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Life Cycle Analysis, its Structural, Emissions and Institutional Regimes as Policy Constraints

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Abstract

This article explores an conceptual extension of the well established frameworks Life Cycle Analysis and Input-Output Analysis to include identification of quantitative policy constraints. This is done by first introducing a nomenclature for the structural regimes. Second identifying the related emissions and seeing them in the context of the structural regimes. Finally the institutional dimension is added to identify how the various institutions govern the various structures and emissions.

Key words: Hybrid Life Cycle Assessment, Environmental Input-Output Analysis,

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1 Introduction

Environmental management is becoming increasingly difficult on all managerial levels as fewer and fewer institutions control major parts of value producing chains and networks. I here use the term institution to cover every level of group of actors in our economy from small businesses and local government to inter-governmental organizations and multi national companies. Increasingly open economies and globalization pose vast challenges in maintaining managerial control as materials, commodities and services are flowing in and out of various institutional regimes at increasing rates. This paper explores an conceptual and, presents sketches of, a methodological framework for analyzing the structural composition, emission regimes and institutional regimes of a product life cycle for identifying policy constraints.

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2 Structural Regimes

Life cycle analysis, hybrid LCA and input-output LCA all aim to describe the interconnectivity between, it be, processes, sector or commodities related to the production of a given object. This interconnectivity can be thought of as a network of nodes with flows between them. The nodes will then, for example as in input-output, be the sectors of the economy and the flows will then be the purchases in monetary units between them.

For a better appreciation the work presented here it is preferable to have a qualitative understanding of what types of networks, input-output, hybrid LCA and LCA describe. LCA aims at describing the flows between the most important nodes, with respect to environmental issues, throughout the life cycle of the object in study. Obviously, distinguishing the most important nodes from the rest is challenging, and a critique against LCA can be aimed at this partialness. Input-Output tables describes the flows of commodities between the various sectors of the economy in a more consistent framework than LCA today. However this consistency at macro level does not, in practice, that easily allow for as high resolution as in LCA. Input-output tables commonly operates with higher levels of aggregation than LCA process databases. As a result of these differences the networks representing typical data structures for LCA and input-output will look principally different. An input output network can be thought to have a network with large nodes all tightly woven together with wide lines. The large nodes represent the aggregated sectors and the wide lines represent a the aggregated commodity groups. An LCA network would, using the same metaphors have smaller nodes with thinner lines, even within the large nodes of the input-output system, but it would be much more sparse than than the IO-network. Other differences are also important to bear in mind. We have here discussed structural differences. I will in addition here bring up differences in the geographical and time dimensions of the two methods. Within the input-output framework there are methods to describe several economies and over time. However an IO table is established for one economy and one year. Inter-linkages with other economies requires to have separately complete IO tables for these. LCA is, due to it's focus on processes, is not concerned with natational boundaries. Due to the high resolution, the technology dependency of the inter-connectivity between the processes is more explicitly present than in input-output where the aggregation conceal this. In other words, a gas turbine is the same in Africa and in Europe but the electricity grid mix is quite different. This means that, knowing what technology is being used, a description of a set of processes and their inter-connectivity with other processes can be described without having to be concerned with the geographical location of the process. As for the issue of time, we know that the input output tables are a developed to represent one year at the time. However within the IO framework there are methods to perform projections that can be made as to how the flows in the economy will change given a set of assumptions. Still the challenge of changing prices over time of for example energy favors physical units as in LCA and PIOT.

Over the later years the combination of LCA and input output approaches into Hybrid LCA has been found beneficial. Preserving the better of two worlds the Hybrid LCA

