Incorporating Methane into Ecological Footprint Analysis.

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Abstract

Carbon dioxide (CO_2) accounting has been one of the foremost aspects of ecological footprint analysis. However methane (CH_4), with its associated global warming potential (GWP) of 23 times carbon dioxide should not be neglected as an environmental indicator for informed environmental management. Subak (1995) calculates embodied organic CH_4 based on imported animal products and selected plant products (such as rice). While this is a significant component, the CH_4 associated with imported embodied energy should not be dismissed. This study is an attempt to incorporate methane into ecological footprint analysis. In order to account for differences in methane intensities from exporting countries, methane intensities for OECD countries were calculated using emission and energy consumption estimates taken directly from National Inventory Reports (NIR), published in conjunction with the IPCC (Intergovernmental Panel on Climate Change). For other countries the methane intensities were estimated using energy balances published by the International Energy Association (IEA) and IPCC default emission factors. In order to estimate embodied organic methane, material imports and exports were translated into units (such as live animals) that can be readily converted into methane emissions. The methodology applied demonstrates a significant increase in Ireland's footprint when the Global Warming Potential of methane is included within the calculation.

Key words: Methane, Imports, Embodied, Organic, Inorganic.

Introduction

Global warming and its possible consequences, such as climatic instability have replaced Ozone depletion as perhaps the most publicly recognised environmental issue. While the scientific community differs on the extent of humanities influence, there is a general consensus that anthropogenic carbon contributes to increasing global temperatures. The Intergovernmental Panel on Climate Change is in the process of publishing its Forth Assessment Report. A summary for policy makers demonstrates a "*very high confidence*" (IPCC, 2007) that the net effect of human activity since industrialisation has been one of warming. Regardless of whether this is commonly accepted, there is a greater acknowledgement of the global consequences of human action. In order to satisfy the requirements of the Kyoto protocol, signatories are required to compile Green House Gas (GHG) Inventories. National inventories are naturally dominated by carbon dioxide. Carbon dioxide (CO_2) emissions themselves are widely used as environmental indicators. While allowing for the effects of trade in carbon dioxide accounting is vital in order to satisfy the responsibility principle, (allocating the environmental cost to consumers) its role has rarely been considered in methane (CH_4) accounting. The prescription of the responsibility principle (i.e. allocating the environmental cost to the consumer) suggests that GHG inventories should incorporate the effect of trade. This paper reports on an attempt to estimate the extent to which Irelands footprint will increase if methane is included in the calculation (2003 is taken as the study year). This is important given that methane has an associated global warming potential of 23 times CO_2. An example of an attempt to integrate trade date into methane accounts is demonstrated in Subak (1995) and has influenced the methods applied in this paper.

The Ecological Footprint concept

The footprint concept as demonstrated in Wackernagel and Rees (1996) provided the one of the first examples of land-use as metric of sustainability. The original model divided consumption into five main categories: food, housing, transportation, consumer goods, and services. These are quantified by trade corrected consumption data. Once sufficient data has been collected, the model can calculate a national footprint and scale it down to an approximate per capita figure. This method can be applied to any number of categories, for example, arable land to produce food, energy land to sequester the CO_2 emissions from industry, transport, and so on. A national or regional ecological footprint can be compared against locally or globally available bio-capacity. When expressed using global yields and averages, a per capita footprint can be compared to the 'global earth share', the average global per capita land area, as a means of illustrating the finite nature of natural capital. To summarise, footprinting challenges the view that sustainable development is not quantifiable, and may allow for the practical application of the sustainability precept "think globally and act locally". Footprinting itself has developed in the years since its inception. The original method has been described as compound footprinting, since many consumption categories are in an aggregated form and national trade data are used in calculations. Component methods allow detailed footprints that account for various products and practices but may comprise a greater degree of uncertainty. Compound footprinting may result in a more robust overall value but do not reliably account for the disaggregated sub-components. In theory, if calculated correctly a compound footprint should contain all the information contained in the component footprint. Simmons *et al.* (2000) argues that neither method should be regarded in isolation, as both have advantages and disadvantages. Which method is adopted is dependent on available data and the purpose of the footprinting. It may be better to adopt the position that any footprint calculation exercise should not be based on either compound or component methods, but rather explore the possibility of applying the best elements of each method. Other methods include the calculation of a footprint using actual hectares Erb (2004), or the application of input output analysis to allocate consumption categories, (Wiedmann et. al, 2006).

Each successive methodological change reinforces the point the footprinting is an iterative process with each successive modification providing additional tools, accepting that this process has no definitive end-point.

Methane Issues.

Methane has not been applied as an indicator of environmental as readily as CO_2. There are many reasons why this may be the case. Firstly methane emissions are generally lower for activates which people can directly influence such as transport or home heating. Secondly methane emissions are dependent on specific technologies and prevalent practices, general assessments such as those published in National Inventory Reports, are based on a number of assumptions. Anthropogenic methane emissions account for between 60 and 70% of global emissions and are the result of a varied set of activities. It should be noted that any emission of methane represents a waste of a potentially valuable fuel, particularly as it can be recovered (Muller and Bartsch, 1999). As methane emissions are nationally dependent, accounting for traded embodied methane has implications for emission targets. As stated in Subak (1995) a country could conceivably reduce its reported emissions by reducing production of certain commodities. Substituting these commodities with increased imports from countries with no GHG abatement policies would amplify the actual methane demand while appearing to reduce domestic emissions. This is complicated by the fact that many of the materials that have embodied methane (such as rice) are not easily substituted.

Methane Sources.

The majority of methane emissions are the result of a number of anthropogenic practices. These include fugitive emissions of fuel production, the rearing of livestock and the production of rice. These will be discussed briefly below.

The quantity of fugitive methane generated in coalmines depends on several main factors: the quality of coal, the degree of compression; pressure, temperature and depth of the coal seam. (Muller and Bartsch, 1999). Emissions from both oil and gas production are dominated by venting, flaring and leakages. While intentional emissions can be reasonably characterized, leakages by their nature are difficult to predict and measure. This inherent uncertainty makes sub-national or site-specific emission factors more accurate as information is available in more disaggregated categories.

