Norwegian Consumption, Chinese Pollution

An example of how OECD imports generate CO_2 emissions in developing countries.

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Executive summary

Carbon Footprint

A country's CO_2 emissions are usually estimated by an inventory of emissions *within* the country. This does not take into account that a country's consumption also instigates production and hence pollution outside of the country. The global CO_2 emissions from *consumption within* a country are known as the carbon footprint.

Background: Norway, China and Carbon

Norway is a rich country with 4.7 million inhabitants. Petroleum revenues constitute 25% of Norway's GDP. Being a top nation on the UN Human Development Index, Norway has a welfare level many countries aspire to. Nevertheless, the Norwegian model is fundamentally unsustainable. If every person on the planet is to consume as many natural resources as the average Norwegian does, we would need 3.4 earths.

Norway is a signatory to the Kyoto Protocol. Yet, in 2006 Norway's emissions of CO_2 were 6.8% above its Kyoto commitments (ca. 11.5 tonnes per capita). Norway is dependent on offsetting emissions to fulfil promised targets. The Norwegian Government aims for Norway to become "carbon neutral" by 2050 through "significant" domestic reductions and offsetting.

The Norwegian way of life is heavily dependent on imported products. It is a significant question whether promised reductions of CO_2 emissions in Norway will come at the expense of increased emissions outside of Norway through increased imports from low cost countries such as China. This question is especially important as growth is expected to continue, driven by increased demand for Norwegian commodities (which to a significant extent is generated by economic expansion in China).

The People's Republic of China is a developing country with a population of over 1.3 billion and the world's fourth largest economy. China is now the leading emitter of CO_2, yet China emits a more modest 3.9 tonnes per capita which is lower than most developed countries. The Chinese Government aims to reduce energy use per unit GDP by 20% in the period 2006-2010 and increase the amount of renewable energy it produces. The International Energy Agency estimates that 34% of China's CO_2 emissions stem from production of exports. The Chinese Government now argues that countries importing energy-intensive Chinese products should have responsibility for the emissions from their manufacture.

China's primary energy demand is projected to more than double from 2005 to 2030, relying heavily on CO_2 intensive coal. Cumulative investments in energy-supply infrastructure are estimated to be 3.7 trillion dollars a year (2006 dollars) in the same period. This effectively implies that *how* China's energy needs are provided over the next decades will decide to what degree mankind can reduce global CO_2 emissions in the 21^{st} century.

Findings

While Norway's CO_2 emissions remain fairly stable at 55-57 Mt per year, Norway's carbon footprint abroad is growing fast (33% 2001-2006, to 39 Mt) and will in the near future likely surpass domestic emissions.

Promised future reductions of CO_2 emissions in Norway may be outweighed by increased emissions abroad through increased imports - especially since increased growth is expected.

Trade data indicate a shift in trade towards countries and types of products that are more pollution intensive. Norway's increasing emissions associated with imports from countries without emission constraints is an example of unchecked carbon leakage. While increasing focus on domestic carbon reduction policies leads to stabilisation of carbon emissions in many OECD countries, emissions continue to grow in non-OECD countries and some of these emissions are for the production of goods exported to the OECD.

Norway's CO_2 footprint in developing countries increased 65% from 2001 to 2006. Almost one half (45%) of Norway's footprint abroad now occur in developing nations. In 2001 about 37% (11 million tonnes) of Norway's carbon footprint was in developing countries. By 2006 this had increased to 45% (18 Mt) of the total footprint, equalling about one third of Norway's total domestic emissions (54 Mt in 2003). With current trends Norway will in near future have a larger CO_2 footprint in developing countries than in developed ones.

Norway's carbon footprint in countries receiving direct Norwegian development aid doubled from 2001 to 2006, reaching 10 Mt.
This is more than total Norwegian CO_2 emissions from domestic road traffic (9.6 Mt in 2005). Norway's CO_2 footprint in India is equal to the CO_2 emissions for non-electric heating of Norwegian households (0.7 Mt in 2005).

China is the developing country where Norway's carbon footprint is largest and increasing most rapidly, almost tripling from 2.4 Mt in 2001 to 6.8 Mt in 2006. In this period, the import mix of products from China shifted to more CO_2 intensive products. On average every Norwegian causes emissions of 1.5 tonnes of CO_2 in China. The mass of imports from China to Norway increased only 90% in the same period. The import of more CO_2 intensive products, such as machinery, electric appliances, computers and office equipment increased more than the import of less CO_2 intensive products such as clothing.

Norwegian consumption is leading to more than 2 million tonnes of annual CO_2 emissions from coal fired power plants in China.
In China almost half (46%) of the CO_2 emissions from producing Norwegian imports came from electricity generation of which about 70% stems from coal fired power plants.

If Norway is to address its CO_2 footprint in China, the most effective will be to assist China in reducing energy needs and developing "clean coal" technologies or renewable energy solutions that can substitute coal.

By putting a price on Norway's carbon footprint in developing countries using an estimated EU carbon market price of €20 per ton, the price of Norway's footprint in 2006 can be estimated to €357 million.
This can be broken down on countries such as China (€136 million), India (€13 million), Brazil (€10 million), South Africa (€7 million), and Indonesia (€4 million). The price of Norway's CO_2 in developing countries (€357 million), equals the Norwegian Government's *daily* revenue from petroleum extraction that year (ca. €350 million).

Presuming that Norway is an average OECD-country, the price of the OECD CO_2 footprints in developing countries can very roughly be estimated to €51 billion (extrapolating from the fact that Norwegian GDP is 0.7% of OECD GDP).
This number may be seen in context with the Stern Review's estimate of the need to support the market for early-stage technologies in electricity generation with $64-170 billion/annum.

Perspectives: The Need for New Partnerships

Developing nations such as China and India, with one third of the global population, provide not just a challenge for global sustainable development but also an immense opportunity. The speed and scale of development, with low production costs combined with enormous investment flows in new infrastructure as well as research and development over the next decades, provides an unprecedented opportunity for mass market production and implementation of low-carbon technologies and other sustainable solutions.

With increasing innovation and the incentives of an environmental crisis and climate change vulnerability, China may well become the provider of new solutions and low carbon development paths which more complacent OECD countries such as Norway can learn from in their transition towards low carbon development.

In the gradual global transition to a low carbon civilisation all economies are transition economies. Norway's and China's starting points are different – but connected. The Norway-China relationship should become a driver for mutual low carbon development. If that potential can be released, chances increase for Norway and China to become winners in the future low carbon economy.

Recommendations for the Norwegian Government

1. Norway should collaborate in developing an internationally applicable methodology for measuring its CO_2 footprint in developing countries and methods for putting a cost on such a footprint.

2. Norway should mainstream promotion of low carbon development in aid and trade policies, actively exploring "climate smart" relationships that can ensure increased welfare as well as low carbon development in developing countries.

3. Norway should introduce "ethical guidelines of the 21st century" for the Norwegian Pension Fund – Global, introducing positive filtration ensuring systematic and strategic low-risk investment in companies and sectors aiming to serve the needs of the global population in a low-carbon, sustainable manner, particularly in emerging economies. Such guidelines can be presented to the Norwegian Parliament spring 2009, as an outcome of the evaluation of existing guidelines to take place in 2008.

4. Norway should over the state budget annually place an amount equal to the cost of its CO_2 footprint in developing countries – for 2006 an estimated €357 million – in a pilot climate venture capital fund providing risk capital to new companies focussing on providing low carbon solutions, in order to stimulate the innovation needed to reach Millennium Development Goals of securing ecological integrity and ending poverty.

5. Norway should encourage all developed countries to estimate their CO_2 footprints in developing countries and their cost and annually place an equal amount – for 2006 here very roughly estimated to €51 billion – in mechanisms aimed at developing low carbon and high efficiency technologies in these countries.

The quantification in this report should also contribute to a more factual debate about the responsibility of different countries in a post-2012 global climate regime.

Contents

1. Background

Consumption and pollution

When we think of daily activities that cause pollution we tend to think of driving to work, heating the house or washing the clothes. But the biggest impact of individuals is through the products that they buy. Ultimately, it is consumers (including companies and government) buying products, that triggers the chain of events that leads to most pollution.

If you buy a television set, you share responsibility for the energy used by the shop and for the transport of the TV set from its country of assembly. But it does not stop there. Components are typically produced in numerous other countries. Each component is produced in a factory, which requires electricity, chemicals, plastic or metals. If one traces the production system back to its origin it will end in areas such as a coal mine in China, an iron-ore mine in Australia, a bauxite mine in Brazil, and an oil well in Canada. The pollution from these mining activities in distant lands to the purchase of a TV set in a Norwegian shopping centre generates considerable pollution. This pollution lies behind most of our personal footprints.

Our livelihoods depend on consumption, however, we must evaluate *how* and *what* we consume.

Estimating carbon footprints in a global economy

The most common way to evaluate a country's CO_2 emissions is to produce an inventory of emissions *within* the country. Considered in this manner, Norway emitted 54 million tonnes (Mt) of CO_2 in 2003. This is about 11.9 tonnes per Norwegian, a slightly higher average than countries (2003 numbers) such as Germany (10.7 t/cap) and UK (10.3 t/cap), significantly higher than neighbouring Sweden (6.9 t/cap), and much higher than the average per capita emissions of developing nations such as China (3.4 t/cap) or India (1.1 t/cap).[i]

Calculated in this way, the CO_2 emissions do not take into account that a country's consumption also instigates production and hence pollution outside of the country. The global CO_2 emissions from *consumption within* a country is known as a country's carbon footprint. The carbon footprint is essentially the emissions within a country plus imports minus exports. In 2001 – the most recent year with detailed available analysis – the production of Norwegian imports generated 29 Mt CO_2 outside of Norway. The same year the production of Norwegian exports – generated largely by exports of oil and gas and international shipping – entailed emissions of 36 Mt CO_2. Thus in 2001, Norway's total carbon footprint was 47 Mt CO_2 (54+29-36) which is lower than the territorial emissions due to Norway's CO_2 intensive exports.[ii]

Carbon footprint = The global CO_2 emissions from consumption of a person or country.

