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Multisectoral accounting framework and aggregate indicator to avoid negative intersections in environmental policies : around strong sustainability, rebond effects, and the low-tech approach

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Under de direction of Grégoire Walleborn

August 9, 2023

Abstract

After a broad and critical review of the literature on different research areas, we propose a very simple theoretical model for analyzing the design of an environmental public policy in four steps: (i) defining the environmental objective; (ii) defining a set of economic options available to the regulator; (iii) translating the application of the different economic options into cross-sectoral economic restructurings; and (iv) translating the environmental impact of these restructurings using a set of ecological indicators. By presenting and illustrating an assessment method for comparing different environmental policy options based on economic instruments, we identify the opportunity for a research program that focuses on connecting knowledge of the different fields reviewed, that is macroeconomic modeling through Stock Flow Consistent models, input-output analysis and their environmental data computed through the Life Cycle Analysis methodology, as well as studies on environmental indicators and the environmental rebound effect. Though simplistic and approximate, we argue that given the data available today, this method is already operational in its ability to easily furnish orders of magnitude. More generally, we claim that accounting for LCA data would allow policy makers to identify the magnitude of the overall ecological impact of an environmental policy, in a strong sustainability perspective. Finally, we raise the question of the role of technical choices to support a systemic transformation in a strong sustainability framework, as studied with the method pinned in the precedent parts, and focus on two study cases to illustrate to social and political potentiality of the alternative low-tech approach.

Authors' Declarations: No conflicts of interest

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1 Introduction

Since the WCED report (Bruntland, 1987) coined a first, and now widely known definition of sustainable development as “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, the debate still stands about how to define sustainability. Indeed, Cobb and Daly (1989) identified two reactions raised by the definition. They describe “One is to revert to a definition of sustainable development as ”growth as usual”, although at a slower rate. The other reaction is to define sustainable development as ”development without growth in throughput beyond environmental carrying capacity”. Pearce et al. (1990) see this gap in more economic technical terms as the feasibility or not to substitute man-made and natural capital. The consequences of this divergence for economic theory have been further studied (Aryes et al., 1998). In the last decades, IPCC has gained consideration in academic areas and beyond, building bridges between both scientific knowledge and policy challenges (IPCC, 2022). More recently, other approaches have focused on identifying other environmental dimensions that can be interconnected with each other, such as the so-called planet boundaries (Rockström et al., 2008; Steffen et al., 2015). Even a social dimension has arisen in the global political agenda of the United Nations by the introduction of the Sustainable Development Goals (SDG) afterwards (United Nations, 2015). If the debate of what should be included in the sustainability definition is far from closed, it seems reasonable to consider that focusing solely on one environmental dimension (as climate change) could not constitute a strong sustainability perspective.

We claim that the aim of environmental public policies, from a strong sustainability perspective, should be to ”reduce” ecological impact, instead of ”displacing” it. We also claim that the word ”reduce” is generally used in an ambiguous way, precisely because ecological impact can take many different forms, far beyond the mere emission of GHG (Rockström et al., 2008; Steffen et al., 2015). We then raise the following question : is it possible to account for the ecological footprint of an economy precisely enough to allow for the ecological assessment of a public policy in a strong sustainability perspective ? We argue that in the absence of a multidimensional assessment of the ecological impacts associated with an economic transformation or a ”green” policy, the word ”reduce” is ill-defined. Indeed, unless all the different forms of environmental impact (exhaustively considered) are systematically reduced by the transformation of a system, it carries an implicit normative character based on a trade-off between the different forms of ecological impact. For instance, if an effective environmental policy that consists in reducing carbon emission implies metal consumption increase or greater biodiversity degradation, it is, in a strong sustainability view, a trade-off, that can even lead to backfires in some cases (c.f. Saunders (2000) for backfires in terms of rebound effect). One of the goals of this paper is to propose a research program based on the method we introduce. This method is not designed to be used in a normative way to guide policy makers through "environmental trade-off" propositions. Instead, we propose a simple framework that allows the rise of awareness about the environmental side effects that can occur when focusing on only one environmental dimension. In this view, we hope this method could help the policy maker to assess which environmental impact is "reduced" at which price regarding other environmental dimensions, and to prevent any bad intersection with these latest. Moreover, we will focus solely on economic instrument based policy.

In the light of the method we will present, it seemed clear that in order to assess the ecological relevance of any change in production or consumption processes - such as alternative technical choices - it would be necessary to focus on the parameters that will be identified in the section 6. Nevertheless, assessing the ecological relevance of a high-tech/low-tech change requires such a change to be clearly defined upstream. After having reviewed the literature about the relationship between technology and society, and mapping the conceptual landscape of the low-tech approach, we instead choose to illustrate why the transformative potential of the low-tech approach is more social political, rather than purely environmental. In other words, we want to raise the following question : has the low-tech approach the capacity to reduce systemically the environmental burden produced by the production and consumption processes within the different economic sectors of modern societies ?

A crucial goal of this research work is also to connect different research streams. This is why we intend a critical review of the direct and indirect rebound effects studies from the energy economics field (section 2), the concept of environmental rebound effect from industrial ecology and the passed attempts of macroeconomics to adopt environmental considerations as Integrated Assessment Models (IAM) and ecological Stock Flow Consistent (SFC) models (section 3), and the different proposals for environmental indicators and trade-offs (section 4). Then, we propose a method to evaluate side effects of environmental public policies that relies on economic instruments and point out the opportunity for a research program based on this idea in the light of the field previously reviewed (section 5). Then, we raise the question of the role of technical choices to support a systemic transformation in a strong sustainability framework, as studied with the method pinned in the precedent parts, and focus on two study cases to illustrate to social and political potentiality of the alternative low-tech approach (section 6). Section 7 concludes.

2 Direct and indirect rebound effects through energy economics eyes: critical review and state of the art

The historical foundations of the rebound effect took place with the contribution of Jevons and his famous book The Coal Question (Jevons, 1866). The concept originally described the counter intuitive increase in the overall energy consumption succeeding to an improvement in energy efficiency. Despite this early framing, the topic began to be considered with true attention by scholars and policy makers only from the contribution of Khazzoom (1980). In this pioneer article Khazzom proposed the very first formalization that allows for quantifying the rebound effect, essentially through the computation of the own price elasticity of the demand for energy, used as a proxy.

To the best of our knowledge, Mashhadi Rajabi (2022) proposed the very first broad and systematic review of 41 years of rebound effect study, from 1980 to 2021 through a bibliometric approach. Following her analysis, we can separate the direct and indirect rebound effect. The direct rebound effect can be described as the increase in the consumption of a service that experienced efficiency improvement. The indirect rebound effect can be described by considering the effect of efficiency improvement in a specific service or product on the consumption of other services or products. The sum of the direct and indirect rebound effects is often called the “economy-wide rebound effect” (Sorell and Dimitropoulos, 2008).

Mashhadi Rajabi (2022) shows through a quantitative approach that the concept has gained consideration since the middle of the 2000s, with a clear increase in the number of articles published on the subject. Interestingly, we can identify two areas of study when it is about estimating the rebound effect. The microeconomic studies rely on a change in the consumers final energy use after an energy efficiency improvement (seen as a decrease in the energy final price), mostly studied at the household level and including consideration for both direct and indirect rebound effects. The macroeconomic studies main investigation is the extent to which efficiency improvement affects economic growth and production sector (Gillingham 2016).

The famous contribution of Sorell (2007), "The rebound effect : An assessment of the evidence for economy-wide energy savings from improved energy efficiency" coined the principal evidence and lack of the passed research. Among others we can note the following points :

- The concept of energy efficiency is not always defined similarly among scholars, which can lead to misunderstandings, different results and different conclusions ;
- The boundaries of the system on which the estimation of rebound effect takes place are not always the same among studies, making comparisons sometime irrelevant ;
- Energy efficiency enhancements may be associated for industries with improvements in the productivity of capital, labor, and materials inputs ; similarly consumers can save costs on more than energy alone after an energy efficiency improvement : this has to be accounted for prevent researchers to underestimate rebound effect, and overestimate the potential for decoupling between energy consumption and economic output.

Despite the door opened by the rebound concept emergence to connect economic dynamics and social dynamics such as organizational and behavioral effects, we identified two important limitations of traditional rebound effect studies in their ability to contribute to a strong sustainability critical view. First, we consider the focus on the changing energy consumption as a barrier to a broader environmental consideration that the strong sustainability paradigm calls for. Second, the micro and the macro sides of this area of research are strongly separated, mainly because of the existence of different energy efficiency definitions (and in fine, rebound effect definition) for different scales of consideration.

3 Direct and indirect (environmental) rebound effects through industrial ecology eyes: critical review and state of the art

Maybe because of the historical roots of the concept, we notice that the rebound mechanism has been looked at, in the vast majority of the studies, only through energy economics eyes. More recently, some contributions tried to connect this concept with other fields of studies that allows for a broader environmental perspective. This is the case with industrial ecology. In this subsection, we describe the younger part of the literature that intended to build bridges between the rebound literature and the LCA methodology. We will further explain why we consider this connection as a first step in connecting through a unique framework, not only different environmental dimensions, but also both the micro and the macro sides of the rebound literature.

3.1 LCA methodology and the rebound effect

Direct and indirect rebound effects have been studied through industrial ecology eyes, to give birth to the notion of environmental rebound effect. We argue that this new concept has roots in the industrial ecology field, and more precisely in the LCA methodology itself.

