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ENVIRONMENTAL ASSESSMENT OF CARBON CAPTURE AND UTILIZATION: A NEW SYSTEMIC VISION – APPLICATION TO VALORIZATION OF NICKEL SLAGS

A. VENTURA, N. ANTHEAUME

ABSTRACT

With increasing social awareness, concerning impacts of climate change, carbon capture and utilization (CCU) is gaining traction on a world scale. It is being pushed forward by the European Union as one of the important levers to mitigate its greenhouse gases emissions. Life Cycle Assessment (LCA), and its derived carbon footprint method, is thus becoming a crucial point of support to provide a strategic political vision. However, these guidelines rely on current LCA standards and practices and are not adapted to provide a strategic vision. System modelling of environmental impacts of valorization technologies with LCA use substitution scenarios and/or consequential LCA. Consequential LCA only considers unconstrained markets: every product issued from a valorization or CCU process is always considered as a substitute for a determining product. However, this is not always what is observed, especially in the construction and demolition sector. Valorization technologies are always developed according to a given state of external constraints defined by waste composition and amounts as well as existing regulations and their amounts and nature is constantly changing. Thus, the first focus of waste treatment industries is thus to find possible technological means to “get rid of” undesirable amounts of waste or carbon dioxide, but the fact that it can replace existing and determining products is by and large ignored. To reflect actual situation, there is a need to introduce the possibility of constrained markets in the models. With constrained markets, price elasticity cannot be used as the basic relationship between price, demand and produced amounts. Thus, for constrained markets, the product scale is not adapted. To overcome the abovementioned obstacles, we propose a transdisciplinary approach described in this paper. This approach is currently being developed through its application to valorization of New Caledonia nickel slags by CCU, in the CARBOSCORIES 2 and CARBOVAL projects.

1. INTRODUCTION

With increasing social awareness, concerning impacts of climate change, carbon capture and utilization (CCU) is gaining traction on a world scale. It is being pushed forward by the European Union as one of the important levers to mitigate its greenhouse gases emissions.

Life Cycle Assessment (LCA), and its derived carbon footprint method, is thus becoming a crucial point of support to provide a strategic political vision. A guideline document has been recently published [1] to provide decision making support for CCU, promoting a combination of two methods: Technological and Economic Assessment (TEA) and LCA, followed by a Multi-Criteria Decision Analysis.

However, these guidelines rely on current LCA standards and practices and are not adapted to provide a strategic vision as it will be further explained in the following part of this paper.

The purpose of this article is to detail scientific obstacles to current LCA practices, to propose a new methodological approach and to outline its application to the CARBOVAL project.

2. ANALYSIS OF SCIENTIFIC OBSTACLES

Modelling requirements for LCA assessment of CCU technologies are very similar to modelling waste valorization using LCA models. For CCU, specific technologies are being developed to store or valorize carbon dioxide from air and industrial flue gases. This is similar to waste

treatment, for which dedicated technologies are developed to store or valorize waste produced by various human activities. In both cases, these technologies aim at storing or valorizing a given material object (either carbon dioxide or waste), because it is deemed undesirable. The word “undesirable” means negative effects on society and/or the environment. For instance, carbon dioxide contributes to climate change, incineration of waste cause air pollution, and landfill of waste use potentially valuable land and are a possible source of air, water and soil pollution.

The European Union considers that developing waste valorization technologies is important to reduce: global warming for CCU; land occupation and pollution for waste because turning them into useful products also becomes economically worth treating them. Eventually, existing products, often produced using natural resources and fossil resources, can be substituted by valorized waste. The combined environmental and economic benefits that result constitute the virtuous cycle of a circular economy.

Accordingly, both CCU and waste valorization rely upon technological processes that combine at least two objectives: “treating” (to be understood mostly as “getting rid of”) an undesirable material object, and “producing a usable and desirable product” from it. In LCA, these valorization processes can thus have two possible functions that will lead to two different choices for the reference flow [2] as shown in Figure 1. The “getting rid of” objective reflects a function of undesirable matter management that will lead to the amount of undesirable object as an input reference flow. The “producing a usable and desirable good” objective relates to a given functionality provided by the desirable product, which will lead to the amount of product as an output reference flow.

