Evaluation of By-products’ Potentiality for the Reincorporation in New Building Materials

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Abstract. This article explores the potentiality of agro-industrial by-products for the reincorporation into new industrial cycles from a circular economy perspective. Focusing on the chemical characterization of the pineapple by-product coming from the Mexican food industry, the methodology for the evaluation of the most proper and sustainable application of this material into the Mexican social system is shown. The application of pineapple by-product for the production of new low-impact insulation material is proposed to solve a social problem affecting the country: the wide diffusion of self-built houses and their poor habitability features, like a proper thermal comfort. The environmental impacts coming from the production of the insulation material have also been evaluated according to the guidelines given by the International EPD system in order to guarantee the reliability of the methodology and the possible future comparison with other insulation materials.

1. Introduction
Circular economy is one of the most comprehensive approaches to introduce the sustainability model in the current industrial system and in society in general [1]. Closing the cycle, focused on keeping the materials moving, is a good practice to produce more with the same resources: more solutions, more services, and more materials. The industrial production looks forward to giving a reduction in cost, time, and transportation, and this capacity needs to change. The development of new machinery, new technologies, and new energy sources brings more and more possibilities to companies, and after four industrial revolutions, the industry continues to change in order to respond to temporal needs. Nowadays the massive consumption has a big contribution to global problems: problems that keep on the risk of the actual economy model. That’s why industries are trying to understand how their products could face the new necessities and create a new business model in accordance with the actual conditions. The constant increase in the consumption of industrial products is directly related to the increase in industrial waste. The selection of materials for transformation into products is based on their main function, and with a wide availability of different materials choosing the correct combination is not easy [2], since the selection of materials has to respond to ergonomic properties, durability, the relation with the purpose of the product and the user criterion. Thus, sustainability issues are rarely considered. Moreover, the environmental cost is usually not quantified also because of the complexity of the calculation or because the value of that information is not significant for the stakeholders. As a result, most of the time data on environmental performance – and sustainability in general – of products are still not available.
But now that invisible cost has more relevance for the society, the resulting consequence is new and stricter production rules that are pushing to declare more environmental information of products. A potential path is that of environmental labelling, e.g. according to the standard ISO 14025 [3] for Environmental Product Declarations (EPDs), that makes easier the comparison between products with a common functional unit [4].

One of the stakeholders in sustainable development is the food industry that had one of the biggest growth in production and economic development. However, this growth is harmed with the lack of philosophies or practices that guarantee the return of by-products to new cycles. An easy solution for the reincorporation of food by-products is based on biodegradability into the soil. Other uses are the incorporation into the textile sector as the leaf of pineapple or the incorporation into the building sector as for coconut fibres that can be used to reinforce the concrete [5]. However, in Mexico, most of these by-products go directly to the land fields, because processes of reincorporation don’t have the necessary velocity to be performed in comparison with the number of by-products, or as industries don’t have any interest and knowledge on what they could do with them.

On the one hand, the philosophies of recycling could have more negative impacts if the control systems and the consequences are not carefully studied. But on the other hand, the potential use of by-products offers a big opportunity to markets where the raw materials have low reserves. For example, bio-based by-products materials are more and more frequently researched for their use in the building industry, as hempcrete, a bio-based concrete that comes from hemp and that has better possibilities of reintegration to the soil rather than standard concrete, or the incorporation of recycled woods and fibres [6].

The complexity of processing by-products comes from the lack of knowledge of their composition and of the correct time to reincorporate them to new cycles. Products are usually composed of more than one material, that’s why the composition brings characteristics that the single materials haven’t, as resistance to degradation or fermentation. These combinations of materials serve to the main product for its own scope, but in by-products could complicate the characterization and its integration to another cycle, because the original composition, that is very well characterised as raw material, changed into a new one that needs to be characterised again. That is a big obstacle to incorporate by-products to new cycles because the form and properties are not the same, and they need to reprocess in other systems. It is necessary to say that not all the times the same processes have the same impact in all the applications, it depends on the situation. Therefore, new low-impact processes and more biological transformation need to be considered for the transition of the industrial sector to a low-impact system, gradually rethinking the supply chain in order to make this process feasible for the sector.

For reincorporating by-products it is necessary to understand the complexity of their processing, to ensure the benefits of creating new cycles for these materials and to aim at impacts reduction. With all the possible variables in the reincorporation of the by-products, the characterization will play an important role, but mostly a quantitative approach should guide the development of new industrial solutions. This paper focuses on the characteristics of the pineapple by-product of the agro-industry and evaluates its potentiality in the process to reincorporate the by-product to a new cycle. That cycle was selected on current research and the result of a local necessity in the building industry, and the environmental performance has been quantified according to a proper LCA methodology as it already happened for several industrial sectors and applications [7, 8].

