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Territorial sustainability footprint

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Abstract – The carbon footprint is allocated today to CO_2 emission sources, and thus to industries with smokestacks, machines with tailpipes or countries burning coal and oil; emission factors are also calculated, i.e. emissions per unit of production, of use, per capita or per unit of GDP. This is, however, not the only way to allocate emissions in a value chain and this could also be done at the source (cradle) of the carbon that will later end up being oxidized. Comparing countries with this new metrics points to fossil fuel producers as the major "cradle producers" of CO_2, thus giving a fairly different geopolitical view of the "polluting" world. Beyond issues of responsibilities, related to *the polluter pays* principle, this new method can help exhibit solutions for mitigating emissions that usually are not imagined or discussed, and examples thereof are given.

There are many boundary issues related to measuring the sustainability footprint of human activities, and the present paper is a crude attempt at discussing some of them. Space and time are at stake on an equal footing, but the focus here will be mainly on spatial issues and will use Global Warming as an example.

Most of the discussions on Global Warming today are handled at three levels:

- at a political level, the system under consideration is the country and the focus is usually on GHG emitters: emissions are expressed in terms of absolute quantities of CO_2 equivalent, or are normalized by the population (CO_{2eq}/capita) or by the GDP (CO_{2eq}/PIB). This is in line with the fact that countries have been in charge of framing climate policies, of setting directions and targets and of making commitments inside the world governance system set up under the UNFCC;
- at a business level, economic sectors are also getting involved in sectoral approaches, where inventories are carried out, best practices pointed out and new technologies outlined in technological roadmaps. Targets and commitments could also be set at a sectoral level, although this is not very common yet. The system would then be the steel sector, worldwide, or the power generation sector. The unit of reporting would then be CO_{2eq} or GJ per ton of steel or per kWh;
- a more transversal approach, based on the value chain of manufacturing or service activities and on the life cycle of products. In this case, we are cutting across political and business boundaries: the unit of reporting would then be, for example, CO_{2eq}/100 000 miles of travel by car.

The territorial definition of a country, in the above case, is a country made of consumers. GHG emissions are accounted for, as long as they have been released to the atmosphere. This seems to make some sense, from the standpoint of the physics of Climate Change, but this physical dimension is actually somewhat irrelevant as the issue is one of responsibility – not the responsibility for polluting, but the responsibility for looking for solutions to cut emissions and thus bring Climate Change under control.

This kind of responsibility can be allocated to any of the players in the life cycle – from cradle to grave or from well to wheel, or to any of the powers that be – and that can direct to various ways of solving the problem.

The responsibility discussed here ceases to be only an ethical one when large amounts

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of money are attached to it, such as a carbon tax or emission rights. The carbon market, assuming a value of CO_2 of 15 €/t, and anthropogenic emissions of 27 Gt/year, is already potentially worth 400 G€, i.e. the GDP of an economy the size of Australia; at 150 €/t, it would become larger than Japan's! No small amount, especially if some of this money is devoted to developing new green technologies and to jump-starting their initial deployment.

Countries which are large energy producers, especially large energy exporters, have been aware of this responsibility and some have attempted to assuage it by launching programs that deal with the issue: Norway, for example, the largest oil producer in Western Europe, has announced that it will become carbon-neutral as an emitting country by 2030; Australia has launched an organization called the Global CCS Institute, which aims at accelerating the development of CCS at a world level. Other countries, in the Gulf for example, have been consistently voting in international institutions on the side of climate sceptics and have acted to delay setting international targets on mitigation levels.

In terms of money creation, the growth of the carbon market should eventually have the effect of moving the energy rent, mostly the oil rent today, from oil-producing countries to oil-burning countries, by transforming it in the process into a carbon value.

However, this is mainly due to the fact that the carbon value is implicitly generated in the country where CO_2 is spewed out of the smoke stacks or of the tailpipes.

There are other options, which will be analyzed in this paper.

1 Virtual CO_2 emissions

In the analysis presented here, we are taking a different viewpoint from today's mainstream analysis and focusing on the cradle side of the life cycle: we are thus discussing the virtual CO_2 emissions of a coal mine or of an oil field, i.e. allocating to the mine or the field all the emissions that will originate from burning the coal or the oil – or, more precisely oxidizing them, wherever this happens in the world. We are not discussing the use of fossil fuels as feedstock for the chemical industry, which would require a more complex development which is not necessary here, given the focus of this work on allocation methodologies, not on policy-making.

