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THE REGENERATIVE ECONOMY: PRINCIPLES AND IMPLICATIONS FOR ECOLOGICAL ECONOMICS

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1 Abstract

Ecological Economics is interested in studying the pure socio-economic interactions between Ecology and Economy but as well those coming from socio-technical changes. This paper provides a new framework based on a specific (socio-technical) organisation of material flows, the Regenerative Economy, which mitigates systematically resource extraction and cuts pollutant emissions. It therefore transcends previous conceptions of the physical metabolism of an economy and hence its (socio-economic) intra- and inter-generational consequences. Thus, both socio-economic and socio-technical interactions between Ecology and Economy need to be re-examined under the Regenerative Economy theory. This research aims to be the foundation stone of this analysis.

First, this paper defines the Regenerative Economy's organisational principles, i.e. the theoretical organisation of the material flows exchanged between the economy and the environment. Then, the organisational principles are translated into operational principles which orchestrate the re-organization of the materials flows under a (socio-)technical perspective. The technical consequences for the current production-consumption structure are discussed.

Secondly, this research analyses the intra- and inter-generational implications of a regenerative economy compared to the current practices. Also, the concept ecosystems services is re-examined under the Regenerative Economy perspective

Finally, the main challenges to advance towards a regenerative economy are discussed.

2 Previous considerations

2.1 The production-consumption structure

The Production-Consumption Structure (PCS) can be defined as the set of processes and infrastructure which extract, transform, use and dispose of the different materials involved in any economic activity. So the PCS is a chain of processes linking producers and consumers within the established infrastructure. In other words, it is the underlying structure of the physical metabolism of an economy. Production and consumption are intimately linked since what is produced is to be consumed and the way it is produced defines the way it is consumed.

The current production-consumption structure is linear. In other words, the economy works as a conveyor belt which extracts resources from the environment and returns them to the environment in the form of waste and pollution. This structure is applied to most materials used in an economy. For example, minerals and metals are mined, refined, transformed in components which are subsequently assembled in final goods, the goods are consumed and finally disposed and released back to the environment.

Improving the efficiency of a process does not change the structure of the system even if it improves the overall system performance. If the efficiency of a link is improved, the improvement spreads throughout the chain so the overall system will require less resources and pollute less. However, the linear structure of the system is maintained so, even if at a lower rate, producing more goods will produce more pollution and wastes.

Technological improvement has not managed to crush the resource requirements of humans. Despite all technological improvements, resource extraction has consistently risen throughout this last century: worldwide resource extraction has increased eight times between 1900 and 2005 and the consumption per capita has doubled (Krausmann et al. 2009).

Technological improvement has neither managed to crush the emission derived from the use of the extracted resources. For example, carbon dioxide emissions have consistently risen in the same period (IPCC 2007).

End-of-Pipe (EoP) solutions has been employed to mitigate other pollutants. For example, the emissions of sulphur gases have been reduced through desulphurisation processes in power plants. However, EoP solutions do not change the Production-Consumption Structure, i.e. the physical metabolism of the economy.

Industrial Ecology has suggested other options to mitigate the effects of pollution and improve the resource efficiency of the economy. Some of the suggestions, such as closing the material cycles (Ayres 1996) or Cleaner Production (Graedel and Howard-Grenville 2005) could potentially change the structure of the economy if there was an overarching strategy to systematically reorganize the material flows of the economy.

However, there is no comprehensive theory that allows to organise all material flows within the economy so as to mitigate resource depletion and environmental degradation systematically.

The Regenerative Economy suggest an overarching strategy to do so.

2.2 The full-recycling discussion

Georgescu-Roegen explored the physical limits of the economy by analysing the consequences of the 2nd law of thermodynamics for the economic processes (Georgescu-Roegen 1971). He postulated two conclusions which cut the discussion on fully recycling economies. First, that the economy would degrade the natural resources and the environment irreversibly due to the 2nd law of thermodynamics. Secondly, that full recycling is impossible due to the dissipative losses which happen in any process. The 1st statement is misleading because the earth is in fact an open system regarding energy and this energy can compensate the entropy loss. So, resources and environment on earth are not doomed to degradation as long as energy (from the sun) to compensate the entropy loss is available (in fact the environment had survived millions of years by compensating the natural entropy loss in this manner). The second postulate is analysed in depth in next paragraph.

Ayres (1999) reviewed Georgescu-Roegen's work and he found that full recycling is possible. He demonstrates that a fully recycling system requires a specific structure with at least an intermediary "reservoir" where the dissipated material losses are accumulated so they can be recycled at a later stage. He made this demonstration thinking on the recycling of scarce industrial such as metals. However, the description of the system he does is actually how the nature works. In fact what he calls sub-systems can be associated to the different natural reservoirs, and the different processes linking them can be called BioGeoChemical Cycles (Butcher 1992; Bethke 2007). The BioGeoChemical Cycles (BGCC) are in fact the natural processes that transform and mobilise substances between the different parts of the environment. Those different parts of the environment can be segmented in 5 main geospheres: the atmosphere, pedosphere, hydrospheres and biosphere which can be further compartmentalised. The Earth System Science studies those cycles from a physical and chemical approach.

So, (part of) the Earth System is an example of a fully-recycling system. Some Biogeochemical cycles use energy from the sun to compensate the natural entropy losses (e.g. the cycles related to photosynthesis process: e.g. carbon, phosphate, nitrate cycles.). So, an example is the Carbon cycle whereby the same carbon has been oxidised and reduced millions of times in a fully-recycling process, for millions of years.

Hence, an "almost" fully-recycling economy is feasible and would totally change the production-consumption structure. Most of what Ayres calls dissipative losses are in fact avoidable losses if the material flows within the economy are properly managed. Thus, they can be reduced to negligible losses – this is the underlying idea of what will be called the Isolation principle. It is worth noting that some materials already follow this pattern as some metals (Graedel et al. 2011). Additionally, even if some losses are "unavoidable", they can be identified and managed so that the dissipation does not incur in any environmental impact – this is the underlying idea of what will be called the Integration principle. Those principles are the general principles which define the functioning of the Regenerative Economy. They are described in the next section.