The first LCA (Life Cycle Assessment) approaches, consisting of tracing environmental impacts through a product life cycle inventory (LCI hereafter), date back to the 1970s (Boustead, 1996; Hunt al., 1996). However, it was not until the early 1990s that some authors proposed the inclusion of market information in the LCIs of products (Weidema, 1993). Van Der Voet al (2014) argue that, although the rebound effect was not explicitly mentioned by Weidema, the idea that the demand for a product is determined by market conditions then appeared in the LCA literature. Today, part of the literature on the rebound effect seeks to include consumer behavior in the LCA approach (Kondo et al., 2006 ; Thiesen et al. 2006).

Symmetrically, the literature on the rebound effect has picked up on the methodology and data provided by the LCA community. The literature review by Van der Voet and Font Vivanco (2014) includes 17 studies that investigate the rebound effect while using LCA. But only 4 of them studied the evolution of environmental indicators that deal with aspects other than climate change (Takase et al., 2005; Thiesen et al., 2006; Weidema et al., 2008; Thomas and Azevedo, 2013b). The authors conclude their review by arguing that the interest in a broader assessment of sustainability, then not restricted to energy consumption or greenhouse gas emissions, allows for a broadening of existing definitions of the rebound effect. Through a literature search using the same method as Font Vivanco and Van der Voet (2014) - that is, considering articles with combinations of the words "rebound effect", "LCA", and "Life Cycle Assessment" - we found more recent studies fulfilling this criterion, but they remain scarce and always specific to a sector (energy, for instance) or even a single type of product (Munoz et al., 2018; Pohl et al., 2019, Antonanzas et al. 2021).

In order to establish trade-offs between the different environmental dimensions, Van Halen et al. (1999) first used the notion of the 'environmental rebound effect' (ERE hereafter) to designate 'the effect that the world's environmental load increases as an indirect result of a function fulfillment optimisation in both ecological and economic way'. Several definitions have subsequently emerged, and are reviewed and discussed by Freire-González and Vivanco (2017). For example, Takahashi et al. (2014) include in the ERE ecological degradation resulting from long chains of causal relationships from the micro level, involving time and space effects. Spielmann et al. (2008) refer to the change in the environmental performance of a system due to the demand adjustment following a time-saving technological innovation. Murray (2013) also proposes to define ERE as "the amount of energy, resources or externality, generated by offsetting consumption, as a percentage of potential reductions where not offsetting consumption occurs". Font Vivanco et al. (2016) point out that the ERE perspective is heavily more influenced by the LCA approach than the one linked to the original definition of the rebound effect from energy economics. They pretend that this notion is now constituting a broader field of environmental analysis. Their point, in line with the contributions of Hertwich (2005) or Takase et al. (2005), is that the vision of the industrial ecology perspective has reinterpreted the classical definitions of the rebound effect to embrace other effects of interest linked to environmental analysis while following the same logic as the initial effect.

3.2 Environmental rebound effect: first formalizations and limitations

We consider the work of Freire-González and Font Vivanco (2017) pioneering in the theoretical formalization of an environmental rebound effect, or as they call it, the cross rebound effect. Based on a formalism already thought by Freire-González (2011), Druckman et al. (2011) and Thomas and Azevedo (2013a, 2013b), they use a re-spending model through an IO approach that allows them to study what are the new consumptions following the increase in energy efficiency of a service (interpreted here as a gain in income). Like Thomas and Azevedo (2013a, 2013b), the energy efficiency gain is interpreted as a gain in income. Thus, the cross rebound effect can be calculated through a re-spending model that studies which sector benefits from the new expenditure. The fundamental difference between Freire-González and Font Vivanco (2017) and Thomas and Azevedo (2013a) approaches lies in the proxy that calculates the environmental impact of the new consumption. For Thomas and Azevedo (2013a), an intensity vector that transforms monetary expenditures into embodied energy is obtained by an EEIO model (Miller and Blair, 2009). Unlike them, Freire-González and Font Vivanco (2017) innovatively use a matrix that obtains the environmental footprint of new expenditures, not only their energy intensity, but also the intensity of material use, water use, or land use, for example. In doing so, they define a new notion which they call "cross rebound effect" as "an increase in other resource use after an energy efficiency improvement, due to the increase of available income". The expressed the DICRE (Direct and Indirect Cross Rebound Effect) as :

$$DICRE = \frac{\textit{Calculated resource savings - Real resource savings}}{\textit{Calculated resource savings}} \tag{1}$$

Obviously, the core of the ERE, as of the indirect rebound effect assessment, relies fundamentally on the re-spending model. The re-spending model used in the work of Freire-González and Font Vivanco (2017) is simplistic (new spending proportionally follows the old consumption pattern) since the purpose of their contribution was only to illustrate their concept of the cross-sectional rebound effect. The re-spending models used by Thomas and Azevedo (2013a, 2013b) are more elaborate and rely on the Slutsky decomposition (necessary to isolate the substitution effect and the income effect), while including the direct and indirect rebound effects (the second being bounded by the first). However, these re-spending models require the calculation of a cross elasticity, which makes the concept less easy to operationalize. We claim that these two contributions form a first milestone in the study of the cross rebound effect, through which the broad environmental impact of an energy efficiency gain can be suitably studied. Indeed, considering like in the energy economics definition of rebound effect that the rebound only applies in one direction, that is the one on which the efficiency gain was focused, may lead us to ignore the worsening of another ecological indicator. This is precisely this worsening that is called a “cross rebound” by Freire-González and Font Vivanco (2017).

Firstly, we identify a clear inconsistency in the definition (1) coined by Freire-González and Vivanco (2017). The initial concept of rebound effect studies is always considering the energy consumption relative to a (fictitious) counterfactual scenario that would have taken place without an efficiency enhancement. However, in the case of the environmental rebound effect, one can claim that there was no metal or water footprint reduction expected from an energy efficiency improvement (the so-called, “Calculated ressource savings” in the formula (1)). The answer of the authors is that, from a global and LCA perspective, if less money is allocated to the energy sector than before the efficiency gain, less resource would be consumed by this sector for producing his output, leading to the expectation of a reduction in the environmental footprint of this sector. However, we consider that expressing the increase in metal or water consumption relative to the one expected by an energy efficiency improvement cannot be relevant, precisely because the aim of an energy efficiency improvement is generally not to improve the metal or water consumption efficiency as well. Nevertheless, we consider the LCA coefficients based method used by the authors to build the notion of cross rebound effect as inspiring to adopt a strong sustainability perspective.

Secondly, despite the broader environmental perspective allowed by the concept of environmental rebound effect, the second limitation we identified in the traditional rebound literature (that is, from energy economics) still stands. Indeed, the environmental rebound concept is still much more designed to adopt a micro scale perspective and does not really allow for macroeconomic consideration. This point can be understood because of the utilization of cross elasticities and LCA coefficients, which rely on the LCA methodology, that is, a product-centered approach calling for attributing the environmental burden to a final consumption. As already said, we consider all the same the LCA methodology and the data it can provide as very powerful to adopt a strong sustainability perspective. Therefore, a clear gap to connect the micro and the macro approach with this perspective could consist in the ability to use LCA coefficient in a framework that allows for macroeconomic modelling.

3.3 A note on macroeconomic models intending to include environmental consideration

Although this research work does not go into detail directly on the place of the rebound effect in integrated macroeconomic assessment analysis, it is worth briefly recalling the trends involved. Two main types of IAM can be considered: those known as "top-down" and those known as "bottom-up". The former are highly aggregated, like the seminal DICE and its various regionalized variations (e.g. RICE) or the ecological SFC of Bovary et al. (2018) based on the Goodwin-Keen model. Typically, only one type of good is considered, with a single abatement cost, this good actually representing real GDP. With such a level of aggregation, rebound effects are generally neglected - at least indirect rebound effects - although there are notable exceptions such as the ecological Stock-Flow-Fund-Consistent model of Dafermos et al. (2017), which postulates that investment depends on the rate of growth of energy intensity, the idea being that a lower energy intensity reduces production costs, thus encouraging firms to invest more. This approach makes it possible to integrate the direct rebound effect not only into household energy consumption but also into the dynamics of investment, and thus of economic growth and potential medium- and long-term backfires.

Concerning multidimensional rebound effects, with an impact on other ecological dimensions, these are also very rare because these aggregated IAM classes generally only take into account the temperature anomaly through CO2 emission, thus restricting these considerations, with the exception of certain models with a large number of environmental sectors and representation of ecological issues such as the FUND model, integrating for example agriculture and biodiversity elements. Similarly, the indirect rebound effect requires the consideration of material stocks and flows, whereas aggregate IAM of the DICE type only focus on energy (recalling the energy dogma in the sense of Goergescu-Roegen, 1979). Dafermos et al (2017) propose a coherent stock-flow-fund framework that allows for the integration of physical materials and resources. Similarly, the macro-energy models of the World Energy Agency (e.g. IEA World Energy model or WEPS+), although representing the direct rebound effect through the price elasticity of certain goods and services, do not represent the indirect rebound effect (Brockway et al., 2021).