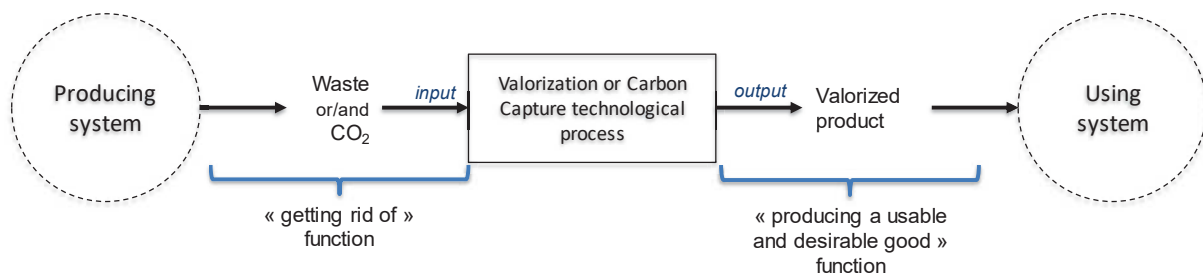


Figure 8. The two possible reference flows of a waste valorization or CCU process in LCA

In addition, the possible environmental benefits of these technologies can only be evaluated by comparison with both what is avoided when not valorizing carbon dioxide or waste, and with what is substituted by the valorized product.

Several models correspond to this type of evaluation, but most current ones are based on substitution scenarios and consequential LCA. An abundant literature is available on both methods. They both originate in the late 1990's [3] and were later improved by their initial author [4]–[6] as well as by many case studies leading to various methodological improvements. In consequential LCA, a determining product is a product whose production is driven by market demand, whereas a co-product is a product whose production depends on the production of the determining product. The market of a co-product is called a “constraint” market, as its production is not driven by demand but by the production of a determining product. Consequential LCA method use market displacement models; these are based on the price elasticity generated by the market displacement that results from valorized product introduction into the existing market. However, price elasticity models can only be applied to unconstrained markets (because they rely upon law of supply and demand), and consequential LCA thus only considers unconstrained markets [7]. In other words, every product issued from a valorization or CCU process is always considered as a substitute for a determining product.

However, this is not always what is observed. In the construction and demolition sector, cement concrete demolition waste can potentially be used as recycled concrete aggregates (RCA) and thus as a substitute for aggregates produced by a quarry [8]. More generally, valorization

processing technologies are always developed according to a given state of external constraints defined by waste composition and amounts as well as existing regulations [9]. Because the amounts and nature of undesirable material objects is constantly changing [9], the first focus of waste treatment industries is thus to find possible technological means to “get rid of” undesirable amounts of material objects, but the fact that it can replace existing and determining products is by and large ignored.

To reflect actual situations, there is a need to introduce the possibility of constrained markets in the models. With constrained markets, price elasticity cannot be used as the basic relationship between price, demand and produced amounts. Thus, for constrained markets, the product scale is not adapted.

An illustration is given in Figure 2: ten units of a valorized product are produced and replace 100% of an existing product. In that example, the existing product contributes 200 units of an impact (i.e. Global Warming Potential), whereas the valorized product (from CCU or waste valorization) only contributes 100.

At the product scale, let us assume for the example that a classical consequential LCA model based on price elasticity with unconstrained markets can result in a 100% substitution. One will thus find that one unit of a valorized product can reduce the impacts by 50% compared to one unit of a substituted product. This is the possible result that can be obtained by either substitution scenarios or consequential LCA with a 100% substitution.

However, for constrained markets, the balance between the mass flows of valorized and substituted products must be considered. Figure 2 depicts three possibilities. In market A, market volume is important, i.e. 1,000 units of products in that example. With the 100% substitution scenario, the valorized product gains a market share that corresponds the 10 produced units; the impacts are then reduced by 5%. In market B, market volume is small, but the valorized product is still competitive. As the amount of valorized product is constrained, 10 units are produced, but the constrained market of substituted products only requires 1 such unit. The current product is then substituted by the valorized product, avoiding 200 impact units, but the 9 other units of valorized product are still produced because constrained amounts are determined by the need “to get rid of” and not by the market demand. The overall impact will then increase by 300%, and 9 units of valorized product will have to be stocked. Finally, in the case of market C, market volume is small and the valorized product is not competitive. If valorized product is still being produced (again as per the need “to get rid of” and not by the market demand), the overall impact jumps 500% as current product is not avoided, and 10 units of valorized product must then be stocked.