2.3 The Earth System

The Regenerative Economy can only be understood by contextualising the economy within the Earth System.

The Earth System can be compartmentalised in following 5 chemically homogeneous sections called the *geospheres:*

1. the *atmosphere* which is the gaseous envelope of the earth,
2. the *lithosphere* which comprises all rocks on (and under) the earth,
3. the *pedosphere* which represent the soils on the Earth's crust, covering the lithosphere in some parts of the Earth,

4. the *hydrosphere*, which represents all water, either in gaseous, liquid or solid form, and
5. the *biosphere*, which contains all living things and can be present in the any of the previous geospheres.

In this text, the term *environment* can refer to one or several geospheres.

The BioGeoChemical Cycles (BGCC) are at the heart of the Earth System functioning. All geospheres transform and exchange materials flows with each other: those natural cycles are the BGCC. All materials in the earth system are linked through one or various BGCC. Different BGCC have different mobilisation/ transformation rates. The BGCCs can have different geographic scales, i.e. they can be local and/ or global.

For the time scale of the Regenerative Economy (a few hundred years), some materials are considered isolated from the BGCC. In other words, the natural mobilisation or transformation rates of some substances are negligible for the time frame under study. This is the case of substances isolated in natural reservoirs, usually within the lithosphere, such as oil or gas pockets.

Humans interact with the BGCCs in different manners: either by extracting (subtracting) materials from them or by releasing (adding) materials to them. This interaction leads to environmental degradation if the BGCC are altered significantly. Each BGCC has specific extraction and emissions thresholds above which the BGCC is unbalanced. To understand better how the thresholds work, it is important to understand the difference between extinguishable and non-extinguishable substances.

Materials can be divided in two categories: extinguishable and non-durable. Biomass is extinguishable since it can extinguish if a certain balance is not kept in the BGCC regenerating it. Minerals and metals are non-extinguishable because they are elemental substances which cannot be further decomposed. Both material types are renewable since they can be renewed (cycled) through different reactions: e.g. metals can be oxidized and reduced in a cyclic manner and biomass can be decomposed and recomposed through specific BGCCs.

Biomass extraction has specific threshold levels above which the renewal is impaired and can lead to depletion (extinction) of the resource. For example when too much fisheries are caught, the fishery regenerates itself at lower rates. Depending on the degree of unbalance of the BGCC, the disturbance can cascade throughout other linked BGCCs. For example, the if the fishery is further extracted, it collapses and this affects the surrounding ecosystem.

Emissions to the environment affect the BGCC through two different mechanisms. Some materials are inherently toxic for BGCC, and thus are considered pollutants because they disrupt systematically the BGCC (e.g. heavy metals and other persistent organic pollutants). However, there are other materials that are not toxic but can cause disruptions in the BGCC when emitted in excess to a particular BGCC (e.g. excess nutrients released in a water stream cause eutrophication problems – this is an unbalance of the Nitrate or Phosphate cycle). In general, thresholds levels are of the order of the natural flow, so for toxic emission they are very low since those substances are not naturally present in the BGCC while thresholds for non-toxic substances are much higher. Therefore, emissions have also different thresholds above which they cause disruptions in the BGCCs.

To summarise, the Earth System is a network of material flows from which humans (the economy) can extract and release materials to fulfil their needs. This interaction creates environmental degradation if the extraction and release alter significantly the natural BGCC, i.e. extract and/ or emit above certain thresholds.

3 The Regenerative Economy

3.1 The organisational principles

There are two organisational principles that orchestrate the material flows of the Regenerative economy: the “Isolation” and the “Integration” principle.

The Isolation principle means that a specific substance is isolated within the economy. From the pollutant mitigation perspective, the benefits of isolation are straight forward: the substance is not released to the environment and therefore there is no more pollution derived from the use of the substance. There are two possibilities: the static one (linear accumulation) and the dynamic one (closed-loop circulation). The static approach to isolation means to isolate the substance by accumulating it in special landfills/ storages. This solution preserves the linearity of the PCS and is therefore of no interest here. The dynamic one means that the substance is (re)cycled within the economy, avoiding storage issues. Hence, this solution requires a structural change of the PCS. Additionally, due to the recirculation, resource requirements are systematically lowered. The Regenerative Economy is interested in operationalising the latter.

The Integration principle is means that the material flows extracted by and released from the economy are integrated with the functioning of the Earth System. That means that materials are extracted from and released to the environment at rates that respect its natural limits. The direct consequence of integration is that the interaction economy-environment does not cause environmental degradation due to the exchange of material flows, i.e. extraction of resources and release of emissions.

All materials necessary for the economy can be either Isolated or Integrated as it will be seen in the operational principles section. This does not imply that absolutely all materials can be isolated or integrated. However, the Regenerative Economy relies on the fact that those materials can be substituted by others that can be Isolated or Integrated.

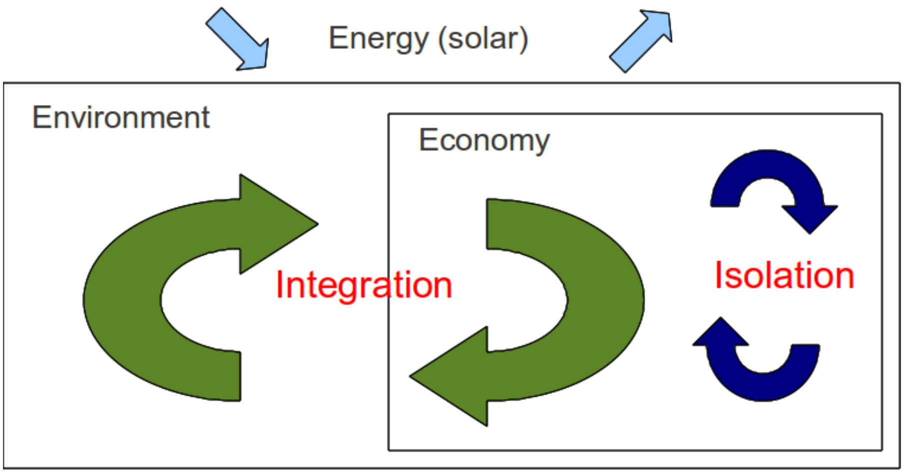


Illustration 3.1: Organisational principles of the Regenerative

To sum up, the Isolation preserves materials within the economy in a manner that can be reused indefinitely, cutting the extraction needs of the isolated material and maintaining the emissions to negligible levels regarding environmental pollution. The Integration principle allows other material flows to be exchanged with the environment without causing environmental degradation and subsequent depletion of renewable resources. Therefore, the rearrangement of the economy's material flows according to the Isolation and Integration principles provide a long-term strategy to cut current resource depletion and mitigate pollutant emissions.