2. Materials and methods

In Mexico, most of the population does not have the possibility of having a good quality of life because of the characteristics of their houses. The Mexican building market is characterised by two kinds of buildings: on the one hand, we can find regulated constructions, designed according to the local codes, normative, and also certificated by energy or low impacts methodologies; but on the other hand, there’s a widespread presence of buildings that were built out of the regulation, illegally, following the basic refuge concept only to delimit the space, using the materials available in the place. These kinds of buildings were designed only considering the stability and the mechanical requirements for the structure, but they mostly ignore the thermal comfort and the energy requirement. Thus, this results in high consumption and the need for electric or thermal energy extra local [9].
There are multiple characteristics and properties that during a building design have to be considered in order to ensure inhabitants’ comfort, but one of the most relevant and often forgotten in Mexican houses is thermal comfort. This is defined as the mental condition that expresses satisfaction with the thermal environment, therefore it is related to the interactions between the human body and the indoor temperature: these interactions create different and subjective reactions to the human body [10].

Creating a thermal indoor environment in which people feel comfortable is only possible with good energy management, achieved following simple strategies, keeping the indoor temperature at 22 °C and having efficient thermal insulation of the building envelope. The thermal insulation has the task of reducing the heat transference between the external environment and the indoor one: each material of the building envelope is characterised by an R-value that depends on the thickness, type of material and its density [10].

Insulation with a higher R-value will perform better than a material with a lower value. Efficient building insulation keeps the heat inside, and also for warm climates, it keeps the heat outside. Despite in most of the country, there are strict laws about the thermal characteristics and requirement of buildings, that are becoming every year stricter about the thermic resistance, in Mexico most of the buildings have low insulation.

Mexico has different types of climate according to its topography, it is arid and warm in the central northern zone and it is moderately rainy in the southern plateaus and very rainy in some tropical areas. These climate conditions made it necessary to manage the heat transfer, but both the lack of knowledge in the use of insulation materials and the costs of the products made it difficult for some part of the population, especially in the communities with less economic development.

At the moment, most of the Mexican insulation materials are imported from other countries and this market domination increases the cost and decreases the overall affordability.

In 2015, Mexico had more than 30 million houses, and more than 40% of these had thermal problems. Building better houses, bringing health to the people and making the self-built houses more comfortable is only possible if the necessary resources to insulate the Mexican houses are easily available for the population, and this target could be possible only if the country could self-produce thermal insulation materials at low cost. It is important to consider also that, as most of the production of the commercial materials depends on fossil and mineral resources, the demand for insulation could increase the emissions and resources depletion, two of the biggest global problems. Therefore, the necessary solution to be sought is creating “clean” and efficient industrial processes. A cleaner production represents an opportunity for the industry, especially for the possibility of rethinking the process using the by-products.

An example of this is the Mexican pineapple market, one of the most growing in the world. In Mexico, the pineapple production was 840,486.46 tons in 2015 and 14.4% of it was industrially processed for juices, concentrates and conserves production [11]. However, the industrial process uses only between 60% and 74% of the fruit disposing of the rest in landfills, and rarely reintegrating the by-products in new cycles. The lack of value on this material is due to the absence of food applications as it corresponds to the bitter part of the fruit [12].

The idea of the project was to integrate lignocellulosic waste (LCW) as a harvesting strategy based on a biomass economy [13]. Plant residues may contain usable substances with high value in the development of co-products: for the particular case of the pineapple agricultural waste, the valuable residue is the pineapple peel. With this strategy, it is possible to keep the value of the whole agricultural product, evaluating the potentiality of using the by-products to solve social issues with low impact. Pineapple peel contains cellulose, hemicellulose, and lignin that can be used as a filler to improve the performance of the composite. Both the recycling of waste and its treatment in industrial plants allow the systemic reduction of losses and become profitable in both economic and ecological terms [14].

Therefore, besides the analysis of the technical and market opportunities offered by the wide amount of pineapple by-product generated by the food industry, the work aimed to evaluate also the environmental impacts linked with the production of the prototyped insulation material testing its potential environmental sustainability and benefits.