In most GHG inventories, majority of Methane emissions are the result of enteric fermentation; (the process whereby microbial action breaks down fibrous material into products that can be used by the animal, with Methane as a by-product). Ruminant livestock have a large chamber, the rumen, within their digestive tract that allows rigorous microbial action (Eggleston et al, 2006). The enteric fermentation is dependent on a wide number of factors, including age, weight, exercise, and species. The most important factor is the type and quantity of food intake. Non-ruminant animals have a much lower emission factor because much less methane-producing fermentation takes place in their digestive systems. The storage and use of manure as a fertilizer also has associated emissions, with uncovered anaerobic lagoons and liquid resulting in the highest emissions.

It has been suggests that rice is a major constituent of the diet of over half of the world's population. Any rice crop will be grown either under continual or intermittent flooding. When grown under submerged conditions the mainly anaerobic rice soils stimulate the production of methane through anaerobic decomposition of the resident or added organic matter. The production of methane is dependent on a number of factors such as redox-potential, pH, mineralizable carbon and temperature (Wassman et al. 2000).

Methodology

As with CO_2, the direct combustion of fossil fuel is a source of methane emissions. These however are quantitatively less than the fugitive emissions released in the production and consumption of fuel. In order to calculate inorganic methane emissions embodied in trade, the methane intensity of energy has to be calculated. For exporting countries that have published GHG inventories this calculation can be readily made. The total methane emissions due to combustion, and fugitive emission were divided by the total energy consumption. This intensity, (expressed in Kg/Mj), can be used with in conjunction with embodied energy estimates, (expressed in Mj/Kg), to translate import tonnages into methane estimates. Irelands domestic methane energy intensity was calculated in this manner.

This is complicated for states that do not published GHG inventories. In these cases methane emissions were estimated using Energy Balances published by the International Energy Agency (IEA) and default fugitive emissions published by the IPCC. Since these balances are expressed in terms of energy units, emission factors from the revised *1996 IPCC Guidelines* (Houghton et al. 1997) were used. The *2006 IPCC guidelines* (Eggleston et al, 2006) provide units that are not as readily compatible, such as Gg/M^3 produced, or Gg/M^3 raw gas feed.

The role of fugitive emissions has implications for the application of the responsibility principle. This will be discussed later in the paper. When total emissions were calculated an overall methane intensity of energy was estimated in the same way. It should be noted that fugitive emission factors suffer from high degrees of uncertainty. Newer conversion factors published in the 2006 *IPCC Guidelines* also incur high degrees of uncertainty (in some cases +/- 100%). This is to be expected given the considerable variety in fuel production technologies and is inevitable when attempting to approximate data on a national scale. For combustion estimates emission factors for each category was averaged from the IPCC default emission factor database. Table 1 demonstrates the range of emission factors used. Total inorganic emissions embodied in traded goods (CAO, 2004) is demonstrated in Table 4.

Insert Table 1

Table 2 provides examples of the carbon intensities of energy calculated for a range of countries. These are dependent on location, nature and extent of fuel production, and therefore vary considerably. For example, EU countries will generally have lower intensities as comparatively less fuel is produced.

Insert Table 2

The organic Methane embodied in imported foodstuffs was calculated in a manner comparable with Subak (1995). Live animal imports and exports were available in terms of animal number and so were easily converted into methane emission equivalents. Physical imported were translated into units that can be readily translated methane using default emission factors. For meat and dairy products this involved converting imports into live head equivalents. This involved a number of steps. Firstly meat product tonnage was translated into carcass weight equivalent (CWE) using conversion factors provided by *Economic Research Service of the US Department of Agriculture* (ERSUDA, 2006). This is dependent on whether the product itself has been removed from skeleton. An average "Dressing Percentage" of 62% was used to translate carcass weight, based on recommendations from the University of Dakota beef-grading scheme, into live weight. Based on the same system an average weight of 500 kg was used, for example to translate live weight into cattle numbers. Region specific emission factors from Houghton et al. (1997) were used to estimate total Methane emissions. A similar approach was taken for other meat types.

- In 2003, 2,850 tonnes of fresh boneless beef were imported.
- 2,850 T (fresh) X 1.36 =3876 tonnes of Carcass Weight Equivalent (CWE).
- Assuming average dressing percentage of 62%.
- 3,876/0.62=6,251 tonnes live weight.
- Assuming a beef live weight of 500kg this results in 12,502 individuals.
- Multiplying by the IPCC default emission factor of 48 Kg CH_4 /Hd/Yr (for enteric fermentation) results in 275 tonnes of CH_4.

An attempt was made to account for prevailing farming practices using the IPCC "tier 2" methodology. This method estimated the total energy required to maintain the herd (including animals up to point of slaughter) and translated it into methane emissions. The overall estimates were similar to emissions reported in Irelands latest GHG inventory report (McGettigan *et al.* 2006), which are based on farm surveys. This included an alternative allocation of manure management practices as reported in Menzi (2002). The estimated emission factors are presented in Table 3 below along with those published in (McGettigan *et al.* 2006).

Insert Table 3

The estimates are mostly comparable with published emission factors, (the discrepancy seen in the manure management emission factor of two year olds can be explained by fact that the comparison was made against generic categories, which may not be entirely accurate). These estimates, calculated and published, were averaged and applied to meat exports. The combined emission factors of 53 and 130 Kg CH_4/hd/yr for non-dairy and dairy animals respectively, are close to the combined emission factors of 56 and 132 Kg CH_4 per head per year demonstrated in Irelands GHG inventory spreadsheet.

The same method was adopted for imported dairy products. Tonnages of products were converted into raw milk equivalents (RME) using conversion factors taken from FAO (1978). Total raw milk imports were translated into cattle numbers using regional milk yields taken from Houghton et al. (1997). As with meat products, region specific emission factors from the above publication were used to estimate total Methane emissions. An example of the calculation method is provided below. For exported dairy produce a similar approach was taken. The *Dairy Council of Ireland* provided the amounts of raw milk used in production of dairy goods. By comparing dairy production with export estimates, the quantity of fresh milk exported was estimated. This was then used with dairy yield estimates publish by the *Department of Agriculture* (DAF, 2004) to estimate population numbers. The total emissions embodied in traded meat products are demonstrated in Tables 5 and 6 and those embodied in dairy are embodied in Tables 7 and 8.