The next section demonstrates the technical feasibility of the organisational principles by operationalising them. The socio-economic implications of the Regenerative economy (which can be derived directly from the organisational principles) will be explored after the operational principles section.

3.2 Operational principles

Each organisational principles is translated in an operational principle.

3.2.1 From Isolation to Strong-Recycling

Isolation is operationalised through the principle of “Strong-Recycling” which is opposed to conventional “recycling” practices. The aim of the Isolation principle is to isolate materials indefinitely within the economy through cycling. The fact that the isolation needs to be infinite in time poses a constraint on the nature of the cycling: it cannot degrade the material itself. In other words, the material need to be able to gain the original properties after being cycled through the economy, i.e. it needs to be regenerated within the economy. Not all types of recycling match this requirement.

There are different types of recycling and not all comply to the non-degradation requirement. This is due to the fact that the current definition of recycling is too ambiguous regarding the processes that materials undergo (European Parliament 2008). There are three different cases of what is commonly known as recycling:

- materials that are recycled but degrade in the same recycling process so they ultimately become waste after a few cycles (E.g. paper).
- materials that are recycled as different material so this can be done just once (e.g. glass when used as cement aggregate, or solid waste when incinerated).
- materials that are recycled as the same material without loosing its material properties, (e.g. glass and metals when recycled as same material). This is the only recycling case where materials are not degraded and preserve all their material properties after recycling.

The operationalisation of Isolation can only be achieved through using the latter example of recycling, from now onwards called “Strong-Recycling”.

3.2.2 From Integration to Global Balance through local extraction and restoration

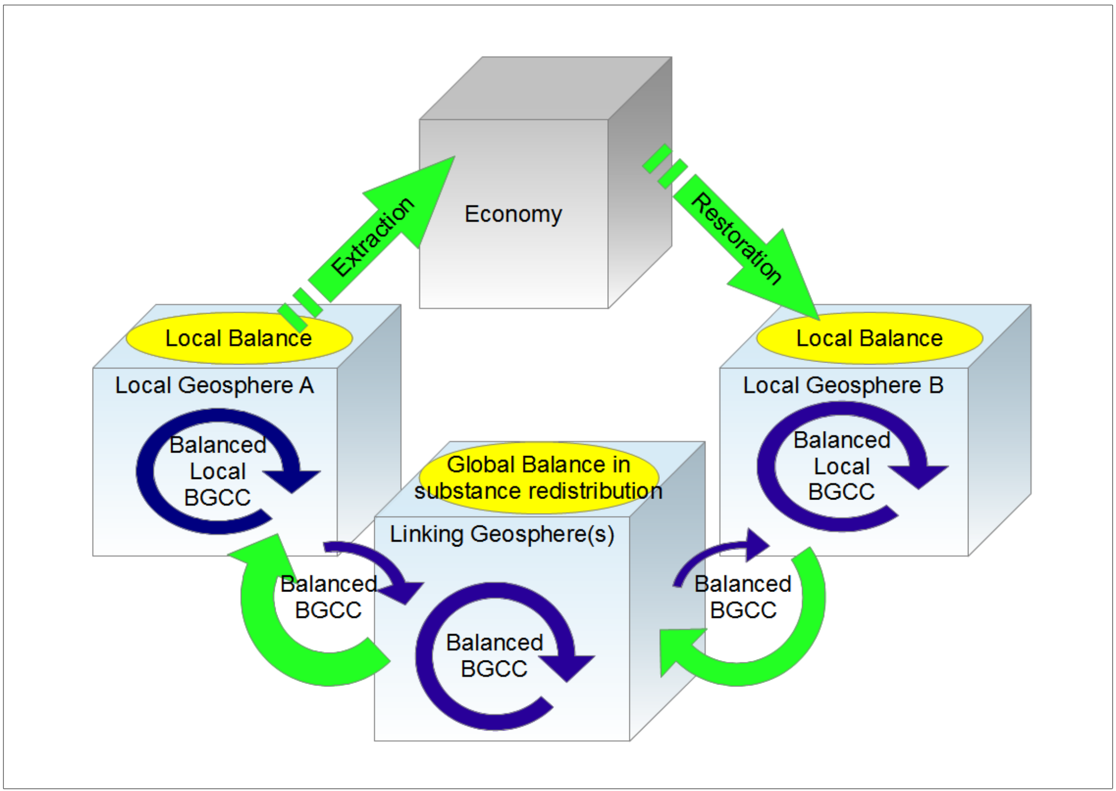
The integration principle is operationalised by introducing the concept of biogeochemical cycles (BGCC) as a description of the Earth System. The Integration principle aims to re-arrange the exchange of material between the economy and the environment in a manner to avoid environmental degradation and subsequent resource depletion. Recalling that the environmental degradation deriving from pollution is in fact due to the alteration of material flows in the BGCCs, the integration principle can be operationalised by managing the exchange of material flows between the economy and the environment, specifically by avoiding altering the BGCCs' material flows in an unbalancing manner. The BGCC have specific threshold for substances above which the whole BGCC is affected, therefore the extraction and restoration of substances from and to the different BGCC must be done without surpassing those threshold. Hence, the integration is operationalised through the principle of balanced extraction and restoration.

Additionally, the Balanced Extraction and Restoration principle has two dimensions, the local and the global.