CO_2 is by far the most important greenhouse gas (GHG) responsible for about 72% of total global warming potential.[iii] Greenhouse gas emissions cause the same climate effects wherever they are emitted. If one tonne of CO_2 is emitted in China, it causes exactly the same climatic effect as if it was emitted in Argentina, Botswana, Canada or Norway itself. Taking account of CO_2 emitted elsewhere but caused by Norwegian consumption is therefore both an ethical duty and in the self-interest of Norwegians.

Developed nations and developing nations

In a globalised world economy, estimating the carbon footprint – and placing responsibility for pollution in accordance with the polluter pays principle – is a complicated exercise. If Norway is to be held responsible for the CO_2 emissions embedded in its imports, then other countries should be held responsible for CO_2 emissions from Norwegian exports. This can quickly become complicated and impractical.

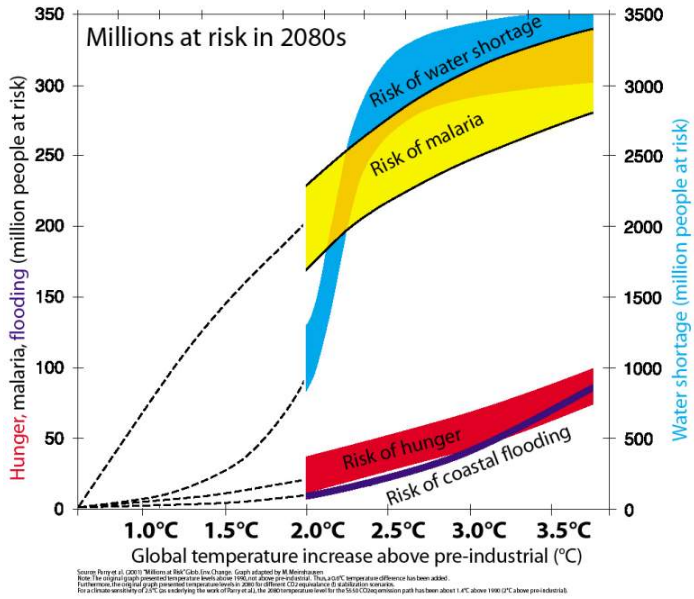
This study takes a pragmatic approach to the question of responsibility for CO_2 emissions embedded in imports. For climate policy, we consider the importance of trade between OECD countries that have accepted emission caps under the Kyoto Protocol (so-called Annex B countries) as less important than trade between such countries and developing countries. As an example, Norwegian imports from the UK generate CO_2 emissions in the UK and vice versa. Norway and the UK are both developed countries with the financial and technological resources as well as advanced environmental policies and pollution control regimes to reduce emissions. Both countries are in a position to tackle the CO_2 emissions from the production of products for consumption in other countries. Importantly, both the UK and Norway have committed to binding emission caps through the Kyoto Protocol.

The situation is quite different when Annex B countries import from developing countries. Most developing countries have ratified the Kyoto Protocol, but are not committed to binding emission caps. In this case, international trade results in increased pollution in countries with often weak pollution control systems and lack of necessary human, financial and technological resources to address pollution challenges.

Ensuring development within environmental limits

Developing countries need to develop their economies to alleviate poverty and reach higher standards of living. Yet, it is a key fact that there are not enough natural resources on the planet for the developing countries to emulate Western living standards with current forms of production and consumption. In a longer term perspective, it is actually physically impossible for every Chinese and India to consume like the average Norwegian currently does.[iv]

In addition, developing countries trying to raise living standards using current modes of production will lead to CO_2 emissions over the next decades that, according to the projections of *World Energy Outlook 2007* and the scenarios of the UN Intergovernmental Panel on Climate Change (IPCC), will provoke global warming of far more than an average +2° Celsius, the accepted threshold for dangerous interference with the climate system. The effects of such warming are predicted to be extremely detrimental, first and foremost for the populations in the developing world.



Graph showing estimated increased risks for millions of people from global warming. (Source: Global Environmental Change 11:3, 2001).

New solutions will be necessary to raise living standards globally whilst still ensuring the ecological and climatic integrity humankind ultimately depends upon for livelihoods. Transfer of resources and know-how from developed nations to developing nations is an important step in developing new solutions that can ensure global sustainability, as recognised by the UN Framework Convention on Climate Change.

Norway and China in focus

This study focuses on CO_2 in Norway's trade-relationship with developing countries, primarily China. There are several reasons for this being a relationship of general interest. Most basically, Norway and China are increasingly interlinked in the global economy and both need to change radically – from very different starting points.

Source: Human Development Report 2007-08	**Norway**	**China**
Population	*4.6 million*	*1.3 billion*
Size in km²	323,802	9,596,960
Population density	*1/14 km²*	*135/1 km²*
Gini* (year 2000/2004)	*25.8 (6th lowest)*	*46.9 (medium)*
GDP (2005)	*295.5 billion US$*	*2,234.3billion US$*
Purchasing Power Parity (2005)	*191.5 billion US$*	*8,814.9 billion US$*
GDP / capita (2005)	*72,306 $ (2rd)*	*1,713 US$*
Purchasing Power Parity / capita (2005)	*46,300 $ (3rd)*	*6,757 US$*
Annual growth rate 1975 – 2005 (%)	*2.6*	*8.4*
CO_2 emissions (2003/2004)	*54 Mt*	*5,007.1 Mt*
CO_2 emissions per capita (2003/2004)	*11.5 Mt*	*3.8 Mt*
Human Development Index (2005)	*2*	*81*

Table 1: *Key facts about Norway and China. (The CIA World Fact Book is the source of population, size and Gini. The Gini coefficient is a measure of statistical dispersion used as a measure of inequality of income distribution or inequality of wealth distribution.)*

Norway: A rich, small OECD-country in a global economy

With 4.7 million people on an area of 323,802 km², Norway is one of the wealthiest countries in the world. The wealth is equally distributed to an extent rarely seen, the education level is high, the population density is low, and climatic conditions are stable and generally benevolent. Norway is rated the most peaceful country in the Global Peace Index (2007). Norway has since 2001 consistently been rated the top country on the UN Human Development Index, in 2007 being adjusted to second place after Iceland. Norway is the country providing the largest percentage of its GDP – 0.92 % - to overseas development aid. In many ways Norway is a model country, representing a welfare level many countries aspire to.

The Norwegian way of life is heavily dependent on imported products, from staple food products, "luxury" items such as televisions and cars, and specialized machinery used in industry. With Norway's heavy dependence on imports, it is reasonable to consider whether reductions of greenhouse gas emissions in Norway will come at the expense of increased emissions outside of Norway through increased imports. Especially since continued economic growth is expected.

Norway is a signatory to the Kyoto Protocol. Norway has, nevertheless, seen a growth in CO_2 emissions since signing the protocol. In 2006, Norway's emissions of CO_2 were 6.8 % above its Kyoto commitments (7.8 % above 1990-level, as Norway is allowed to increase its emissions to 1% above 1990 levels). Norway is therefore dependent on offsetting emissions through using mechanisms such as the Clean Development Mechanism (CDM) of the Kyoto Protocol. China is considered to be a main country for future Norwegian CDM-investments.

The Norwegian Government in 2007 launched new climate policy goals for Norway, stating that Norway will

- "over-fulfill" commitments for emission cuts under the Kyoto Protocol by 10 % in the period 2008-2012 (including using the Clean Development Mechanism under the Kyoto Protocol to purchase emission reductions abroad),
- reduce greenhouse gas emissions by 30 % by 2030 (enforcing between half and two-thirds of the reduction domestically, and the rest through offsets),
- become carbon neutral by 2050 through "significant" domestic reductions and offsetting

Norway's economic progress is caused in part by the exploitation of oil and gas reserves in the North Sea. Oil revenues constitute 25 % of Norway's GDP and 24 % of total investments (2007). As a commodity exporter Norway is projected to see a significant net increase in GDP during the next decades, driven by increased demand caused to a large extent by the economic expansion in China and India. At the same time Norwegian consumer products will remain cheap due to increased production of such imports in low cost countries such as China. This secures Norway a very profitable position in the current world economy.

Norway may be a top nation on the UN Human Development Index. Nevertheless, the Norwegian model is fundamentally unsustainable. If every person on the planet is to consume as many natural resources as the average Norwegian does, we will need 3.4 planets like the earth to serve that need.[v] If every country is to emit as much CO_2 per person as Norwegians, global warming will lead to devastating impacts globally – primarily in developing countries.

China: A huge developing country in a global economy

The People's Republic of China is the largest country in East Asia and one of the largest countries in the world. With a population of over 1.3 billion, roughly a fifth of the earth's total population, it is the most populous country in the world. It has the world's fourth largest economy and second largest measured using purchasing power parity.

China is a developing country ranking 81 on the UN Human Development Index. The rate of economic development over the last thirty years is unparalleled globally (also historically). Since 1978, China's market-based economic reforms have helped to lift over 400 million Chinese out of poverty, bringing down the poverty rate from 53% of population in 1981 to 8% by 2001 (World Bank 2006). China provides an example for other developing countries.

Because of its vast population, rapidly growing economy, huge research and infrastructure development investments[vi], the world's growing dependence on low cost Chinese products, and its huge spending on military, China is considered an emerging superpower. However, the Chinese model is faced with a number of problems, maybe the most important being increasing income gaps, disruption of the social fabric and environmental degradation of a severity and scale that possibly is unparalleled globally (also historically). The environmental crisis threatens to undermine and may, according to some analysts, even end the development towards higher welfare levels for the Chinese population.[vii]

With current trends, China's primary energy demand is projected to more than double from 2005 to 2030. The International Energy Agency (IEA) projects that China will become the world's largest energy consumer in 2010. The use of CO_2 intensive coal is expected to grow rapidly and its share of total primary energy demand will, with current trends, stay high - at over 60 % in 2030. China's per-capita emissions will reach current European levels by 2030. China and India alone will account for 56% of the projected global increase of CO_2 emissions 2005-2030, from 27 gigatonnes (Gt) to 42 Gt.

Projected cumulative investments in China's energy-supply infrastructure are estimated to 3.7 trillion year-2006 dollars over the period 2006-2030. This effectively means that *how* China invests and provides its energy needs over the next decades will to an overwhelming extent determine how mankind will be able to reduce global CO_2 emissions and prevent global warming from triggering the worst future scenarios of the IPCC.

