Development of Input indicators based on extraction equipments

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Abstract

Extractors are defined as all human tools enabling extraction of materials (including air and water) from their natural state. These include excavators, explosives, dredgers, tractors and tillage tools, pumps and dams, forestry engines, oil and gas wells, fishing nets & firearms, leisure vehicles...

Over human history extractors have been associated with the development of material extraction, culminating in modern history with the development of combustion engines and explosives. As extractors initiate extractions, their study could serve as basis for the evaluation of amounts of materials moved in a given region or activity.

The paper explores the methodology of the study of extractors in order to:

- Support data on Total Material Input for the calculation of direct material consumption and hidden flows: data on vehicles are used to obtain data on CO2 emissions. In the same manner, data on excavators would be used to obtain data on tons of earth moved.
- Develop a new streamlined extractors-based indicator, setting then goals to really reduce the level of extractors use in regions or to fulfil certain tasks.

Different examples of extractors are studied, and the potential benefits and drawbacks of the use of extractors-based indicators are discussed.

1 Introduction

Coal fire plants, cars or trucks or explosives are well known *emitters* of pollutants into the environment. It is generally acknowledged that inventory of pollutant emissions can be obtained with data on the number of emitters, their level of use, and their rate of emissions. It is also acknowledged that reducing the number of emitters would have an effect on the general level of emissions. The same approach at the level of inputs from the environment is developed here.
Extraction engines and mining explosives are e*xtractors* of materials from the environment. The amounts of materials extracted from the environment by different human activities are usually not obtained from information on these agents of extraction. Our expectation is that the information on the population of these tools could be very useful to calculate the contribution of regions, companies or whatever activity to the extraction of total materials and specific substances. This data could also represent an interesting base of information on future trends and support the development of strategies towards more sustainable human societies.

We present here a first exploration of this concept for the potential in MFA.

2 Perspective on extraction and tools for extraction –

Extractors were and are fundamental to extraction.

2.1 Before Watt's invention

Extraction has always been part of human activities. But it was only with the development of tools for extraction (extractors) that humans really became important modifiers of their environment. In Palaeolithic times, primitive extraction tools made of stone, bone and wood were used for digging plants, for construction and for

mining. Earth moving and general resource extractions remained on a rather low scale. Around 9000 years ago, agriculture and mud constructions developed with the creation of wooden and stone tools. Though it was with the invention of bronze and iron melting that humans could gradually succeed on important road and city building, canal digging and larger agricultural activities. Tools used included hoes, spades, pikes, hammers, chisels, rakes, towels, and ploughs. Animal-drawn blades and scoops were also used. In roman times simple machines were developed to ventilate, pump, or to lift rocks.
According to Hooke (2000) until the invention of steam engine, intentional movements of material are negligible compared to the unintentional earth movements linked to cropland and pastures (erosion). It may be said that at this time the vast majority of material used reintegrated natural cycles over a short period of time.

2.2 After Watt's invention

A very important development occurred at the beginning of the 19th century with the invention of steam power engines, creating an added need for coal mining as well the mechanised means to achieve further excavations. The development of excavators and explosives may be viewed as the fundamental spark enabling a large-scale industrial revolution. With new extractive tools it has been possible to go beyond the limits of human physical strength and of animal, wind or waterpower (Schmidt-Bleek 1994). Machines more and more efficient at moving earth have been developed. An impressive example is the bucket wheel excavator operated by 5 people, developed in West Germany weighting 14,000 t and excavating daily 240,000 m3 of material (Grimshaw 1985). In short it was in our recent history, with the developments of machines in the last 200 years, that humans substantially developed the level of resource extraction. Nowadays most of extractions are the result of machines based on the internal combustion engine and explosives.

2.3 Wealth with extractors

Extraction and extractors are fundamentally linked to modern human activities. Today powered extraction tools and explosives are fundamental to the development of many human activities. The application of digging engines range from building and construction to the creation of transportation features such as roads, railways and airports; they enable public services such as reservoirs and pipelines. Dredgers and bulldozers enable the construction and maintenance of harbours and canals. Excavators and explosives are vital for mining coal and other minerals such as bauxite, copper and iron ore; they excavate building materials, including limestone for cement, clay for bricks, sand and gravel (Grimshaw 1985). They enable the construction of energy infrastructure like dams, underground cable or pylons for the transport of electricity. Oil and gas wells, built with the help of excavators and forage machinery, enable the extraction of oil and gas throughout the world
Excavators carry out agricultural work including irrigation systems and fertilizer production while tractors and additional tools enable the tillage and soil preparation. Excavators enable the construction of forest roads, while chain saws and trucks permit the extraction of wooden resources. Fishing boats and nets enable the harvest of fish resources from the world water bodies.