Extraction and restoration must happen in *local balance,* i.e. in balance with the BGCCs in the local geosphere. The local balance implies that materials are extracted from or restored to the corresponding geosphere without causing any disruption or unbalance to the local geosphere and BGCC during the very process of extraction or restoration. (For example, no local balanced extraction if in am agricultural exploitation, the pedosphere is depleted from nutrients, impeding the cycling of N and P and leading to crop "dying"). However, the extraction of a fishery which allows enough time for the fishery to be repopulated is in local balance with the geosphere and BGCC.

However, even the extraction or restoration happen in (local and momentary) balance, they imply a constant subtraction or addition of materials which will eventually lead to local or global unbalance. The unbalance at local level can avoided if the materials are (re)balanced through linking BGCC globally.

Therefore, the local extraction and restoration must also be part of the *global balance* of the material flows which in turn restores the *local balance*. The *global balance* process between the local extraction and restoration of substances in different geospheres is achieved through a balanced linkage of the BGCC linking the local geospheres where extraction and restoration takes place. Such local-global-local cycling already happens naturally in the environment.



Therefore, a necessary condition for *global balance* is the mass balance through the different stages. In other word, the materials locally extracted by the economy must be equal to the materials locally restored. This is also true for the local geospheres. The extracted materials by the economy must be restored naturally in the same quantity by the corresponding BGCC. Similarly, the restored materials by the economy must be brought forward by same quantity the corresponding BGCC.

3.2.3 Isolation vs Integration

Whether a substance should or can be isolated or integrated depends on the nature of the substance.

Regarding the interaction with the BGCCs, two groups are identified. First, the toxic substances which can only be isolated since they cannot be integrated. Second, substances that are regenerated through the BGCC (e.g. biomass related substances). Note that in some cases, the latter can also be isolated (e.g. growing crops in a dome (Allen 1992)), so unless deemed necessary, biomass will preferably be integrated.

Regarding the resource availability also two groups can be identified. First, non-renewable sources of materials which can eventually be depleted. Applying the Isolation principle to them would avoid or at least mitigate their depletion. Secondly, renewable sources of materials are good candidates for Integration, since integration implies that their renewal rates will be maintained.

Organisational Principles	Isolation	Integration
System defintion	Economy	Economy-Environment
Organisational concept	Full-recycling within the economy	Full-recycling between the economy and the environement
Operational principle	Strong-recycling	Balanced extraction and restoration
Target materials: related to the extraction of:	Non-renewable resources	Renewable resources
Target materials: related to the emission of:	Toxic substances	Non-toxic substances

Table 3.1: Summary table of the Regenerative Economy concept

It is worth noting that, in general, non-renewable resources do fall in the toxic category since they are not naturally present in the BGCC (or in small quantities compared to anthropogenic mobilisation rates).

In fact, some substances could be partially integrated and partially isolated. For example, some substances as Copper can be toxic when released above certain threshold in certain geospheres but are at the same time a basic constituent of biomass in extremely low quantities.

For simplicity, the next section assumes that non-renewable resources are Isolated and renewable resources are Integrated. Also, that naturally isolated, extinguishable materials (such as oil or gas) are not used, because otherwise the BGCC would be systematically unbalanced. This poses two main challenges that are discussed in the "Main Challenges" section.

3.3 Socio-technical implications

The regenerative economy is based on a specific arrangement of material flows therefore the direct implications for the economy are primarily technical.

The Regenerative Economy implies a radical change in the production-consumption structure of the economy because the current linear structure is linear and needs to be changed into a non-linear, regenerative one. Therefore, the current industrial processes and goods need to be rethought under the regenerative principles. In fact, there are some design guidelines for sustainability (UNEP and TU-Delft 2010) and recycling (Gaustad, Olivetti, and Kirchain 2010), but there is still no comprehensive strategy to re-organise material flows and design goods and production processes accordingly. The operational principles used as design guidelines provide such to provide such overarching strategy.

An interesting point is that there are many ways to turn a linear structure into a regenerative one. For example, country A might prefer to substitute a specific substance (e.g. lead in batteries) for another other material while country B might prefer to isolate it (e.g. by creating the required infrastructure of waste management and treatment to ensure a full recycling of the material). Therefore each country can follow a specific development plan which fits better their current industrial structure, linkage with the environment and available resources.

Another interesting point is that is that different regenerative economies will have different resource and energy efficiencies between them. Those efficiencies might even be lower than in a linear economy but this does not invalidate the fact that a regenerative economy has negligible environmental impact compared to a linear economy.

So, the Regenerative Economy provides a technical framework to orchestrate future technological developments towards a materially sustainable future. The systematic introduction of this framework in any industrial development plan is therefore recommended. Otherwise, technological *lock-in* of non-regenerative technologies may happen since technologies that fail to win early adoption success might eventually find themselves locked-out from the market (Perkins 2003). In other words, lock-in means that a specific technology is still in use even if more environmentally friendly technologies are readily available.

The regenerative economy concept allows physical growth at absolute and/ or relative levels. Those growth patterns have different implications depending whether stemming from non-renewable or renewable resources.

For the (Isolated) non-renewable resource case,

Absolute growth means that resources are still extracted. Therefore the stock-in-use of those substances within the economy grows because non-renewable resources are isolated. In this case, the regenerative economy still depletes non-renewable resources, although at a much minor pace than current economies.

Relative growth means that, given a set of isolated resources in use, more goods are produced by unit of resource. In other words, the resource (and/ or energy) efficiency is improved.

For the (Integrated) renewable resource case,

Absolute growth means that more resources are extracted and therefore emitted. The extraction and emission does not cause BGCCs unbalances. However, there is a limit to the total amount of a substance that can be Integrated (see "Main Challenges" section).

Relative growth means that, given a set of integrated exchange of materials between the economy and the environment, more goods are produced by unit of material exchanged. In other words, the resource (and/ or energy) efficiency of the economy is improved.

So, the Regenerative Economy provides a technical solution for totally delinking the economy from its environmental impact. Nevertheless, whether and how to achieve a regenerative economy system lies on the social part of the socio-technical challenge. The social linkage to the technological implementation of the regenerative economy is discussed below, the social implications at ethical level are examined in the next section.