The chosen methodology for the assessment of the environmental impacts was the Life Cycle Assessment (LCA) as defined by the standards ISO 14040-44 [15, 16]. In order to ensure the comparability with other market products, the LCA model and the system boundaries have been chosen.
and developed also according to the specific Product Category Rules (PCR) furnished by the International EPD System.

On the one hand, even though in Europe LCA and EPDs are becoming more and more applied as decisional parameters and indicators in the building sector, not only for the selection of construction materials but also for the management of existing buildings [17], nowadays the environmental labelling and the LCA methodology in general are far from being a guiding parameter in the Mexican building sector for both customers and companies. But on the other hand, the chosen approach may forestall the potential shift of the market towards environmental sustainability as some companies are beginning to show some interest in using ecolabels as part of their sustainability strategies [18].

### 3. Results

The configuration proposed is a biopolymeric matrix based on pineapple peel extract (Ananas comosus) and small amounts of additives, and its subsequent integration with a fibre-reinforced clay of the same peel. The main mechanism of forming is the polymerization/gelation (thermal) by heating, whose main characteristic is its drying after consolidation, that is, it does not require a subsequent burning thus significantly reducing costs.

The composition of the by-product (Table 1) shows that the pulp on the peel is the most present element, and mixed with water increases the volume of cellulose and gel necessary for the polymerization. But in other ways, the fibre obtained by the by-product needs to be characterised by other parameters to identify the correct application.

#### Table 1. Basic chemical composition of pineapple peel (bracts of leaves, peel and core).

| Unit            | Pulp       | Bracts of leaves | Peel       | Core       |
|-----------------|------------|-----------------|------------|------------|
| Total protein   | g          | 1.58 ± 0.01     | 0.70 ± 0.01| 0.75 ± 0.01| 0.85 ± 0.01|
| Ash             | g          | 3.0 ± 0.01      | 7.37 ± 0.0 | 1.5 ± 0.0  | 1.3 ± 0.0  |
| Raw Fat         | g          | 3.19 ± 0.0      | 3.5 ± 0.0  | 2.0 ± 0.0  | 3.17 ± 0.0 |
| Raw Fibre       | g          | 24.14 ± 0.01    | 62.5 ± 0.0 | 65 ± 0.0   | 47.6 ± 0.0 |
| NFE             | g          | 68.79 ± 0.0     | 25.93 ± 0.02| 32.1 ± 0.02| 47.08 ± 0.01|

The environmental impacts have been evaluated according to impact categories required by the International EPD System (Table 2) and they aim at giving the opportunity to improve the conceptualized process for the production of the new insulation material and at allowing its comparison with other insulation products available on the market.

#### Table 2. Environmental impacts.

| Unit                      | Pulp       |
|---------------------------|------------|
| Acidification potential   | kg SO₂ eq  | 0.0934     |
| Eutrophication potential  | kg PO₄³⁻ eq| 0.0253     |
| Global warming potential  | kg CO₂ eq  | 15.8       |
| Photochemical oxidation   | kg C₃H₈ eq | 0.0026     |
| Ozone layer depletion     | kg CFC-11 eq| 0.0000021  |
| Abiotic depletion, elements| kg Sb eq | 0.000056   |
| Abiotic depletion, fossil fuels | MJ | 210 |

### 4. Conclusions

By-products valorisation brings a new vision of industrial production, solving both social and industrial issues. The Mexican food industry should know the potential benefits that can be generated by the food waste, in order to create new co-products with similar processes that could be also part of the same supply-chain, saving money, energy, and raw materials. Moreover, production processes should become
more and more sustainable due to the high impact that the industry has on facilities and on the local community, especially in the growing countries.
Mexican buildings' insulation could be improved using the by-products of the pineapple industry, one of the main productive sectors of the country, where more than 30% of the fruits aren’t used in the food industry due to its taste or edibility. Especially because agriculture is a common practice in vulnerable communities, where energy poverty is high.
Characterization and revalorization of materials bring more possibilities to the future sustainability challenge and to solve the present problems of industrial production. When this knowledge and mindset are involved starting from the design phase of all industrial processes, then it is possible to create different co-products with similar processes in the same system, making it easier than if applied to other phases. So, a circular economy approach could increase the overall exploitation of the same raw materials and then the productivity, reducing the necessary resources for the production and bringing new possibilities of development to local communities.
The designed application of pineapple by-product for the production of a cheap insulation material affordable for Mexican communities could have a potentially high impact on both the social and environmental sustainability of the Mexican building sector and the LCA methodology is a valuable decision support tool in order to pursue a more sustainable development from a fully comprehensive point of view still lacking in the sector.

5. References
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