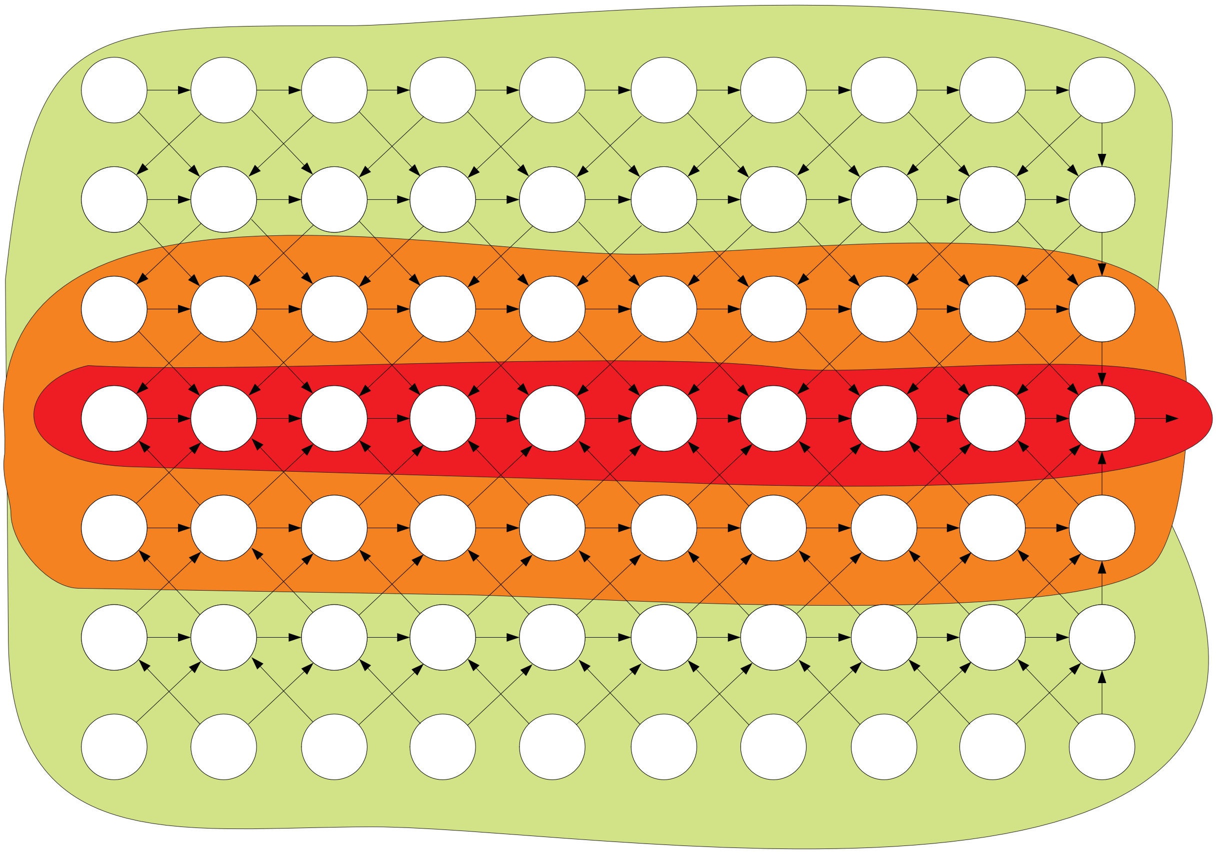

Fig. 1. Structural Regimes

approach allows for a detailed description of the processes in study and simultaneously, by describing their inter-connectivity with the rest of the economy, getting a good description of the repercussions in the economy caused by these.

The mathematical representation of these type of networks done by matrices. Following Leontief [1], this network is represented by the requirements, or coefficients, matrix $A_{n,n}$, where n denotes the industry dimension. The columns of this matrix describe the intermediate inputs an industry buys, from itself and other industries, to produce one unit of output. In Eq. 1 the industry output vector, x_n, is the sum of the final demand vector, y, plus the industry activity required to supply input to the production, the intermediate demand, $A_{n,n}x_n$.

$$A_{n,n}x_n + y_n = x_n \tag{1}$$

Solving for x_n to find the resulting industry output for a given demand y_n;

$$(I_{n,n} - A_{n,n})x_n = y_n \Leftrightarrow x_n = (I_{n,n} - A_{n,n})^{-1}y_n \tag{2}$$

Having established an understanding of various approaches to describe process interconnectivity networks, we are now going to present a framework for categorizing a given network. This categorization is, in principal, applicable irrespective of the approach used to describe the network.