The Methane emissions embodied in rice imports incur the highest degree of uncertainly for organic Methane. As the trade data does not distinguish the origin of imported rice an average emission factor for Asian rice fields had to be estimated. Harvested paddy area in each Asian country was estimated in conjunction with the distribution of water management schemes and nutrient management, upon which the emission factors are based. These were taken from Houghton et al. (1997) and were augmented with more recent date from the available literature, such as Li (2006). The main reason for uncertainty lies in the scale of rice plantations. Particularly in the case of India and China, where the large areas used for rice production reduce the accuracy of any national estimate of irrigation practices. The overall emissions from Asian rice paddies is comparable to the aggregated value calculated in Yan et al (2003), but differ for certain individual states. This is complicated by the continuous up-take of new water management schemes in an attempt to increase resource efficiency. The total emissions embodied in imported rice are demonstrated in Table 9. The overall emission estimate is divided by total rice production to estimate the Methane intensity of Asian rice. An example of the calculation is presented below.

- It has been estimated that approximately 1,615,000 hectares of rice are grown using intermittent irrigation in Japan.

- The IPCC default method requires that land area be expressed in M^2 **x** 10^{-9}.

- 1,615,000 ha X 10^4 X10^{-9}= 16.15 (M^2 **x** 10^{-9}).

- Multiplying the emission factor for continually flooded Japanese rice paddies by the scaling factor for intermittent flooding (.5) and the default correction factor for organic amendment (2)

- 15g CH_4/M^2 X 0.5 X 2= 15g CH_4/M^2.

- 15g CH_4/M^2 X 16.15 (M^2 **x** 10^{-9})=242 Gg CH_4.

Keppler at al (2006) demonstrates that forest products are also sources of Methane emissions. In order to estimate imported Methane the tonnage of imported wood and paper products were translated into Wood Raw Material Equivalent or standing tree volume equivalent, based on data published by the *UK Forestry Commission* (UKFC, 2004). These were translated in dry tonnes based on a conversion factors published in the *IPCC Guidelines for Lucuf* (Penman et al, 2003). Conversion factors in Keppler et al. (2006) were used to convert dry matter into Methane. This is dependent on the growing period and sunlight hours experienced in the region where the trees grew. While a fuller understanding of the extent to which forestry acts as a Methane source is desirable, this does not detract from its valuable carbon sequestration service. The total emissions embodied in imported wood products are demonstrated in Tables 10 and 11. An example of the calculation is presented below.

- 436 tonnes of fuel wood are imported. It is assumed that this is hard wood with a basic density of 0.46 T DM/ M^3 Fresh and a green density of 800 Kg/M^3

- 436 X 1.2 = 523 WRME (M3) underbark.

- Basic density = 0.46 T DM/ M^3 Fresh.

- 523 Green M^3 X 0.46 = 240 dry tonnes.

- It is assumed this is grown in a temperate zone with 6 hours of sunlight and a growing season of 250 days.

- Assuming 374 ng CH_4 /Dry g/Sunlit Hour and 119 ng CH_4 /Dry g/Dark Hour. This results in 263 Kg of CH_4.

The GHG inventory does not include the methane emitted from forestry. In order to estimate this a value for the national standing stock was taken from *National Report to the Fourth Session of the United Nations Forum on Forests* (DAF, 2003). Using the method above, this value of 50,859,000 m^3 yielded an estimate of approximately 25,653 tonnes of methane. This was added to the estimate for domestic methane production of

654 KT of methane. The overall methane balance is presented in Table 12. As can be seen from the table Ireland is an exporter of methane emissions. The amount gained through material imports is exceeded due to the large quantities of agricultural products exported. The total amount of methane consumed was estimated to be approximately 570 KT methane. This was translated into a footprint value based on the amount of carbon sequestered by annual forestry increment, and then translated into a land area of global average bio-productivity (GFN, 2005). An example of the method is shown below.

- Methane and carbon have a molecular weight of 16 and 12 respectively.
- Therefore 1 tonne of Methane results in 0.75 tonnes of carbon.
- It is assumed that 27% of carbon is assimilated by the oceans.
- 1 T CH_4 X 0.75 T C/T CH_4 X 0.73=0.5475 Tonnes of C
- Given that approximately 1 tonne of carbon is sequestered per ha of forest land this results in the same area value.
- Given that forestland is more productive than global average land an equivalence factor of 1.38 gha/ha is used to translate into 0.75 global hectares.

Results

As can be seen from the table below the largest source of inorganic methane emissions is the importation of manufactured metal apparatus. This is due to both the large tonnage involved as well as the high-embodied energy. As with all such calculations, based on large numbers of official data results may be influenced by data unreliability.

Insert Table 4.

As shown in Table 5, beef and pork imports dominate the imported organic methane. In the interests of conciseness several categories have been amalgamated. As can be seen from the table, while pork products are present in considerably quantity, their embodied methane emissions are less than beef. It should be noted that poultry does not have an associated enteric fermentation emission factor; therefore only emissions due to manure management were included in the calculation.

Insert Table 5.

The exported meat calculation, as seen in Table 6 is dominated by beef exports. This is compounded by the fact that Irish produced beef has a higher associated emission factor. Indeed this value may be a slight underestimate given that there was no CWE factor available for poultry offal and extracts. However, this is unlikely to be significant when compared with beef as extracts (being by-products) have a lower CWE and poultry has a lower emission factor.

Insert Table 6.

Table 7 demonstrates imported emissions due to dairy goods. Given the extra energy required to produce large quantities of milk the emission factors are greater than that for non-dairy animals. As can be seen from Table 4 liquid milk imports incorporate the most embodied methane, despite having the lowest methane intensity. If liquid milk were substituted for other dairy products the overall emissions would rise as liquid milk has the lowest raw milk equivalent.

Insert Table 7.

The majority of Irish milk products are used in the production of commodities for the export market. This is most evident for butter, which demonstrates for that over 90% of the milk used is ultimately exported.

As with beef, Irish exports of milk are especially methane intensive high methane intensity of Irish milk.

Insert Table 8.