To adopt technical options is both a technical and social decision. This is explicit in the definition of the production-consumption structure since production is made to satisfy consumer needs. The social part of the production-consumption structure need to "sympathise" with the technical part (i.e. the new production processes, material and product) in order to adopt the new regenerative production-consumption structure. Additionally, new goods might provides the same or similar services (e.g. a plastic derived from bio-polymers might not look and feel as traditional oil-based plastic, although functionally identical). The latter case might require social "sympathy".

3.4 From Ecosystem Services to Biogeochemical cycles

Ecological Economics has embraced the concept of Ecosystem Services (Daily 1997) as a framework to model the economics of human-environment interactions. Ecosystem services can be a good starting point to study the complex interactions between humans and the environment. However this approach can be misleading. In fact, the ecosystem service approach pre-selects the system of study according to the relevance for human purposes. In other words, the very concept of ecosystem service leads to a partial study of the ecosystems which do not take into account the interaction with other ecosystems or natural cycles. For example, the different planetary boundaries (Rockstrom et al. 2009) cannot be captured by an ecosystem service approach.

Therefore, this paper calls for a shift from the Ecosystem service approach towards a more comprehensive and materially sustainable one: the Biogeochemical Cycles integration as defined previously in this paper. The Regenerative economy, which is based on integrating the economy's material flows with different Biogeochemical Cycles, preserves the environment while meeting human needs. Therefore, all ecosystem services will be preserved if the Biogeochemical cycles are kept in balance. So, the Biogeochemical approach provide a better understanding of the underlying natural processes of the environment, including the ecosystem services. The only drawback is that understanding the interactions of socio-economic factors with the Biogeochemical Cycles requires a broader framework with new modelling tools.

Ecological Economics has already developed some tools to model complex natural systems and their interactions with the economy (Anon. 2001; Voinov 2008). However, further development are required because modelling BGCC requires a different approach on treating the ecology (Krapivin 2008; Melillo, Field, and Moldan 2003; Steffen 2005; Gruber and Galloway 2008). At this stage, modelling the interaction between BGCC and socio-economic factors is an unexplored field, but necessary if a regenerative economy is to be achieved.

4 Socio-economic implications

4.1 *Ethical implications*

4.1.1 Intra-generational issues

First, the intra-generational consequences of the current linear economy are assessed based on the egalitarian principle that everybody has the same rights and therefore is entitled to the same amount of resources and environmental quality.

The current linear structure leads to intra-generational conflicts in resource allocation because some countries consume more goods and therefore require more resource extraction than others. The linear production-consumption structure extracts those resources constantly in order to produce a constant flux of consumption goods, depleting those resources. The resources are extracted according to the demand level of final goods and energy. Therefore, since countries have different consumption patterns, there is an unequal distribution of resources, and more precisely of their use as final good.

This unequal allocation of resources can be represented by the concept of material "rucksack", i.e. the amount of resources extracted per person to satisfy its own consumption. The rucksacks for raw resource extraction and final good consumption are clearly unequal amongst different countries (SERI 2009).

The current linear structure leads to intra-generational conflicts in pollution allocation. Similarly, the flows of pollution derived from a linear economy are also unequal since some countries consume more and therefore create more waste and pollutants. In some cases, the waste and pollution is directly emitted within the country (e.g. carbon dioxide emissions and Municipal Solid Waste production). However, in other cases, pollutants and waste can be mobilised to other countries either by shipping them (e.g. 6856 tonnes of WEEE were exported out of Germany alone in 2007 (Ongondo, Williams, and Cherrett 2011)) or importing final goods and therefore avoiding the environmental costs of the production (e.g. the emission of greenhouse gases (Machado, Schaeffer, and Worrell 2001; Wiedmann et al. 2007; Peters and Hertwich 2008)). In any case, the pollution allocation is different between different areas and does not necessarily correspond to the countries where initial resource extraction took place nor to countries where final products where consumed, leading to intra-generational issues. ((Muradian and Martinez-Alier 2001a; Muradian and Martinez-Alier 2001b; Muradian, O'Connor, and Martinez-Alier 2002))

To sum up, in a linear economy, the intra-generational conflicts due to resource extraction, use and pollutant emissions arise due to the relative de-linkage amongst them. In other words, some countries benefit of the clean use of final goods while other see their environment degraded.

Now, an analysis of the different intra-generational issues derived from regenerative economy compared to a linear economy is performed. First, the analysis is based on the assumption of steady consumption and population and finds that the regenerative economy mitigates intra-generational issues. Then, intra-generational issues are analysed under absolute physical growth. It is found that the previous results hold.

Consider a fully implemented regenerative economy and a linear economy, both with a steady population and steady consumption.

A regenerative economy mitigates the intra-generational conflicts due to non-renewable resource extraction compared to a linear economy. A Regenerative Economy fully-recycles non-renewable resources according to the isolation principle and therefore it does not extract non-renewable resource to produce the same goods as a linear economy. Although different countries might have different amounts of materials isolated as stock-in-use (i.e. unequal allocation of previously extracted resources), intra-generational conflicts are not increased because there is no more resource extraction. Thus, the intra-generational conflicts derived from resource extraction are mitigated compared to the linear economy.

A regenerative economy cuts the intra-generational conflicts due to renewable resource extraction compared to a linear economy. A Regenerative Economy exchanges material flows with the environment in an integrated manner. Therefore, a regenerative economy provokes no depletion of renewable resources to produce the same goods as the linear economy. The intra-generational conflicts derived from renewable resource extraction are non-existent because, even if different countries have different extraction rates of renewable resources, the extraction does not systematically lead unequal allocation of renewable resources. In other words, since extraction follows the Integration principle, it warranties that the resources are still available and there is environmental degradation associated to the extraction.

A regenerative economy cuts the intra-generational conflicts due to pollutant emissions compared to a linear economy. A Regenerative Economy “integrates” and “isolates” all material flows so there are no pollutant emissions. Therefore, a regenerative economy does not produce pollution to produce the same goods as the linear economy. Therefore, the intra-generational conflicts derived from the allocation of pollutant emission are non-existent.

