consumer-based model that calculates the total CO_2 emissions linked to the life cycle of a product (from its source to its ultimate consumption and disposal, including all scopes). The sum of the product consumed can thereby constitute the carbon footprint of the consuming unit, such as an individual. It is impossible to reduce CO_2 emissions to zero with this model. Regardless of how much we reduce our emissions, we will always consume a minimal amount of basic goods (food, clothing, shelters, education, and health care, among others) that will always emit some CO_2.

The second approach is a geographically based model that calculates the total energy and CO_2 emissions produced and captured within a geographically circumscribed area (typically a municipality or a nation). The carbon footprint is calculated by adding all CO_2 emitted within the geographical unit and subtracting the emissions substituted by all renewable energies produced within the same boundaries, regardless of whether that energy is consumed locally or exported. If enough renewable energy is exported out of the geographical unit, then the carbon footprint of this unit can be said to be neutral or can even be negative. With this model, it is therefore possible for an actor (a company, a municipality or a country, for example), to claim to be CO_2-neutral simply by transferring CO_2 emissions to someone else's carbon footprint.

Consumption-based carbon footprints

Consumption-based carbon footprints of products are calculated by adding the CO_2 emitted throughout the production chain, and including all scopes, while the consumption-based carbon footprints of individuals are based on the total sum of all carbon footprints of all the products and services consumed by that individual.

What makes these calculations difficult is the fact that each product (and each sub-part used to make that product) combines different scopes. For example, when a farmer produces pigs, he uses Scope 1 energy (the fuel used in his engines or in heating his building) as well as Scope 2 energy (the electricity that he buys to light his buildings and to make his electric equipment work). Scopes 1 and 2 emissions represent around 4 kg CO_2 per kg of pork (which is carcass weight, including skin and bones, and which actually equals 6.6 kg CO_2 per kg meat). But this does not take into account the amount of emissions coming from the broader infrastructure that makes pig production possible (fodder, veterinary interventions, official controls, education of the farmer, road infrastructure, among others), all of which could be counted in the carbon footprint of one kg of meat (Chrintz 2012).

The pig is bought by a middleman (let's say a butcher or a supermarket), who also uses Scope 1 and 2 energy while transporting the pig to a slaughterhouse, lighting and heating the butchery or supermarket, paying salaries to employees (who will use part of it on transport from home to work) and processing the meat. Like the farmer, a butcher indirectly produces CO_2 depending on the energy provider. And finally, he has Scope 3-related CO_2 emissions related to the materials and the emissions from sub-contractors that he uses. It takes energy to produce butcher knives, buildings, packaging material, and butchers have very little control on how much CO_2 is produced in these activities. Moreover, like the farmer, the butcher depends on a well-functioning infrastructure of transport, education and health. The three scopes of the butcher significantly increase the carbon footprint of one kg of meat product.

The story continues: the meat is sold to a consumer. Scope 1 and Scope 2 are present in the form of the energy consumed to do the shopping, keep the meat in the refrigerator and cook it. The consumer is in direct or indirect control of these aspects and can choose to shop by bicycle rather than by car, buy a low-energy refrigerator and adopt environmentally-friendly cooking habits. Scope 3 includes, once more, the pot, water, road, education and health infrastructure that make it possible to buy and consume meat.

By the time the consumer eats the meat, the total carbon footprint of all scopes and all actors' amounts to 28 kg CO_2 per kg of pork meat, which is much more than the amount of CO_2 produced in Scope 1 and 2 at the farm. If the meat has been processed even further to produce pâté or sausages, for example, and handled several times more, the total carbon footprint can easily be up to 50 kg CO_2 per kg of meat product served at dinner. This means that waste at the end of the chain of users is much more damaging to the environment than waste at the beginning of the chain. If a pig dies at the farm the day before being sent to the slaughterhouse, the emissions represent 4 kg CO_2 per kg of pig wasted; if a consumer throws out pâté or sausage because the expiry date has been passed or left over from the dinner, then the CO_2 emission wasted can be more than 10 times higher (Chrintz 2012).