This is in essence contrasting virtual emissions against "real" ones, i.e. true or physical ones, or cradle emissions against smokestack or tailpipe ones.

The analysis is simple to do and was carried out for coal, oil and natural gas, based on production and consumption data per country and on the conversion of coal, oil or gas into CO_2, using emission factors. All data are from 2006, unless specified otherwise.

2 Coal-related CO_2 emissions

Coal production and consumption are shown in Figure 1. China dwarfs all the other players and more or less balances out production and consumption. The US and India come next and also consume their own production. The next in row are large exporters, such as Russia, South Africa, Indonesia, Poland, Kazakhstan, etc. Germany, at rank 8, breaks away from this pattern due to the strength of its industrial sector and therefore to its coal imports. The classification of producers and consumers introduces a dual path in the list behind the first three players, China, the US and India.

Figure 2 projects the same message as the previous graph, corrected by the emission factor of the coal mix and translated into CO_2 volume[1]. Some countries are net exporters of CO_2 (India, Australia, South Africa, Indonesia, etc.), while others are importers (China, Germany). China remains self-centered on its own, enormous needs.

If coal miners considered it their responsibility to deal with the Climate Change threat, what would they do? They could acquire emission rights and attach them to coal in commercial transactions, at a price certainly. They could also move to cut the carbon content of coal, not such a paradoxical solution as it sounds: coal to liquid technology, which carries a hefty cost, would

[1] 2.1 t of CO_2 per ton of anthracite and 1.1 t for lignite (brown coal).

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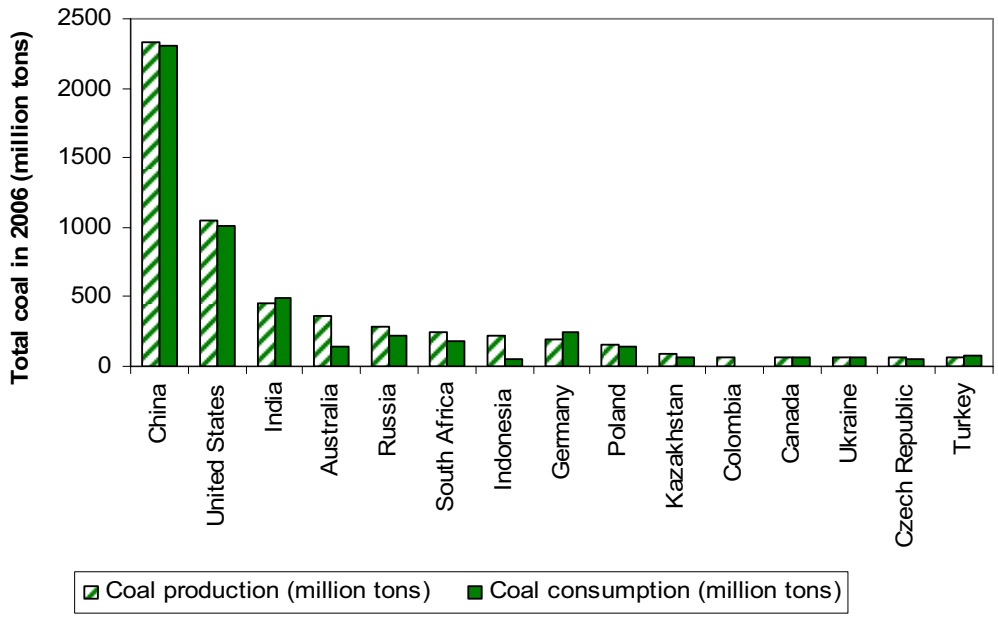


Fig. 1. Coal producers (up to rank 15 in the world) and coal consumers, ranked in order of decreasing production.