According to the IEA, China overtook the USA as the biggest emitter of CO_2 in 2007. China has ratified the Kyoto Protocol but is not required to reduce carbon emissions because of its status as a developing country and since it historically is the developed nations that have mainly been responsible for the current CO_2 atmospheric concentrations and have the financial and technical ability to mitigate. From 1900 to 2005, the United States (USA) and European Union (EU) countries accounted for just over half of cumulative global emissions, while China accounted for only 8%. With current trends, in 2030 China (16%) will still have a smaller share of total cumulative global emissions since 1900 compared to the USA (25%) and EU (18%). Measured on a per-capita basis, CO_2 emissions in China were 3.8-3.9 tonnes in 2005, approximately one third (35%) of those of the OECD (11 tonnes per capita).[viii] A recent study estimates that net exports in 2004 accounted for 24% of China's total CO_2 emissions.[ix] The IEA estimates that 34% of China's CO_2 emissions stem from production of exports. In 2007, the Chinese government made the point that "countries importing energy-intensive Chinese exports should assume some responsibility for the emissions their manufacture generated".[x]

In June of 2007, China unveiled a 62-page climate change plan reiterating China's aim to reduce energy use per unit GDP by 20% in the period 2006-2010 and increase the amount of renewable energy it produces. The Chinese Government promised to put climate change at the heart of its energy policies but also insisted that developed countries had an "unshirkable responsibility" to take the lead on cutting greenhouse gas emissions, referring to the "common but differentiated responsibility" principle agreed on in the UN agreements on climate change. The Chinese government also called for transfer of technology to developing nations, in accordance with Kyoto Protocol commitments commenting that "We have heard a lot of thunder but have yet to see the rain".[xi]

China's predicament illustrates the fact that developing countries will not be able to emulate Western welfare levels using the same development model as the West has. To reach high living standards China must develop and implement more resource and energy effective solutions than OECD-countries currently apply. It is of global interest that China succeeds in this. For one, China has the potential for mass market production of low cost low-carbon technologies that can help OECD countries to reach *their* CO_2 reduction targets – for instance the production of compact fluorescent lamps, electric cars, or wind turbines. Secondly, the effect of China not succeeding in implementing new low-carbon solutions will be felt globally in the form of escalating global warming.

2. Norwegian imports = Chinese CO_2 emissions

Norway's carbon footprint is growing

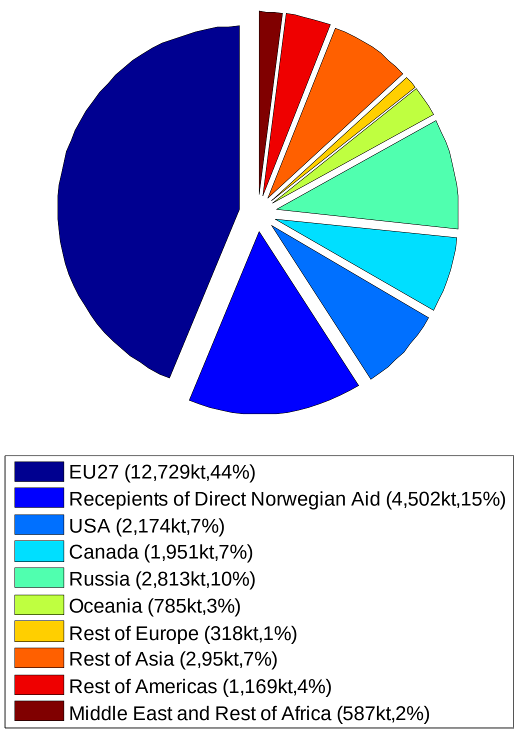
In 2001, Norwegian imports generated 29 million tonnes of CO_2 emissions abroad. Projections for 2006 suggest that the emissions embodied in Norwegian imports increased up to one-third over the next five years, to 39 million tonnes.[xii] Thus, in 2006 more than 8 tonnes of CO_2 was emitted per Norwegian in production of their imports.

Norway's domestic CO_2 emissions have remained relatively static from 2001 to 2006, indicating that the emissions embodied in export (36 Mt in 2001) are also relatively static. But Norway's carbon footprint abroad is growing steadily. With current trends, Norway's CO_2 emissions abroad will most likely surpass domestic CO_2 emissions in the near future.

The mass of imports into Norway has grown 10% from 2001 to 2006, while the emissions occurring abroad have grown almost 35%. This is because Norway is increasingly importing products and from countries with comparatively large CO_2 footprints for the production processes in question. Therefore the growth in the CO_2 emissions embodied in imports is greater than the growth in the mass of imports.

Norway's carbon footprint in countries it gives development support

Norway's CO_2 emissions abroad occur in many different countries. Figure 1 gives a breakdown of the regions that emit the most CO_2 emissions in the production of imports to Norway (2001).



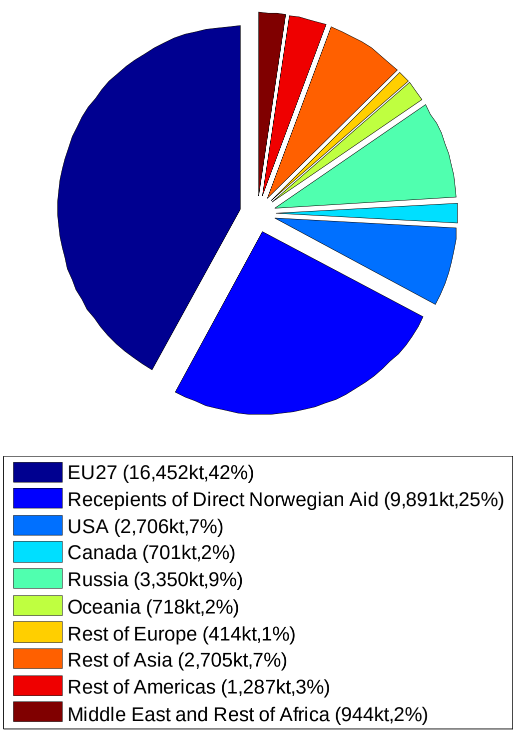


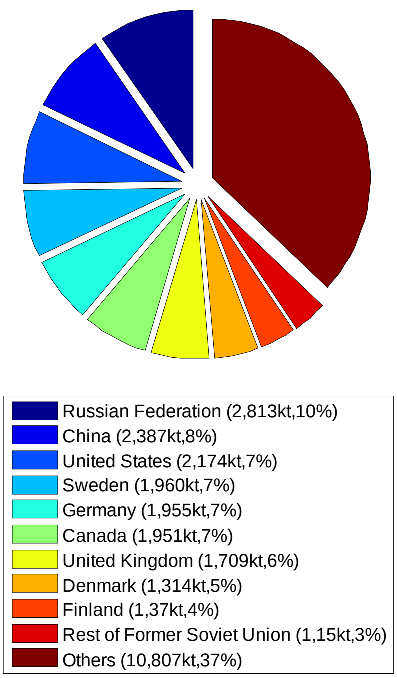
Figure 1 (left): Regions producing CO_2 emissions to make Norwegian imports 2001. 100% = 29 Mt CO_2.
Figure 2 (right): Regions producing CO_2 emissions to make Norwegian imports 2006 (estimate). 100% = 39 Mt.

Not surprisingly, the largest contribution comes from the EU27 due to geographic proximity and close economic integration (hence large import). Russia is the third highest, again due to geographic location and close economic links. The big and well established economies of the USA and Canada appear next, followed by aggregated regions comprising the rest of the world. Interestingly, the countries that receive direct development aid from Norway rank second highest.

In 2007, a number of countries received direct Norwegian development support, from Least Developed Countries such as Bangladesh, Tanzania and Uganda, Low Income Countries such as Kenya and Tajikistan, Lower Middle Income Countries such as China, Serbia and Sri Lanka, and two Upper Middle Income Countries: Croatia and South Africa.[xiii] These are countries for which the Norwegian Government takes a special long term responsibility to support the achievement of the UN Millennium Development Goals, ranging from eradicating poverty and hunger to ensuring environmental sustainability and develop a global partnership for development. Norway's gross Overseas Development Aid in 2005 was about 18 billion NOK (ca. 2.25 billion €).

In 2001 17% of Norway's CO_2 emissions abroad (5 million tonnes) occurred in countries receiving Norwegian development aid directly. This doubled, reaching 10 million tonnes in 2006, 25% of Norway's CO_2 emissions abroad that year. Currently, on average every Norwegian is responsible for emissions of more than 2 tonnes of CO_2 in the countries Norway provides with development support. Norway's CO_2 footprint in these countries are larger than the total Norwegian CO_2 emissions from domestic road traffic (9.6 Mt in 2005).

Top ten countries of Norway's carbon footprint abroad



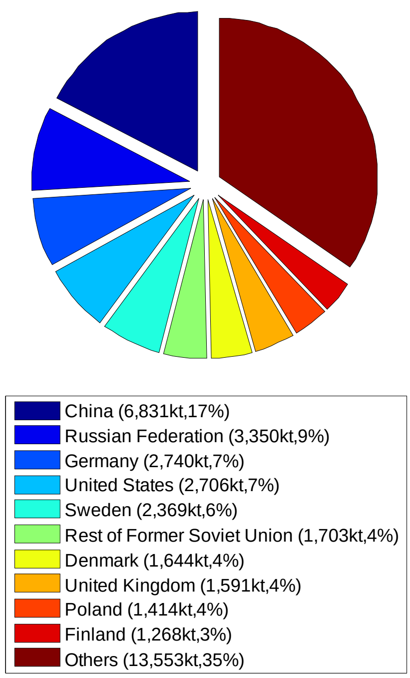


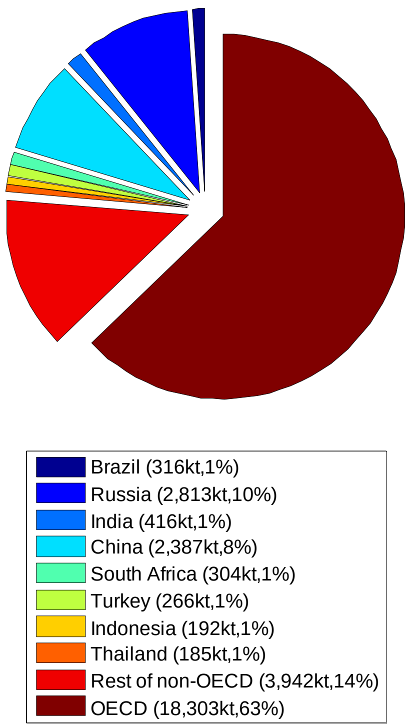
Fig 3 (left): The ten countries where Norwegian imports generate most CO_2 emissions, 2001. 100% = 29 Mt.
Fig 4 (right): The ten countries where Norwegian imports generate most CO_2, 2006 estimate. 100% = 39 Mt.