As can be seen from Table 9, imported rice does not contribute greatly to the overall emissions. The environmental cost of rice may be more of a concern for countries that experience a greater demand for Asian food and of course is of great importance to rice producing countries.

Insert Table 9.

Table 10 shows that the majority of methane emissions are contained within worked wood and paper products. In order to conserve space, several categories are presented as summaries. As can be seen from the Table, worked wood has the highest associated methane emission. This is due to the fact that the conversion factor for worked wood requires the tonnage to be converted into volume equivalents. Because of this additional step in the calculation the value for worked wood may incur greater uncertainty than similar products.

Insert Table 10.

Notes that exported and imported wood products have an overall similar embodied methane. However the array of exports products differs than that of imports, with many conifers contributing largely to the overall value.

Insert Table 11.

The overall methane balance is summarised in Table 12. As previously stated, Ireland is a net exporter of methane. When this is translated into a footprint value this results in a per capita value 0.11 gha/cap. This may not appear significant when compared with Ireland's per capita footprint of 5 gha/cap as published in the 2006 Living Planet Report. (WWF, 2006). However if the GWP of methane is accounted for this increases the per capita methane footprint to 2.5 gha/cap.

Insert Table 12.

Discussion

As can be seen from the results, the imported inorganic methane exceeds that of organic imports. This due to the fact that Ireland is largely dependent on material imports. It should be noted that the estimates calculated do not include the emissions from imported fuel, as these are already included within the GHG inventory (McGettigan *et al.* 2006). By incorporating the methane embodied in traded materials into the GHG inventory methane emissions would drop by approximately 16%. Again these estimates should be presented with a caveat due to the high degree of uncertainty incurred.

The issue of fugitive emissions

The method applied in this paper estimated total methane emission intensities including those due to fuel production. It may be argued that such fugitive emissions should not be incorporated into energy intensity estimates of the producing state, as they are not the result of direct energy consumed nationally. However fuel production is geographically dependent and does require energy consumed within the producing country. One of the potential disadvantages of retaining fugitive production emissions within the calculation of the methane intensity of the producing country is that it may reduce the apparent methane intensities of developed countries, which produce little fuel. Countries that can import the majority of their energy needs will have lower methane intensities. These are generally countries, which are economically stronger and consume large amounts of energy in order to satisfy resource intensive lifestyles. This is also the case for Ireland. Ireland produces little fuel, being dependent on energy imports. If the fugitive emissions of production were allocated to consumption as opposed to geographic location then Ireland's domestic methane emissions would rise significantly. In addition Ireland also imports many products from European countries, some of which are also dependent on imported energy. In order to satisfy the responsibility principle only the fugitive production emissions of fuel consumed within the country should be included in fugitive production emissions. Unfortunately this is problematic given the difficulties in distinguishing domestically and foreign produced fuel, each with differing fugitive emission factors (Houghton, 1997). The alternative is to calculate a methane energy coefficient, which retains all the fugitive emissions (based both on production and consumption) contained within the study region. The choice of method is dependent on the priority placed on allocating consumer responsibility or accurately representing reality. This issue is complicated by the fact that in many of these developing countries, the energy production sector is of major economic importance. Altering energy supply may indirectly affect the quality of life of whole communities. Changing import practices to favour wealthier countries (which generally have a least some GHG abatement policies) may result in considerable loss of revenue for these exporting developing countries. While the need to change prevailing practices is recognised and strongly enforced, reduction of emissions should not be sought within an economic vacuum. Any change in technology or farming practices must be balanced with attempts to lessen the potential economic difficulties for communities most affected.

The impact of livestock and other organic sources.

While inorganic methane represents the largest single import category, the imported cattle equivalents represent the highest methane intensity per tonne of product. This is unsurprising given that livestock is the highest contributor to domestic methane emissions. While pork imports exceeds beef in terms of tonnage, beef and dairy goods result in significantly greater emissions. Interestingly a decrease in imported beef and dairy stuffs may result in an overall increase in methane emissions if domestic production is used as a substitute, since Irish cattle production is likely to be more intensive. This is due to the intensive rearing system practiced in Ireland, which focuses on high milk yields and high weight gains. The emissions of manure management are also included in the calculations and are equally susceptible to a large degree of uncertainty. The means by which animal waste is stored and utilized is dependent on prevalent farming practices, the level of technology, type of housing, as well as the average size of holding. It should be noted that while a source of methane emissions, in many cases the production of crops and grassland are dependent on manure as a fertilizer, which increases bio-capacity. The overall impact of livestock is not contained within methane emissions. The amount of energy required to produce feed and fertilizer alone is considerable. This is compounded for the fact that in certain countries (e.g. Brazil) the areas of pastureland is increasing. This will affect biodiversity but also alter the soil carbon cycle, which is dependent on the influx of dead plant matter and its subsequent decomposition (Steinfeld *et al.* 2007). This may include the transition of natural cover to intensive cropland (for growing cattle feed constituents), or indeed overgrazing itself. These practices may increase emissions from the large carbon stocks stored within soils.

Rice is one of staple foodstuffs for many of the world's countries. As populations increase it becoming apparent that more land must be used for crop production. The alternative is that it becomes less resource intensive. The main resource in question is water. Water shortages (particularly in the developed world) have serious ramifications for rice cultivation. It is likely that the emissions from rice production will change significantly in the future as irrigation practises change in order to conserve more water, such as in China (Cabangon et al 2001), or in response to climatic instability, such as in India (Frolking et al. 2006). Interestingly emissions form rice paddies may be considered another indirect environmental cost of livestock, as animal waste is a prevalent form of fertilizer.

As mentioned previously the emissions of methane from tress does not detract from the services of sequestration. Methane emissions generally offset sequestration by between 4% and 8%. However this may be different for long-lived trees whose sequestration ultimately becomes negligible. However Keppler *et al*. (2006) does not account for the role of forest soils, which may negate this decrease in sequestration as succession progresses.

The inclusion of global warming potential (GWP).