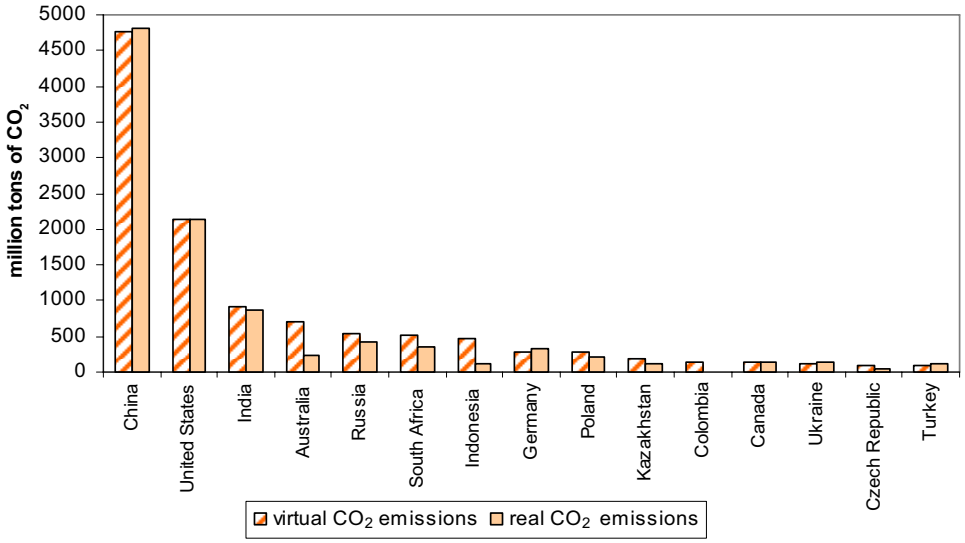


Fig. 2. Virtual vs. real CO_2 emissions originating from coal.

be one solution in which some of the carbon would be replaced by hydrogen; coal gasification would be another solution; it could be shifted completely to producing pure hydrogen. Of course, all these operations would need to be compensated for in terms of CO_2 emissions, most effectively by removing them from the anthroposphere through CO_2 Capture and Storage (CCS). This would be a major shift from the way that CCS is considered today, as the technology would move away from energy-consuming economies to energy-producing ones. Moneywise, the oil rent would still be waning, but the carbon rent that replaces it would stay in the producer countries.

These solutions are in no way simple to implement and it might be quite unrealistic even to imagine doing this, especially in terms of cost: one issue, actually, is where

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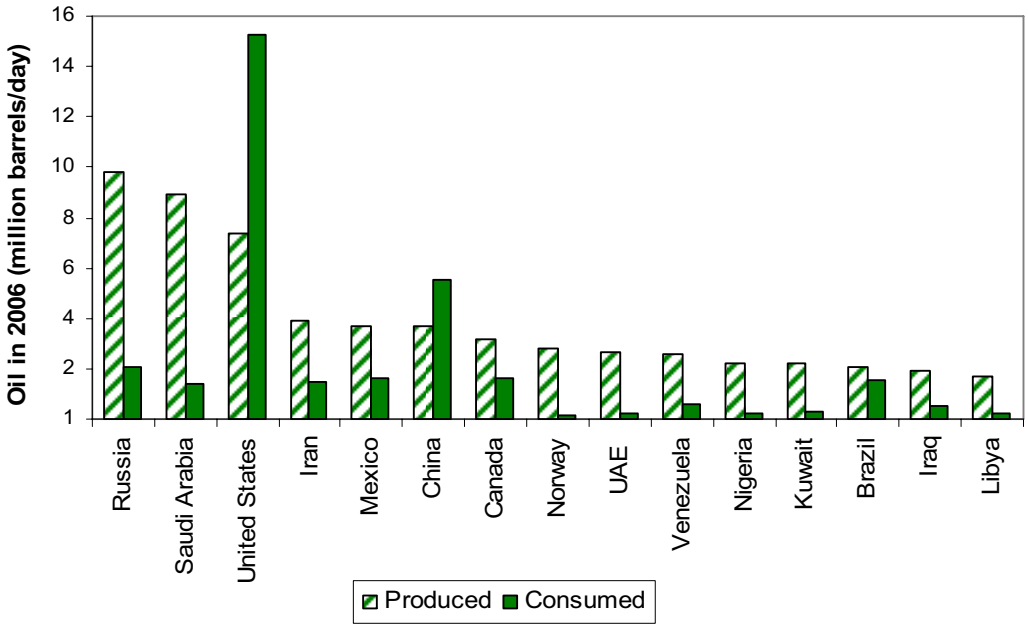


Fig. 3. Oil producers (up to rank 15 in the world) and oil consumers, ranked in order of decreasing production.