2.4 Impacts with Extractors

However this level of extraction of materials is unsustainable. And this is especially preoccupying when we are aware that 80% of the world, the so called "underdeveloped" world, intend to follow the OECD consumption patterns, currently responsible for the largest share of the world's extractions.
Hooke (2000) estimated that the total earth moved in the last 5000 years (including erosion linked to agriculture) would be sufficient to build a 4000 m high mountain range 40 km wide and 100 km long. If the current rate of increase persists, another identical mountain will be built in the next 100 years. There are two reasons for this astonishing increase: the rise of the world population and the development of technologies. Douglas & Lawson 1997 estimated that the disturbance by human activities may be as high as 3 orders of magnitude greater than the rate of operation of natural geomorphic processes. While not yet approaching the effect of rivers and glaciers over millions of years, today's excavators can literally move mountains in an unprecedented way in geologic history (Hooke 2000).
A large share of the materials extracted is transformed in such a way that it cannot easily integrate back the natural cycles. It contributes to a fast increase of the world's entropy.
The most direct problems associated to extractions are the loss of productive land, degradation of scenic beauty, fragmentation and disturbance of habitats, and increased pressure on biodiversity (Mathews et al. 2000). High-level extractive capacities may create a shortage in a large array of materials at medium to short term or for future generations. As material stocks grow, so do the potential future waste volumes and emissions [Schmidt-Bleek 1994]. This means that the most important and really preventive measure for environmental impacts requires some reduction of extraction i.e. reduction in the use of extractors.

2.5 A dematerialised wealth or wealth with less extractors

Are we ineluctably bound to generate high level of extractions in order to create wealth in our societies? More and more specialists think that such fatalism is unnecessary.
To prevent environmental problems, new systems are developing and new visions have appeared stating that welfare could also exist with much less material use (dematerialisation) and much less toxic flows (detoxification).

With improved design for cities, transport, companies, lifestyles and products, societies can use existing stocks of materials and use them far more efficiently (Worldwatch 2003).

- Cities represent a very large stock of materials to be reused. Stocks of many minerals are now higher than the estimated remaining reserves
- Redesigning transport system in order to centralise the use of materials can have an important impact on the infrastructure building and the levels of reuse.
- Companies can manage better raw and auxiliary materials use (good management practices);
- Consumers can be taught to consume more according to their real needs and with ethical and environmental criteria (sustainable consumption);
- Products can be built with less or different materials incorporated, last longer and consume less during use time (ecodesign);

- Better extraction practices can be developed, especially reversing the trends of using low-grade ores and open pits
- Less substances leading to specific environmental impacts, like chlorinated compounds and Cadmium, could be used

All these measures would ultimately result in a dramatic reduction of the extraction of virgin resources; and since extraction is linked to the use of extractors, this would mean a reduction of the use of extractors.

3 Extraction and extractors

3.1 Definition

Extraction is defined here as removal of material[1] away from their natural state. It includes extraction of ores, soil, fossil resources, wild animals, water for agricultural, industrial or domestic uses and gases like oxygen and nitrogen.
Extractors are defined as all human tools enabling the extraction of materials (including air and water) from their natural state. These include excavators, explosives, dredgers, tractors and tillage tools, pumps and dams, forestry engines, oil and gas wells, fishing nets & firearms, leisure vehicles, haber-bosh process to extract nitrogen. Also all combustion processes extract oxygen from air (these examples will be further developed in 3.3).

3.2 Types of extraction

Extractor move materials voluntarily. But an unintentional extraction will also occur under the action of eroding elements like water and wind which would not occur if the soil was not modified in the first place by extractors. This is the unintentional action of extractors. This secondary extraction exists with basically all extractors but it especially has a large recognised importance in agriculture and in infrastructure building. Douglas & Lawson 1997 mention a study in Malaysia where sediment removal by streams affected by urban construction is more than 40 times higher than streams in natural forest.