Figure 2.3 illustrates how the output from one industrial sector becomes the input of another sector, and how someone's Scope 1 emissions can become someone else's Scope 3 emissions (see Matthews *et al.* 2008; Wiedmann 2009). In addition, Figure 2.3 illustrates how the emissions change over time as actors change subcontractors. This makes it difficult to precisely define the carbon footprint of a product.

Another example: the carbon footprint of travelling by air (another important source of GHGs) is also controversial. The airline companies that currently inform customers about the carbon footprint of their air flights usually use Scope 1 figures based exclusively on the amount of fuel consumed per passenger and per trip. But one should not forget the energy spent on building aircrafts, airports, control towers, controlling passengers, selling tickets and building offices for the employees and travel agencies. Thus, in reality, the carbon footprint of traveling by air announced by airline companies represents only a small fraction of the total carbon footprint of travelling by air.

Taking Scope 3 emissions into consideration can cause dilemmas for customers, who have to choose between keeping an old item that has high energy consumption and replacing it with a newer and more efficient item. For example, is it a good idea to replace an old refrigerator with a high-energy consumption by a new A+++ refrigerator? Or, is it a good idea to replace an old fuel-consuming car with a new energy-efficient or electric vehicle? The manufacturing of a new refrigerator or smart car causes additional CO_2 emissions. While in use, the smart car or the refrigerator emits less CO_2 per kilometre (km) or per hour, but its higher energy efficiency has to compensate for the emissions produced during the manufacturing of the car, too. In order to optimise CO_2 emissions, climate-friendly purchases of more energy-efficient equipment should generally occur when the old equipment is worn out. However, if the end goal is the raising of environmental awareness instead of the absolute amount of reduced CO_2 emissions, then promoting the replacement of old equipment can play a significant role in the motivation for green technology.

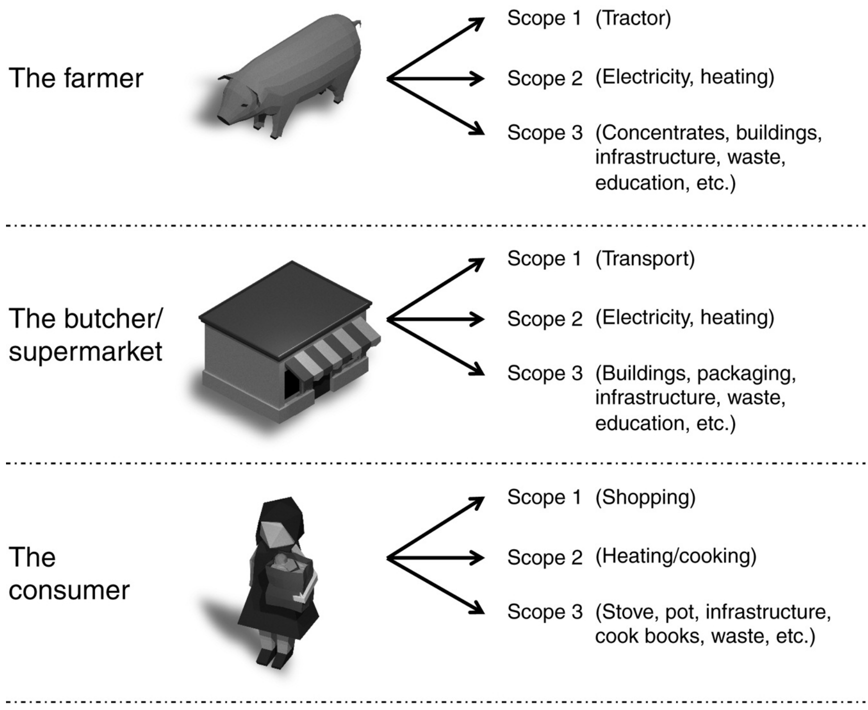

Figure 2.3 Scopes and actors in the chain from production to consumption of pork meat