CCS would be most effective, at the source of coal production or at the spot of CO_2 generation – very much of an open question without further analysis. Other solutions would consist of producing electricity locally and exporting it rather than hydrogen; not a winning option, though, with today's technology that has no large-scale solution for storing electricity.

As a matter of fact, large coal producers such as Rio Tinto in Australia have a policy in connection with Climate Change, which they relate to their social responsibility as a business [1].

3 Oil-related CO_2 emissions

A parallel analysis was carried out below for oil, with the results shown in Figures 3 and 4. Tons of coal are now replaced by barrels of oil.

Compared with the previous section, the rank of countries has now been reshuffled to show oil wealth and the overall picture is quite different in many ways from that of coal. Russia and Saudi Arabia stand in first place as producers, followed by the US, Iran, Mexico, etc. The exact balance of consumption and production is a rare case for oil (Indonesia, not shown in the graph), as it is intrinsically easier to move than coal due to its physical state and to its price and is therefore the privileged access to energy of most economies. Except for the US and China, which are large producers but even larger consumers, countries split up into producer or consumer families.

Note that apart from the very large producers, CO_2 exporting countries – in the particular sense of the present analysis – are contributing an order of magnitude of 500 Mt per year, similar to that of coal exports.

In the case of oil, countermeasures to exporting CO_2 are the same as for coal: emission rights or hydrogen enrichment of the fuel, all the way to pure hydrogen.

4 Natural gas-related CO_2 emissions

A parallel analysis was carried out below for natural gas, with the results shown in Figures 5 and 6. The unit is now millions of cubic meters of natural gas.

Russia and the US are the largest gas producers, with Russia exporting heavily, while the US needs to complement its production by imports. Most other countries exhibit a

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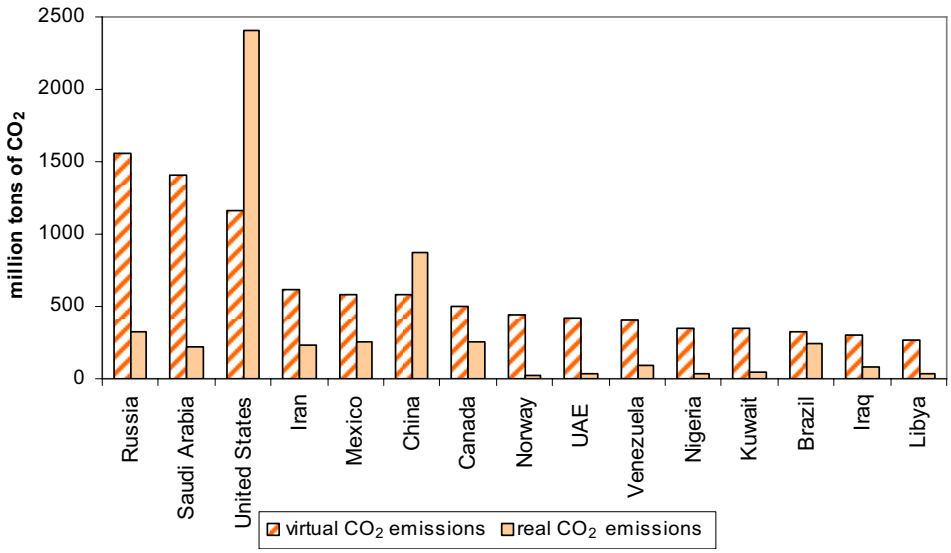


Fig. 4. Virtual vs. real CO_2 emissions originating from oil.