Materials extracted voluntarily include materials that acquire an economic value: Used Flows. These comprehend all the materials – domestic and imported - that are used for production including agricultural harvest, minerals, fossil fuels, fish and wood.
But extractors also extract materials that will never acquire value: Unused flows or Hidden Flows. These include the unintentional extractions (erosion) but also intentional extractions like vegetation scraping, overburden and earth moved in agriculture. They are all the materials moved in mining, construction, agriculture, dredging and other activities, that have no monetary value in the economic system.

Another characteristic of extracted materials is their physical state. One often thinks of solids like ores and earth but we should not forget air and water which amount for large quantities.

[1] The concept could be extented to energy and space, but we limit our focus on materials in this paper

3.3 Extractors' types

The following table gives a small overview of the sectors based on extractions, the material moved, the extractors involved in each sectors and other possibly interesting data.

Table 1: Association between material moved and extractors by activity sector

	Unused Extraction	**Used Extraction**	**Other Material moved**	**Primary extractors**	**Secondary extractors**
Agriculture	Earth ploughed	Agricultural products	Water	Tillage tools, pumps	Tractors
Dredging	Material dredged	Sand		Dredgers	
Mineral Extraction	Overburden, vegetation cover	minerals		Explosives & Digging engines	Other engines
Leisure	Soil	Wild game		Cross-country vehicle and firearms	
Forestry	Vegetation	Wood		Forestry engines	Forestry trucks
Infrastructure creation	Soil, vegetation cover			Explosives & Digging engines	Other engines
Energy	Overburden, vegetation cover	Petrol, Coal, Gas	Water, O2	Oil and gas wells, Explosives & Digging engines, Dams	
Fishing	Discarded sea resources	Sea resources		Nets and other fishing equipment	Fishing boats
Air extractors			N2, O2	HaberBosh process Combustion engines and other processes	

- The main extraction in agriculture is done ploughing the soil with heavy machinery. Agriculture has an important responsibility in water extraction with the direct use of pumps.
- Dredgers are involved in canals and rivers as well as in harbours.
- Mineral extraction is done with digging engines and explosives. The situation is very different in the case of open-pit mining or underground mining.
- Leisure activities also involve extraction but are rarely studied. Direct statistics on earth moving by these activities is has not been found. Data on cross-country vehicles (including cars and motorbikes) would be a good base of information.
- Forestry involves the use of chain saws or more elaborated tools. Trucks are used to carry logs.
- Surface scraping, levelling and digging for foundations in order to create either transport infrastructure or buildings involve excavators and explosives as well as other secondary-extracting agents.

- The energy sector involves very different types of extractors. Coal and uranium involves the same extractors as mineral mining. Dam building is a special case of infrastructure building. Oil and gas extraction involves forage and wells. In comparison with these extractors, the impact of solar and wind energy is very limited in terms of material extraction.
- Fishing involves nets and other fishing equipments as well as boats.
- Air extraction is a special case. The extraction of nitrogen from air to produce N-chemicals is the perfect example of an extraction causing much environmental problem but no material shortage since nitrogen is the most abundant gas in the atmosphere. Ester van der Voet has shown that the transformation of N_2 into fertilizers was the main ultimate origin of NH_3 acidic depositions and accumulation of nitrate in groundwater and costal waters. As anthropogenic activity has doubled the global rate of nitrogen fixation, the extensive use of nitrogen-based chemicals is affecting the fragile equilibrium of Nitrogen cycles. N-chemicals accumulate without capacity of the denitrifying bacteria to cope with them closing the cycles. Ninety per cent of the ammonia produced in the world is ultimately used as fertilizer. The use of nitrogen as explosive is another aspect leading to tremendous environmental consequences. Identifying the extractor N_2 is quite straightforward because ammonia is an intermediate for all nitrogen chemicals and Ammonia is virtually entirely produced through the so-called Haber-Bosh process.

- The extraction of oxygen by combustion is a very important extraction, done by a very large variety of processes and engines. However it is very linked to the energy use indicator, and can be approached by other means than extractors analysis, especially with the data on the use of combustibles. These extractors are considered here for completeness.

- One could also add the military weapons as extractors. The recent heavy bombing in former-Yugoslavia and Iraq have obviously had an important extractive capacity. We touch here an aspect that is slightly different, as most built weapons (especially atomic bomb) are not used in "normal activities" and are hopefully not going to be used. These are potential extractors.

4 MFA -Material Flow Analysis-

MFA combine information from different statistics (production, trade, environmental data etc.) and from direct data gathered into a coherent framework establishing a structured database that is used to derive indicators of progress towards sustainability. This information basis can also be used as a physical account for integrated and environmental reporting [Bringezu *et. al.*, 1998].