The advantage of calculating the carbon footprint of a product in a consumer-based approach is that it can help them make environmentally conscious choices when they buy products, which can indirectly trigger environmentally friendly changes in the production chain. But it is difficult to use such tools directly in order to encourage the reduction of the carbon footprint of a product, since the responsibility for the carbon footprint is spread over the large number of people involved in its production, transformation and marketing. Moreover, the scope involved depends on the actors involved: while the energy used to produce aircrafts is a Scope 1 activity for the aircraft manufacturer, Scope 3 is applicable to the airlines flying the aircrafts. Calculators trying to evaluate GHG emissions linked to consumption seldom include all scopes, and when they do, they are complicated and difficult to understand. Encouraging people or companies to reduce their individual carbon footprint might therefore require another type of CO_2 calculator, which is called the geographically based carbon footprint.

The geographically based carbon footprint

Calculating the carbon footprint of a geographical unit, such as a nation, a municipality, or even a household (if it produces energy through a wind turbine or solar cells at the same time as it consumes energy), boils down to adding up how much energy is consumed within the entity's geographical boundaries (counted in CO_2) and subtracting the amount of renewable energy produced within the boundaries (translated into CO_2), as well as the amount of CO_2 sequestered (captured and taken out of the atmosphere by growing trees, for example).

At the national level, these calculations are relatively easy to make, as national governments generally collect statistics of energy imports and exports, which can include all actors and all scopes. It should be noted, however, that the carbon footprint of a country is based on the CO_2 emitted while producing goods regardless of where these goods are consumed. This means that a country can reduce its carbon footprint simply by delocalising – or outsourcing – heavy industries abroad and importing goods that it once produced at home. In this scenario, the CO_2 emission is counted abroad even though the original country still has the responsibility for some CO_2 emissions because it continues consuming the same goods as before, at home.

Municipalities also try to calculate their carbon footprints in order to reach environmental goals, such as reducing their carbon footprint or becoming CO_2-neutral within a certain time frame. In Denmark, most municipalities use a calculator developed by the country's National Association of Municipalities, which creates uniform carbon budgets, an overview of emissions by each municipality and assesses the largest carbon sinners. The calculator estimates carbon emissions within a defined area, including both the direct emissions of the given municipality, as well as the emissions generated by citizens and various sectors such as industry and agriculture.

Input data to the calculator are overall figures, including the number of citizens, livestock, type and size of industry and the municipal source of heating and electricity over a certain span of years. A number of Scope 3 services are included in these accounts, including libraries, municipal roads, hospitals, schools and local production. Hence, these calculators do provide an overview of the entire life cycle of products and total GHG emissions. However, producing an energy account for an entire municipality is not an easy task and there is no standard procedure for doing it. Calculations rely largely on gathering data from energy companies about energy production and consumption, on gross estimates of industrial and agricultural production and on using average consumption statistical data, despite the fact that there can be great disparities between the consumption of different social segments (see Jones and Kammen 2011).

When a municipality or a country intends to become CO_2-neutral, its strategy relies upon changing behaviour and reducing consumption. But even more important, its strategy also relies upon its producing renewable ('climate change-neutral') energy, often encountered as the equivalent to CO_2-neutral energy. For example, burning wood, straw or biofuels is considered CO_2-neutral because one assumes that the CO_2 released into the atmosphere will be captured again by growing trees or crops. This is despite the fact that there can be significant Scope 3 emissions related to the production of wood, and that converting non-farm land to crop-based biofuels or forest bioenergy production can create a heavy 'carbon debt' by releasing more CO_2 than would be gained annually by the displacement of fossil fuel (Fargione *et al.* 2008; Searchinger *et al.* 2008; Mitchell *et al.* 2012).

Moreover, in energy calculations, any CO_2-neutral energy produced within a certain boundary but sold outside that boundary is counted negatively (subtracted) in the CO_2 account of the producing unit, and is counted positively (added) in the CO_2 account of the purchasing geographical unit. In practice, this means that a municipality (or country) can become CO_2-neutral solely by exporting wind or solar energy without having to reduce its own consumption and/or without having to change its old practices. For example, in the strategy of the municipality of Copenhagen to become CO_2-neutral by 2025, the production of surplus wind power in its harbour and the export of CO_2-neutral district heating to neighbouring municipalities totals two-thirds of the expected reduction of the carbon footprint (Københavns Kommune 2012).