As can be seen from the overall footprint, the inclusion of methane does not greatly increase Ireland's footprint unless GWP is included. In relation to footprint standards the calculation of footprints there is debate as to or whether methane should simply be translated into the equivalent mass of carbon or whether GWP should be accounted for. Adopting GWP would significantly increase the effect of methane on the overall result. The advantage of GWP is that it reflects the greater impact of methane as opposed to carbon dioxide, whereas simply translating to mass of carbon does not. However while methane has a GWP factor of 23, it does not require 23 times the land area to sequester it. While increasing global temperatures are a serious issue, in certain instances (such as sub-tundra areas) they may actually increase bio-capacity. Also if GWP is adopted this suggests that other gases with higher GWP estimates should be incorporated. Unfortunately many of these chemicals are not readily assimilated into the biosphere, complicating their inclusion into footprinting methodology. A compromise between these two methods may be to include GWP but allocate the methane footprint along its atmospheric life span of 12 years. Unfortunately this would also require the methane allocation of previous years to be calculated. Regardless of which approach is taken it should be noted that the inclusion of methane in ecological footprinting should be viewed as another step in the ongoing processes of improving the overall footprint methodology.

Abatement and its implications

The reduction of international methane emissions entails many potential difficulties due to the prominence of livestock and rice production in global methane emissions. Firstly there is little substitute for many of these products. This can be expressed geographically, (it would be difficult to cultivate rice in Norway for example) or socially (i.e. the cultural significance of farming or the vital role of rice as a staple food). Subak (1995) suggests altering export tariffs to favour the adoption of emission reduction targets, or augmenting agricultural subsidies (where relevant) to reduce herd size for example. Given the potential range of indirect environmental effects, it is difficult to ascertain the overall result of such economic measures. A decrease in herd size may be due to an increase in farming intensity, including, for example, greater fertilizer use. The paper also states that certain restrictions, such as a tax on rice are untenable due to both practical and ethical reasons. Another constraint is influencing prevalent practices within the foreign exporting country. (Munksgaard and Pedersen, 2001). This is complicated by the likely reluctance of producers to incur additional cost. Any economic restrictions would require wide enforcement to ensure comparable results across countries.

However these issues should not provide a disincentive for the uptake of such measures. As methane has a high GWP, considerable reductions in global warming capacity are achievable at a potentially low cost while incurring complementary benefits. For example, the recovery of ventilation streams of mine shafts will help reduce the likelihood of an explosion as well as provide a valuable fuel. Similarly for oil and gas, the implementation of industrial practices to reduce leakages and incorporate recovery into the venting cycle will have economic benefit (Muller and Bartsch, 1999). Strategic placing of overland oil pipelines will also reduce the rate of emissions and could help improve the public image of energy companies. Reafforestation initiatives can help reduce soil erosion, offer community employment and also provide a valuable amenity. As previously stated the main method of reducing livestock emissions would be to lower stocking rates. Another possibility would be to increase the digestibility of the feed, through the increase of grain based feed. If this can be accomplished without intensive land use change or additional fertilizer use, (e.g., using brewery or baking wastes to supplement feeds) the potential emission reduction may be considerable. A 10% change in digestibility can affect emissions by between 12 and 20%. It has also been suggested that a gradual shift towards pork as an increased source of protein would contribute to reducing global methane emissions. However this has serious socio-economic implications, particularly given the prohibition placed on pork products by a number of religions. Given the increasing global population, the production of methane embodying products is likely to increase. Therefore the emphasis should be on decreasing methane (and other GHG) intensity of the commodities themselves. This is particularly true of rice cultivation, as rice feeds approximately half the world's population, and irrigated rice accounts for over 75% of global production. Reducing continually flooded rice production will not only save water but also decrease emissions. Reducing fertilizer use in trials in China (Srinivasan, 2006) has not only reduced NO_x emissions but also improved water quality and reduced ammonia emissions. While it may be easier to influence inorganic methane emissions (such as through the adoption of renewable energy), changing agricultural practices will likely have a greater overall effect. While it might not be feasible to radically reduce the enteric fermentation of cattle for example, altering the indirect emissions of meat production may be more practical. This may be supplemented by obligating producers to offset a fraction of their emissions such as allotting a portion of land for forestry for example. Regardless of whether the consumer or the producer is deemed culpable for GHG emissions, their reduction will require a range of measures both economic and practical, including preventative measures as well as emission offsetting.

Conclusions

The inclusion of methane within the ecological footprint increased Ireland's per capita footprint by 2% without accounting for GWP, but by 50% when GWP was accounted for. Altering how fugitive emissions are allocated may further increase this value. The task of reducing global methane emissions is a daunting one that has consequences for social, economic and environmental pillars of sustainable development. For Ireland's the biggest methane emission reduction are achievable by changes in agricultural practices and reduction in our dependence on imported energy and materials.

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TABLES

Table 1: Range of fugitive emissions as taken from revised 1996 IPCC guidelines

	Western Europe	US & Canada	E.Europe	Other Oil Exporters	Rest of the World
	Kg CH4 /PJ				
Oil and Gas Production					
Oil Production	300 – 5,000	300 – 5,000	300 – 5,000	300 – 5,000	301 – 5,000
Gas Production	15,000 – 27,000	46,000 – 84,000	140,000 – 314,000	46,000 – 96,000	47,000 – 96,000
Venting and Flaring of Oil and Gas	-	3000 – 14,000	-	-	-
Venting and Flaring of Oil	1000 – 3,000	-	-	-	-
Venting and Flaring of Gas	-	-	5,000 – 30,000	758,000 – 1,046,000	175,000 – 209,000
Crude Oil Transportation, refining and storage					
Transportation of tankered Oil.	745	745	745	745	746
Refining of refined Oil.	90 – 1,400	90 – 1,400	90 – 1,400	90 – 1,400	91 – 1,400
Storage of refined Oil	20 - 250	20 - 250	20 – 250	20 - 250	21 - 250
Natural Gas Processing, Transport and Distribution					
Processing, Distribution and Transmission of Gas produced	-	-	288,000 – 628,000	288,000 (high)	289,000 (high)
Processing, Distribution and Transmission of Gas consumed	72,000 – 133,000	57,000 – 118,000	-	118,000 (low)	119,000 (low)
Leakage at industrial plants and power stations					
Non-residential Gas Consumed	-	-	175,000 – 384,000	0 – 175,000	1 – 175,000
Leakage in the residential and commercial sectors					
Residential Gas Consumed	-	-	87,000 – 192,000	0 – 87,000	1 – 87,000