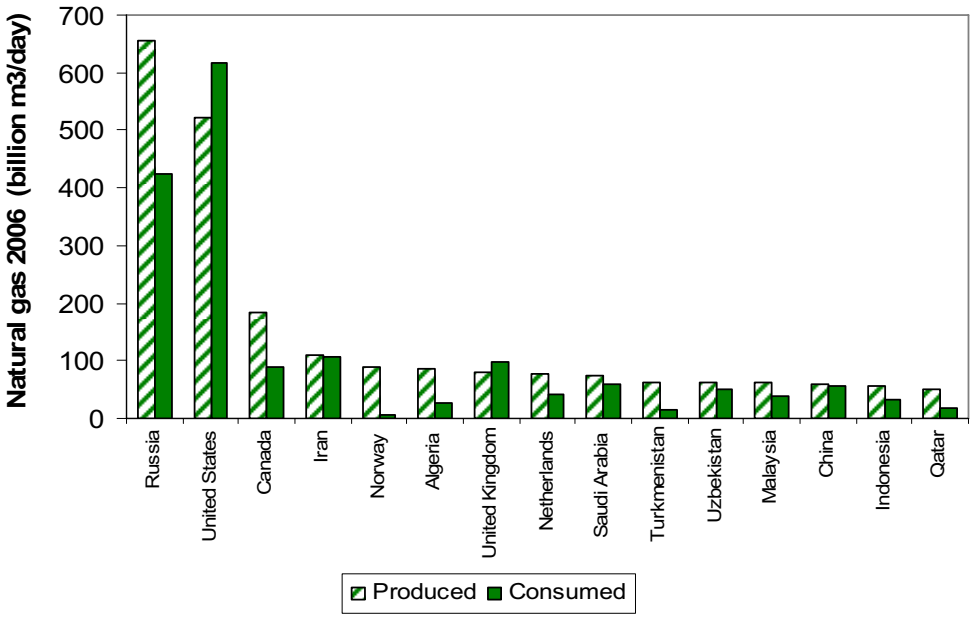


Fig. 5. Gas producers (up to rank 15 in the world) and gas consumers, ranked in order of decreasing production.

split between producers and consumers, as was the case for oil, with exceptions such as Iran, the UK or China. The distinction between importers and exporters of CO_2 is therefore rather strong in this case again.

Note that, apart from the very large producers, CO_2 exporting countries are contributing an order of magnitude of 200 Mt per year, two times less than that of oil and coal exports.

Local production of hydrogen would be an option to avoid exporting virtual CO_2 from producing countries.

5 Overall CO_2 emissions generated from fossil fuels

Adding up all CO_2 emissions from the three kinds of fossil fuels leads to the results

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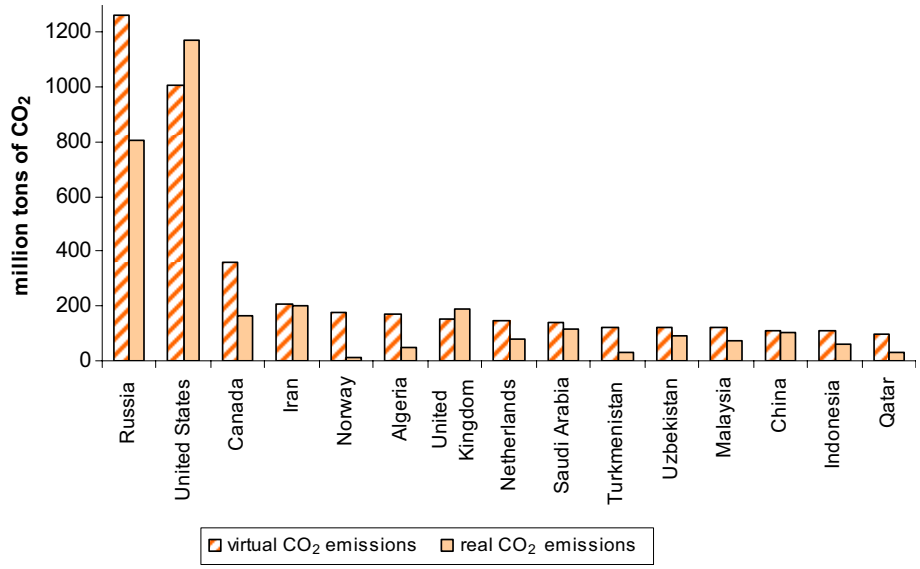


Fig. 6. Virtual vs. real CO_2 emissions originating from natural gas.