The district heating system of the municipality of Copenhagen produces high-pressure steam in a large incinerator. The steam is distributed to residential homes and industrial buildings for heating and industrial processes. The steam is recovered from waste energy produced in large industrial plants burning coal, in large electric power plants and by burning waste from households and industries. The district heating produced from burning waste or recovering energy spillages from electricity production is claimed to be CO_2-neutral because the CO_2 emitted is included in the carbon footprint of the electricity company or in the consumer's footprint relative to the buying and disposing of goods.

Thus, the current accounting system allows a district heating plant to declare itself CO_2-neutral even though it releases large amounts of CO_2, simply because it sends the CO_2 bill to the consumer who has thrown waste in the garbage or to the company that produces electricity. The accounting system also allows a municipality to declare itself CO_2-neutral even though it produces large amounts of CO_2 through transport, heating and agriculture, among others, simply because it can 'send' the CO_2 bill to neighbouring municipalities that buy wind energy or so-called 'CO_2-neutral' district heating.

Obviously, these accounting tricks can work only as long as there are buyers for wind energy or district heating in neighbouring municipalities, and as long as one is allowed to keep the account within the narrowly defined boundaries of the municipality. Moreover, this system discourages efforts to reduce consumption and improve the recycling of waste products, since the CO_2 neutrality of the district heating system depends upon a large and regular supply of waste to be burned. (For example, the municipality of Copenhagen has a very wide network of district heating and a rather archaic system of waste recycling). Even though district heating works effectively to trigger important CO_2 reductions at the municipal level, the system clearly has important limitations.

Different accounting tricks can also be used at the level of private companies. The University of Copenhagen, for example, prides itself for having reduced its energy consumption by 18.3 per cent and its CO_2 emissions by 24.1 per cent between 2006 and 2012 (Copenhagen University 2012). But this result is calculated per full-time student and employee (Copenhagen University 2012). In reality, the total electricity consumption has increased by 6.2 per cent in that period; real CO_2 emissions have indeed been reduced, but by only 8.2 per cent, not 24 per cent. The University has invested important resources in energy savings, and this has had a certain impact, but it has also enrolled more students and hired more staff (a total increase of 18.5 per cent for both categories in six years), which account for the lion's share of the energy and CO_2 reduction when counted per head. Had calculations been made per square metre occupied, the picture would have been gloomier, because the University total 'stock of buildings' decreased slightly between 2006 and 2012. If air flights had been counted as part of the University's CO_2 emissions, the picture would probably have been even less flattering: a significant proportion of its employees are frequent flyers to conferences and research sites all over the world.

Another way to reduce one's emissions on paper without changing one's behaviour and without reducing global emissions is to buy CO_2 caps by using an Emission Trading System (ETS). This can be done by individuals who want to offset the carbon emissions of travel by plane, for example, as well as by companies (or municipalities) who wish to reduce their carbon footprints. The first ETS was created by the EU in 2005 and regulates a wide range of factories, power stations and other installations that are collectively responsible for about half of the EU's emissions of CO_2. Each of the installations participating in the ETS is allocated a cap of how much CO_2 they are allowed to emit. If the installation emits less, it can sell its excess quota of CO_2 to an installation that emits more than the allocated cap and has to purchase 'unused' CO_2 emissions on the ETS market (Wagner 2004; Schleich and Betz 2005; Hufbauer *et al.* 2009).

In theory, buying CO_2 caps on the ETS should force industries to reduce their own emissions or prevent them from emitting as much CO_2 as they do. In practice, however, one buys someone else's right to emit CO_2 instead of buying or financing a CO_2 reduction, unless the money is invested in, for example, a project of reforestation or carbon sequestration. Buying emission permits thus allows someone to get rid of an excess of CO_2 by transferring it onto someone else's carbon footprint. This type of system can work only as long as one finds people willing to take on waste for money. When nobody is willing to do this, the system collapses and there is no alternative than to deal directly with one's own waste or unsustainable practices.