Table 2: Estimated Methane Intensity of Energy

Based on GHG Inventory Reports	Non- OECD: Based on Energy Balances

Country	Gg/TJ	Country	Gg/TJ	Country	Gg/TJ	Country	Gg/TJ
Australia	0.00026	Albania	0.00003	Hong Kong	0.00002	Saudi Arabia	0.00057
Austria	0.00004	Algeria	0.00319	India	0.00027	Senegal	0.00008
Belgium	0.00002	Angola	0.00024	Indonesia	0.00038	Serbia M.	0.00008
Bulgaria	0.00015	Argentina	0.00087	Iran	0.00072	Singapore	0.00007
Canada	0.00029	Armenia	0.00017	Iraq	0.00011	South Africa	0.00048
Czech Republic	0.00019	Azerbaijan	0.00031	Israel	0.00001	Sri Lanka	0.00010
Denmark	0.00004	Bahrain	0.00060	Ivory Coast	0.00042	Sudan	0.00010
Estonia	0.00016	Bangledesh	0.00042	Jamaica	0.00012	Syria	0.00050
(EU 15)	0.00006	Belarus	0.00025	Jordon	0.00004	Tajikistan	0.00004
Finland	0.00002	Benin	0.00013	Kazakhstan	0.00076	Tanzania	0.00019
France	0.00006	Bolivia	0.00064	Kenya	0.00014	Thailand	0.00019
Germany	0.00008	Bosnia and Her.	0.00017	Korea DPR	0.00010	Togo	0.00012
Greece	0.00008	Brazil	0.00009	Korea Republic of	0.00050	Trinidad and T.	0.00260
Hungary	0.00014	Brunei and Dar.	0.00505	Kuwait	0.00053	Tunisia	0.00048
Iceland	0.00001	Bulagria	0.00010	Kyrgyzstan	0.00009	Turkmenistan	0.00214
Ireland	0.00006	Cameroon	0.00023	Lebannon	0.00001	United Arab E.	0.00133
Italy	0.00005	Chile	0.00012	Libya	0.00044	Uruguay	0.00004
Japan	0.00000	China	0.00046	Macedonia	0.00004	Uzbekistan	0.00091
Latvia	0.00011	Chinese Taipei	0.00002	Malaysia	0.00099	Venezuela	0.00062
Liechtenstein	0.00002	Columbia	0.00041	Malta	0.00002	Vietnam	0.00024
Lithuania	0.00017	Congo D.R.	0.00019	Moldova	0.00026	Yemen	0.00010
Luxembourg	0.00002	Congo	0.00017	Morocco	0.00002	Zambia	0.00014
Monaco	0.00002	Costa Rica	0.00002	Mozambique	0.00017	Zimbabwe	0.00020
Mexico	0.00036	Croatia	0.00025	Burma	0.00048		
Netherlands	0.00003	Cuba	0.00005	Nambia	0.00004	**World**	0.00034
New Zealand	0.00009	Cyprus	0.00001	Nepal	0.00022		
Norway	0.00009	Dominican Rep.	0.00003	Netherlands A.	0.00001		
Poland	0.00023	Ecuador	0.00010	Nicaragua	0.00011		
Portugal	0.00006	Egypt	0.00035	Oman	0.00174		
Romania	0.00038	El Salvador	0.00007	Other Africa	0.00019		
Slovakia	0.00012	Eritrea	0.00014	Other Asia	0.00020		
Slovenia	0.00009	Ethiopia	0.00027	Other Latin A.	0.00001		
Spain	0.00003	Gabon	0.00048	Pakistan	0.00033		
Sweden	0.00002	Georgia	0.00016	Panama	0.00004		
Switzerland	0.00002	Ghana	0.00012	Paraguay	0.00008		
Turkey	0.00006	Gibralter	0.00001	Peru	0.00009		
Ukraine	0.00072	Guatemala	0.00012	Phillipenes	0.00008		
United Kingdom	0.00008	Haiti	0.00010	Qatar	0.00244		
USA	0.00012	Honduras	0.00009	Russia	0.00084		

Table 3: Comparison of estimated and published emission factors for cattle.

	Published (kg/h/yr)		Estimated (kg/h/yr)		Average
Enteric Fermentation	M	F	M	F	
0-12 months	30	28	35	34	**32**
12-24 months	60	45	63	61	**57**
24+	34	22	76	49	**45**
Dairy		100		108	**104**
Manure Management	M	F	M	F	
0-12 months	9	8	6	6	**7**
12-24 months	14	9	11	10	**11**
24+	2	0	13	8	**6**
Dairy		21		31	**26**

Table 4: Summary of embodied Methane in traded commodities.

Import category	Imported Tonnes CH4	Exported Tonnes CH4
Live Animals	215	253
Meat	1,223	2,472
Dairy	1,284	1,255
Eggs	27	7
Fish	765	1,266
Grain	944	273
Fruit & Veg	1,069	55
Sugar	482	88
Tea Coffe and Coco	220	224
Spices	2,995	513
Margerine	67	25
Edible Preparations	289	305
Beverages	906	342
Tobacco	60	20
Oilseeds	116	2
Hides and Skins	0	36
Rubber	378	2
Cork	0	0
Wood Fuel and Chips	897	92
Rough Wood	115	67
Pulp and Waste	363	501
Cotton and Other Fibers	2	4
Synthetic Fibers	866	692
Worn Wool and Clothing	19	92
Crude Fertilizers	9	4
Stone Sand and Gravel	37	10
Natural Abrashives	88	3
Scrap and ore	1,986	1,106
Crude Material	833	32
Animal and Vegetable Oils	1,166	20

Chemical Dyes	6,538	472
Perfumes & Soap	1,802	2,537
Fertilizers	1,756	3
Plastic	5,580	649
Chemical Material & Leather	2,787	401
Cork and Wood	995	493
Paper	2,813	174
Textiles	1,744	299
Non-Metallic Minerals	853	300
Iron and Steel	4,417	112
Non-Ferrous Metals	2,385	157
Metal Manufactures & Equipment	30,574	7,379
Prefab buildings	664	119
Furniture	981	75
Clothing	981	75
Precision & Cinematographic Equipment	1,430	684
Misc. Manufacturing	3,162	951
Total	**86,880**	**24,641**

Table 5: Summary of imported Methane from animal products.