4.1 Substance Flow Analysis

Concerned with the "detoxification" of the economy and management of substance flows the Substance Flow Analysis (SFA) are methodologies that systematically organise and analyse data concerning the flows of a substance or a group of substance in a given region and time (a year generally).The general objective of SFA is to

deliver information about the management of specific pollutants at the level of region like actions and policies to improve the environmental situation.
Three types of analysis are possible: Accounting, static modelling and dynamic modelling (Van der VOET (96)).

The main discovery of SFA has been that emission prevention will not solve the problems of environmental pressure. As inflow always equals outflow the only way to reduce the outflow to the environment is to reduce the inflow from the environment to the society. This is exactly where the study of extractors can intervene in a fruitful manner.

SFA can benefit from the study of extractors at three levels:

- help gathering data at the level of environmental inputs into the region
- development of substance input indicators
- development of policies based on the reduction of extractors use

Help gathering data at the level of environmental inputs into the region
The study on extractors at the level of a specific process or activity can help gathering data. Every time we study an activity we also know what type of material is extracted and through the specificities of extractors, the amounts extracted may be derived. Knowledge on pumps use and capacities can bring knowledge on water flows.

Development of substance input indicators
SFA can be used to develop indicators based on flows of certain substance and especially relevant are the indicators based on the extraction from the environment of given substances. For this data on extractions at the level of activities, companies can be useful to develop this type of input indicator.

Development of policies based on the reduction of extractors use
In order to tackle a problem linked to a given substance, the study of extractors might give possibilities of preventive policies, as the link to the tools for extractions would be very obvious. Very often SFA lead to complicated data on the flow of substances which are not always easy to translate into efficient policies because the action needed is not clear when we only deal with tons of substance. The link with extractors has the potential to turn the reality more obvious for politicians as we are touching something more concrete.

4.2 Total Mass Flows Analysis

Total Mass Flows analyses are concerned with the volume and structure of the total system throughput. Bulk MFA may be applied at the level of Products or services or at the level of regions (generally a country). In Bulk-MFA as well as in SFA, the studies performed have made us realise the fundamental importance of the input side.

Schmidt-Bleek developed the idea that it is essential to look at the total amount of material extracted from the ecosphere. This vision aims to reduce all types of environmental impacts. As an input indicator, the Total Material Input provides an effective link to the root cause of impacts. Only if we can reduce inputs we will be able to reduce the outputs and the associated ecological consequences (on source and

final destination). Their relative simplicity makes these indicators good candidates for the evaluation of complex systems.
The MIPS, Material Inputs Per Unit of Service, compiles all materials used linked to a given product or service from cradle to grave, that is from the extraction of virgin resources until the final waste treatment. All the processes of Regional bulk MFA are linked to the assessment of material flows in the perspective of the society metabolism.

The study of extractors can intervene in a fruitful manner for inputs based Bulk-MFA:

- by helping data gathering
- development of indicators based on the study of extractors
- for the development of environmental sustainability policies based on the reduction of extraction

The study of extractors can support and complement the analysis of total material movements.

Data gathering
Aside other sources, data gathering can benefit of the study of extractors at the level of enterprises but also at the level of national statistics (number of tractors, number of explosives etc.). Following the development of a factor of extraction (amount of extraction for the specific extractor) we can calculate the total extraction of one or all the Extractors for given time (e.g. one year).

Development of indicators based on the study of extractors

The amount of extraction would include information on used and unused flows. That value of extraction can be expressed in two ways depending on the use we want to make of the indicators:

- extractive capacity
- extractive potential

Extractive Capacity
Each extraction equipment has a given capacity measured e.g. by the volume of the bucket (or cubic meters of material for each excavation operation), the pump strength (or cubic meters of water per hour), or the blast power (or cubic meters of materials removed per kilogram of explosive). We may calculate the capacity (tons of material extracted) if those equipments are fully used.

Extractive potential
Usually equipments are not fully used. For instance, in any building construction work extraction machines are not operating all the time or even all machines are not working at the same time. We can account the quantity of extraction that could be made if all equipments were used for a standard period (say 8 hours per day, 300 days per year). This indicator corresponds to the maximum extraction that is possible with the population of extractors within the system studied. For a given region or country we can have the Total Extractive Potential

Development of environmental sustainability policies based on the reduction of extraction

We have seen that in MFA, the study of inputs and the development of input indicators was of fundamental importance. Reducing the extraction will reduce futures outputs of any kind preventively. But we can look even further and consider the extractors. They can actually be more preventive than the amounts of materials extracted since they are the tools and machines that have been achieving extractions.