Conversely, bottom-up models, structured in such a way as to represent a multi-sector economy (such as the class of Computable general equilibrium models - CGE, the MESSAGEix or IMAGE models) are better able to represent indirect rebound effects through cross-elasticity, but often only in the context of energy consumption (with the integration of land use and agricultural production in the IMAGE model). Also, the SFC approach of Dafermos et al. representing the application of a rigorous accounting framework to a multi-process matrix that depicts the physical inflows and outflows that take place during the various economic processes, in a desire to represent the first and second laws of thermodynamics, is a first approach to the integration of not only energy but multidimensional environmental rebound effects, an integration that requires a strong and disaggregated multisectoriality as well as environmental feedback loops that go far beyond the simple temperature anomaly, currently often the only ecological dimension taken into account by the canonical IAM. Nevertheless, there is a body of literature that suggests incorporating LCA coefficients into the construction of IAM in order to model more representative trajectories (c.f. Arvesen et al., 2018).

4 Environmental indicators and trade-offs: critical review and state of the art

The diversity of environmental issues is a source of complexity. Finding trade-offs between different environmental problems is a classic, if not the core business, of industrial ecology, and partly gave rise to the LCA methodology (Boustead, 1996; Hunt al., 1996; Laurin, 2017). To illustrate the complexity and diversity of environmental problems, scientists of the Stockholm Resilience Center have introduced the notion of planetary boundaries (Rockström et al., 2008; Steffen et al., 2015). Another field of research even focuses on establishing the interactions, correlations and contradictions between the different Sustainable Development Goals (SDGs) introduced by the United Nations in 2015 (United Nations, 2015; Singh et al., 2018) which also include social issues. Since then, the diversity of environmental indicators is increasing, and some authors are even trying to produce methodologies to build relevant indicators (Best, 2008). Enrolled in a strong sustainability perspective, our aim is less to study if an environmental policy is expected to properly reach his goal than to reveal some eventual hidden impacts, side effects, in other environmental dimensions than the one initially targeted by the policy target. An illustration to the logic behind our approach lies in the Special Report: Global Warming of 1.5° from IPCC (2018). In chapter five of this report, Table 5.2 shows a comparative assessment of different technological solutions that aim to reduce the greenhouse gas emission responsible for human induced climate change. The particularity of this assessment is that it is performed precisely against all the SDGs excepting the number 13 (relative to climate change). Though we will not consider any social dimensions in the methodology presented in section 5, we consider this example as good inspiration when it is about addressing strong sustainability complexity.

Amidst this diversity of indicators, we note that the LCA methodology has the advantage of having been fruitfully coupled with the IO methodology for several years, providing intensity coefficients, expressed in physical unit per monetary unit. This framework, generally referred to as ”IO-LCA approach” is now widely used and has given rise to numerous and accessible databases (EXIOBASE; www.eiolca.net; Eurostat). These databases are regularly referred to as using a Multi Regional Input Output (MRIO) framework, or MRIO-LCA when LCI data in physical units are included in the analysis, as they try to build consistency in physical and monetary flows between different geographical regions.

Using the LCA data currently available, Eurostat (2017) proposes to use a set of four headline indicators to guide policy makers (material use, land use, water use and carbon footprint). Some authors wanted to check whether this choice would allow a relevant representation of all the environmental impact information statistically contained in a large amount of LCA datas. Indeed, Steinmann and colleagues (2016, 2017) showed how a selection of a small number of indicators can capture (in a statistical sense) the vast majority of the information contained in the LCA data of an MRIO table. They used principal component analysis to show high correlation rates on a set of

105 environmental indicators constructed using data in physical units contained in the EXIOBASE MRIO tables (Steinmann and colleagues 2016) and in the ecoinvent LCA database (Steinmann and colleagues 2017). According to the authors, the four headline indicators proposed by Eurostat (2017) capture 60% of the statistical information on environmental data contained in EXIOBASE. They conclude by proposing that it is possible to capture 95.2% of this statistical information by adding only five other indicators (marine ecotoxicity with twenty years time horizon, terrestrial ecotoxicity with infinite time horizon, photochemical oxidant formation, and terrestrial acidification). This result suffers from few limitations as for instance, the absence of metal scarcity, ozone depletion and ionizing radiation assessment categories in the initial set of data (because not available in EXIOBASE), and therefore, the overestimation of the amount of variance that can be explained with a limited number of indicators. However, despite the several limitations of their approach, we argue that it could be possible to use a simple (because limited) set of indicators to guide policy making in the "mapping" of the environmental burden evolution of a public policy while not losing the ability to adopt a strong sustainability perspective.

5 Designing a (strong) sustainability public policy: a research program proposition for connecting the knowledge of different fields

Here, we are interested in an ex-ante evaluation method, that is, when the evaluation takes place before the policy implementation. Lot of work have been done on the side of evaluating policy instrument and their potential effects on the subsystem considered (for instance, see Stavins 1997, and Grazi and van den Bergh 2008 on climate change adaptation; Hellegers and van Ierland 2003 on agricultural groundwater extraction; Cubbage et al. 2007, on forest policy). However, the side effects potentially induced by the policy implementation are as important as the evaluation of the effectiveness itself. This is the point of Gysen (2006) who defines "effect evaluation" as "an effect evaluation brings together the findings of an effectiveness evaluation and a side effects evaluation". The author also claims that "the difference between side effects and main effects is based on the criterion of ‘intention’.”. We consider this point as the starting point of our analysis. In this section, we will consider that the evaluation of “effectiveness” is not included in our analysis because, as we will see, it relies on the economic model chosen to be used. Instead, we isolate the second part of the effect evaluation, in the sense of Gysen (2006). Indeed, we aim to propose a simple framework to evaluate the order of magnitude of any side (environmental) effects that can arise from the implementation of an environmental public policy, opening the door to a strong sustainability perspective. Moreover, we will focus on economic instrument based-policy.

5.1 Context and scope of the proposition: conceptual model for the design of environmental public policies

To contextualize our discussion, we propose to define the ”life cycle of a public environmental policy” in four stages: (i) the definition of the desired goal, (ii) the choice of economic instruments available to the regulator, (iii) the modeling of the economic implications of the options studied by the regulator, and (iv) the environmental consequences of these economic implications. The ex-ante and ex-post evaluation stages could be added to reach six stages. The method we propose is part of an ex-ante evaluation of a public environmental policy.

Step (i) consists of setting the environmental objective to be achieved, which can take different forms: reduction of greenhouse gas emissions, reduction of household energy consumption, slowing down or stopping the artificialization of the land in a given area, and so on. Step (ii) consists of defining a set of economic instruments that will be compared between each other later: carbon tax, increase in the price of energy at consumption peak times, subsidies for electric vehicles, introduction of a quota market, and so on. We argue that choosing among the economic options available in step (ii) while avoiding side environmental effects should be subject to backward induction. Indeed, the reasoning behind our method is based on a backward induction: we argue that comparing different policy options (ii), requires comparing the economic restructurings they imply (iii), vis-à-vis the environmental consequences of these restructurings (iv). In the following, we describe a method for the ex-ante evaluation of environmental public policies, framing our methodology on these four steps.

5.2 Step (ii): set of economic policy options and preliminary assumptions

As previously said, the economic options available in step (ii) can be taxes, subsidies, introduction of a quota market, and so on. The consequences of their application should be subject to ex-ante economic modelling. Today, several types of macroeconomic models exist to assess the economic impacts following a shock (such as the introduction of a new public policy). A comparative critique of these models is beyond the scope of this contribution. Non-exhaustive examples include econometric models (ThreeME from ADEME, 2013); agent-based models (ABM) (Gaffard and Napoletano, 2012); computable partial equilibrium (CPE) or computable general equilibrium (CGE) models (Dandres et al., 2012; Earles et al., 2013; Schubert et al. 2022); or SFC models (Godley and Lavoie, 2006; Almeida et al., 2022a). Since step (iii) consists in assessing the economic impacts of the shock caused by the introduction of an environmental public policy, we need to identify two requirements that the model used has to fit before describing the following steps of our method.

First, we assume that the consequences of a public policy can be simplified in a relevant way into a cross-sectoral reconfiguration of the economy (in the sense of Leontief, see following section). Here, the word relevant means "without compromising the objective of the method, that is to deliver orders of magnitude of the ecological impacts implied by the implementation of the public policy under study". The precise description, relevance and limitations of this assumption are discussed in the next section.

Secondly, we assume that there is a model, here not explicitly chosen, capable of providing as an output the intersectoral transformation of the economy (in the sense of Leontief, see next section) following an economic shock, in discrete time year after year. Thus, the model chosen must allow for the identification of which cross-sectoral transformations would result from the implementation of economic instruments considered in step (ii). On one hand, this could be seen as a limitation, as providing a discrete year-by-year evolution of the Leontief matrix of an economy following an economic shock is not a feature that is not fit by every type of economic model. This is clearly part of the research agenda that we would open with the method we present here. Indeed, some models already allow for this and are discussed in the next section. On the other hand, we argue that the wide availability of numerous databases based on MRIO tables and environmental impacts makes it easy to establish a strong link between the economic instruments considered and the final assessment of environmental impacts from a strong sustainability perspective. We argue that this last point is the main positive point of our method, namely that it is clearly operationalizable with the data currently available.