	Imported	**CWE**	**Carcass Equiv.**	**Live Equiv.**	**No**	**EF**	**EF**	**CH4**
						Enteric F.	Manure	
	Tonnes		Tonnes	Tonnes		(kg CH4/hd/yr)		Tonnes
Beef with bone	1,779	1	1779	2869	5739	48	21	396
Beef boneless								
EU	1,233	1.36	1677	2705	5409	48	21	373
Non EU	1,617	1.36	2199	3547	7094	43	3	326
Frozen Beef/V with bone	349	1	349	563	1126	48	21	
Frozen Beef/no bone								
UK	1,151	1.36	1565	2525	5050	48	21	348
Other EU	1,586	1.36	2157	3479	6958	48	21	480
Non EU	3,247	1.36	4416	7122	14245	43	3	655
Mutton fresh or chilled	1,034	1.5	1551	3447	53026	6.5	0.22	356
Mutton, frozen	426	1.5	639	1420	21846	6.5	0.22	147
Pig meat								
Germany	3,543	1.47	5,208	8,400	16,801	1.25	7	139
Denmark	4,029	1.47	5,923	9,553	19,105	1.25	7	158
UK	3,149	1.47	4,629	7,466	14,932	1.25	7	123
Other EU	9,086	1.47	13,356	21,543	43,085	1.25	7	355
Non EU	2	1.47	3	5	9	1.25	7	0

Pig Meat Frozen								
EU	4,829	1.03	4,974	6,632	66,318	1.25	7	547
Non EU	50	1.03	52	69	687	1.25	7	6
Poultry	39793	-	-	-	-	-	-	609
Edible Offal	1126	-	-	-	-	-	-	230
Hams, Bellies etc	15513	-	-	-	-	-	-	1,557
Extracts etc	52318	-	-	-	-	-	-	677
Total								**7,483**

Table 6: Summary of exported Methane from animal products.

	Exported	**CWE**	**Carcass Equiv.**	**Live Equiv.**	**No**	**EF**	**EF**	**CH4**
						Enteric F.	Manure	
	Tonnes		Tonnes	Tonnes		(kg CH4/hd/yr)		Tonnes
Beef with bone	64,315	1	64,315	103,734	198,344	45	8	10,512
Beef boneless	182,723	1.36	248,503	400,812	766,370	45	8	6,131
Frozen Beef/V with bone	567	1	567	915	1,749	45	8	93
Frozen Beef/no bone	71,629	1.36	97,415	157,122	300,424	45	8	15,922
Mutton fresh or chilled	41,192	1.5	61,788	137,307	2,112,410	6.1	0.17	13,245
Mutton, frozen	2,979	1.5	4,469	9,930	152,769	6.1	0.17	958
Pig meat	40,124	1.47	58,982	78,643	786,430	0.44	12.38	10,082
Pig meat frozen	31,710	1.03	32,661	43,548	435,484	0.44	12.38	5,583
Poultry	39, 857	-	-	-	-	-	-	816
Edible Offal	47,588	-	-	-	-	-	-	12,847
Hams, Bellies etc	5,144	-	-	-	-	-	-	942
Extracts etc	110,971	-	-	-	-	-	-	2,761
Total								**79,892**

Table 7: Summary of imported Methane from dairy products.

	Import	RME	Yields	No	EF	EF	Tonne CH4
	Tonnes		T/head/yr		Enteric F.	Manure	
					(kg CH4/hd/yr)		
Milk of a fat content by weight not exceeding 1%							
EU	5,347	1	4.2	1,273	118	46	209
Non EU	28	1	2.1	13	66	16	
Milk of a fat content by weight of 1% to 6%							
of which							
UK	220,400	1	4.2	52,476	118	46	8,606
Other EU	18,367	1	4.2	4,373	118	46	717
Non EU	5	1	2.1	2	66	16	0
Cream of a fat content by weight not exceeding 6%							
UK	1,898	2	4.2	904	118	46	148
Other EU	491	2	4.2	234	118	46	38
Non EU	1	2	2.1	1	66	16	0
Milk in solid form, of a fat content not exceeding 1.5%							
EU	1,570	7.6	4.2	2,841	118	46	466
Non EU	5	7.6	2.1	18	66	16	1
Milk and cream in solid form, of a fat content exceeding 1.5%	5,514	7.6	4.2	9,978	118	46	1,636
Milk and cream not in solid form, concentrated, not containing added sugar or other sweeteners.	8,655	2	4.2	4,121	118	46	676
Milk and cream not in solid form, concentrated, containing added sugar or other sweeteners.	361	2	4.2	172	118	46	28
Yogurt							
UK	4,198	2	4.2	1,999	118	46	328
Other EU	17,053	2	4.2	8,120	118	46	1,332
Non EU	19	2	2.1	18	66	16	1
Buttermilk, curdled milk and cream, kephir etc	7,158	2	4.2	3,409	118	46	559

Ice cream and other edible ice							
UK	6,496	2	4.2	3,093	118	46	507
Other EU	6,073	2	4.2	2,892	118	46	474
Whey	27,168	2	4.2	12,937	118	46	2,122
Products consisting of natural milk constituents, n.e.c.	393	2	4.2	187	118	46	31
Butter and other fats and oils derived from milk	4,371	6.6	4.2	6,869	118	46	1,126
Grated or powdered cheese							
of which							
EU	1,613	4.4	4.2	1,690	118	46	277
Non EU	1	4.4	2.1	2	66	16	0
Processed cheese not grated or powdered							
EU	6,785	4.4	4.2	7,108	118	46	1,166
Non EU	4	4.4	2.1	8	66	16	1
Blue veined cheese	566	4.4	4.2	593	118	*46*	97
Fresh and whey cheese and curd	7,652	4.4	4.2	8,016	118	*46*	1,315
Other cheese							
UK	11,102	4.4	*4.2*	*11,631*	118	*46*	1,907
Other EU	5,011	4.4	*4.2*	*5,250*	118	*46*	861
Non EU	607	4.4	*2.1*	*1,272*	66	*16*	104
Total							**24,736**

Table 8: Summary of exported Methane from dairy products.