These differences hold for a non-steady case. Consider a fully implemented regenerative economy and on the other a linear economy, both with increasing demand for products, either due to an increase of population or of consumption.

A regenerative economy mitigates the intra-generational conflicts due to non-renewable resource extraction compared to a linear economy. The Regenerative Economy extracts punctually an increment of non-renewable resources for each increment of consumption demanded whereas a linear economy extracts in continuum an increased amount of non-renewable resources. Therefore, a regenerative economy requires less non-renewable resource extraction to produce the same goods as a linear economy. Because a Regenerative Economy extracts significantly less resources, the intra-generational conflicts due to resource extraction are lower than in the case of a linear economy, given other things equal.

A regenerative economy cuts the intra-generational conflicts due to renewable resource extraction compared to a linear economy. The Regenerative Economy exchanges material flows with the environment in an integrated manner. Therefore, a regenerative economy with increased demand will require more resources from the environment; however, due to its production-consumption structure integrated with the environment, the increased demand will not deplete renewable resources nor lead to environmental degradation. Therefore, the regenerative economy does not lead to intra-generational conflicts derived from renewable resource extraction.

A regenerative economy cuts the intra-generational conflicts due to pollutant emissions compared to a linear economy. The Regenerative Economy exchanges material flows (mostly biomass related) with the environment in an integrated manner and isolates the material flows which are toxic pollutants. Therefore, a regenerative economy with increased demand does not produce pollutants even if there is an increased demand for goods. The Regenerative economy does not lead to any intra-generational conflict regarding pollution allocation because it does not produce any pollution or waste.

To sum up, the regenerative economy performs better than the current economy in terms of avoiding intra-generational issues derived from renewable and non-renewable resource extraction and from pollutant release.

4.1.2 Inter-generational issues

The Regenerative Economy also cuts or mitigates the inter-generational issues derived from resource extraction and pollutant emissions. Additionally, in this case, assuming that the allocation of resources between the different countries or groups remains constant, the regenerative economy also mitigates the inter-generational issues within each of those countries or groups. An interesting corollary of this is that if intra-generational issues were solved, the inter-generational issues would also be solved. All those claims are discussed below and are based on the egalitarian view that future generations do have rights and therefore inter-generational conflicts arise when there is an unequal allocation of resources or environmental degradation amongst the different generations.

First, the inter-generational implications of the current linear economy are explored.

A linear economy creates inter-generational issues due to the extraction of non-renewable resources because those resources are depleted and future generations cannot use them.

A linear economy creates inter-generational issues due to the extraction of renewable resources when the extraction degrades the environment and/ or the capacity of the resource to renew itself. Then, the resource availability is diminished for future generations resulting in an unequal allocation between generations. The same applies when the environment is degraded. Currently, much of the renewable resource extraction is above the carrying capacity of the Earth System (Rockstrom et al. 2009; Wackernagel and Rees 1996; Global Footprint Network 2009), reducing it regenerative capacity and degrading the environment. Therefore, this current situation leads to an inter-generational conflicts since future generation will not have the same chances to use current renewable resources and environment.

Finally, a linear economy creates inter-generational issues due to the emission of pollutants when those emissions degrade the environment. Then, future generation will have a more degraded environment compared to the current one leading to unequal allocation of the environment and hence to inter-generational issues.

Now, an analysis of the different inter-generational issues derived from regenerative economy compared to a linear economy is performed. First, the analysis is based on the assumption of steady consumption and population and finds that the regenerative economy mitigates inter-generational issues. Then, inter-generational issues are analysed under absolute physical growth. It is found that the previous results hold.

Consider a fully implemented regenerative economy and a linear economy, both with a steady population and steady consumption.

A regenerative economy cuts the inter-generational conflicts due to non-renewable resource extraction compared to a linear economy. The Regenerative Economy fully-recycles non-renewable resources according to the isolation principle. Therefore, a regenerative economy does not extract non-renewable resource to produce the same goods as the linear economy. Future generation will be have the same non-renewable resources available as current generations (i.e. none of the generations make use of the resources) so inter-generational conflicts derived from non-renewable resource extraction are non-existent.

A regenerative economy cuts the inter-generational conflicts due to renewable resource extraction compared to a linear economy. The Regenerative Economy exchanges material flows with the environment in an integrated manner. Therefore, a regenerative economy does not deplete renewable resources to produce the same goods as the linear economy. All generations have the same chances to use the renewable resource. Therefore, the inter-generational conflicts derived from renewable resource extraction are hence non-existent.

A regenerative economy cuts the inter-generational conflicts due to pollutant emissions compared to a linear economy. The Regenerative Economy "integrates" and "isolates" all material flows so there are no pollutant emissions. Therefore, a regenerative economy does not produce pollution to produce the same goods as the linear economy. The inter-generational conflicts derived from pollution are hence non-existent.

These differences hold for a non-steady case, as follows.

A regenerative economy mitigates the inter-generational conflicts due to non-renewable resource extraction compared to a linear economy. The Regenerative Economy extracts punctually an increment of non-renewable resources for each increment of consumption demanded whereas a linear economy extracts in continuum an increased amount of non-renewable resources. Therefore, a regenerative economy requires less non-renewable resource extraction to produce the same goods as the linear economy. So, although future generation will be have less non-renewable resources available than current generations, they will have more than if the same production was produced with a linear system. Therefore, the inter-generational conflicts due to non-renewable resource extraction are lower in a regenerative economy compared to a linear economy.

A regenerative economy cuts the inter-generational conflicts due to renewable resource extraction compared to a linear economy. The Regenerative Economy exchanges material flows with the environment in an integrated manner. Therefore, a regenerative economy with increased demand will require more resources from the environment; however, due to its production-consumption structure integrated with the environment, the increased demand will not deplete renewable resources nor lead to environmental degradation. Therefore, the regenerative economy does not lead to inter-generational conflicts because the renewable resources and the environment are preserved.