Flow matching between valorized and substituted products, coupled with market analysis and modeling are all necessary to derive an acceptable strategic political vision.

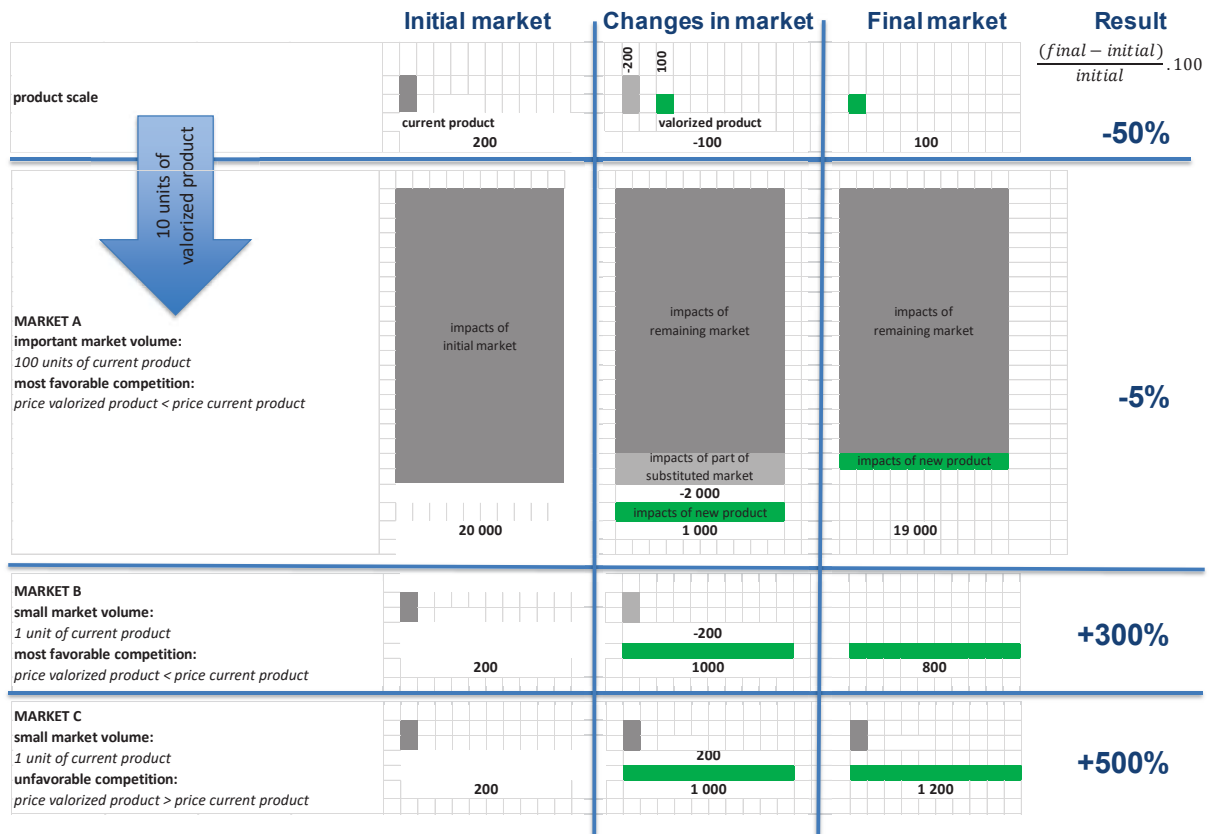


Figure 9. Effects on environmental impacts of a change induced by a valorized product (from waste or CCU), at market scale versus product scale