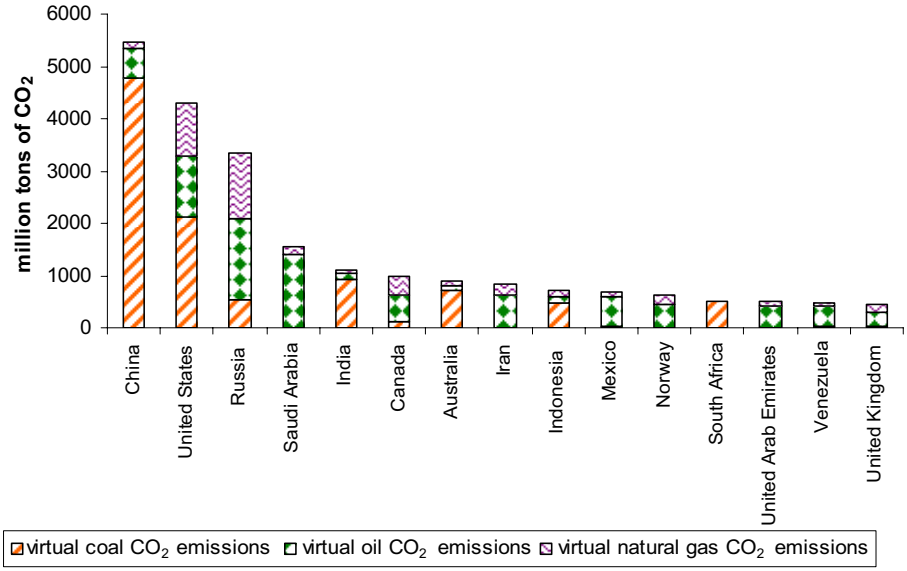


Fig. 7. Virtual CO_2 emissions originating from fossil fuels.

shown in Figures 7 and 8, with the volume of CO_2 as the common yardstick.

This presentation brings to the fore the major producers of coal and oil, with China standing out as number 1 as a "raw" CO_2 producer, but as number 2 still in 2006 as a consumer-emitter. Then countries remain split behind the two roles.

Now, one can question the relevance of confronting these two allocations of emissions: all CO_2 eventually ends up in the atmosphere and contributes equally to Climate Change. The distinction has been introduced with LCT in mind, where the approach avoids shifting emissions from one life cycle phase to another and thus to optimize the whole LC and therefore cut emissions. It is not clear that this kind of optimization can be accomplished by putting the emission burden on the shoulders of the energy resource producer rather than on those of the consumer, but it might happen

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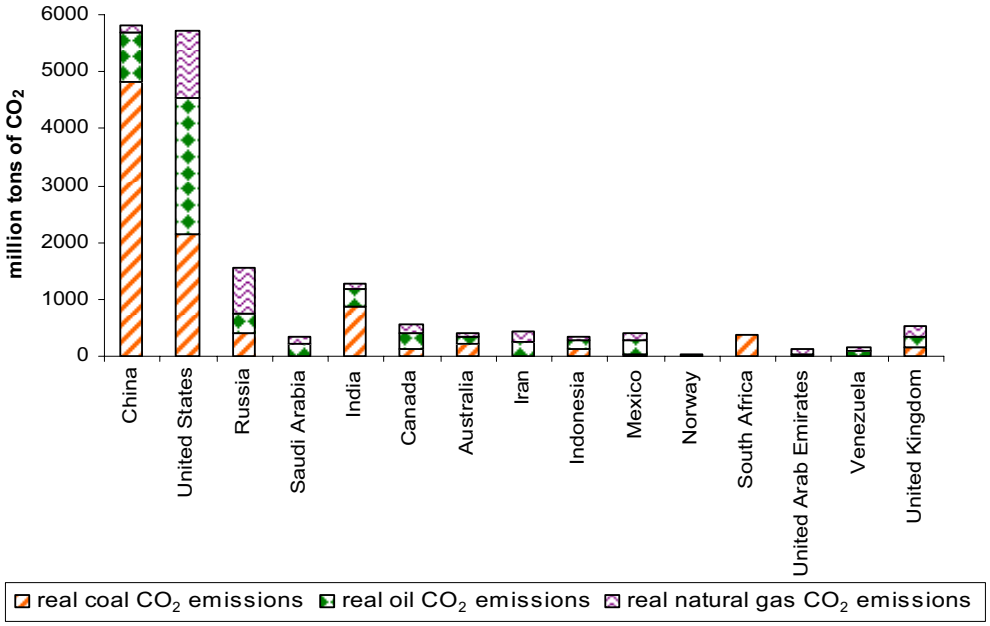


Fig. 8. Real CO_2 emissions originating from fossil fuels.

in some cases: applying CCS at the source, for example, is a kind of pre-combustion capture extended at a geographical rather than a process level and it might be an effective way to optimize the system. On the other hand, the virtue of this approach would also lie in turning the energy resource producers into active players in the search for green technologies. Last and probably not least, it would redistribute carbon money among countries in a different way.