5 Discussion

5.1 Advantages

Preventive vision
The analysis of environmental problems is often achieved by studying the state of the environment or the level of emissions. There is a considerable buffer between the measure and the actual action required. And there might always be a transfer from one environmental problem to the other. To identify and reduce the laps between the problem and the action, the situation needs to be studied before problems or outputs of any kinds occur. When we deal with extractors we develop a very preventive vision, as extractors need to exist before extractions themselves - the source of all types of environmental impacts.

Data
Data is a very important part of the work in MFA. The study of extractors represents an innovative source of input-data to be explored. The processes creating extraction involve a limited number of extractors: this has the potential to limit the number of sources that one needs to study. The study of extractors is about obtaining data on direct extractions from an activity or region. The study of extractors can improve the data at the level of each activity. The activities might also involve indirect extractions, and indirect use of extractors through the life cycle of the products and services used. It is also important to deal with the use of extractors (and the extractions associated) that are hidden in importations.

Development of indicators
In order to measure progress towards sustainability proper indicators need to be developed. These include indicators for economic, social and environmental dimensions. These indicators need to be easy to calculate, should take into account indirect effects (it would not be sufficient to transfer problem in another place) and should be easily understood and recognised. We focus here on the environmental dimension. The study of extractors can contribute to this development.

Concrete objects for concrete policy
An extractor is less “hidden”, and more concrete than “Hidden Flows” but in the same time represent a path to evaluate them. It may be argued that the use of extractors is more representative of hidden flows than the collected data that is subject to far more approximations. The study of extractors can help us locate where we should act. It is a difficult step to go from the Material Flow Analysis to the practical political decisions. For this purpose, dealing with extractors can make us understand that acting preventively to reduce environmental problems could involve the reduction of excavators and explosives.
Image of the future

At present considering the rhythm at which statistics become available researchers usually deal with values one, two years old, or even more. To assess trends they have to deal with long chronological series of huge quantities of data. Although important they usually show accurately how countries have behaved and not really how they are behaving right now or how they'll expectedly behave in the near future. This relatively limits decision-making and planning.
Being equipments, extractors have a life period and their prices justify that they are going to be used. Material Movers are usually machines in which the entrepreneur invests a considerable quantity of money. To recover the investment the machine will have to be used for some years. This means that beyond what they extract today it is also relevant what they are going to extract tomorrow. Having numbers on extractors' present population (extractors park) and extractors' sales and considering a given life expectancy we can estimate what will be extracted in the near time.

5.2 Disadvantages

We have seen that taking into account extractor-based indicators had advantages. However there exist also some perceived disadvantages. Considering the specificity of this kind of indicator and its dependency on a machine, a tool or a structure it is foreseeable that there are some factors that will influence the result:

Technological change
Technology of extractors is evolving every year, and the type of population has different characteristics in terms of amount of work that can be achieved. This has to be considered especially when we are attempting to make estimations on future extraction values.

Specificity of the environment of the site
Hard rocks need for example more explosive charge than soft ones to move the same amount of materials. The same is true for excavating a harder and rocky soil. This means that for the same kind of equipment, sites with different characteristics result in different extractive capacities

Specificity of the resource management in each site
Some machines might be used far more efficiently in some regions compared to others. This is even true for different sites in the same region. This can have as consequence over esteemed extractive capacity values.

Age of extractors' population
Older materials tend to be used less often as their quality lower.. Older and/or badly maintained equipments have pretty different performances than those that are advanced in equipment catalogues.

We have to consider these disadvantages in the context of material flow calculations. The link between impacts and input indicator is not always linear, the evaluation of masses are linked to high uncertainties. However we should consider this in the context of high uncertainties existing with material flows accounting. Most importantly extractors are a very relevant data to prevent the occurrence of environmental problems.

6 Concluding discussion

It is revealing that the most published literature on excavators is children books. A long way seem necessary before their role as important source of environmental impacts is acknowledged.
We have presented a first exploration of the idea of studying extractors in order to develop the most preventive indicators.
We make here a call for the development of international cooperation in this area of research.
Do we find similar factors in different countries and regions?
Could we develop unified methodologies for the study of extractors?

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