5.3 Step (iii): modelling economic implications of a policy and availability of a relevant model to do so

Our first hypothesis can be translated as follows: to a first approximation, the concrete aim of any economic instrument based policy always remains, directly or indirectly, to modify the demand for a good or service, and in fine, the cross-sectoral relations of the economy (in the sense of Leontief, 1936, 1970). In particular, we argue that a technological change can be seen as a change in the cross-sectoral relationships of the economy. For instance, the automobile sector no longer has the same cross-sectoral 'dependencies' if the production of thermal-motorized cars has stopped in favor of the production of electric cars. We deal with the case of disruptive technological change in section 6.f. Similarly, a change in usage (change in demand) implies a restructuring of the Leontief matrix describing the cross-sectoral relations of an economy. Of course, the existence of feedback loops between these two modes of reconfiguration is certainly possible, but this does not call into question our hypothesis. Moreover, we recall that the aim of our method is not to reveal environmental impacts with the same precision as microeconomic studies on the rebound effect. We argue that, despite this approximation, our method will be able to adequately highlight the orders of magnitude of the different environmental impacts following the implementation of a given economic instrument based policy.

Our second hypothesis assumes that these cross-sectoral transformations can be modeled using an iterative discrete-time model involving an input-output (IO) matrix, i.e. [sector x sector]. We argue that, while far from being a weak assumption, this feature is already fit by some models. For example, the contribution of Almeida et al (2022a) proposes to use an SFC model to analyze the economic impact of the evolution of demand for several goods and services in the context of a transition of the building sector. The LCA data characteristic of these goods and services are used through an IO approach in order to evaluate the environmental impact from a perspective that integrates the macro-economic consequences of a change in the demand side. Following the view of the authors, the model proposed is able to account for what they called the ”first-order effects” linked to the new expenditures after a first wave of redistribution of the new economic flows following a change in demand. Almeida et al (2022b) also show that we can find a formal framework modeling the inter-sectoral reconfigurations following an exogenous shock on demand using an SFC model coupled with a Leontief matrix. Moreover, their proposal allows us to take into account the first- and second-order effects of a shock on demand, i.e. the effects due to new expenditures following new (re)distributions, taking place in the years following the implementation of the public policy.

Therefore, we consider in the following that intersectoral transformations following an environmental public policy can be modeled using a model (arguably not yet identified, because this is part of the research program we want to open with this contribution). Furthermore, we present through the contributions of Almeida et al (2022a, 2022b), that SFC analysis is for the moment a preferred class of models to connect a dynamic macroeconomic modelization in discrete time with the IO framework of Leontief. As we will see in the following sections, this connection is crucial to operationalize our method thanks to the large MRIO-LCAdatabases available today.

After having modeled the economic impacts of an environmental public policy (seen as a cross-sectoral reconfiguration), it is necessary to establish the environmental consequences of these economic transformations. We discuss this point in the following section.

5.4 Step (iv): an aggregate indicator as guide for policy option comparison

In section 4, we discussed the large diversity of existing environmental indicators. We then discussed the possibility to reduce the number of a big set of these indicators without losing consideration for the largely multidimensional ecological impact embedded in a life cycle analysis that one could expect from a strong sustainability based assessment. After having modeled the economic consequences of an economic perturbation in the demand that could be induced by different policy options available at step (ii) in the form of an intersectoral transformation at step (iii), the step (iv) of our method consists in the choice and the computation of a restricted set of headline indicators. Restricted here means “to allow for a simple comparative visualization between scenarios”. This is precisely in order to fit this ultimate computation that the output of the step (iii) shall present the evolution of the Leontief matrix of the economy studied, in discrete time, year by year. Our last requirement is then that the headline indicators chosen shall then allow for a computation through the data of an MRIO-LCA database (as EXIOBASE, for instance). For instance, the nine headline indicators identified by Steinmann and colleagues (2017) could fit these requirements.

This last step will merely consist in the computation of the headline indicators chosen against the change in the output of each industry during the years consecutive to the shock in the demande side (induced by the policy application). For an example, see the following section. The nine headline indicators identified by Steinmann and colleagues (2017) as statistically representative of the information contained in such a database could fit this feature. Then, the environmental burden evolution due to the intersectoral transformation of the economy (output of the step (iii)) could be assessed by a comparison between the computed headline indicators in the case of different scenarios corresponding to the implementation of different policy option (that is, again, different intersectoral transformations).

In the case of a comparison against a counterfactual scenario, this one should of course come from the same model used at the step (iii) to traduce the available policy options in an intersectoral transformation. However, we want to note here that our methodology is designed for comparing two policy options vis-à-vis their impact on other ecological dimensions than the one initially considered by these options, by revealing some orders of magnitudes of hidden impacts. Indeed, it was not designed to assess how much a public policy is expected to achieve its goal. Instead, the critical comparison between different policy options, against strong sustainability criterias that could have been forgotten during the policy design, remains the case for which it was designed.

5.5 Illustration by a simplistic study case

Let us consider a very non realistic, theoric case with arbitrarily chosen data to illustrate our methodology. We consider two policy options A and B (it could have been more). Let's consider that these policies aim to reduce the carbon emission in a fictitious economy. They are supposed to take the form of economic mechanisms (as a carbon tax) aiming to induce a shift in the demand of any carbon intensive good or product.

We now consider an economy described by 4 sectors : Agriculture, Energy, Metal Product, Services. We call L the traditional Leontief matrix describing this economy through an intersectoral framework :

$$L = (I - A)^{-1} \tag{2}$$

This latest is then a [4x4] matrix (in monetary unit), thanks to which we can compute the total output of each sector derived from a certain demand.

Let us assume that the economic model used (whatever his structure) allows for computing a change in the Leotief matrix consecutive to a change in the final demand initially targeted by the A and B options. This change in the final demand is the input of the model, and it provokes a change in the intersectoral relationships of the economy in the year $n = 1$. Then, the model used takes the lead in giving the following intersectoral relationship matrixes for the subsequent years, that is, for $n > 1$. The restructuring process of the intersectoral relationship of the economy is then modeled by the output of the model, from the given set of two policy options A and B. It takes the shape of a matrix sequence indexed on a yearly basis. We then obtain :

$$L_{n,A}, L_{n,B} \tag{3}$$

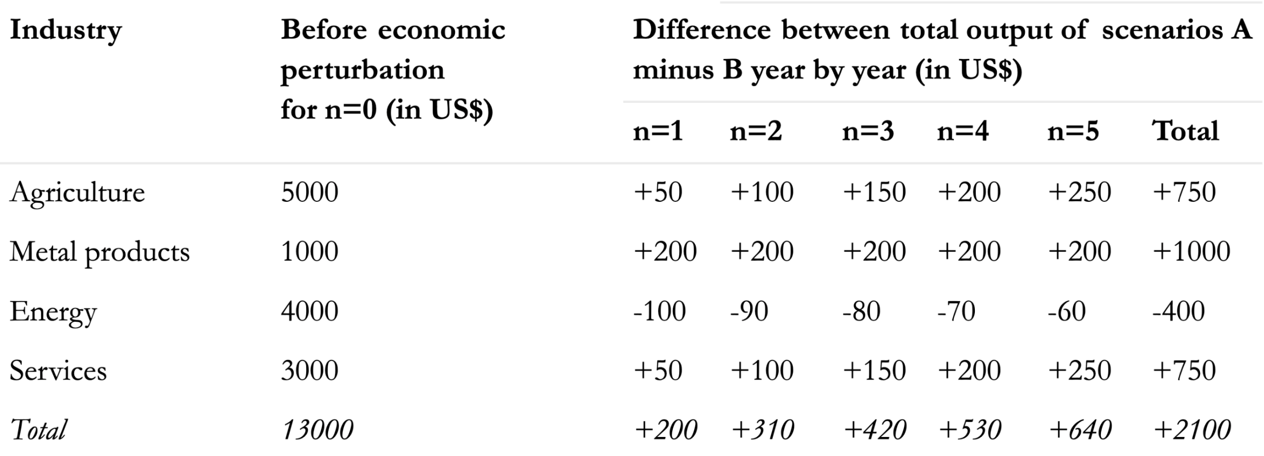
The Leontief matrix sequences representing the intersectoral transformations with respect to the two different scenarios (policy A application and policy B application), where n is the year. We should notice that n =0 is the year from which the policy will apply. So, the only common point between these sequences is, a priori, that :

$$L_{0,A} = L_{0,B} \tag{4}$$

Then we can compute the difference in the total output of each sector in the scenarios A and B. As in our example the set of policies compared is only made of two options, we go straightforward in computing directly the interesting differences between the two scenarios, without exhibiting the sequences themselves. This allows us to simplify the presentation. In the following, the differences presented in **Table 1** are always calculated for each year n under the form :

$$\textit{Total output of industry X in the scenario A - Total output of industry X in the scenario B} \tag{5}$$

For instance, we see in **Table 1** that the difference in the agriculture industry's total output is increasing year after year. This means that the total output of the agriculture industry is greater in scenario A than in scenario B. In contrast, less energy is outputted by the industry in charge in scenario A than in scenario B, leading to a negative value, while the difference between both scenarios is reducing year after year for this industry.



Industry	**Before economic perturbation for n=0 (in US$)**	**Difference between total output of scenarios A minus B year by year (in US$)**					
		n=1	**n=2**	**n=3**	**n=4**	**n=5**	**Total**
Agriculture	5000	+50	+100	+150	+200	+250	+750
Metal products	1000	+200	+200	+200	+200	+200	+1000
Energy	4000	-100	-90	-80	-70	-60	-400
Services	3000	+50	+100	+150	+200	+250	+750
Total	*13000*	*+200*	*+310*	*+420*	*+530*	*+640*	*+2100*

Figure 1: Total output in the year $n = 0$ for each industry and difference between the total outputs of each industry between the two scenarios in the subsequent years.