A regenerative economy cuts the inter-generational conflicts due to pollutant emissions compared to a linear economy. The Regenerative Economy exchanges material flows with the environment in an integrated manner and isolates the material flows which are toxic pollutants. Therefore, a regenerative economy with increased demand does not produce pollutants even if there is an increased demand for goods. So, future generation will have the same environmental quality and therefore there will not be inter-generational conflict due to the allocation of pollutant emission.

To sum up, a regenerative economy performs better than a linear economy in terms of avoiding inter-generational issues derived from non-renewable resource allocation, renewable resource allocation, and environmental degradation allocation. In the steady-state situation, it even provides an inter-generational solution to the dilemma of distributing finite resources to infinite number of generations.

4.2 *Towards personal material allowances?*

Under a Regenerative Economy, a personal material allowance is conceivable and might even be desirable vis-a-vis mitigating intra- and inter-generational issues derived from resource allocation. A personal allowance would mean that a physical steady state of the economy could be maintained and it would be increased gradually, according to the number of people composing the economy. This would cut the intra-generational issues derived from resource allocation and inter-generational issues (assuming there are enough non-renewable resources for all people to be born).

So, allocating the same personal material allocation (or material rucksack (SERI 2009)) amongst people in a specific generation can be a starting point since it would mean at fairer initial distribution although not necessarily an equal use. In fact, more industrialised countries with higher resource efficiencies could produce more given the same amount of resources. Also, with the same energy and given their higher energy efficiency, they would be able to make them cycle faster, being able to produce more in the same period.

5 Main challenges for a Regenerative Economy

The technical development of a Regenerative Economy has three main challenges:

First, develop a regenerative energy infrastructure. Since hydrocarbons and nuclear materials do not fit under the operational principles, an energy grid based on solar-derived energy is required. Some studies have treated the physical feasibility of such development. They found that a worldwide infrastructure of notable dimensions is required and possible (Jacobson and Delucchi 2011; Delucchi and Jacobson 2011). The socio-economics of it still remain uncertain.

Secondly, substituting oil-derived materials. The current economy is heavily based on oil not only for energy purposes but for material purposes. Some applications of basic plastics can easily be substituted with traditional materials (glass, paper, wood, biomass), although the transition needs to be planned. The substitution of more technologically developed materials required further material research.

Thirdly, understand better the Biogeochemical Cycles and their anthropogenic influence (Gruber and Galloway 2008). On the one hand, this will help devising more efficient regenerative economies. On the other, also find the limits of integration.

In order to account accurately for the degree of regeneration of an economy, more accurate analytical methods are required.

First, a shift from resource and product accounting to waste accounting in the System of National Accounts is required. The Regenerative Economy is based on the strong-recycling of waste flows, therefore waste flows need to be monitored accurately. In fact, current resources efficiency indicators based on resource or products flows cannot capture the real efficiency of an economy, because such efficiency is ultimately given by the amount of waste and emissions produced by unit produced (Herman, Ardekani, and Ausubel 1990).

Secondly, to capture the inter-industrial material flows with accuracy and be able to devise an accurate material flow map of the economy, a more detailed and powerful accountancy on material flows is required. In particular, a better integration of the physical flows of the economy within the national accounts system. Some developments have been done and some countries have integrated bulk-MFA integrated in their SNA (OECD 2008a; OECD 2008b; OECD 2008c; OECD 2008d). However, this level of information is not detailed enough. Some countries, however, already construct this databases in the form of accurate physical Input-Output Tables (Nakamura and Kondo 2009)

Finally, some socio-economic aspects needs to be further explored:

First, understand the socio-economic motivations and drivers for transition towards a regenerative economy. In other words, devise an industrial and social plan to develop towards a regenerative economy. The organisational principles and operational principles of the regenerative economy provide some technical guidelines but the social “solution” still needs to be devised.

Secondly, accurately model the possibilities for development and growth (or any other patterns) within a partially physically constrained economy as the regenerative economy. Victor (2008) performed a similar exercise but with a linear economy.

6 References

Allen, John. 1992. “Biosphere 2: Description, Purpose, and Conceptual Design” presented at the International Conference on Life Support and Biospherics at the University, Alabama. http://www.biospheres.com/pubdescpurpcon.html.

Anon. 2001. *Institutions, Ecosystems, and Sustainability*. Boca Raton: Lewis Publishers.

Ayres, Robert U. 1996. *Industrial Ecology: Towards Closing the Materials Cycle*. Cheltenham UK; Brookfield Vt. US: E. Elgar.

———. 1999. “The Second Law, the Fourth Law, Recycling and Limits to Growth.” *Ecological Economics* 29 (3) (June): 473–483. doi:10.1016/S0921-8009(98)00098-6.

Bethke, Craig. 2007. *Geochemical and Biogeochemical Reaction Modeling*. 2. ed. Cambridge: Cambridge University Press.

Butcher, Samuel S. 1992. *Global Biogeochemical Cycles*. Academic Press. http://ul-newton.lib.cam.ac.uk/vwebv/holdingsInfo?searchId=13488&recCount=25&recPointer=22&bibId=5066488.

Daily, Gretchen C. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems.* Annandale: ABBE Pub.Assoc.of Washington.

Delucchi, Mark A., and Mark Z. Jacobson. 2011. “Providing All Global Energy with Wind, Water, and Solar Power, Part II: Reliability, System and Transmission Costs, and Policies.” *Energy Policy* 39 (3) (March): 1170–1190. doi:16/j.enpol.2010.11.045.

European Parliament. 2008. “Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives (Text with EEA Relevance)”. Official Journal of the European Union. http://europa.eu/legislation_summaries/environment/waste_management/ev0010_en.htm.

Gaustad, Gabrielle, Elsa Olivetti, and Randolph Kirchain. 2010. “Design for Recycling.” *Journal of Industrial Ecology* 14 (2) (March 1): 286–308. doi:10.1111/j.1530-9290.2010.00229.x.

Georgescu-Roegen, Nicholas. 1971. *The Entropy Law and the Economic Process*. Harvard University Press.

Global Footprint Network. 2009. *Ecological Footprint Atlas 2009*.