Further information is provided by considering the individual countries producing imports for Norway. Figures 3 and 4 show the top 10 countries emitting CO_2 in the production of imports to Norway. Several countries have had a large change in their emissions from 2001 to 2006.

What really stands out is that China's contribution almost tripled (increased 180%), from 2.4 to 6.8 Mt CO_2 - 17% of Norway's CO_2 footprint abroad, making it the biggest emitter of CO_2 emissions for imports into Norway. On average every Norwegian has a CO_2 footprint of 1.5 tonnes in China. In contrast, the mass of imports from China to Norway increased only 90% in the same period. This indicates that not only is the volume of imports from China growing, but the import mix is shifting to more CO_2 intensive products (see also below).

The CO_2 emissions occurring in the Rest of the Former Soviet Union increased 67%, with Ukraine being the main country. Most other countries in the top 10 increased around 20%: Russia (19%), Germany (40%), USA (25%), Sweden (21%), Denmark (25%), UK (7% decrease).

Norway's CO_2 footprint in developing countries and emerging economies



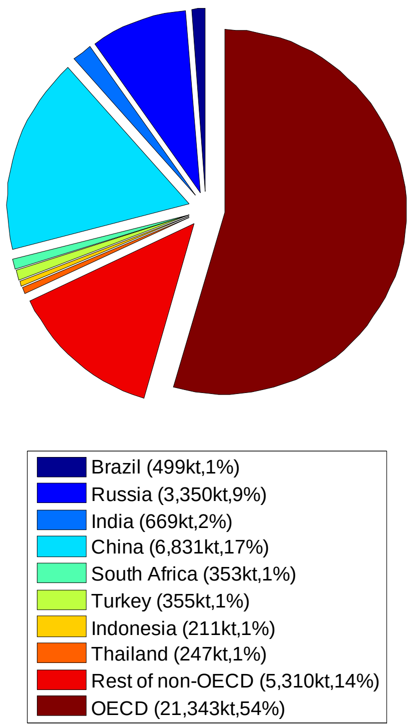


Fig 5 (left): Developing countries where Norwegian imports generate most CO_2 emissions, 2001. 100% = 29 Mt.
Fig 6 (right): Developing countries where Norwegian imports generate most CO_2 emissions, 2006 estimate. 100% = 39 Mt.

In 2001 about 37% (10.8 million tonnes) of Norway's carbon footprint abroad was in developing countries. By 2006 this had increased to 45% (17.8 million tonnes), equalling one third of Norway's total domestic emissions (54 Mt in 2003) – or almost 4.5 tonnes of CO_2 per

Norwegian. This suggests that "carbon leakage" is occurring in Norway, with Norwegians increasingly causing emissions in countries without emission constraints.

With current trends Norway will soon have a larger CO_2 footprint in developing countries than in developed ones. Moreover, the trade data shows a shift in trade patterns towards countries and types of products that are more pollution intensive.[xiv] A similar trend has been reported for UK, indicating that this might be a general phenomenon for OECD countries.[xv]

The CO_2 emissions from Norwegian imports from the rising BRICS-economies (Brazil, Russia, India, China, and South Africa) grew from 6.2 million tonnes to 11.8 million tonnes in 2006 – a growth rate of 88%. The growth of Norway's CO_2 footprint in these countries was larger than the growth in developing countries in general, which was approximately 65% in this period.

If we look at the top eight developing countries where production of Norwegian imports generate the most CO_2 (BRICS + Turkey, Indonesia and Thailand), we see that the Norwegian CO_2 footprint (12.5 Mt) is about equal to the total Norwegian domestic emissions from oil and gas production (12.7 Mt in 2005). Norway's CO_2 footprint in India (0.7 Mt) equals the CO_2 emissions from non-electric heating of Norwegian households (0.7 Mt in 2005).

Putting a price on CO_2 emissions embodied in Norwegian imports

As the Chinese Government has pointed out, if OECD imports are responsible for a certain amount of CO_2 emissions in China, then one could argue that the OECD countries in question – such as Norway – has a responsibility for those emissions.[xvi]

One way to develop a systematic approach for Norway's to address its carbon footprint in developing countries is to use the average price put on CO_2 emissions in OECD countries to calculate the cost. In this way, we obtain a price on the CO_2 emissions an OECD country generates via its imports. In Europe it would be natural to use an estimate of the price for a CO_2-quota in the EU carbon trading scheme. The Norwegian Pollution Control Authority and the European Commission estimates the CO_2 quota price for 2008 to be approximately 20 Euros (160 NOK), a price that is estimated to rise to 37 Euros by 2020.

Putting a price on Norway's CO_2 footprint in developing countries 2006		
Country	*Amount of CO2*	*Price of Norway's footprint*
China	6.8 Million tonnes	136 Million €
Russia	3.4 Million tonnes	68 Million €
India	0.7 Million tonnes	13 Million €
Brazil	0.5 Million tonnes	10 Million €
South Africa	0.4 Million tonnes	7 Million €
Turkey	0.4 Million tonnes	7 Million €
Thailand	0.2 Million tonnes	4 Million €
Indonesia	0.2 Million tonnes	4 Million €
Developing countries (total)	17.8 Million tonnes	357 Million €
Recipients of Direct Aid	9.9 Million tonnes	180 Million €

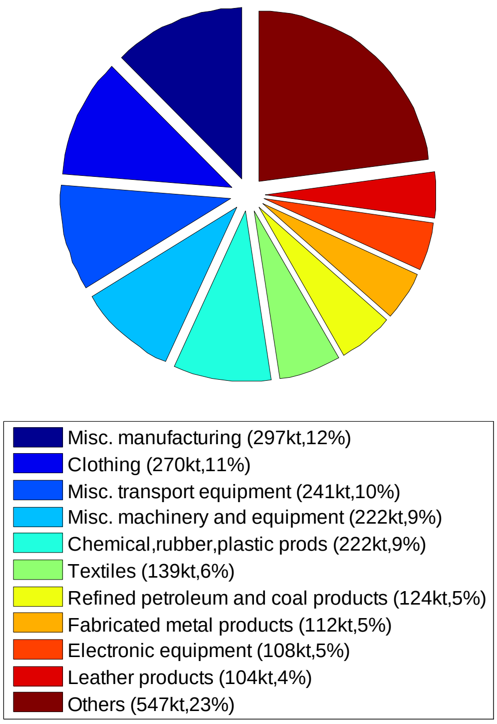
Table 2: Putting a price on Norway's CO_2 footprint in developing countries (estimation for 2006).

With this methodology the price of Norway's CO_2 footprint in developing countries was €357 million (ca. 2.9 billion NOK), which is equal to the Norwegian Government's *daily* revenue from petroleum extraction in 2006 (ca. 2.8 billion NOK).

These numbers for Norway's footprint should not be considered fixed, they rather indicate the financial scale of the issue of Norway's carbon footprint if we apply EU carbon market principles. The estimations of CO_2 embodied in Norwegian imports in 2006 need further refinement. Moreover, a general consensus and well-considered methodology must be developed for how to estimate the CO_2 emissions embodied in imports. Nevertheless, the numbers are interesting as they, in financial terms, indicate the possible scale of the issue of CO_2 embodied in imports.

Which Chinese products lie behind Norway's CO_2 footprint?

China plays a significant role in the carbon footprint of Norway, both in terms of absolute CO_2 emitted and high growth rates. The following figures show the CO_2 emissions embodied in the various product imports from China to Norway for 2001 and 2006.



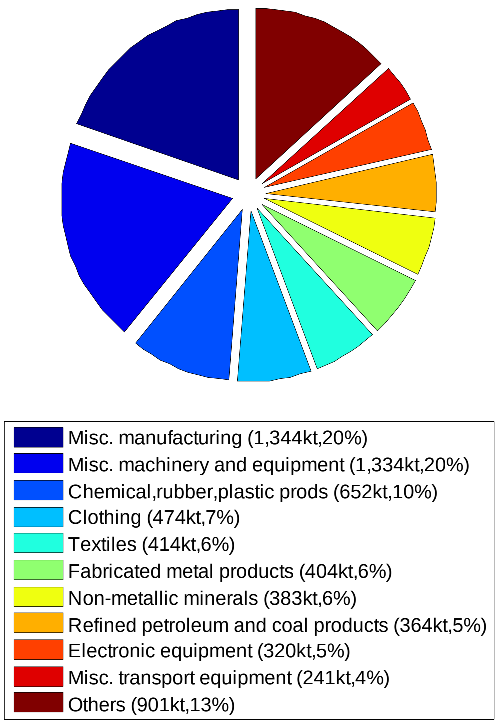


Figure 7 (left): The Chinese products imported to Norway with the most embodied CO_2 emissions, 2001.
Figure 8 (right): The Chinese products imported to Norway with the most embodied CO_2 emissions, 2006.

Figures 7 and 8 show that manufactured and electronic products account for about one half of the CO_2 emissions embodied in imports from China. Most product groups had huge growth from 2001 to 2006. "Miscellaneous machinery and equipment" grew 500% representing not only standard machinery and equipment, but also electric appliances, computers, office equipment, and so on. The import of "miscellaneous manufacturing" grew 350% from 2001 to 2006 (furniture, sports equipment, toys, and so on). "Fabricated metal products" (such as nuts and bolts, wire, metal doors and windows etc.) grew 300%. The other products in the figures grew around 200%. In total, the emissions embodied in imports from China grew over 180% from 2001 to 2006.