Let us now consider four headline indicators (it could have been more) : aggregate material use (M), blue water footprint (W), land use (L), and carbon footprint (C). Let us also introduce the (arbitrary chosen) intensity coefficients specific to each sector relative to this set of indicators. These coefficients are indicated in **Table 2**, in the units that generally characterize them in the currently available MRIO-LCA databases (as EXIOBASE, for instance).

Indicator	**Industry**			
	Agriculture	Metal products	Energy	Services
M (in t/US$)	0.0002	0.02	0.008	0.002
W (in L/US$)	0.05	0.007	0.002	0.0004
L (in Ha/US$)	0.1	0.006	0.004	0.0003
C (in CO2e/US$)	0.06	0.03	0,21	0.009

Figure 2: Intensity coefficients of each industry against four headline indicators.

Then, considering the sum of the difference in the total output of each industry through the years, available in the last column of **Table 1**, we can now compute the different scores of both the A and B cases with respect to the headline indicators. The results are presented in **Table 3**.

Indicator	**Industry**				
	Agriculture	Metal products	Energy	Services	Total
M (in t)	0,15	20	-3,2	1,5	18,45
W (in L)	37,5	7	-0,8	0,3	44
L (in Ha)	75	6	-1,6	0,225	79,625
C (in CO2e)	45	30	-84	6,75	-2,25

Figure 3: Difference of the environmental burden associated with the total output of the two scenarios, considering the total period modelled.

Through this computation, we can observe that, if both scenarios lead to (almost) equal carbon emissions, scenario A is much more intensive in land use, blue water use, and material use. In this case, our environmental impact assessment methodology leads then to favor policy B, in order to tackle climate change with almost the same strength as in scenario A, while accounting for other environmental dimensions. This very simplistic example show that, it is technically feasible (ie with the today's available models and databases) to build a very simple guide for discriminating against several environmental public policies in a strong sustainability perspective. We claim that this methodology could open the door to a new research program by connecting the knowledge already well advanced in different fields such as macroeconomic modeling, environmentally extended input-output analysis, environmental rebound effect studies, and considering the large MRIO-LCA databases currently available and their associated environmental indicators. This methodology relies therefore crucially in considering several headline indicators representative of a broader environmental consideration.

Our proposition is not about dealing with trade off between environmental burdens, but propose a very simple methodological tool that could be fruitfully further developed to raise the policy maker awareness about the broader environmental burden linked with a set of different policy options. In this view, we proposed this methodology specifically to allow the policy maker to easily account for the order of magnitude of different ecological burdens than can be ignored by focusing on only one environmental dimension. Nevertheless, one of the main recommendations that can already be given to the policy makers, representative to the core of our methodology, is to keep in mind a consideration for the life cycle assessment of the goods and products of which the production and consumption could be encouraged by any environmental public policy. We claim that this consideration is a first crucial step to prevent any environmental burden displacement.

5.6 Scope, limitation and further research requirements

The reasoning behind this method is based on a backward induction: comparing different policy options (ii), asking to compare the economic restructurings they imply (iii), by assessing the environmental consequences of these restructurings (iv). The limitations of this work are numerous, so we will address them by listing the main characteristics of our method in this section, and finally justify the choices that could be made for future research.

Our first approximation is to identify the economic consequences of a public policy as a cross-sectoral restructuring in discrete time, year by year. One can claim that in the case of a very disruptive technological improvement, the footprint of a sector (assessed by the coefficients we proposed, expressed in physical units per monetary unit) could be reduced. But, from where such a reduction would come from ? First, we consider that, the main feature of any technological innovation is precisely, to allow for an industry to less rely on extra-sectoral input to produce the output : this is always, directly or indirectly, a gain in production efficiency. Second, the coefficient calculated through a database as EXIOBASE rely precisely on the cross-sectoral relationship of the economy (see www.exiobase.eu and EXIOBASE documentation). Therefore, we claim that our first approximation of viewing an economic shift as an intersectoral transformation is still consistent in the case of the apparition of a tremendous gain of productivity in one sector (for example, in the case of an energy industry newly able to furnish energy without relying on fossil fuel extraction). However, we recognize that, the eventual skyrocketing apparition of a new sector that was not initially included in our Leontief matrix describing an economy could be problematic. This point forces us to disagree with Nordhaus (1973), by assuming that the apparition of a “backstop technology” is not supposed to happen in a time window considered here, that is, characteristic of the policy consequences assessment. This time window could be reasonably considered to be inferior to one decade, because the aim of today’s environmental policies should be to involve radical and quick changes (GIEC 2022). First, this assumption, contrary to Nordhaus view - and arguably pessimistic - is based on the idea that technological innovation is very slow in spreading massively a change in global consumption and production. Generally, revolutionary transformation takes from a few decades until more than one century (Edgerton, 1999). Moreover, some historians of techniques claim that new technologies are generally very slow to replace one another, due to their, not only competitive, but also symbiotic nature (Fressoz, 2022).

A clear limitation of our method is that the computation of indicators relies entirely on the LCA-based coefficients furnished by a large MRIO database as EXIOBASE. These data are computed through a certain level of disaggregation, that is, involving 163 industries and around 200 different products. Given this, three points should be highlighted.

First, without a tremendously higher disaggregation level, the life cycle of products (and in fine, of industries) are then obviously approximate. This leads to the inability of our method to account for precise (ie at the micro scale) different consequences of the environmental burden of different policy applications. However, we note that microeconomic impacts as direct rebound effects in usages could be, to some extent, accounted for in the modelling of the perturbation of the demand consecutive to the application of the environmental policy. Indeed, Almeida et al. (2022a) used an econometric model that accounts for the rebound effect when it was about dealing with the economic consequences of a policy application on the demand side. Then the SFC model they use aims to assess the economic impact of a change in the demand side, a change itself assessed previously by the econometric model used upstream. This combination is an interesting avenue for further consideration in the research program we propose to open in this contribution. Moreover, we argue again that the aim of our methodology is to furnish a very simple tool that allows for a broad environmental consideration, by giving the order of magnitude of unexpected ecological impacts in other environmental dimensions than the one initially considered in the policy design.

Secondly, LCA data are generally derived from the traditional LCA methodology, based on ISO 14040. An interesting perspective to study the environmental life cycle of products has been introduced by Almeida and colleagues (2022b). The study proposes an SFC framework to trace second-order economic and environmental effects, i.e. effects caused by expenditures following the remuneration of primary factors (such as wages and taxes). They argue that it is possible and relevant to take into account not only the rebound effects related to product prices (first-order effects), but also the second-order effects, i.e. the economic and environmental effects resulting from the redistribution of income from the remuneration of primary factors by the population groups concerned. One can claim that accounting for these second-order effects call for including all the activities of the whole economy "until the end of the world" in the analysis (Weidema et al., 2015). However, the authors show that, since only a share of primary factor remuneration is involved in changing consumption patterns (the untaxed share), higher-order effect magnitude decreases when the order increases. If an SFC model is used to model the impact of a public policy on cross-sectoral recomposition, then incorporating higher-order effects could decrease the uncertainty of our method.

Thirdly, the indicators considered should be proxies computable through LCA data. Because of this, some environmental dimensions may be difficult to assess. While climate impact is easily assessed using CO2e emissions data, biodiversity issues require a more in-depth analysis as they present impacts with multiple causes. Indeed, even if land use is an impact accounted for by MRIO-LCA databases such as EXIOBASE, it could not be enough to build a proxy for assessing the total biodiversity burdening of one economic activity (IPBES, 2019). Even if there are accounting methods for biodiversity issues (Feger and Mermet, 2021), it does not seem easy to assess the biodiversity impact with LCA data. Biodiversity burdening and climate change present also a typical example of the interconnectedness between environmental dimensions (IPBES and IPCC, 2021). Therefore, not all environmental dimensions are easily assessed by our method because the proxies that can be used to create relevant indicators must be based on LCA data. An alternative could be to directly use the flows in monetary units present in the MRIO matrix considered to derive an indicator. An interesting point for further research could be to evaluate the feasibility of computing an indicator through monetary flows.

Another crucial point of improvement lies in the fact that there is no consideration for social dimensions. Moreover, in our proposal, the demand for a product remains confined to an aggregate of economic transactions. Traditional economic theory deals with the consumer theory, through notions such as rational choices and preferences. Some authors challenge this vision. For example, Hofstetter and Madjar (2003) argue that a change in behavior can also come from time, information, or skills. They also propose that quality of life or (subjective) well-being plays an important role in the decision. Therefore, an interesting point for future research can be found in the contribution of Suski et al. (2021), who introduce the notion of ”social practices”. With the idea that each ”social practice” includes specific consumptions, they establish a theoretical framework to link these ”social practices” to the product life cycle inventory. For them, the idea that consumption boils down to an economic transaction is too poor to study the environmental impacts of the economic process in a holistic way. Although it provides an interesting framework for analysis, especially for differentiating the effects of consumption across cultural areas with very different consumption patterns, this framework still requires empirical validation.

Finally, we consider that our contribution could be interestingly looked at in light of the debate about decoupling. The term growingly used in the literature call for a possibly feasible disconnection between economic growth and environmental impact. However, after a wide and systematic review of the literature on the concept, involving the examination of 11 500 scientific papers and 835 empirical studies, Haberl et al. (2020a) identified a strong focus on only three biophysical considerations : energy use, energy and material use, and emissions. However, a strong sustainability point of view calls for a broader definition of “decoupling”. Indeed, there is no immediate reason for which decoupling economic growth from GHG emissions implies the same decoupling with biodiversity degradation, chemical pollution, land use, water use, or any other environmental dimension.