3. PROPOSED METHODOLOGY

To overcome the abovementioned obstacles, we propose the approach illustrated in Figure 3. Step 1 relates to the process model of the CCU technology, including modelling of inventory flows for LCA and cost calculations (OPEX and CAPEX). Step 2 investigates possible usage scenarios of the valorized product. These scenarios embed the product characteristics (physical, chemical, sensorial...), which can depend on both the waste properties (in the case of waste valorization processes only) and the operating parameters of the CCU technology. Expected functionalities of the valorized product ought to match current or expected market requirements, as defined by market research. Indeed, whereas engineering studies target functionalities, only usage can validate them [10]. Step 3 is an analysis of competitiveness of the valorized product in comparison with current products for the targeted market. In step 4, a market model is used to predict the total amount substituted by the change induced from introducing the valorized product in the market. This model is developed at the market scale (as previously explained from Figure 2), and thus integrates actual market volumes in a given geographical area according to Material Flow Analysis (MFA) studies. In step 5, both the nature and amount of substituted products are identified, so that LCA of the multi-product system can be conducted. As all steps from 1 to 6 are parametrized and interconnected, a detailed sensitivity analysis can be conducted to identify improvement levers for all actors of the system and both environmental impacts and competitiveness, following previously developed methodologies [11]–[13].