It is only when making calculations at the global level that accounting tricks no longer work and consumer- and geographically based calculations coincide. Figure 2.4 illustrates global emissions defined by both sectors and by end-use/activity (WRI 2009). Producing a CO_2 budget with a CO_2 calculator at a scale below the global level implies making choices regarding which sectors to include or leave out. The advantage of making such calculations at the global level is

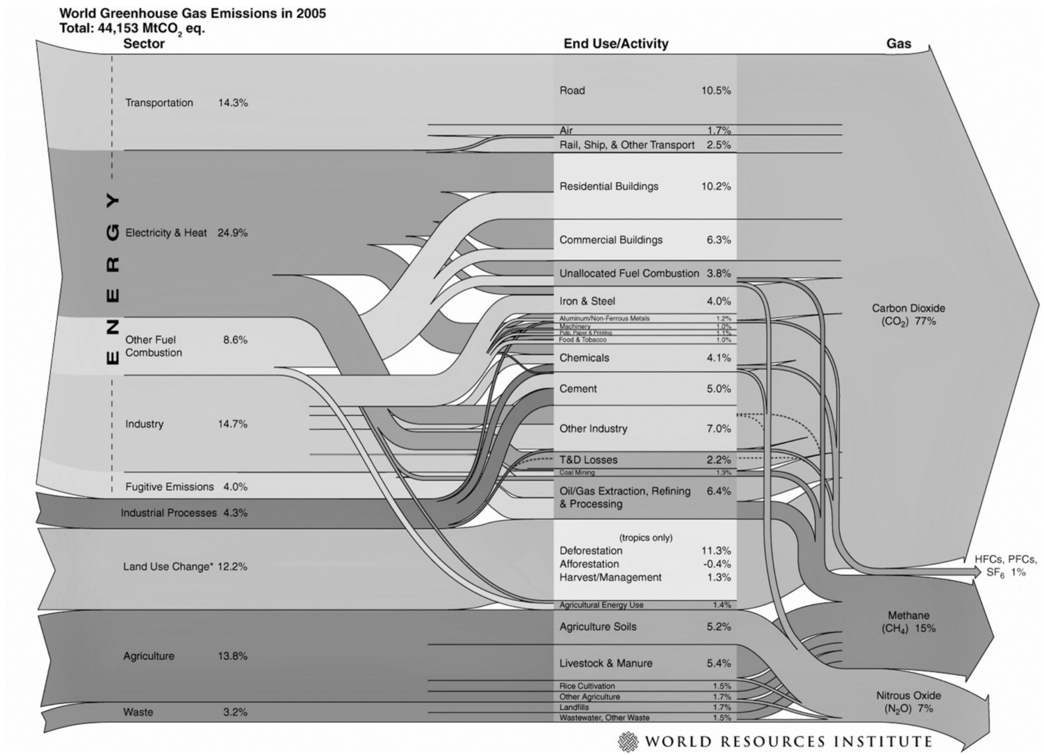

Figure 2.4 World GHG Emission. The flow chart is divided into sectors, end-users/activity and GHG production. Notice that when moving from left to right, sectors change depending on end-users/activities

Source: WRI 2009

that everything is taken into account; one cannot delocalise part of the account (or deny the responsibility for CO_2 emissions) onto a neighbouring actor.

Furthermore, what seems to be a governing factor on a worldwide scale might not be that significant when defining a nation-wide scaled budget. For example, whilst deforestation does not play a major role in Denmark, where most forests were removed centuries ago, the removal of tropical forests impacts the global CO_2 by about 18 per cent and is a major contributor to the carbon footprint of a country like Brazil. The drawback of looking at that scale is that to date the international community has been unable to agree on how to distribute the efforts to reduce CO_2 emissions. When such initiatives are taken, they occur at a lower level, either continental (such as the EU), or national, municipal and even personal. Initiatives are always a good thing wherever they occur, but actions below the global level suffer from the fact that not all aspects of a real reduction of CO_2 emission are taken into account in lower-level carbon footprints.