Table 1
Structural regimes Nomenclature

Base nodes	Nodes where the material being refined is flowing through
Close upstream nodes	1st tier upstream nodes from base nodes
Distant upstream nodes	2nd and higher tier upstream nodess

We here apply a very stylistic case in exemplifying our framework. We have chosen to use what we refer to as a refining value chain. This is simply a value chain that is refining a material from extraction to a final product. This could for example be a value chain involving the processes from mining of bauxite to the finished product of an aluminum bumper. This type of value chains has that unique quality that a single raw material is the origin of the mass flowing through all the nodes of the value chain.

A motivation for describing these types of value chains is to be able to perform a consistent environmental assessment of the change from one technology to another along such a path. An example could be to study the effects of replacing an old aluminum plant with a new plant. Another possibility is to replace an existing commodity and it's value chain with an alternative one. An example of this could the change from gasoline for transportation to another fuel, like hydrogen.

In this process a conceptual framework and nomenclature for describing the structure of the flows is desirable.We start by defining the flow path itself. In figure 1the red field contains the nodes in which the substance in study flows through from extraction, to refining, through production, distribution and to final product or end use. This is defined as the substance path. An example of this could be natural gas from extraction to use in households or in transportation. We refer to these nodes as the base nodes. See table 1 for an overview of our suggested nomenclature. The orange field contains the first upstream nodes who supply inputs directly to the actors that are a part of the base nodes. These are for example suppliers of maintenance to transport services in the base nodes. These are distinguished from the 2nd and higher tier upstream nodes, the green field. This is done to separate the actors, in the rest of the economy, which trade directly with base nodes and those who do not. Several more levels can obviously be introduced but for simplicity we keep it to three here. Base nodes, and to some extent close upstream nodes, can further be split into extraction, distribution, production, retail, end use etc.

$$X_{n,s} = ((I_{n,n} - A_{n,n})^{-1} y_n) S_{n,s} \tag{3}$$

The mathematical operationalization of this involves defining the $S_{n,s}$ matrix describing how the various nodes, here industries n belongs to the various regimes, s. If an element, $s_{n,s} = 1$, the node is a member of that regime. If it is zero the node is not a member. In principal the same node can be a member of several regimes. An example could be that one node is defined to both be a part of the base nodes and the distribution part of the value chain. How to finding the activity in various regimes is shown in Eq 3. There the $S_{n,s}$ is multiplied with the x_s vector giving the $X_{n,s}$ matrix which gives of the magnitude of activity of in all the nodes belonging to the various regimes, s.

3 Emission Regimes

Identifying emissions and categorizing the environmental impact generated in each node, as a result of a given activity, is an essential part of in LCA, EIO and Hybrid LCA which all are based on Leontief [2].

Introducing the emissions matrix $E_{e,n}$ which gives the direct emissions of type, e, from each node,n. Equation 4 shows how the $B_{e,s}$ matrix giving the amount of various emissions generated within a given structural regime.

$$B_{e,s} = E_{e,n}((I_{n,n} - A_{n,n})^{-1}y_n)S_{n,s} \tag{4}$$

The assessment matrix $W_{w,e}$ contains characterization factors for emissions giving impact indicators(w). Having this information the impacts generated within each regime $C_{w,s}$ from global warming potential can be found. This is shown generally in equation 5.

$$C_{w,s} = W_{w,e}E_{e,n}((I_{n,n} - A_{n,n})^{-1}y_n)S_{n,s} \tag{5}$$

This involves to the interpret the emission data in context with the structural categories presented in the previous chapter. The motivation for doing this is to be able to relate the origins of emissions to these categories. From a policy design perspective it can often be of interest to know if the majority of impacts are located at the base nodes or at far upstream nodes. In figure 2 a conceptual representation of this is presented. The dark gray field illustrates the nodes that have point emissions higher than, for example X% of the total, and the light gray Y% of the total. Obviously such maps can be generated with other fraction criteria so we define the impact fraction matrix which gives the fraction of total impacts generated for each node,$F_{n,w}$ or each structural regime,$F_{n,w}$. We start by summing over all nodes finding the total impacts generated c_w, see equation 6.

$$c_w = C'_{w,n}i \tag{6}$$

The desired F matrix can then be found by normalizing impact matrix,$C_{w,n}$, with the diagonalized vector of total impacts $\hat{c_w}^{-}1$ as shown in equation 7.