Used in the manufacture of:	Million litres	T Produced	L/tonne	T Exported	% exported	ML
Butter	3,121	137,318	22,728	125,346	0.91	2,849
Cheese	1,092	1,119,000	976	111,639	0.10	109
Cream	207	19,000	10,895	2,000	0.11	22
Whole milk powder	252	31,037	8,119	44,052	1.42	358
Chocolate crumb	140	74,000	1,892	20,508	0.28	39
Miscellaneous products	665	N/A	N/A	N/A	N/A	N/A
Exported Liquid						36
Total						**3412**

Mik Yield (L/head/yr)	E. Ferm.	Manure Management	Cow Equiv	T CH4		
	Kg/h/yr	Kg/h/yr				
4510	104	26	756,564	**98,353**		

Table 9: Summary of Asian Rice Methane emissions and estimate of imported Methane.

Country	Emission	Production
	Gg CH4	Tonnes
Brunei	0	547
Hong Kong	0	0
Syria	0	0
Turkey	26	372,000
India	5,454	132,200,000
Pakistan	984	72,714,000
Bangladesh	2,871	39,090,000
Myanmar	1,724	23,146,270
Nepal	446	4,455,772
Afghanistan	69	260,000
Bhutan	9	46,000
China	3,990	162,304,280
Indonesia	1,791	52,137,600
Iran	224	2,931,000
Iraq	31	90,000
Japan	252	9,740,000
Malaysia	203	2,257,000
Philippines	1,534	13,499,900
Sri Lanka	221	3,071,200
Taiwan	272	1,396,274
Thailand	1,691	27,038,000
Cambodia (Kampuchea)	588	4,710,957
Laos	80	2,375,100
Vietnam	2,176	34,568,800
Democratic Republic Korea	138	2,244,000
Republic of Korea	166	6,015,000
Total	**24,941**	**596,663,700**
Tonnes CH4/Tonne Rice		0.042
Imported Rice	**Rice**	**CH4**
Rice in the husk	6,710	282
Rice, husked	314	13
Rice, semi or wholly milled	7,415	311

Broken rice	98	4
Total		**611**

Table 10: Summary of Methane embodied in Wood Product Imports.

	Tonnes	M^3	WRME	WRME Underbark	Dry Tonnes	CH4 (Tonnes)
Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms (excluding wood waste)	436		1.2	523.	241	0.26
Wood charcoal (including shell or nut charcoal), whether or not agglomerated	428		6	2,568	1,181	1
Coniferous Wood in chips or particles	80,534		1.2	96,641	44,455	49
Non-Coniferous Wood in chips or particles	48		1.2	58	26	0.05
Sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms	12,684		1.2	15,221	7,002	8
Wood in the rough or roughly squared, treated with paint, stains or other preservatives						
Finland (Boreal)	29,089	36,361	1.1	39,997	18,399	11
Other EU (Temperate)	23,561	31,572	1.1	34,729	15,975	18
Non EU	235	315	1.1	346	159	0.2
Wood of coniferous species, in the rough or roughly squared, but not treated						
Finland (Boreal)	28,379	35,474	1	35,474	16,318	9
Other EU (Temperate)	52,856	75,584	1	75,584	34,769	38
Non EU	1,212	1,733	1	1,733	797	1
Wood of Tropical species, in the rough (whether or not stripped of bark or sapwood) or roughly squared, but not treated with paint, stains or other preservatives	5,723	7,154	1.2	6,868	3,915	7
Wood of other non-coniferous species, in the rough (whether or not stripped of bark or sapwood) or roughly squared, but not treated with paint, stains or other preservatives	15,045	18,806	1	18,806	10,720	19
Wood simply worked	455,471	-	-	-	-	756
Waste and scrap paper	27,600	-	-	-	-	42

Veneer and Plywood	178,768	-	-	-	-	295
Miscellaneous Wood products	53,321	-	-	-	-	64
Paper and paper products	699,570	-	-	-	-	734
Total						**2,057**

Table 11: Summary of Methane embodied in Wood Product exports.

	Tonnes	**M^3**	**WRME**	**WRME Underbark**	**Dry Tonnes**	**CH4 (Tonnes)**
Fuel wood, in logs, in billets, in twigs, etc	1,156		1.2	1,387	638	1
Wood charcoal	8		6	48	22	0
Coniferous Wood in chips or particles	10,749		1.2	12,899	5,933	7
Non-Coniferous Wood in chips or particles	70		1.2	84	39	0
Sawdust and wood waste and scrap,	44,086		1.2	52,903	24,335	27
Wood in the rough, treated	13,566	16,958	1.1	18,653	8,580	9
Wood of coniferous species, in the rough	233,258	291,573	1	291,573	134,123	147
Wood of Tropical species, in the rough	184	230	1.2	221	126	0
Wood of other non-coniferous species, in the rough	203	254	1	254	117	0
Railway or tramway sleepers (cross-ties) of wood, not impregnated	0	0	1.58	0	0	0
Railway or tramway sleepers (cross-ties) of wood, impregnated	2	3	1.58	5	2	0
Wood of coniferous species, sawn or chipped	275,807	501,969	2	1,003,937	572,244	627

Wood of coniferous species continuously shaped	213	388	2	775	357	0
Wood of non-coniferous species,	4,382	6,266	2.5	15,666	8,929	10
Wood of non-coniferous species continuously shaped	724	1,035	2.5	2,588	1,191	1
Waste and scrap paper	243,127	-	-	-	-	355
Veneer and Plywood	465,059	-	-	-	-	667
Misc Wood products	5,710	-	-	-	-	8
Paper and paper products	92,734	-	-	-	-	131
Total						**1,990**

Table 12: Summary of main results.

	Tonnes Methane				No GWP		GWP
	Imports	Production	Exports	Consumption	Gha	Gha/cap	Gha/cap
Organic	35,762	567,365	208,526	394,600	298,140	0.07	1.72
Inorganic	86,880	112,410	24,641	174,649	131,956	0.03	0.76
Total	**122,642**	**679,775**	**233,167**	**569,249**	**430,096**	**0.11**	**2.49**