Discussion

Ideally, calculating GHG emissions at individual, household, company, municipal, national or continental levels should take into account as much production and consumption as possible in a holistic way. However, in practice, people designing carbon footprint calculators face the challenge of deciding what to include in or exclude from the calculation. The most basic and easiest calculations concern primarily the daily consumption of fuel and energy at home (transport, heating and lighting). While some calculators also include other daily products such as food, clothing, electronic equipment and housing, they encounter the problems of calculating the carbon footprint of the products discussed above.

The advantage of this type of calculator is that it is fairly simple and recommend actions that individuals can easily take to save energy and reduce emissions. Saving money is often a strong focus of these calculators, as it is believed to be one of the most important incentives for behaviour change. The disadvantage of this type of calculator is that it oversimplifies the calculation of CO_2 emissions, and focuses on a few aspects that only represent a fraction of the total emissions.

Other CO_2 calculators are more ambitious: they include a share of Scope 3 deriving from the public infrastructure (including public transport, roads, schools, hospitals and administration), typically by aggregating national data and by dividing total consumption by population size. The advantage of this type of calculator is that it includes many more aspects; the disadvantage is that it is impossible with this type of calculator to adopt a behaviour that is completely CO_2-neutral.

Even people who live in a self-made wooden hut, walk every day, never buy clothes and eat only what they produce still have the responsibility for the public infrastructure that can upset their CO_2 balance. On the one hand, this can prove fairly discouraging for people who would like to change their behaviour. On the other hand, this can trigger a stronger political engagement, because the CO_2 balance deriving from the share of the public infrastructure can only be improved systemically, for example, by petitioning political decision makers for greener policies.

As we have seen, choosing one calculating method always implies including some things and excluding others. This can lead to very different carbon footprints for the same individual. For example, what is the carbon footprint of an average Dane? When the Danish government launched a national campaign in March 2007 under the heading '1-tonne-less' as part of its preparation for the 15th Conference of the Parties (COP15) Summit in 2009, it developed a simple calculator that focused on the personal consumption of Danes and established a yearly average CO_2 emission of six tons per person. This included Scope 1 (2 tons from fuel), Scope 2 (2.5 tons from heat and electricity) and some Scope 3 emissions (1.5 tons from food and goods) (Miljøministeriet 2007).

The *MapMyClimate.com* website adopted a similar concept for a carbon footprint calculator that allows individuals to estimate their personal carbon footprint online. It chose to include some Scope 3 emissions from non-food, governmental activities and infrastructure development over which individual citizens have no direct control, which increased the average carbon footprint to 8 tonnes per capita in 2010 (Erichsen and Arnskov 2010). This number is close to the carbon footprint calculated by the World Bank for 2010 (8.3 tons, or 15 per cent less than in 1990), calculated on the basis of the burning of fossil fuel and the manufacture of cement (World Bank 2013).

According to Denmark's national statistics, when applying the standards defined by the Kyoto Protocol (including Scope 3 from goods manufactured within the country), the carbon footprint is 9.5 tons per capita in 2007 (2 per cent less than in 1990) (Gravgård *et al.* 2009a, 2009b; Gravgård 2013). When including CO_2 equivalents from CH_4 and N_2O, the carbon footprint becomes 10.8 tons in 2010 (see Figure 2.5), a decrease of about 20 per cent when compared to 1990 (Færgeman 2012, 2013).

But these numbers do not take into account the goods that are produced abroad, imported and consumed in Denmark. While emissions calculated within the national boundaries have dropped since mid-1990s, this is mainly due to the delocalisation of heavy industries to other countries (Chrintz 2012; Færgeman 2012), a trend that is also found in other industrialised countries (see for example Weber and Matthews 2008; Druckman and Jackson 2009; Minx *et al.* 2009). Globally, imports account for about 40 per cent of regional carbon footprints (Andrews *et al.* 2009; Wilting and Vringer 2009).