$$F_{n,w} = C_{w,n}\hat{c_w}^{-1} \tag{7}$$

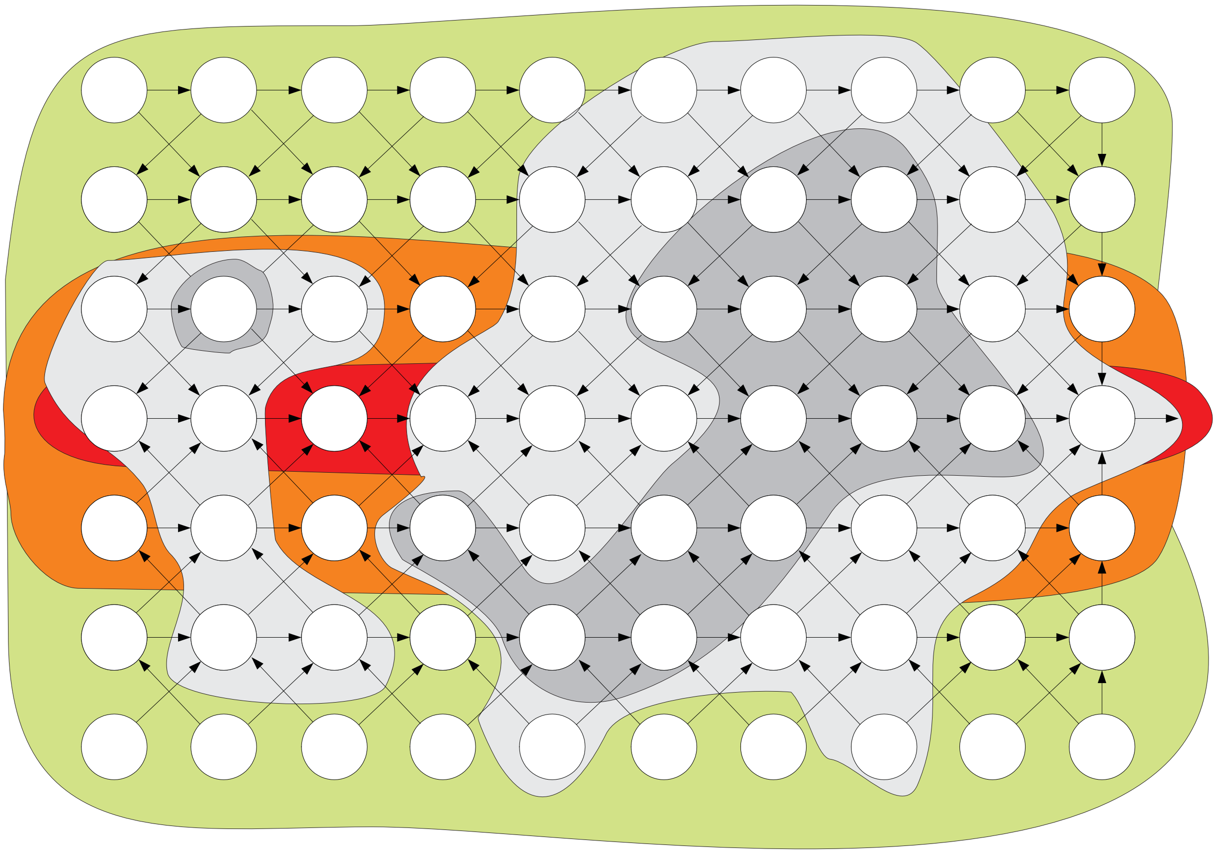

Fig. 2. Emission Regimes

4 Institutional Regimes

The last step in the suggested framework is to identify how the various structural and emission regimes belong to different institutional regimes. Knowledge on this can assist policy design and recommendations. An example could be to perform such an analysis on behalf of the regulatory regime where the product is being consumed. Their motivation would be to identify improving options for increased sustainability the product. I doing so it is obvious that knowing how large fraction of the total impacts that occur under within their institutional regime is of great importance. The institutions could be private companies up to international bodies. In figure 3 an example of two companies which operate on the path base nodes is shown with blue lines. One of the companies operates across the border of a larger institutional body, brown lines, this could for example be national borders.