Interestingly, Haberl et al. (2020b) found that the decoupling observed in some industrialized countries is weaker when it is considered between economic growth and production emissions than between economic growth and consumption-based emissions. In the same way, Wiedmann et al. (2015) found that if, “as wealth grows, countries tend to reduce their domestic portion of materials extraction through international trade, [...] the overall mass of material consumption generally increases”, presenting a 0.6 elasticity between GDP and material footprint. This is why we think this debate could be enriched by a life cycle point of view. Therefore, we claim that the debate about the feasibility of a decoupling between economic growth and environmental impact not only lies on the empirical evidence but also, and maybe more, on what is hidden behind the term “environmental impact”. In this sense, we argue that our method could be interestingly used to imagine a new definition of decoupling that embraces broader environmental dimension, specially through the utilization of LCA coefficients or other indicators that could be derived from them, while being easily operationalizable.

6 Technical choices within societies : the case for the low-tech approach and energy communities

At this point, we should have been about answering the following question : "has the low-tech approach the capacity to reduce systemically the environmental burden produced by the production and consumption processes in the different economical sectors of modern societies ?" In the light of the method presented above, it seemed clear that in order to assess the ecological relevance of any change in production or consumption processes - such as moving from a high-tech to a low-tech process - it would be necessary to focus on three parameters:

- - firstly, the ecological footprint values for a monetary unit in each sector,
- - secondly, the inter-sectoral links, or coefficient of the matrix L,
- - thirdly, the employment and human capital required in each sector.

However, as we shall see in this section, the issue becomes more complex when it comes to definition. Assessing the ecological relevance of a high-tech/low-tech change requires such a change to be clearly defined upstream. To this end, we will briefly review the relationship between technology and society, before reviewing the literature on the low-tech concept and drawing conclusions for this study. Finally, we will present two study cases showing that the real potentiality of such change is less environmental than social an political.

6.1 Technology and society

Over the last few decades, social science researchers have largely deconstructed the idea that the place of technology in human societies is the result of the inexorable linear and teleological advance of technological progress. By denaturalising technical developments, especially those that have occurred since the century of the first industrial revolutions, they have exposed the political choices that gave rise to them (Gras, 2007; Jarrige and Vrignon, 2020). What's more, they have also lifted the veil on the issues of power - economic, political, symbolic and social - and the asymmetries that characterise them, and the collusion between the sacralisation of technique and technology on the one hand and the implicit defence of vested interests that have structured the equation between technique and progress on the other (Malm, 2018; Bonneuil and Fressoz, 2013). This is why some authors prefer to refer to this new geological era, which others still call the Anthropocene, as the Capitalocene (Gemenne and Rankovic, 2019), which began with the first industrial revolution and in which humans are said to be the main force modifying the biosphere (Steffen et al., 2015).

This characteristic of technology in our societies, as the fruit of political choices that see it come into being but also modify it and make it evolve, justifies the notion of a "socio-technical system" (Akrich, 1989), where social dynamics and technical objects are intertwined. However, technology is not simply a category that is not independent of politics. According to Jacques Ellul (1954), it is an entity that has become autonomous since the twentieth century: human beings are gradually losing control over the course of development of a technology that they make sacred, which, according to Ellul, characterises the transition from industrial society to the 'technological society'. According to Ellulian logic, it is the absence of a critical spirit with regard to a technology considered to be 'neutral', i.e. whose effects depend solely on its use, that has led it to become part of the new human environment.

Without falling into a primary technological determinism, some authors nevertheless raise the issue of governance in relation to technical choices, whether it be an eco-algorithmic dystopia enabled by information technologies (Abrassart, 2020), or the governance of common goods based on Ostromian principles (Ostrom, 1990) as the only one compatible with a 'low-tech' society according to Bourg et al. (2020). However - and this is not entirely at odds with Jacques Ellul's analysis - techniques could have a variety of characteristics."Whether they are 'intermediary' (Schumacher, 1973), 'liberating' (Bookchin, 1980), 'democratic' (Mumford, 1950) or 'user-friendly' (Illich, 1973), they are not inevitably alienating; better still, they could have an emancipating potential.

On the subject of energy production technologies in particular, some authors invite us to consider technical choices in terms of 'technological potentialism' (Rumpala, 2013), or, when describing any type of object or visual environment, the notion of affordance (Gibson, 1979), sometimes translated into French as 'promission' (Latour, 2000). Rumpala (2013), for example, refers to the potential of renewable energies in terms of the following oppositions:

- from centralisation to decentralisation (reconfiguration of polarisations),
- from remoteness to proximity (reconfiguration of scales),
- from dependence to self-sufficiency (reconfiguration of relationships with macro technical systems).

While it is the fruit of political choices, technology also appears to be deeply dependent on the social interactions and social contexts that help to bring it about, develop it and/or call it into question, and even on the choice between different models of governance for societies. Technology is born, developed, hegemonised or reduced, but it also enables, encourages, facilitates or, on the contrary, prohibits, prevents or hinders.

6.2 Low-tech : from the adjective to the conceptual approach

The term "low-tech", which probably appeared in the 1970s (Schumacher, 1973), originally refers to the idea of temperance, of sufficiency, in the use of technical objects, in conjunction with a reflection on the needs they are intended to meet. According to Jarrige and Vrignon (2020), it is not an entirely new idea per se, since there was already an opposition in the post-war period between a centralising vision (governed by "technocrats") and a decentralising vision (appropriated by "do-it-yourselfers") of so-called "alternative" energies (to fossil fuels). Nevertheless, the term has been enjoying a resurgence - and perhaps an appearance in the French-speaking world - since the 2010s (Bihouix 2014), which suggests that it should be associated with the notions of open-source, accessibility, sustainability and sobriety. At first glance, then, the potential of low-technologies is intuitively characterised by both improved accessibility and the need to reflect on the needs they are intended to meet.

A brief literature review was conducted by Morgand et al. (2021), largely based on the French context, which has seen the birth of a real conceptual nebula around the term low-tech:

- "According to the French organization *Low-tech Lab*, a system is low-tech if it is : useful, accessible, sustainable.The system is useful if it meets an essential need such as water, energy, food, waste management, materials, housing, transport, hygiene or health. It is accessible if it can be used by a large population. This means that the system can be repaired locally, that everyone can understand how it works and that it does not cost a lot of money. Finally, it is sustainable if the stages in its life cycle are optimised in ecological, societal and environmental terms,

- The Frenche organization *La Fabrique Ecologique* gives its own definition : "Low-tech, as opposed to high-tech, is an approach that aims, with a view to sustainability, to question our real needs and develop solutions that are as low-tech as possible, minimise the energy required for production and use, use as few rare resources or materials as possible, and do not impose hidden costs on society. They are based on techniques that are as simple as possible, that depend as little as possible on non-renewable resources, on products that can be repaired and maintained over time, that facilitate the circular economy, reuse and recycling, and that rely on knowledge and dignified human labour.This approach is not only technological, but also systemic.It aims to challenge economic, organisational, social and cultural models. As such, it is broader than eco-design.",

- In his book L'Âge des low-tech. Vers une civilisation techniquement soutenable, P. Bihouix talks more about low technology than low-tech.The aim of low-tech is to reduce resource consumption.Since an object that we don't make requires the fewest resources, we need to question our needs.The object must be designed to last, i.e. made from renewable materials, easily recyclable (so accessible to everyone), and made to last as long as possible.In his view, the local population needs to be able to make it, repair it and, above all, control it,

- In an illustration by M. Joumard in the Socialter special issue about low-tech (2019)[1], low-tech is associated with the following keywords: reparable, free, open, minimalist, biodegradable, modular, recyclable, no rebound effect and sober,

- According to J. Carrey and S. Lachaize (2020), a low-tech system is an elementary brick

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[1] *L'avenir sera low-tech.* URL : https://www.socialter.fr/produit/hors-serie-n-6

of a perennial system. Every technical system is divided into elementary bricks, and it is these bricks that are judged for their input-output stability. The inputs are the labour, materials and energy required to manufacture the system, while the outputs are waste and impacts (societal and environmental).According to the authors, inputs and outputs are stable if they are identical over several millennia and if they allow a constant level of production.The essential needs considered here are drinking, food and shelter,

- According to T. Bauwens (2020), a low-tech system requires less RD activity. It is designed as simply as possible, with as few resources as possible, and is characterised by the low level of knowledge required to understand it. Low-tech can lead to changes in behaviour. A definition is even given: "Technologies designed to be as simple as possible, characterized by low RD investment and low knowledge transfer costs",
- On his website[2], G. Roussilhe defines low-tech as a political approach that makes it possible to recompose one's relationship with a world constrained by technology. The author prefers to speak of "low-technology high-technics". This term refers to a society in which high-tech objects are used sparingly and production is geared towards sustainability and the development of a social culture. Essential needs are grouped according to the Manfred Max-Neef matrix. This matrix was designed to avoid classifying human needs."

In this effort to define low-technology systems, we can note the importance of the approach used through the entire life cycle of the system, from the extraction of material, the design, and the utilization phase notably. According to these definition, it seems less important to know, through any pure dichotomic classification process, wether a system is low-tech or high-tech. Finally, it seems preferable to speak about a low-tech approach, than a low-tech system. In the same idea, it seems more relevant to speak about "lower-tech" systems, as far as these latest show the characteristics discussed in the definitions pinned here.