When including imports of all goods consumed in Denmark (and subtracting exports), as shown in Figure 2.5, the average Danish carbon footprint per capita is between 18.4 and 19 tons in 2010, an increase of about 10 per cent since 1990 (Chrintz 2012; Færgeman 2012). Finally, when biomass and international transports are included in the calculation (Denmark has an important shipping sector that makes a significant contribution to the gross national product), then the carbon footprint jumps to a staggering 24 tons per capita in 2007, which is 65 per

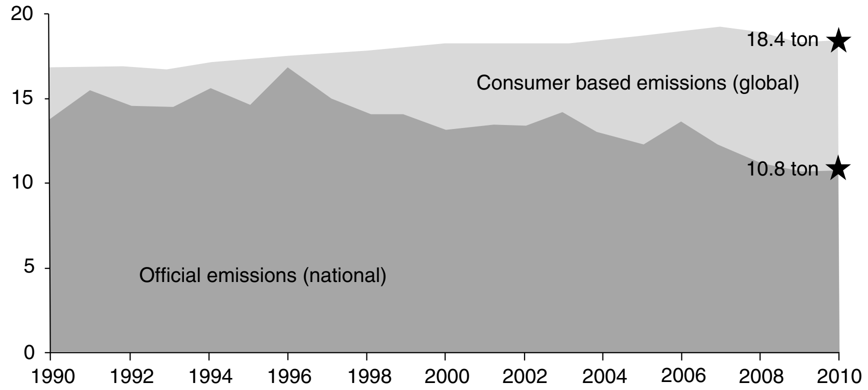

Figure 2.5 Consumption-based calculation of the CO_2 emission (tonnes per year per person) for an average Danish citizen with emissions produced within Denmark (dark grey) and emissions from production outside Denmark (light grey)

Source: Modified after Færgeman 2013

cent more than in 1990 (Gravgård *et al.* 2009a, 2009b; Gravgård 2013). This ranks Danes as having one of the highest ecological footprints in the world, just behind Kuwait, Qatar and the United Arab Emirates (WWF 2014).

Thus, the calculation of the average carbon footprint of a Dane depends on the calculation method, the types of activities and scopes included, the span of years taken into consideration and whether it is calculated on the basis of production, consumption or economic activities. One needs to consider how imports and exports are included, whether the numbers are exact or normalised values and whether they are corrected for the import and export of electricity. The average carbon footprint calculation also depends on whether it includes the CO_2 equivalent of all GHGs, e.g. N_2O and CH_4, emissions from biomass and sequestration from carbon sinks (forests, agriculture and soil), whether the method corrects for the cumulative wind speed of the year and so on. All of these parameters are subject to some uncertainty; the accumulated uncertainty is even bigger and varies with the span of years used as the basis for the calculations. All this must be kept in mind when discussing and using calculated carbon footprint.

We must pause here and ask some questions. Have Danish CO_2 emissions declined by 20 per cent or increased by 65 per cent between 1990 and 2007–2010? Is Denmark one of the greenest countries on Earth or one of the countries with the highest carbon footprint per capita? Can Denmark become CO_2-neutral in 2050? It all depends on how carbon footprints are calculated and which part of the total CO_2 emissions is included or excluded. The lack of standards for calculating GHG emissions causes contradictory figures, and the lack of clarity about the method used and the complexity of the technical aspects make it complicated to compare.

Yet, calculating CO_2 emissions remains important for at least three reasons. First, quantifying emissions makes them visible, which is extremely useful since most people do not have much of a clue about how much CO_2 they emit or where it originates. Second, it creates a benchmark upon which one can measure progress made in reducing emissions, even though the reduction can happen just on paper simply by delocalising production elsewhere. Third, it attributes the responsibility for emissions (and the responsibility to reduce emissions). For all these reasons, CO_2 calculators are social technologies that are central to tackling global warming.