In contrast to the international trade based on fossil fuels that we experience today, we might shift towards a world where a hydrogen grid or an interconnected electrical grid would emerge as the main highways for moving energy around. Such a system would actually make some room for renewable energy and nuclear power and thus integrate the fossil fuel resource producers into this extended system.

6 Per capita overall CO_2 emissions generated from fossil fuels, etc.

Emissions are often analyzed per capita in an attempt to separate the influence of the size of an economy from that of its population, i.e. from the wealth and well-being of people. The corresponding results aggregated for all fossil fuels are shown in Figure 9.

This kind of presentation does not seem relevant for our purpose in this paper. It points out that oil-rich countries usually export their oil or gas in large volumes, often thus generating revenue for a small population: this is true in the Gulf, with Qatar, Kuwait, the UAE, etc. and in Europe with Norway. This in a way is also saying that the revenue is generated by exporting CO_2, as long as this statement is not understood as an ethical one. Qatar, for example, exports 200 t of CO_2 per capita, which the consumer in another country will have to compensate for at, say, a cost of 50 €/t, or to the level of 10 000 €/capita.

Another presentation, shown in Figure 10, relates CO_2 emissions to GDP. The analysis then focuses on the dependency of a national economy on the availability of fossil fuel resources, which is also not a relevant matter in our discussion here. It also brings to the fore poor countries in terms of GDP, which is again not at the core of our analysis here. It would be a different matter if we were discussing *intensity of use*, but we have not led the discussion in this direction.

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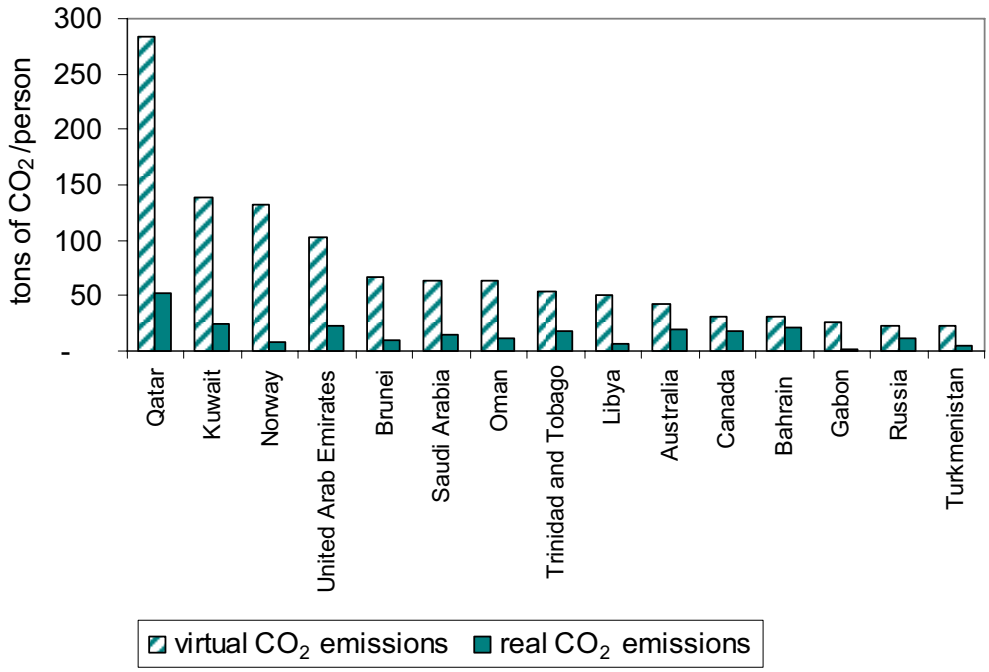


Fig. 9. CO_2 emissions originating from fossil fuels per capita.