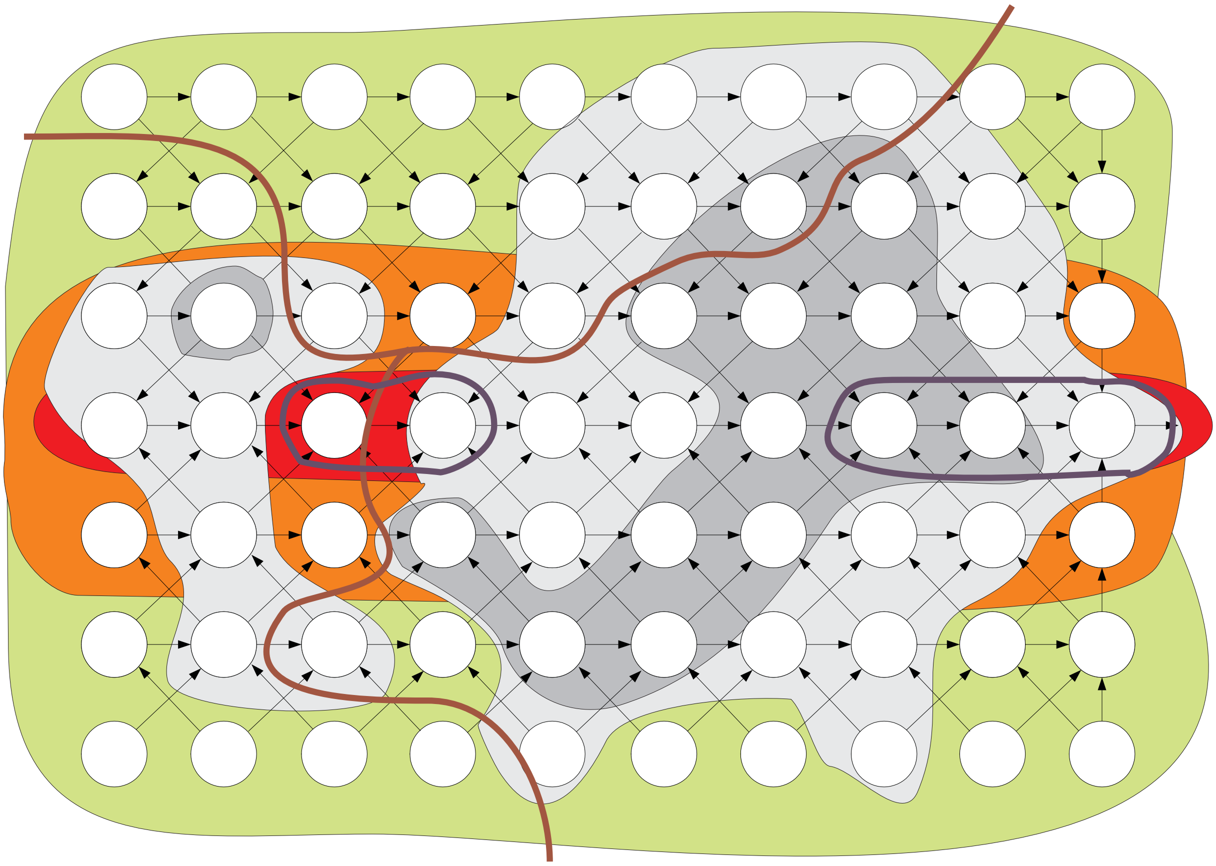

Fig. 3. Institutional Regimes

5 Policy Constraints

The institutions policy constraints with respect to one impact category is the same as the fraction of impacts generated with in their regime. Clearly this favors large institutions. If these are not present or one institution finds these inadequate, but are unable to establish consensus for a stricter regime, other approaches must be applied. One approach is to identify the nodes where the flow crosses the institutional border. It is here suggested that the material path might also the best path for flow of information and communication in order to give incentives for changes. Obviously institutional borders can be seen as barriers for communication since basis for interpreting the information under another institution will be different. Companies on the base path operating across institutional borders, as seen in figure 3, can here act as bridges for communication between base nodes under different institutions.

6 Conclusion

The conceptual framework presented here allows for quantitatively assessing the structural and emission dimensions of a product system in context with institutional aspects. In doing so, quantitative constraints for environmental policy design within given institutional regimes can be identified. This knowledge can be used contribute to the assessment of existing and proposed regulatory and corporate environmental management strategies.

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