The rapid growth in imports from China is due to both imports to final consumers and to industry. Due to low prices, imports are increasingly being supplied by China.

2001	kt CO_2	Million NOK	kg CO_2/NOK
Misc. manufacturing	296.8	1790.4	0.166
Clothing	270.4	2107.2	0.128
Misc. transport equipment	240.5	783.7	0.307
Misc. machinery and equipment	221.9	762.2	0.291
Chemical, rubber, plastic prods	221.9	530.0	0.419
Textiles	139.3	732.0	0.190
Refined petroleum and coal products	124.4	193.8	0.642
Fabricated metal products	112.4	239.2	0.470
Electronic equipment	108.2	758.9	0.143
Leather products	103.8	767.1	0.135
Other	547.1	2004.9	0.273
Total	2386.7	10669.5	0.224

Table 3: Pollution intensity of Norwegian imports from China per NOK (2001)

If we consider the emission intensity per Norwegian *krone* (NOK) of producing products in China, one can see there is large variation across products. However, some of the "cleaner" products cause significant CO_2 emissions due to the shear quantity that is imported. For instance, in 2001, "clothing" was one of the cleanest sectors, but contributed the second highest CO_2 emissions. While clothing has a relatively "low" pollution intensity compared to other Chinese products, the Chinese emission intensity is up to ten times worse than some countries - such as European countries.

To reduce Norway's CO_2 footprint in China, Norway needs to invest and develop trade incentives that reduce the CO_2-intensity of various products in China. Table 3 identifies which imported products need the most attention, but to know where to invest requires understanding why certain products are pollution intensive.

Coal - the main culprit behind the scenes

We have considered the volumes of different Chinese products being imported into Norway and the carbon intensity of the different products. The production of these products leads to CO_2 emissions, but usually most of the emissions do not occur directly in the factory of production, but further along the supply chain. For instance, sewing together textiles to produce clothing is not necessarily pollution intensive; rather, it is the purchases and production of chemicals, electricity, and so on used in the clothing factory that causes the emissions.

The following figure shows which Chinese industries that emit most CO_2 to produce Norway's imports for 2001.

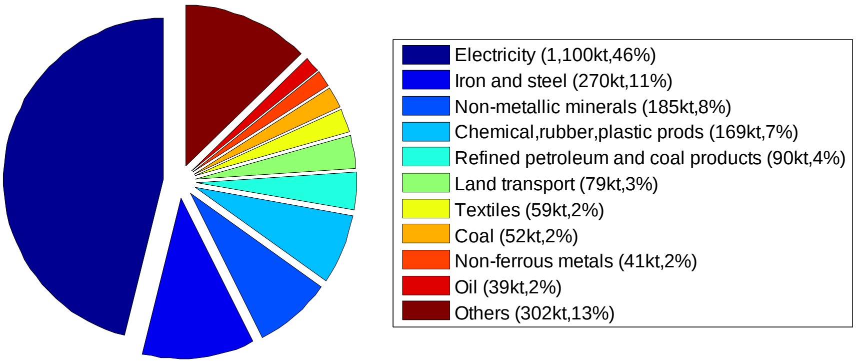


Figure 9: The sectors in China which emit the most CO_2 emissions to produce Norwegian imports (2001).

Not surprisingly, the inputs of electricity into factories and other industries in the supply chain is the largest cause of CO_2 emissions. Currently, 69% of the energy production in China comes from CO_2-intensive coal-burning.[xvii] Presuming that Norway's carbon footprint in China is distributed in a similar manner among sectors in 2006, this effectively means that Norwegian consumption leads to more than 2 million tonnes of CO_2 emissions from coal plants in China annually (6.8 Mt x 0.46 x 0.69 = 2.16 Mt). Following electricity suppliers, we find the various energy intensive industries providing products or materials which have a significant carbon footprint from their own production process.

Thus, while the import of manufactured products drives the emissions in China, it is the electricity and energy intensive industries in China that actually emit the CO_2. Norway can therefore make a difference by investing in raising environmental standards and energy-efficiency in Chinese energy intensive industries. Most urgent, is for developing countries to assist China in shifting its electricity mix to a lower carbon intensity.

If Norway is to get to the heart of the problem of its CO_2 footprint in China, Norway must invest to help develop "clean coal" technologies and scale-up application of renewable energy solutions that gradually can substitute the use of fossil fuels.

3. Perspectives

The need for new partnerships

Huge developing nations such as China and India, with one third of the global population, provide not just a challenge for global sustainable development but also an immense opportunity if it is handled correctly. The speed and scale of development, with low production costs combined with enormous investment flows in new infrastructure as well as research and development over the next twenty years, provides an unprecedented opportunity for mass market production and implementation of low-carbon technologies and other sustainable solutions. The very scale could, in fact, transform the global economy, as countries jostle to gain a leading competitive position in the race to be the ones to provide the low carbon, sustainable solutions of the future. It would be a win-win opportunity of enormous magnitude, if the future growth of a country like China could come from developing the solutions that will save the planet.[xviii]

With increasing innovation and the incentives of an environmental crisis and climate change vulnerability, China may well become the provider of new solutions and low carbon development paths which, possibly more complacent, OECD countries such as Norway can learn from in their transition towards low carbon development.

In the gradual global transition to a low carbon civilisation all economies are transition economies. Norway's and China's starting points are different – but connected. The Norway-China relationship should become a driver for mutual low carbon development. If that potential can be released, chances increase for Norway and China to become winners in the future low carbon economy.

The Clean Development Mechanism and low carbon innovation

The Kyoto Protocol acknowledges that OECD nations have benefited from emitting CO_2 and therefore also must take the lead in reducing emissions. In the developing world CO_2 emissions will likely increase in the short term. Until an agreement can be reached on a global caps for CO_2 emissions, there will be different mechanisms channelling resources from OECD countries to developing countries.

The Clean Development Mechanism (CDM) of the Kyoto Protocol allows Annex B countries (countries with emission obligations under the Kyoto Protocol) to offset CO_2 emissions through investing in CO_2 reducing activities in developing countries. The Norwegian Government is relying on this mechanism to reach its goals for reducing CO_2 emissions, with China as a main market. The CDM mechanism typically helps developing countries approach Western standards in energy efficiency and pollution control. Whilst beneficial, the CDM is not enough to solve the climate change problem.[xix] Therefore, offsetting through CDM must be accompanied by active promotion of new sustainable low carbon solutions in developing countries.

Development aid and climate change

Climate change is only one of a range of urgent global challenges that are often interconnected. Eliminating extreme poverty and improving child mortality are two of those that need to be dealt with urgently. Their interconnection with climate change is also evident. There is little doubt that people need to afford other energy sources than wood if deforestation in Africa is to stop. Child mortality must be reduced in the poorest countries if people are to dare give birth to fewer children and human population is to stabilise.

In other words, even if imports may cause greater CO_2 emissions than domestic production would have caused, we need to consider impacts of trade versus non-trade on other global challenges. If trade lifts people out of poverty, then that may in many circumstances be overall beneficial – even if it leads to more CO_2 intensive production or transport.

An example is air-freight of fresh fruits and vegetables from Sub-Saharan Africa to the UK. This represents less than 0.1% of total UK carbon emissions, but injects about GBP 200 million into rural Africa and provides 100,000-120,000 direct jobs. When dependents and service providers are factored in, an estimated 1-1.5 million Africans' livelihoods depend in part on these exports.[xx] Clearly, these air-freight emissions may be amongst the most beneficial amongst the UK's carbon footprint to global sustainable development. Conversely, air-freight of grapes from California when they are out of season in Europe epitomises unnecessary GHG emissions.

Norway's gross Overseas Development Aid in 2005 was about 18 billion NOK (ca. 2.25 billion €). On average every Norwegian has an estimated CO_2 footprint of more than 2 tonnes of CO_2 in the countries Norway provides with development support (2006), and this number is rising. On the positive side, the increasing footprint indicates an opportunity in so far as the numbers reflect increased openness to trade with these countries. Through supporting low-carbon development and "climate smart" trade relationships, Norway has an opportunity to jointly combat poverty, unemployment, climate change, and also increase trade.

Consumption and trade for sustainable development

Current modes of production are too resource and pollution intensive for current levels of global (predominantly Western) consumption to be sustained. It is not, however, necessarily consumption itself that is the problem, but rather what we consume. Norway should work to eliminate trade barriers to environment-friendly goods and services, in national policies and in international frameworks for trade such as EU and the WTO.[xxi] Consumption and trade can be part of the solution, a driver for sustainability, if the right framework is provided.

Trade generally requires transport. Air and road transport are very CO_2 intensive.[xxii] Life-cycle assessment has shown that this may be an important factor in the overall global warming impact of a traded product, but that it depends on a number of variables, in particular the mode of transport. In fact, (long) transport is in itself not necessarily a good variable for determining a product's carbon footprint. For instance, some studies show that a Kenyan flower that is air-freighted to Europe emits one third of the CO_2 of flowers grown in Holland (where *inter alia* greenhouses adds to the footprint). Other studies show that New Zealand lamb that is transported to the United Kingdom can actually generate 70% less CO_2 than lamb produced in the UK.[xxiii]

That Norwegian trade embodies large amounts of CO_2 is not an argument against trade. It is primarily an argument for Norwegians to consume less embodied CO_2 (whether in imports or domestic products) and to encourage trade in certain products more than in other products.

Investing in low carbon sustainable development

Investments can perpetuate current practices or it can stimulate innovation. OECD countries like Norway should actively stimulate application of best practises and innovation, particularly in those countries that will be the largest economic powers of the next decades.

OECD governments like Norway should provide tax incentives for private investors or companies that invest in leapfrogging current Western standards in developing countries. This should be supplemented by greening government policies for furnishing guarantees and insurance of export credits, in Norway provided by GIEK (*Garanti-Instituttet for Eksport Kreditt*). Currently, such policies promotes export of Norwegian goods and services and Norwegian investment abroad, indiscriminately of whether these contribute to long-term, low carbon, sustainable solutions or not.