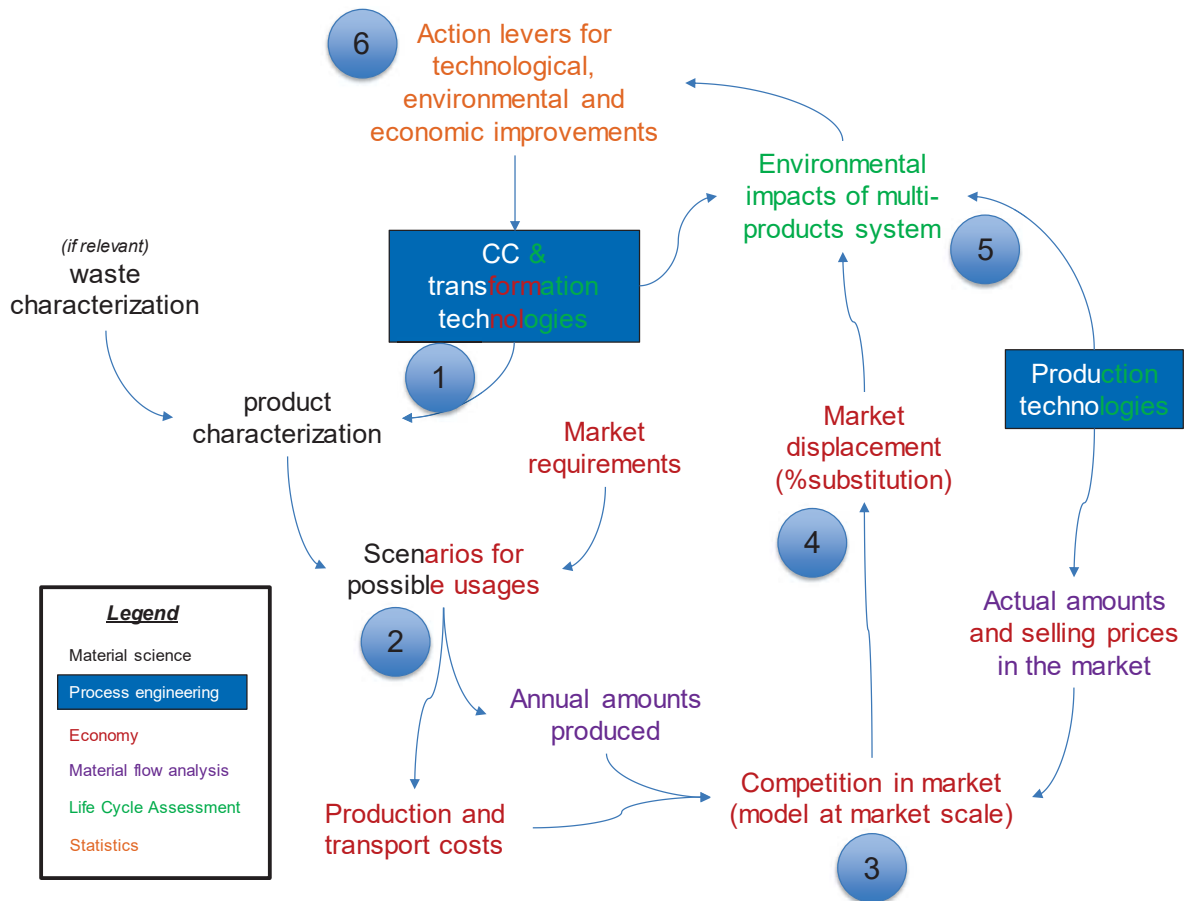


Figure 10. Transdisciplinary approach for environmental assessment of CCU technologies

The proposed method could thus correspond to a system expansion, for which expansion is based on equivalent functionalities of products. Functional units of products are a key issue in step 2, 3 and 4. In step 2, they can be defined using current LCA methodology, but analysis of market requirements is necessary to validate the choice of substituted products. With the global multi-products system, the expanded system is used to establish a strategic political vision; it is not oriented on a given product, and provides improvements at country and/or global scales.

The burden sharing between products is not a crucial point for a strategic political vision, which requires assessing environmental improvements at country and/or global scales. With this objective in mind, the question of allocation methods is not a key issue. However, this can be a key issue for companies that are responsible for products involved in the overall studied system. Furthermore, many of the technologies involved can be based on industrial symbiosis, especially when environmental performance is a target. However, the choice of burden sharing rules cannot be based on scientific evidence, as it is also a political choice [14]. It could be tested as an additional parameter in the modelled system in order to favour the most efficient cooperation between actors towards environmental improvements. Moreover, efficient cooperation for industrial symbiosis is very dependent on local conditions and we are of the opinion that it should be up to the cooperating partners to define and agree upon the sharing burdens rules through private contracts: they will necessarily reach an agreement that is financially positive for all of them.

4. FUTURE APPLICATION: VALORIZATION OF NICKEL SLAGS BY CCU

A research consortium consisting of LGC, CNRT and BRGM, three French research institutes based in metropolitan France and New Caledonia have previously established an innovative CCU mineralization solution [15]. This technology is currently being further developed with the objective of valorizing pyrometallurgical Nickel slags produced in New Caledonia into valuable construction products (hydraulic binders, pozzolanes, ...). Using such products in the construction sector could be highly beneficial from several standpoints, including preservation of natural resources, greenhouse gas mitigation, and reduction of land use for slag disposal. The latter is particularly critical in the constrained environment of the New-Caledonian territory, a 19,000 km² island in the southwest Pacific Ocean.

It goes without saying that the actual environmental benefits of the Ni slag valorization project, through the proposed mineralization process and possible product valorization routes, must be assessed. This endeavor is one of cornerstones of the CARBOSCORIES 2 and CARBOVAL projects, which are funded by the French Environment and Energy Management Agency (ADEME) and the Caledonian Energy Agency (ACE). These projects bring together a multidisciplinary research team that includes several institutes, namely LGC, CNRT, BRGM, LMDC, IFSTTAR, ESO and LEMNA. The transdisciplinary approach described in Figure 3 is coordinated by IRSTV, a research federation dedicated to urban science and technology [16]. The actual contributors from IRSTV are IFSTTAR for the LCA component of the approach, LEMNA for the economic analysis and associated models, and ESO for the urban metabolism vision. The IRSTV team will develop and implement the approach depicted in Figure 3 to the Nickel slags valorization project using mineralization. The context of the project will provide the IRSTV team with the perfect case study for implementing, improving and testing the approach discussed in this paper. In addition to guiding the research team towards viable valorization routes for Nickel slags, the research work will develop a methodology that is expected to be transferable to other situations where CCU, through mineralization for example, is considered as a pathway for waste valorization.

5. CONCLUSION

The basis for a transdisciplinary approach have been set to respond to issues of environmental assessment of CCU and waste valorization. Although based on consequential Life Cycle Assessment, this new approach differs from it as the model: is based on multi-products system, considers market scale, and includes possibility of constrained market models. Still, it has to be tested on actual case studies.

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