In Denmark alone, one finds a variety of different calculators, most of them accessible online. Some websites, such as *CO2-Guide.dk* or *husetsweb.dk*, concentrate on private energy consumption at home, but might also include transport and daily shopping (*CO2-guide.dk*), and focus at least as much on saving money as on reducing CO_2 emissions. (These two goals are at times contradictory, since the money saved can be spent on a plane travel abroad, for example, which can end up releasing more CO_2 than what was reduced). These websites refer to tangible consumption and behaviour and provide specific advice on how to reduce CO_2 emissions and save money at the same time. One of their drawbacks, however, is that they seldom advertise possibilities that will reduce CO_2 emissions but will cost something instead of saving money (for example, the longest 'payback time' promoted for investments made is 30 years).

MapMyClimate.dk takes the same point of departure, but adds a few Scope 3 emissions. Its aim here is to educate people and make them realise the seriousness of the threat posed by global warming, with the hope that they would use their new knowledge and consciousness to influence policy makers to make bold decisions with regard to infrastructure and social changes. The drawback of this approach is that it can appear to demotivate individuals when they realise that they do not have much control over a large part of their CO_2 emissions.

For example, when a beta-version of the *MapMyClimate* calculator was tested, it was assumed that if people did not use their own car for transport, they would use public transport, with the consequence that people could never reach zero emission even if they set all the cursors in the website's programme (for transport, heat and daily shopping) to zero. Including some Scope 3 emissions did not make sense to the people testing the site (see also Papazu and Scheele 2014): This was changed in the later version of the website calculator. One finds other calculators that include Scope 3 emissions (such as the 'smartbudget' on *nykredit.dk*, which is the homepage of a bank) that end up giving a very high average CO_2 emission per capita, regardless of how little individuals using the calculator consume in their daily life. The aim of such type of information is more to raise awareness and possibly trigger political changes in the longer run, since little can be done to address these problems here and now at the individual level.

Conclusions

Asking citizens to change behaviour presupposes that they know the consequences of their behaviour and can act accordingly. CO_2 calculations are social technologies that inform users and allow them to calculate their individual production of GHGs or, in other words, their carbon footprint. Calculating the carbon footprint of products can help consumers make environmentally conscious choices when they buy goods; calculating the carbon footprint of actors can also help them prioritise their reduction strategies according to the sector in which the reduction potential is the biggest, or the scope in which the control is the highest and where change is easiest.

Because the information that the footprint calculator provides can change citizens' behaviour, all types of calculators can play an important role in reducing our carbon footprint. But calculators are only useful if they are used with the genuine intent to reduce CO_2 emissions. If, on the contrary, they are used as a means for green-washing to deceptively give the impression that an organisation or product is environmentally friendly, they might be counterproductive. Having the goal of becoming CO_2-neutral by 2050 can be a powerful incentive for change, but only if it translates into a genuine reduction of emissions. Merely transferring emissions to someone else's account by delocalising production, exporting green energy to compensate for the brown energy consumed at home and taking as benchmarks the criteria that will make our progress appear in the most favourable light can create the misleading impression that we are on the right track to reduce our emissions. Whilst carbon footprint calculators are as good as the criteria that they take into account and the convention that makes them work, they should be regarded critically for no more than what they really are: a man-made social technology designed to shed some light on our emissions and inform us about what we want to know – as well as to keep us ignorant of what we don't want to hear.

Calculators targeting individuals and focusing on Scope 1 and Scope 2 emissions tend to save little CO_2 in absolute figures, while calculators used at the municipal or a higher level that include Scope 3 emissions tend to have a much bigger impact. Yet, it might be argued that the change at the individual level might require more sacrifice than the changes performed at the municipal level. Reducing the consumption of meat and dairy products, selling one's car to use public transport or bicycle, spending one's holiday at home instead of in an exotic country and changing daily habits require genuine, conscious effort that might be even more difficult to make than the decision to change a municipal infrastructure.

By triggering behaviour changes that require sacrificing some comfort, calculators can contribute to raising awareness, changing mentalities and social norms and ultimately influence politicians to make bold moves and adopt ambitious environmental policies. In this sense, calculators can have even wider consequences than the individual amounts of CO_2 emissions that are reduced at Scope 1 or Scope 2. The value of energy calculators as social technologies lies at least as much in their potential to raise awareness and trigger more profound long-term changes in society as in their potential to directly reduce emissions in the here and now.

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