The Norwegian Government *Pension Fund – Global* manages about 250 billion €. Managers of large pension funds or similar assets, should generally make low-risk, strategic investments in drivers for sustainable development; the companies and sectors that are aiming to serve the needs of the global population in a low-carbon, sustainable manner. In the 21st century it is not enough that so called ethical guidelines for investments (which the Norwegian pension fund has pioneered) helps avoiding or improving the worst of companies in terms of environmental and social standards. The real ethical challenge for OECD countries is to instigate systemic *change* that can make welfare also in developing countries possible within the limits of the one planet we share and spare billions of people in the third world from the most devastating of the global warming scenarios of the IPCC. Sound and systematic investments in sectors and companies promoting sustainable low carbon development is to invest in long term stability and security that may ensure return on investments for many generations to come.

Putting a price on CO_2 footprints

In this study, we have suggested that developed countries like Norway put a price on the CO_2 emissions embedded in their imports from developing countries, for instance with €20 per ton (an estimated CO_2 quota price in the EU in 2008). The alternative measure of putting a "carbon tax" on imported products from developing countries will, in WWF's view, be against the Kyoto Protocol principle of "shared but differentiated responsibility" and hamper third world exports at the compromise of development.[xxiv]

Based on our quite crude projections for 2006, we estimated the price of the CO_2 embedded in Norway's imports from developing countries to amount to €357 million that year. Provided a firm methodology can be put in place, a sum equal to Norway's CO_2 footprint in developing countries could be made available over the Norwegian state budget each year for investments in low carbon development technologies.

Moreover, such a principle could be applied in all OECD countries' CO_2 footprints in the developing world. In 2001 the CO_2 emissions embodied in all imports into developing countries (Annex B including USA) from developing countries (non-Annex B) was 1585.3 Mt.[xxv] With €20 per tonne this amounts to €31.7 billion euros.

A very rough current estimate can be made by extrapolating from the fact Norway's GDP is 0.7% of the OECD total (2006 estimate)[xxvi]. Presuming that Norway is a typical OECD country, the 2008 price for the OECD CO_2 footprints in the developing countries can very roughly be estimated to lie around €51 billion per year (357 million = 0.7%, then 51 000 million = 100%).

The carbon footprint estimates for OECD in developing countries may be seen in context with the Stern Review's estimates of the need for increased public spending on technology policies (from research and development to demonstration and early deployment). The Review argues that the scale of existing deployment incentives worldwide, particularly to support the market for early-stage technologies in electricity generation, should increase two to five times, from the current level of around $34 billion per annum, in order to effectively counter climate change.[xxvii]

A climate venture fund?

Without innovation, it will not be possible to reach the UN Millennium Development Goals of ending poverty and securing ecological integrity on the planet. Current modes of production are simply too resource and pollution intensive to be able to provide sustainable welfare and security to mankind as a whole.

A country like Norway could annually place an amount equal to the price of its CO_2 footprint in developing countries in a pilot "climate venture capital fund". Like venture capital funds, a climate venture fund will provide capital to high-risk, new, growth businesses, but in this case for companies focussing on scaling up use of existing renewable energy solutions or developing new solutions with potential to transform current non-sustainable practises with sustainable, low carbon ones. The fund could invest globally in what is considered the most promising possibilities, based on the principle that breakthroughs will have a global impact irrespective of where they are made commercially or technologically viable. Return on investments could be reinvested or go to financing the global policy process aimed at developing and upholding a joint, global and equitable approach to climate change.

In venture capital funds investments are risky, but offer potential for above-average returns. In this fund, investments will be high risk. But then the potential return is awesome; it could be the practical implementation or new development of solutions that save humankind – first and foremost hundreds of millions in the developing world – from devastating negative effects of fossil fuel induced climate change. It may be a risk the petroleum nation Norway should take.

4. Five recommendations to the Norwegian Government

WWF encourages the Norwegian Government to take the lead in all fields related to ensuring low carbon development. In particular, the Norway-China relationship should become a driver for mutual low carbon development. If that potential can be released, chances increase for Norway as well as China to become winners in the future low carbon economy.

1. Norway should collaborate in developing an internationally applicable methodology for measuring its CO_2 footprint in developing countries and methods for putting a cost on such a footprint.

2. Norway should mainstream promotion of low carbon development in aid and trade policies, actively exploring “climate smart” relationships that can ensure increased welfare as well as low carbon development in developing countries.

3. Norway should introduce “ethical guidelines of the 21^{st} century” for the Norwegian Pension Fund – Global, introducing positive filtration ensuring systematic and strategic low-risk investment in companies and sectors aiming to serve the needs of the global population in a low-carbon, sustainable manner, particularly in emerging economies. Such guidelines can be presented to the Norwegian Parliament spring 2009, as an outcome of the evaluation of existing guidelines to take place in 2008.

4. Norway should over the state budget annually place an amount equal to the cost of its CO_2 footprint in developing countries – for 2006 an estimated €357 million – in a pilot climate venture capital fund providing risk capital to new companies focussing on providing low carbon solutions, in order to stimulate the innovation needed to reach Millennium Development Goals of securing ecological integrity and ending poverty.

5. Norway should encourage all developed countries to estimate their CO_2 footprints in developing countries and their cost and annually place an equal amount – for 2006 roughly estimated to €51 billion – in mechanisms aimed at developing low carbon and high efficiency technologies in these countries.

The quantification in this report should also contribute to a more factual debate about the responsibility of different countries in a post-2012 global climate regime.

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Appendix: The methodology behind this study

What is "pollution embodied in trade"[1]?

The production of goods and services generates pollution through production processes and through the energy consumption required in production. The cumulative pollution emitted through the entire chain of production, starting from resource extraction to final sale, is said to be "embodied" in that product. If the product is further traded across national borders, then this is "pollution embodied in trade".

The concept of pollution embodied in trade shares many characteristics with material flow analysis. In traditional material flow analysis the physical flow of the material of interest, iron for example, is traced around the globe. For pollution embodied in trade, the pollutant is not physically a part of the traded product, but rather the pollution emitted in the production of that product. Consequently, some published research refers to "hidden" or "virtual" flows of pollution.

The main method for calculating emissions embodied in trade is input-output analysis. Input-output analysis originated in economics and is a widely accepted method for analyzing the interconnections between different economic sectors (its founder, Wassily Leontief, received a Nobel Prize). For calculations of pollution embodied in trade, the standard input-output model must be generalized into a multi-regional model to account for the different production technologies in different countries. The main methodological issue for pollution embodied in trade is linking the input-output data from different countries through trade statistics.

The calculation and analysis of the pollution embodied in trade is useful in many areas of environmental system analysis. Pollution embodied in trade gives a good measure of how consumption choices in one country affect the environment in other countries. It also can demonstrate a quantitative change if countries increasingly shift polluting production off-shore while pursuing a less polluting knowledge-based domestic economy. These applications are particularly relevant for addressing the connection between trade and the environment.

Calculating "pollution embodied in trade"

The production of most products for final consumption requires a complex production network usually spanning numerous countries. For instance, car production in Germany may resemble more car *assembly* rather than car *production*. The car producer in Germany will source the components of the car from numerous suppliers: the leather on the car seat may come from China, the suspension from South Africa, the radio from Japan, the engine from a German manufacturer, and the car tyres from the USA. In addition, the car producer needs to purchase electricity to run the plant, financial and insurance services, human labour, and so on. In turn, each company that supplies to the car producer needs to assemble or produce their products. The leather seat requires inputs from agriculture, chemicals, metals, electricity, and so on. Ultimately, many of materials in the car originate in various mines around the world – such as South Africa, Australia, and Chile – and pollution is emitted mining, transporting, and transforming these processes. Each step in the global production chain required to produce one car in Germany requires millions of transactions and each of those transactions releases some pollution.

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[1] Adapted from http://www.eoearth.org/article/Pollution_embodied_in_trade

Calculating the global pollution from complex production systems is a non-trivial task, but was made considerably easier through an economic tool called input-output analysis (IOA). The backbone of IOA is an input-output table (IOT) where each row and column represents a different sector of the economy – ranging from tens to hundreds of sectors, depending on the country. Each entry in the IOT describes the relationship between two sectors in the economy, and is constructed in such a way that the columns of the table are like production recipes in a recipe book. For instance, the column to produce a car shows that to produce one car you need, one car frame, one car engine, two front seats, one back seat, four wheels, a steering wheel, radio, electricity, insurance, labour, and so on. There is a column and production recipe in the IOT for each economic sector in the economy. In general, these tables are collected in monetary units and account for every monetary flow in the economy. The tables are rather aggregated with sectors such as "car manufacturing", "textiles", "insurance", "electricity", and so on. Most countries construct these tables with between fifty to one hundred sectors. The construction of the IOT, or variants of it, are central to economic analysis and are the backbone to calculating fundamental economic measures such as Gross Domestic Product. IOT is the economic equivalent of double-entry book keeping in company accounts.

The framework for IOA can be developed in several ways, but it is quite instructive to develop it in an analogous way to the global production system. This can help understand the way global production networks work in addition to IOA. Suppose we want to produce a product such as a car and we call this y. The minimum output, x, of the economy is at least one car, y,

$$x = y \tag{1}$$

In general, this relationship is expressed using a column of numbers (a vector), for example, one car, zero agriculture, zero metals, zero insurance, etc. To produce the car requires inputs from other parts of the economy. We can use the IOT in a normalized form – the production recipe for each product (a matrix) – to determine these inputs, Ay,

$$x = y + Ay \tag{2}$$

To produce the inputs Ay requires inputs from a range of suppliers

$$x = y + Ay + A(Ay) = y + Ay + A^2 y \tag{3}$$

This, in turn, requires inputs from other suppliers

$$x = y + Ay + A^2 y + A(A^2 y) = y + Ay + A^2 y + A^3 y \tag{4}$$

And this continues infinitely through the global production system,

$$x = y + Ay + A^2 y + A^3 y + A^4 y + ... \tag{5}$$

After some mathematical tricks – the power series expansion – one ends with the standard relationship for IOA,

$$x = (I - A)^{-1} y \tag{6}$$

which given a demand on products, y, finds the global economic activity in every sector, x, given the production recipes for every product in the economy, A. The I is a matrix with ones on the diagonal (equivalent to the number one). Once we know the global economic activity in every sector, it is possible to determine the environmental impacts given the emission intensity, F, in each sector.

$$f = F(I - A)^{-1} y \tag{7}$$

Multi-regional input-output analysis

This section gives a description of how to calculate the "emissions embodied in bilateral trade" (EEBT) required to determine the total emissions embodied in the production of exports or imports. This section assumes some knowledge of environmental IOA. More details on environmental IOA [1] and environmental MRIOA [2-4] can be found elsewhere.