Despite the direction given by the question we raised[3], the very materiality of technical objects does not seem to sum up the technical potentialities, or even in the exo-somatic possibilities they

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[2] *Une erreur de "tech".*. URL : https://gauthierroussilhe.com/articles/une-erreur-de-tech

[3] Has the low-tech approach the capacity to reduce systemically the environmental burden produced by the production and consumption processes in the different economical sectors of modern societies ?

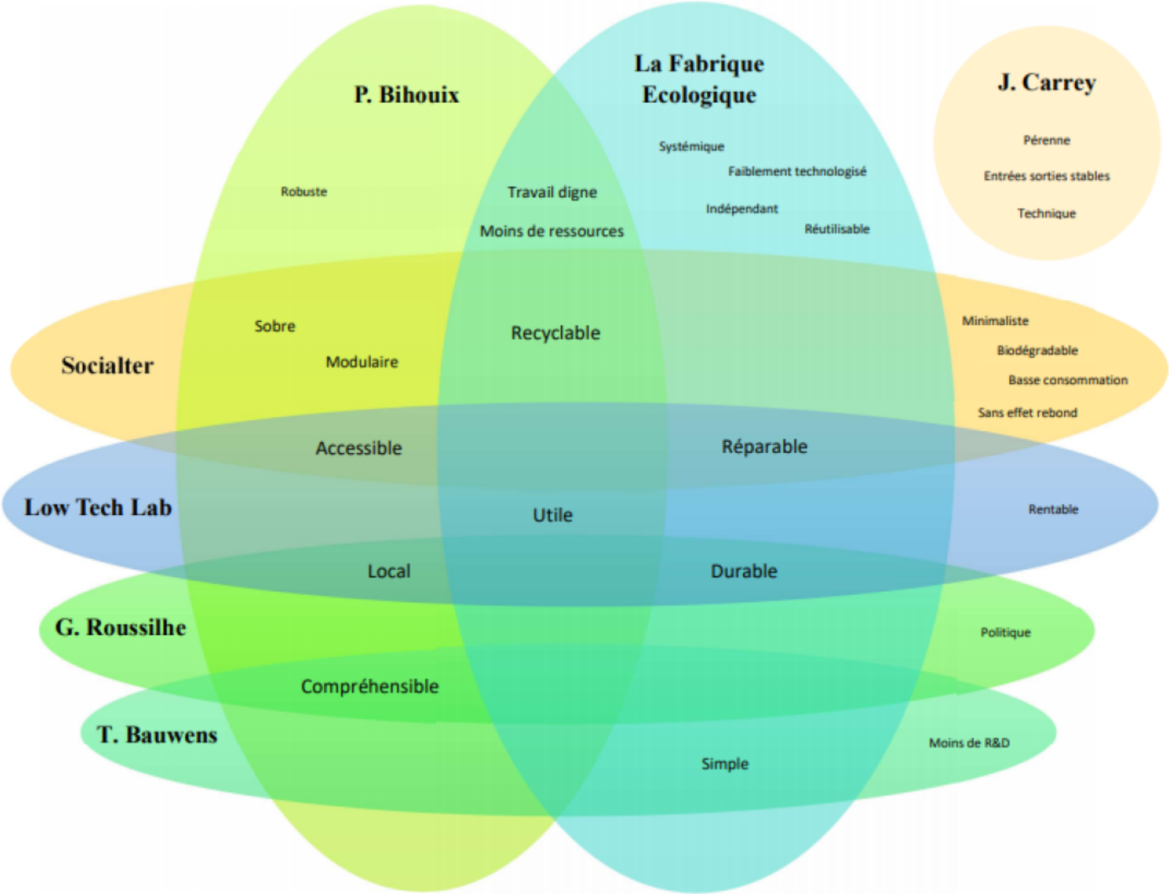

Figure 4: Conceptual mapping of the low-technology definitions, from Morgand et al. (2021).

deploy. In this respect, Grimaud (2017) proposes going beyond a definition of low-tech based solely on the oppositions between high and low, local and global, artisanal and industrial, to recall the importance of a use that constantly reinvents, recovers, reuses, recycles, repairs and reconstructs not only the objects but also the technology itself, through the sometimes unexpected appropriations of the actors who seize it in innovative ways. In this regard, Grimaud quotes Edgerton (2013): "Thinking a history of techniques in use, writes David Edgerton, offers a radically different picture of techniques themselves but also of invention and innovation. A whole invisible world of techniques emerges, leading us to rethink technological time as defined by chronologies based on innovation".

It therefore seems crucial to take an interest in the way in which potential users of technical objects take paths of diversion and re-appropriation, sometimes becoming designers in the process. This is why the low-tech movement is included by the author in a broader 'wild-tech' approach

(Grimaud, 2017).

In the latest definition, the political dimension of the low-tech approach is as important - to not say more - than the pure material life cycle assessment. According to Roussilhe and Mateus (2023), ”while low-tech contains the seeds of solutionism, it falls far short of the promise and hope of advanced high-tech solutions”. Even if in its own terminology, the low-tech approach has defined itself in opposition with the high-tech one, we already pinned the political, situated and non-homogeneous character of the technological development in the first subsection of this part. For the authors, the low-tech approach seeks to ”encourage a new technical culture (which) would involve its reintegration into the social sphere”. This contribution is absolutely central to overtake the question of the socio-ecological potentiality of the low-tech approach to shift the production and consumption systems. Contrary to any other technological innovation, the low-tech approach seeks not to ”scale up”, to intensify, but to ”scale wild”, to disseminate more widely, according to a model that is not so much that of an economy of functionality that we control from end to end, but rather a local and shared open source economy that allows everyone to make it their own. The challenge is to change the industrial nature of the world, and to give birth to a collective and local ownership culture.

6.3 Communities and energy technologies : a study case

At this point, the question is less to know if the low-tech approach could systemically reduce the environmental burden through cleaner production and consumption processes than to know how different technical approaches could influence the social dynamics. Indeed, we know consider that the very potentiality of the low-tech approach is as - to not say more - social than purely material. In this perspective, we should wonder if a low-tech approach, as defined above, allows social agents to reinvent their relationship to thechnology, energy, or even their own needs. To answer this question seems to be first step before investigating more deeply the potentiality of the low-tech approach to overcame systemic and hollistic environmental burden, as caused, for instance, by rebound effects.

Particularly, energy production techniques seem to be highly involved in the creation of social ties, both in terms of the opposition they provoke (Jarrige, 2016) and in terms of the particular ways in which they are appropriated, which can lead to the creation of various forms of ’community’

(Hielscher, 2011).

6.3.1 Community : sociological approach

But what is a community? Before examining/ discussing the extent to which/how energy and its various forms of technical domestication can help to forge social bonds, we need to take a closer look at this term. Whether it is Durkheim's (1897) concept of a 'mechanical' solidarity based on shared norms measured by the suicide rate, or Weber's (1922) process of 'communitisation' through shared economic activities and subjective beliefs, the definition of this term remains a fundamental problem for the discipline of sociology. From the debates that have traversed, and still traverse, sociological literature on the polysemous notion of community, we can nevertheless retain certain essential characteristics. These include participation and the process of recruiting new members (Hoffman and High Pippert, 2009), the importance of trust (Putnam, 1992) - and even greater importance of initial trust (Walker et al., 2009) - and governance (Ison, 2010).

This last point is itself the subject of an in-depth analysis by Elinor Ostrom (1990), who drew up a typology of the broad lines characterising the robustness of the governance of a common resource (such as energy) by a community. The eight principles she identifies are: a clear definition of the community's limits; rules adapted to local needs, conditions and prior objectives; a system of participation in the construction and modification of rules; governance accountable to the community; a graduated system of sanctions; a low-cost system of conflict resolution; self-determination recognised by entities outside the community; and, if necessary, a multi-level organisation based on common resources managed by the community.

Peters and Jackson (2008) challenge the concept of community in sociological literature in the light of collective environmental initiatives. The question of how to define boundaries is a recurring one, as it plays a role in the very definition of what a community is. Field surveys tend to identify two sub-groups (Pelling and High, 2005; Walker 2011): the community of place (defined primarily by its geography), and communities of interest (based on other attributes shared by its members). Cohen (1985) proposes another typology based on the idea of a symbolic boundary, within which members have something in common that specifically differentiates them from members of other potential groups:

"...the boundary thus symbolises the community to its members in two quite different ways: it is the sense they have of its perception by people on the other side – the public face and typical mode – and it is their sense of the community as refracted through all the complexities of their lives and experience – the private face and idiosyncratic mode."

While this might seem less complex to determine, the geographical boundary also raises non-trivial issues: the non-overlapping of topological and administrative boundaries, as well as discontinuous economic interactions between territories, plunge groups of individuals into a tangle from which it is difficult to extract a geographically determined isolate (Chaskin et al. 2001). Geographically, the community can be interpreted as a place of cohesion, of relationships between people (positive aspects), but it can also be perceived as excluding by locals, marginalised or those who are not there or do not feel welcome (Harvey 1996). What's more, even from the inside, communities can be the site of different visions for the future, asymmetries of decision-making power, exclusions and resignations. In this respect, Dalby and Mackenzie (1997) prefer to understand them as "political and social processes rather than established social and geographical entities".