Graedel, T. E, Julian Allwood, Jean-Pierre Birat, Matthias Buchert, Christian Hagelüken, Barbara K Reck, Scott F Sibley, and Guido Sonnemann. 2011. “What Do We Know About Metal Recycling Rates?” *Journal of Industrial Ecology* 15 (3) (June 1): 355–366. F001.005.1. Folder 001. doi:10.1111/j.1530-9290.2011.00342.x.

Graedel, T. E, and Jennifer A. Howard-Grenville. 2005. *Greening the industrial facility perspectives, approaches, and tools*. New York: Springer. http://site.ebrary.com/id/10228644.

Gruber, Nicolas, and James N. Galloway. 2008. “An Earth-system Perspective of the Global Nitrogen Cycle.” *Nature* 451 (7176) (January 17): 293–296. doi:10.1038/nature06592.

Herman, Robert, Siamak A. Ardekani, and Jesse H. Ausubel. 1990. “Dematerialization.” *Technological Forecasting and Social Change* 38 (4) (December): 333–347. doi:10.1016/0040-1625(90)90003-E.

IPCC. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers.*

Jacobson, Mark Z., and Mark A. Delucchi. 2011. “Providing All Global Energy with Wind, Water, and Solar Power, Part I: Technologies, Energy Resources, Quantities and Areas of Infrastructure, and Materials." *Energy Policy* 39 (3) (March): 1154–1169. doi:16/j.enpol.2010.11.040.

Krapivin, Vladimir F. 2008. *Biogeochemical Cycles in Globalization and Sustainable Development*. Springer.

Krausmann, Fridolin, Simone Gingrich, Nina Eisenmenger, Karl-Heinz Erb, Helmut Haberl, and Marina Fischer-Kowalski. 2009. "Growth in Global Materials Use, GDP and Population During the 20th Century." *Ecological Economics* 68 (10) (August 15): 2696–2705. doi:10.1016/j.ecolecon.2009.05.007.

Machado, Giovani, Roberto Schaeffer, and Ernst Worrell. 2001. "Energy and Carbon Embodied in the International Trade of Brazil: An Input-output Approach." *Ecological Economics* 39 (3) (December): 409–424. doi:10.1016/S0921-8009(01)00230-0.

Melillo, Jerry, Christopher B. Field, and B. Moldan. 2003. *Interactions of the Major Biogeochemical Cycles : Global Change and Human Impacts*. Washington: Island Press.

Muradian, Roldan, and Joan Martinez-Alier. 2001a. "South North Materials Flow: History and Environmental Repercussions." *Innovation: The European Journal of Social Science Research* 14 (2): 171–187. doi:10.1080/713670544.

———. 2001b. "Trade and the Environment: From a 'Southern' Perspective." *Ecological Economics* 36 (2) (February): 281–297. doi:10.1016/S0921-8009(00)00229-9.

Muradian, Roldan, Martin O'Connor, and Joan Martinez-Alier. 2002. "Embodied Pollution in Trade: Estimating the Environmental Load Displacement of Industrialised Countries." *Ecological Economics* 41 (1) (April): 51–67. doi:10.1016/S0921-8009(01)00281-6.

Nakamura, Shinichiro, and Yasushi Kondo, eds. 2009. *Waste Input-Output Analysis*. Eco-efficiency in Industry and Science. Dordrecht: Springer Netherlands. http://www.springerlink.com/content/978-1-4020-9901-4#section=46017&page=1&locus=0.

OECD. 2008a. *MEASURING MATERIAL FLOWS AND RESOURCE PRODUCTIVITY - Volume III Inventory of Country Activities*.

———. 2008b. *MEASURING MATERIAL FLOWS AND RESOURCE PRODUCTIVITY - Synthesis Report*.

———. 2008c. *MEASURING MATERIAL FLOWS AND RESOURCE PRODUCTIVITY - Volume I - The OECD Guide*.

———. 2008d. *MEASURING MATERIAL FLOWS AND RESOURCE PRODUCTIVITY - Volume II The Accounting Framework*. FMFA.005. Folder MFA.

Ongondo, F.O., I.D. Williams, and T.J. Cherrett. 2011. "How Are WEEE Doing? A Global Review of the Management of Electrical and Electronic Wastes." *Waste Management* 31 (4) (April): 714–730. doi:10.1016/j.wasman.2010.10.023.

Perkins, Richard. 2003. "Technological 'lock-in'." *Encyclopaedia of Ecological Economics*. http://www.ecoeco.org/education_encyclopedia.php.

Peters, Glen P., and Edgar G. Hertwich. 2008. "CO2 Embodied in International Trade with Implications for Global Climate Policy." *Environmental Science & Technology* 42 (5) (March 1): 1401–1407. doi:10.1021/es072023k.

Rockstrom, Johan, Will Steffen, Kevin Noone, Asa Persson, F. Stuart Chapin, Eric F. Lambin, Timothy M. Lenton, et al. 2009. "A Safe Operating Space for Humanity." *Nature* 461 (7263): 472–475. doi:10.1038/461472a.

SERI. 2009. *Overconsumption*.

Steffen, W. 2005. *Global Change and the Earth System a Planet Under Pressure*.

Berlin ;;New York :: Springer,.
UNEP, and TU-Delft. 2010. *Design for Sustainability - Manual*. http://www.d4s-sbs.org/.
Victor, Peter A. 2008. *Managing without growth slower by design, not disaster*. Cheltenham; Northampton, Mass.: E. Elgar.
Voinov, Alexey. 2008. *Systems science and modeling for ecological economics*. Amsterdam; London: Elsevier Academic Press.
Wackernagel, Mathis, and William E. Rees. 1996. *Our Ecological Footprint*. New Society Publishers.
Wiedmann, Thomas, Manfred Lenzen, Karen Turner, and John Barrett. 2007. "Examining the Global Environmental Impact of Regional Consumption Activities -- Part 2: Review of Input-output Models for the Assessment of Environmental Impacts Embodied in Trade." *Ecological Economics* 61 (1) (February 15): 15–26. doi:10.1016/j.ecolecon.2006.12.003.