The standard IOA framework begins with an accounting balance of monetary flows,

$$x^r = A^r x^r + y^r + e^r - m^r \quad (8)$$

where x is the vector of total output in each sector, y is a vector with the each element representing final consumption – households, governments, and capital – in each industry sector (domestic plus imports), e is the vector of total exports, m is the vector of total imports (for both intermediate and final consumption), A is a matrix where the columns represent the input from each industry (domestic plus imports) to produce one unit of output for each domestic industry, Ax is the vector of total intermediate consumption, and r is the region under investigation. This balance equation holds in all regions. The trade components can also be expressed using bilateral trade data

$$e^r = \sum_s e^{rs} \quad (9)$$

for exports from region r to s and by symmetry the total imports are

$$m^r = \sum_s e^{sr} \quad (10)$$

where e^{rs} is the bilateral trade data.

To perform analysis with this model the imports are usually removed from the system,

$$x^r = A^{rr} x^r + y^{rr} + e^r \quad (11)$$

which expresses the same balance using only domestic activities. The domestic final consumption is decomposed as

$$y^r = y^{rr} + \sum_s y^{sr} \quad (12)$$

and the interindustry requirements are decomposed as

$$A^r = A^{rr} + \sum_s A^{sr} \quad (13)$$

where A^{rr} represents the industry input of domestically produced products and A^{sr} represents the industry input of products from region s to region r.

The environmental impacts are calculated as,

$$f^r = F^r x^r = F^r \left(I - A^{rr}\right)^{-1} \left(y^{rr} + \sum_s e^{rs}\right) \quad (14)$$

where F is the CO_2 emissions per unit industry output (a row vector). These are the emissions that occur domestically to produce both domestic final consumption and total exports.

Emissions Embodied in Bilateral Trade (EEBT)

The emissions embodied in bilateral trade (EEBT) are calculated using monetary bilateral trade statistics. This method does not perform a separate calculation for imports as such, rather it determines the emissions in one region, r, to produce the bilateral trade flow e^{rs}, and these are the emissions embodied in imports from region r to region s. The method does not distinguish between trade to intermediate and final consumption.

A key assumption employed in IOA is that the production technology is based on fixed proportions (i.e. that in a given sector, the production for domestic demand has the same characteristics as production for exports). This allows (14) to be decomposed into components for domestic demand on domestic production in region *r*

$$f^{rr} = F^{r}\left(I - A^{rr}\right)^{-1} y^{rr} \quad (15)$$

and the EEBT from region *r* to region *s*

$$f^{rs} = F^{r}\left(I - A^{rr}\right)^{-1} e^{rs} \quad (16)$$

Adding these gives the total emissions occurring in region *r*

$$f^{r} = f^{rr} + \sum_{s} f^{rs} \quad (17)$$

The direct household emissions can be included in f^{rr}.

The total emissions embodied in bilateral trade for exports (EEBT-E) from region *r* to all other regions can be determined by summation,

$$f^{r*} = \sum_{s} f^{rs} \quad (18)$$

and reversing the summation gives the emissions embodied in bilateral trade for imports (EEBT-I) into *r* from all other regions

$$f^{*r} = \sum_{s} f^{sr} \quad (19)$$

This method covers all global emissions.

Emissions embodied in consumption

While the EEBT methodology is conceptually sound it is not applicable for arbitrary final consumption. The EEBT method determines the emissions occurring in one region to produce the export to another region, but it does not determine the total emissions to produce a given product since some regions require imports to produce exports. For instance, to calculate the emissions embodied in the production of an exported car from region A, one must first determine the production levels and emissions occurring in region A. Then, the shares of imports from B and C into region A to produce the car are required. Given the resulting production and emissions in regions B and C, imports from other regions into B and C are required and so on. This process continues indefinitely through the global production system. This type of analysis is performed using a Multi-Regional Input Output (MRIO) model and is analogous to Life Cycle Assessment (LCA).

In this study, we have used only the EEBT model, and not the full MRIO model. We use the EEBT model as it is transparent and directly related to bilateral trade flows, while the full MRIO model relates to final consumption only. The international shipping sector offers a good example of the difference between the methods in Norway. Using the EEBT model, the international shipping sector represents a major component of Norway's exports, both in financial and environmental terms. However, in the MRIO model, international shipping is allocated differently and hence is not as prominent. The MRIO model only considers the purchases of final consumers, but calculates the industry activity indirectly. Hence, the emissions from Norwegian international shipping are embedded in thousands of different products consumed around the world. In contrast, in the EEBT model, the international shipping sector is prominently allocated as an export from Norway.

Projections to 2006

A key goal of this study was to estimate the emissions embodied in trade as recently as possible. The model used for the study is based on 2001, which is the same year China joined the World Trade Organisation. A lot has changed since 2001, so we made some projections from 2001 to 2006.

The projections project the EEBT from 2001 to 2006 using bilateral trade data from Statistics Norway (SSB). The general approach is:
1) We used the 2001 and 2006 2-digit SITC trade data from Statistics Norway (SSB) for the imports of over 200 countries into Norway
2) We used the physical flows (tonnes) and not the monetary data which is subject to currency fluctuations and price movements
3) We projected sector and country specific growth rates. The SSB SITC data had several inconsistencies with the GTAP data for 2001. If there was a growth rate greater than a factor of ten (the results very sensitive to this), then we assumed this was an outlier and assumed that sector had zero growth
4) We assumed the production technologies remained constant
5) We assumed that trade in services remained constant from 2001 to 2006

Overall, given the uncertainties, caution should be taken with the projections for 2006.

The projections assume that the production technologies and efficiencies have not improved between 2001 and 2006. This is a strong assumption; however, put in context, there are some advantages of using this assumption. The sector and region specific emission intensities are essentially used to weight the trade data based on the emissions from production. Our assumption, more specifically keeps the differences between emission intensities constant. Thus, it essentially assumes that the emission intensity in each country and industry improves at the same rate, which is much weaker assumption. If this assumption is accepted, then the results are robust at detecting changes in the products imported and the country the imports originate. As a consequence, when we consider the pie charts in the report, the percentages are more reliable than the absolute emissions for 2006.

Uncertainties in this study

IndEcol constructs the MRIO models using the Global Trade Analysis Project (GTAP) database, with figures from 2001 [5; https://www.gtap.agecon.purdue.edu/]. The GTAP is a collaboration of various institutions with the goal to construct and maintain a global database for economic modelling. The database contains input-output, bilateral trade, trade protection, energy, and other economic data for 87 world regions and 57 sectors. To understand the uncertainty in the GTAP database requires a brief description of how the GTAP database is constructed:

1. Input-output data is submitted by database contributors
    a. Contributions are voluntary and so the data can be rather old. For instance, Sweden is from 1985, most EU countries are from the early 1990's. The GTAP scales the data to match 2001 GDP in international dollars, which means the data has the *structure* of its base-year, but the *volume* of 2001.
    b. The uncertainty in the original data is not reported and different countries might have different "definitions" making comparisons difficult.
2. Input-output data is harmonized
    a. The data needs to be converted to the GTAP format. This requires various aggregations and disaggregations. Disaggregation is the main issue with some countries aggregated to as low as 20 sectors (Russia). Further disaggregations are performed in the food and agriculture sectors.
    b. The uncertainty introduced in the harmonization process is unknown

3. GTAP includes various additional data, such as trade and energy volumes, to update the input-output data
    a. Once all the data has been linked it has to be "calibrated" to obtain a global equilibrium.
    b. The uncertainty introduced in the balancing is unknown.
4. The CO_2 emissions data are derived from the energy data. GTAP assumed that each country had the same emission factors for fuel combustion. There were also several errors in the data.
    a. IndEcol updated most EU countries, Australia, China, Japan, and USA with more recent data. Using the updated information, some other data was corrected in other countries.
    b. The quality of the CO_2 data is poor and may vary 10-20% from other sources at the national level. Variations may be greater at the sector level.
5. For the projections to 2006, we simply scaled the GTAP trade data with SSB trade data from 2001 to 2006. There are inconsistencies between the GTAP and SSB trade data for 2001.

Thus, the GTAP database has considerable uncertainty, but it is unknown how big this uncertainty is (a common problem with economic data). IndEcol uses the GTAP database as a starting point to construct the MRIO model. This again introduces some additional uncertainty, but without knowing the uncertainty at the start it is not possible to assign uncertainties to the finished product.

Given all the steps in constructing the GTAP database and then converting into a model for LCA it is difficult to give an accurate measure of uncertainty. Given the steps above, it is understandable that one would be concerned about uncertainty. Yet, the GTAP data is at the core of most global economic models and is used by most international organisations. Put in other words, GTAP is widely accepted as a reputable data source for economic analysis.

Putting a measure on the uncertainty in GTAP is difficult. It is not possible to say "we are 95% confident the emissions lie between two values". However, it is possible to compare with other studies, other data sets, and other methods. In general most input-output based studies will use similar data and methods, meaning that there will be some agreement in the analysis. So while it is not possible to give a quantitative measure of uncertainty, it is possible to give a more qualitative description.

Comparisons of our results with other studies have shown reasonable agreement. For aggregated emissions embodied in trade, our results lie between the upper and lower estimates of an OECD study [6]. We recently updated the GTAP data with Norwegian data and found reasonable agreement with our previous work on Norway using a different database [7]. At the aggregate, similar studies using the same data have shown similar results [2]. In general, the rankings of sectors and countries in terms of clean to dirty producers roughly agree with expected results from, for example, LCA studies.

The aggregated results – national totals – are the most accurate since any "errors" average out. We have reasonable confidence that the national totals lies within about 10% of their expected values (noting that we use the manipulated GTAP data, and not country specific data, to construct national totals). At the more detailed level – such as individual sectors – there will be greater uncertainty. A comparison with other studies gives us reasonable confidence that *most* emission intensities are within approximately 25% of their expected values.