6.3.2 Energy communities : interaction between technology and sociology

With this in mind, we need to look more closely at the specific case of energy. Can energy 'form a community', and under what conditions and to what extent? In the UK, a phenomenon similar to this has been widely observed. In a review of the literature on renewable energy communities in the UK, Hielscher (2011) notes the following characteristics: First, energy communities present a wide diversity of projects, which tends to complicate their formal definition. While Hathway (2010) defines them as 'projects that involve local groups developing low-carbon energy appropriate to local circumstances and where the community groups collectively own the outcome', Walker and Devine-Wright (2008) highlight the polysemy of the term. For them, this polysemy has both a positive side (an unstructured approach allowing a link between government energy programmes and the development of local groups of various kinds in terms of form, function, scale and context) and a negative side (community energy projects could lose the local and collective identity that shapes the majority of them, because the concept is too vague). Secondly, these communities often

have different objectives, ranging from simple awareness-raising to the development of renewable energy production, via 'good practice' communities (frugal use, sharing of equipment), even if in practice they pursue several simultaneously (Steward et al., 2009). Thirdly, the 'discursive resources' mobilised by the members (Walker et al., 2007) evoke modalities of process (from local and participative 'openness' to distant and institutional 'closure') and sharing (from collective to private benefit). This point ties in with the framing work (Goffman, 1974), identified by Riollet et al. (2015) within the Mené energy community, through which participants construct a shared history, define themselves in opposition to other groups, and recruit new members.
"The preponderance of political and social motivations, the involvement of members in the initiative, the greater sense of identification, and a greater energy awareness make the cooperative model [including associations] a collective project with a strong vision of sustainability. The second model, known as communal, includes initiatives that come into being through the municipality. In this case, turnkey projects that are less ambitious in terms of governance, managed by professionals in the sector, and with greater scope for negotiating the feed-in tariff, succeed in attracting a different segment of the population" (Serlavos, 2018).

Consequently, it would seem that energy can be 'pooled' without 'forming a community', or rather to very different degrees (with regard to the aforementioned criteria of participation, trust and governance cited as structuring principles of communities). It therefore seems insufficient to associate the role of energy with the creation of social links without any intermediary. Rather than a sui generis social dynamic, the structuring of social ties around energy should therefore also be studied more precisely in the light of the techniques used to domesticate it. Now, the concept of technological potentialism - already mentioned above - seems to work when we talk about the diversity of energy communities in that they present not only differentiated social or geographical dynamics, but also varied relationships to technology.

6.3.3 Around some conceptual pardoxes of energy communities

In a sense, the emergence of energy communities is in itself a noteworthy social fact. It can be seen as paradoxical. Firstly, because the formal principles of the market economy that characterize the "general art of governing" of contemporary states give a cardinal place to individual enterprise (Foucault, 1978-1979). Similarly, individualism is described by some authors as a notable feature of modern societies:

The reality is that 'low group, low grid' societies – characterised by the precedence given to individual rights over group rights, the importance attached to social mobility, light governance and an emphasis on open access to markets, competition and equality of opportunity – paints a picture of an entrepreneurial and individualistic culture that pervades and characterizes much of modern society" (Jackson, 2004).

Secondly, because the energy sector in France, even before it became the subject of economic liberalization in particular in the 2000s, has been organized since the 1970s on a centralist model that depends on a strong State, capable of instituting an electro-nuclear program in which individuals play the role of consumers of an energy they are not directly involved in producing, delivering or organizing (Jarrige and Vrignon, 2020). In this context, how can we explain actors coming together to produce their own energy? Bauwens (2016) identifies heterogeneous motivations among cooperative members depending on whether they remain among the first adherents of a restricted and geographically localized group (ecological convictions, sense of belonging to the group, importance attached to democratic governance), or newcomers to a group already expanded in numerical and territorial terms (material incentive to invest in renewable energies in the expectation of a return on investment). Research also shows that the role of ecological convictions should not be overestimated.

Indeed, Bauwens and Devine-Wright (2018) non-members of an energy cooperative are simply "more undecided" but not more opposed to local renewable electricity generation projects, which depends among other things on the environmental, visual impacts, ownership model, and degree of participation offered by the projects. Consequently, the origin of energy communities requires research beyond the identification of environmental convictions.

6.4 Between low-tech community and social network : the case of the Tripalium organization

The Réseau Tripalium is a particularly interesting case in point. A collective founded in 2007, it aims to kill two birds with one stone by proposing participatory workcamps open to all, to learn how to build a low-tech wind turbine from A to Z, through hands-on construction on a private plot. But it also offers players (known as "pilots") the opportunity to list their particular wind turbine in an open-access database, and to organize meetings which, here too, have the dual function of training course and maintenance operation. In this way, trainers can offer courses to which anyone can sign up. The variables of participation, trust and governance, so dear to sociologists seeking to define the community, can be found in this mode of operation. Moreover, the relationship with energy seems to play a founding role in this network, which links members around self-built renewable energy production devices, in the same way that energy cooperatives bring their members together around a common project, but unlike which the actors participate physically in a systematic way.

This case is also emblematic of a particular potentiality, which makes it possible to organize a network of actors and their meetings around a technical appropriation not observable for other forms of energy production. The durability over time of the links forged by the network is ensured by the maintenance required by these technical devices, which can be appropriated by a simple group of "do-it-yourselfers". This example show perfectly the theorical and conceptual reflexion developed above : without denying that the low-tech approach has a potential to reduce, materially speaking, the holistic environmental burden of production and consumption processes, the outcomes of alternatives socio-technical systems seems to be infinitely deeper than any CO2 or energy consumption reduction.

7 Conclusion

We intended a critical review of different fields that we could, in our view, be suitably connected to develop a strong sustainability assessment process for environmental public policy, and made a first proposition for this connection. Then, we investigate the potentiality of the low-tech approach for driving such public policies. After a conceptual mapping, we focus more on the social potentiality of this approach, rather than on the mere gain in the life cycle efficiency of technical systems, through study cases.

While the literature on direct and indirect rebound effect from energy economics presents lacks of broader environmental consideration than just energy consumption, the concept of environmental rebound effects still needs some formalization that avoids over (or under) estimations that relies on the "calculated ressource savings" that were not targeted by the energy efficiency improvement. Both of these research topics seem also less suitable to a macro scale environmental assessment integration, considering that the evaluation of rebound effect mostly relies on elasticities computation. However, the ideas developed through these areas of research, and specially the life cycle consideration of products of which the consumption has evolved after an economic shock, constitutes, in our view, a good starting point to adopt a strong sustainability vision.

In the macroeconomic literature, we coined the lack of research on the side of broad environmental consideration inherent to the strong sustainability paradigm. While some recent research from the SFC modelling field intends to build integrative vision of monetary, financial, energy and resources flows at the macro-scale, the IAM literature presents big shortcomings in terms of accounting for resources and, more generally, dealing with non-homogeneity of capital and its greening process. However, we claim that some recent contribution in the field of SFC modelling, if coupled with a Leontief cross-sectoral paradigm, could be suitably connected with the large MRIO-LCA databases today available.

The LCA intensity coefficients provided by these databases could present a starting point to account for broad environmental implications of a change in the consumption side. While big, the number of environmental indicators that allow for computation from these coefficients have been considered as reducible to less than ten of them without losing the information statistically available on the large amounts of data presented by large MRIO-LCA databases.

Our contribution aims to propose an ex-ante method of environmental public policy evaluation to compare different alternative proposals within the regulator's reach (seen as cross-sectoral reconfigurations). This method aims to prevent any side effect that can occur after the implementation of an environmental public policy, that could lead to the displacement of an environmental impact from one ecological dimension to another.

While relying on few approximations and presenting some limitations inherent to an LCA-based computation of environmental indicators, we claim that it remains a simple, easily usable, and already operationalizable tool considering the state of the knowledge in the literature reviewed and the availability of relevant data. To allow for the easy computation of orders of magnitude of eventual different environmental impacts is considered as the biggest advantage of this methodology.

By doing so, we also coined, by the introduction of this simple method, the starting point of a research program that could connect the knowledge of the different research streams identified. With further research, consisting in building bridges between SFC modelling, rebound effect, and LCA-based indicators selection, we claim that the way is open to connect the micro and the macro scale of economic consequences of a policy, while adopting a strong sustainability perspective.

Then, we raised the question of the role of technical choices to support a systemic transformation in a strong sustainability framework, as studied with the method pinned in the precedent parts. After a conceptual mapping, it lies that *low-tech* shall better be used as an adjective than a name, and that we could more clearly and relevantly name a low-tech approach than a low-tech system. In this view, a low-tech approach aims to build "lower-tech" systems, it is said, systems built with less materials, simple enough to be appropriated and repaired by local populations, in an open source framework, in order to fulfill essential needs. This clarification, despite vague, still helped us to go out of any (impossible) dichotomous designation of technical systems. Here, we first concluded that, in the view of the conceptual challenges raised by the low-tech approach, it appeared less and less relevant to raise the question of the potentiality of systemic transformation of this approach. Indeed, the social and political dimension of the low-tech approach embeds much more than a pure reduction in the life cycle footprint of technical systems. This is why we finally moved on the social potentiality of this approach, by participating in the fabrication of social ties. We conclude here that the way alternative technical approaches can (re)shape social ties appears like a first step to a more collective and systemic change in the (re)appropriation of technical choices. Less than a pure reduction of the ecological footprint of modern production and consumption processes, this reintegration of technical choices in the social sphere seems to embed a social potentiality, by opening the door to new types of social ties - grounded on the environmental constraints shaped by planet boundaries -, new collective thoughts around the definition of which need is really essential, and new structures and organizations that can fulfill them in an strong sustainability framework.

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