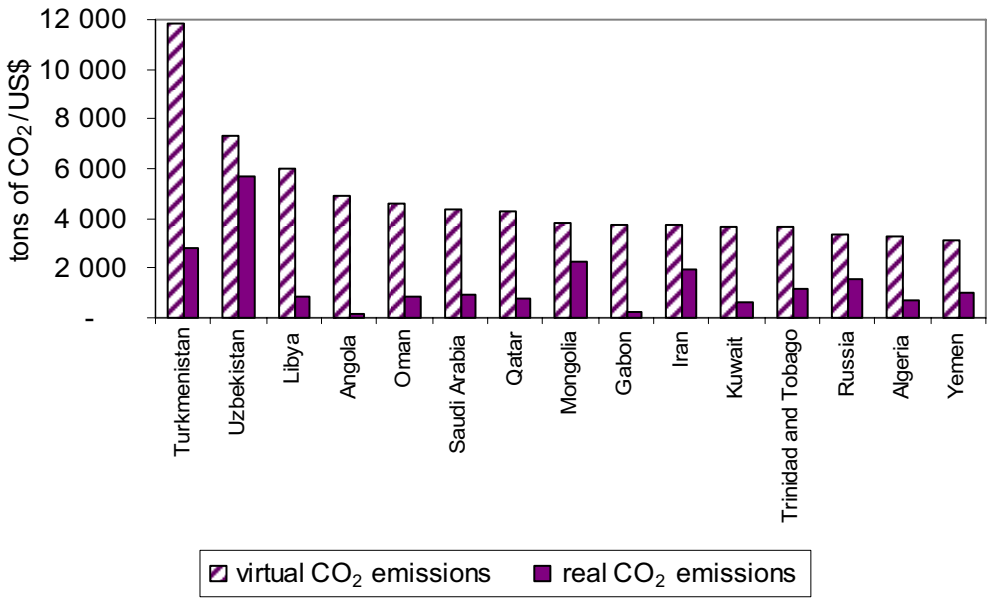


Fig. 10. CO_2 emissions originating from fossil fuels per unit of GDP.

7 Conclusions

The exercise carried out in this paper consisted of experimenting with novel ways of allocating CO_2 emissions to countries. Usually, CO_2 emissions are allocated to the physical emission, smokestack or tailpipe. From a Life Cycle Thinking (LCT) perspective, this sounds like a restrictive choice and we have therefore tried to take a completely different approach by allocating the CO_2 burden to the cradle (the producers of the fossil fuel resource) rather than the grave, the wheel, the stack or the end of the pipe.

This of course gives a completely different geopolitical picture of the world. In

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addition to CO_2 emitters, we have now exhibited a new kind of international player, the virtual CO_2 exporters. The point is not to put any blame on them, but rather to enrol them as active players in the search for green technologies.

In a practical way, this might lead to a new organization of the fight against climate change, with, for example, CO_2 captured and stored close to coal mines and oil and gas fields and a green energy vector traded internationally. This is a conceptual repackaging of the hydrogen economy or of the electricity economy.

The financial consequences of this kind of approach would also be significant, as the carbon money would be handled in energy-producing countries rather than in consuming countries.

However, the real purpose of this paper was not to propose new paradigms for policy-making, but rather to point out that the system in which GHG emission data can be collected is not unique. A geography-based allocation approach is being explored in territorial carbon footprint methodology, a new field that is feeling its way towards original and interesting answers.

For example, on a territory, one can think in terms of residents and of travellers passing through, a kind of stock or flow approach, or of Eulerian vs. Lagrangian description. Both approaches are possible but they lead to different results that emphasize different mitigation solutions: as Climate Change and more generally Sustainability require original and complementary solutions, this may be a way of exhibiting novel ones!

We shall be exploring these avenues in the future.

This type of allocation of CO_2 at the cradle rather than at the smokestack/tailpipe is not radically new and comes up when new large-scale investment involving fossil fuel traded at an international level comes up and asks for permits to operate. The Keystone pipeline project [2] has raised strong objections from Green demonstrators in the US, on the basis of an analysis similar to the one we have proposed here; idem for the Wandoan Mine of Xtrata [3].

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[1] http://www.riotintocoalaustralia.com.au/1995.asp

[2] http://www.transcanada.com/keystone.html

[3] http://indymedia.org.au/2011/03/02/legal-challenge-against-new-xstrata-coal-mine-at-wandoan

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