Apart from the uncertainty of individual data points, a big factor behind uncertainty in MRIO studies is *aggregation error*. Aggregation error arises since each sector represents a weighted average of the products produced in that sector in each country. For instance, the lumber sector includes various products such as railway ties, lumber and wood of different types, woodchips, plywood, panels, fibreboard, veneer, doors, windows, kitchenware, cork, seats, furniture, mattresses, sawdust, and so on. The "average" product in a sector will vary in different countries based on their product mix. The error in choosing a product that is not the "average" is known as aggregation error. Aggregation error occurs both when choosing a sector to analyse and from interindustry transactions in the production chain.

Due to aggregation error it is also difficult to compare products between countries. Countries have different product mixes and this, at times, may make comparisons between countries difficult. For instance, in the iron and steel sector Russia may produce primarily pig-iron, while Germany may import pig-iron and process it into high-grade steel. Thus, the emission intensity between Germany and Russia may vary, not just because of technology and energy mix differences, but because they have a different product mix within a sector. However, note that in the detailed MRIO model the emissions from the iron and steel sector in Germany include any pig-iron imported from Russia.

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[i] Source: European data from Eurostat Environmental Accounts (NAMEA data). China and India from Climate Analysis Indicators Tool (CAIT) Version 5.0. (Washington, DC: World Resources Institute, 2008, cait.wri.org).

[ii] As for monetary trade data, it is tempting to consider a CO_2 balance of exports minus imports. As an example, the CO_2 balance for Norway in 2001 is 36-29=7 Mt, that is, Norway has net CO_2 "exports" of 7 Mt CO_2. In this study we have estimated the emissions embodied in imports for 2006, but not the emissions embodied in exports for 2006, and consequently we do not have the net CO_2 balance for 2006. However, given that Norway's emissions have been relatively stable since 2001, it is likely that the emissions embodied in exports have not changed substantially suggesting that the trade balance has decreased (as imports have increased). A forthcoming

WWF-study will look at EU's CO_2 *balances* with each trading partner, see WWF (2008): "European Consumption, Global Pollution". In this study we have not focused on the CO_2 trade balance as it can be misleading since it may in certain cases cloud the issue of addressing "carbon leakage" - that a country's national CO_2 emission reductions are accompanied by increased emissions in other countries. A large exporter of CO_2 intensive products could import lots of CO_2 and still end up as a net exporter of CO_2. Norway is, in fact, precisely such a country. The CO_2 embodied in Norwegian exports stem largely from CO_2 intensive production of oil and gas and international shipping. As we have seen, Norway's net export of CO_2 in 2001 was 7 Mt. This does not, however, mean that Norway does not have a problem with carbon leakage in its efforts to reduce CO_2 emissions. Rather, it illustrates that Norway *in addition* faces a challenge in its export sectors when adapting to a future low carbon economy. Likewise, it would be natural for small countries with small resource bases, such as Japan, to be net importers of pollution.

[iii] Climate Analysis Indicators Tool (CAIT) Version 4.0. (Washington, DC: World Resources Institute, 2007).

[iv] Living Planet Report 2006 (WWF, Global Footprint Network, Zoological Society of London). In 2003 the biocapacity of the world is estimated to be 11.2 billion global hectares. This year, Norwegians consumed 5.8 per person, far above the 1.8 global hectares per person that would be sustainable globally. For the +2 billion people living in China and India consuming like Norwegians we would need more than 11.6 billion global hectares.

[v] Living Planet Report 2006

[vi] China provided approximately 1.3 % of GDP for R&D, €102 billion. (Overtaking Japan, being third after USA (ca. €248 billion) and EU-25 (1.9% of GDP, some €195 billion, in 2004). (Source: OECD 2006). Projected cumulative investments in China's energy-supply infrastructure is estimated to 3.7 trillion year-2006 dollars over the period 2006-2030, three quarters of which goes to the power sector (World Energy Outlook 2007).

[vii] Pan Yue, number one deputy director of the State Environmental Protection Agency (SEPA) became world famous for his statement "The [economic] miracle will end soon because the environment can not keep pace." (New Statesman, December 2006). See also Elizabeth Economy's analysis in Foreign Affairs Sept/Oct 2007: "The Great Leap Backward?".

[viii] All numbers in these paragraphs are from the International Energy Agency: *World Energy Outlook 2007*.

[ix] Peters, G.P. & Hertwich, E.G., CO_2 Embodied in International Trade with Implications for Global Climate Policy, *Environmental Science and Technology*, 2008. *Forthcoming*.

[x] Quoting Mr. Ma, chairman of the National Development and Reform Commission (the chief economic planning agency that also handles climate change). Financial Times (2007): "China puts growth ahead of climate change", June 4, 2007.

[xi] Quoting Mr. Ma, chairman of the National Development and Reform Commission. Source: "China urges rich nations to lead on climate", Financial Times, June 4, 2007. (The same quote also figures in the article above.)

[xii] Caution should be exercised with the projections for 2006 (ref. appendix with methodology). The projections assume that the production technologies and efficiencies have not improved between 2001 and 2006. This is a strong assumption; however, put in context, there are some advantages of using this assumption. The sector and region specific emission intensities are essentially used to weight the trade data to determine the emissions embodied in trade. Our assumption, essentially assumes that the emission intensity in each country and industry improves at the same rate, which is much weaker assumption. As a consequence of our assumption, when we consider the pie charts in the report, the percentages (location of import) are more reliable than the absolute emissions for 2006.

[xiii] The full list of developing countries we have been able to identify that receive direct, bilateral Norwegian development aid are the so called "partner countries for Norwegian development aid" (*samarbeidsland i norsk bistand*): Afghanistan, Angola, Bangladesh, China, East Timor, Eritrea, Ethiopia, Guatemala, Indonesia, Kenya, Madagascar, Malawi, Mali, Mozambique, Nepal, Nicaragua, Nigeria, Pakistan, Palestinian Territories, South Africa, Sri Lanka, Sudan, Tanzania, Uganda, Vietnam, Zambia. In addition comes direct bilateral support to countries in the Western Balkans and former Soviet republics considered legible for Overseas Development Aid (ODA) support by the OECD Development Assistance Committee: Albania, Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia, and Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kirgizstan, Moldova, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

[xiv] The projections from 2001 to 2006 are based on the trade flows weighted by the region and sector specific emission intensities. The projections assume that the emission intensities are constant at 2001 values. When considering the distribution of emissions between countries this assumption allows the emission intensities to change as long as the changes are uniform in each sector and region. For instance, if the difference between the emission intensity was a factor 2 between clothes and manufacturing in 2001, then we assume that it is still 2 in 2006. Likewise, if production in China is 5 times as emission intensive than Japan in 2001, then we assume the same in 2006. Thus, if the total imports from China increased by 10%, but the emissions embodied in imports increased 50%, then this would mean that relatively more pollution intensive products were imported. Likewise, if the total imports into Norway increase 10%, but in the projections the emissions increases by 40%, then this

shows that the import mix is more pollution intensive either by changes in the product mix or the country that produced the imports.

[xv] In their study "Too Good To Be True. The UK's Climate Change Record", Dieter Helm, Robin Smale and Jonathan Phillips note that "The UK has an increasing propensity to import from more greenhouse gas-intensive economies. 1n 1992, 15% of imports to the UK (in value terms) came from countries with higher than the world average greenhouse gas intensity, and these imports accounted for 45% of greenhouse gas imports. In 2006, 25% of imports came from countries with higher than the world average greenhouse gas intensity, accounting for 64% of greenhouse gas imports." (2007: p. 21).

[xvi] On the other side, one could argue that CO_2 embodied in Norwegian exports to the developing country in question should be subtracted from this. That would be reasonable on a level playing field. In this case, however, developed nations such as Norway are committed to caps on national emissions under the Kyoto Protocol, while developing nations are not since they have urgent development needs and historically have a small share in creating the global warming problem. In Kyoto Norway acknowledged responsibility and targets for reducing its national emissions, while recognizing the need of developing countries for support in tackling the climate change challenge. In line with this, we don't subtract emissions embodied in Norwegian exports to developing countries. (Ref. also footnote 2 above.)

[xvii] British Petroleum: Energy Statistic Review 2006.

[xviii] The two last sentences are paraphrasing James Martin, founder of the James Martin 21st-Century School at the University of Oxford: "The Meaning of the 21st Century", Transworld Publishers 2007.

[xix] See for instance: Wara, M., "Is the global carbon market working?" *Nature*, 2007, vol. 445, pp. 595-596.

[xx] Ben Garside, James MacGregor and Bill Vorley: "Miles better? How 'fair miles' stack up in the sustainable supermarket", Sustainable Development OPINION, International Institute for Environment and Development (IIED) December 2007.

[xxi] For a good overview of EU-China interdependencies and opportunities in the field of trade, energy and climate policy, see Chatham House (2007): "EU-China Interdependencies, Energy and Climate Security. Roundtable 1 December 2006."

[xxii] Note that the GTAP database does not allocate emissions occurring in transport to sectors and countries in a consistent manner. While the study includes CO_2 emissions from all forms of transportation, there is no guarantee that the emissions are correctly allocated to products or countries.

[xxiii] Caroline Saunders, Andrew Barber, Greg Taylor: "Food miles – Comparative Energy/Emissions Performance of New Zealand's Agriculture Industry, AERU Research Report 285/July 2006, Lincoln University. The Kenyan example is taken from WTO Director General Pascal lamy's speech at the Informal Trade Minister's Dialogue on Climate Change at the Bali summit (COP13) in Indonesia, 9 December 2007: "Doha could deliver double win for environment and trade".

[xxiv] Besides, to be consistent with the aim of promoting global low carbon development, a carbon tax system ought to in some way also provide "carbon rebates" to imported products with lower carbon intensity than the product has in the host country.

[xxv] Peters, G.P. & Hertwich, E.G., CO_2 Embodied in International Trade with Implications for Global Climate Policy, *Environmental Science and Technology*, 2008. *Forthcoming*.

[xxvi] Ref. "OECD in figures 2007".

[xxvii] Stern, N. (2006): "Stern Review: The Economics of Climate Change", HM Treasury, UK.