SB&WRC Project

Economic assessment of the prototype 1: Maize pith-based insulation material

June 2019

Abstract of the project

The SB&WRC *(Sustainable Bio&Waste Resources for Construction)* project, an undertaking of more than two years, aims to conceive, produce and test three innovative, low-carbon, thermal insulation materials from agricultural co-products and recycled waste. The project is supported by the development program Interreg France (Channel) England and is co-financed by the ERDF (European Regional Development Fund) for 69% of its total budget which is estimated to be 1.8M€ (including a 1.26M€ contribution from ERDF).

This project, led by Nomadéis, is carried out by a cross-channel partnership which gathers academic research laboratories, private research and consulting companies, manufacturers and professional non-profit organisation of the building sector:

- Nomadéis;
- Veolia Propreté Nord Normandie;
- University of Bath;
- Ecole Supérieure d'Ingénieurs des Travaux de la Construction de Caen (ESITC Caen);
- Construction 21;
- UniLaSalle;
- University of Brighton;
- Alliance for Sustainable Building Products.

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List of acronyms and abbreviations

Acronyms

SB&WRC: Sustainable bio and waste resources for construction
SME: Small and medium enterprises

Abbreviations

€: euro(s)

ha: hectare(s)

K: Kelvin

kg: kilogram(s)

m: metre(s)

t: ton(s)

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1. Introduction

As part of the SB&WRC project, the technical, environmental and economic characteristics of the three low-carbon insulation materials prototypes for construction are assessed in order to gain a comprehensive and multi-dimensional understanding of their strengths and weaknesses. Many innovative products that are developed in research centres never reach the market because they are simply not price-competitive compared to existing products. The economic assessment aims to determine whether the three bio and waste-based insulation materials that were developed would be competitive relative to conventional, mineral-based insulation materials by estimating the selling price of the prototypes. It is also an opportunity to identify the factors that have a large impact on production costs and thus to devise cost-optimisation strategies. These results will be useful in the perspective of mass production and dissemination of insulation products on the market.

This report focuses on the prototype that consists in a maize-pith based insulation material for construction was developed by a team of researchers at private higher education establishment UniLaSalle, France. UniLaSalle devised a novel technique to press maize pith at a certain temperature in order to obtain a non-load bearing panel used for insulation.

2. Methodology and data

The economic assessment of the insulation materials for construction is essentially a simulation exercise because these materials are not yet produced on a large scale given that they are still at the prototype stage. For the purposes of this study, we have conceived a representative and fictitious company that would manufacture the maize pith insulation material in France. Our aim is to explore how the company would produce the prototype, how much this would cost, and at what price the final good could be feasibly sold to consumers on the market, all from the perspective of this company.

For the maize pith insulation material, one scenario, based on a large-scale production, was developed. A factory transforms a mixture of maize pith, water and mulching film into 3-layer panels thanks to a thermocompression machine. These insulation panels can be used for different types of applications: wall (internal or external), floor, or roof insulation. It should be noted that the present analysis is a simulation exercise that relies on certain hypotheses and on the available data. As an example, the production scenarios may be optimised. Thus, selling prices should not be taken at face value. However, these results give a good idea of the magnitude and distribution of production costs, and hence of the selling price under certain conditions.

The modelling methodology that was developed follows a bottom-up approach. First, the unit costs of production were estimated based on a hypothetical production scenario. A realistic profit margin (including the distribution step) was then added to the unit cost of production to develop the selling price of the prototype. Unit costs of production are computed in four stages:

1. The production process of the maize pith insulation material is broken down into its main steps: i) sourcing of raw materials and ii) transformation of raw materials into the insulation material, plus the administrative costs. The amount of inputs required at is estimated each step (e.g. machinery, consumables, labour).
2. All variable and fixed[1] costs associated with each step of the production process are identified and measured in a detailed and comprehensive way. Total annual production costs can thus be derived.
3. Total feasible output over a year for a given production unit is estimated.
4. Unit cost of production is computed as total annual costs divided by total annual output.

[1] Variable costs refer to costs that vary closely with output, while fixed costs do not.

This modelling exercise is particularly data-intensive, since the quantity and unit cost of all inputs (including labour, rent, advertising etc.) must be known, and total output must also be estimated. Data sources mainly include:

- Data from UniLaSalle and discussions with the researchers that were involved in the project.
- Additional researches. For instance, most price data come from the internet or from discussions with suppliers.

3. Prototype description: maize-pith based insulation material for construction

UniLaSalle has developed insulation panels based on maize pith, which is the core, inner part of maize stalks. Currently, in the context of maize cultivation, maize stalks are largely considered as an agricultural co-product, with little or no economic value, other than their use as a source of organic soil amendment. Maize stalks are highly abundant and available in the Interreg zone, especially on the French side. Further, harvesting maize stalks does not compete with food production or other essential uses.

UniLaSalle has shown that the porous structure of maize pith provides them with interesting thermal properties that can be exploited to create insulation materials for construction. They have created insulation panels that consist of 3 layers: two thin and dense outer layers (1mm and 400kg.m^3 each) enclose a thick but less dense inner layer (25 mm; 50 kg.m^3). The two outer layers essentially protect the core layer and maintain the structural and mechanical integrity of the panel. The core layer acts as the insulation material. Figure 1 shows the 3 layers.

Each layer is produced by thermocompressing a mixture of maize pith granulates (64%) and water (36%) into a square panel. As suggested by its name, the thermocompression machine applies heat (200°C) and pressure (2.5 bars) to transform the mixture into rigid panels. The panels are then cooled by the machine before their exit. The two outer layers are thermocompressed more strongly than the core layer, which is less dense and thicker. However, all layers spend the same amount of time in the thermocompression machine: 9 minutes. The 3 layers are bound together by two pieces of a biodegradable mulching film commonly used in agriculture. Thermocompression melts the mulching film, thus binding the layers together.

Prototype dimensions and characteristics are described in table 1. The insulation panels are large, yet thin and light, owing to their low density. Thermal conductivity of maize pith panels is low (λ=0.042 W/m.K) and competes well with conventional insulation materials. However, the low thickness of insulation panels reduces their thermal performance (R), which is the ratio of thickness over thermal conductivity: $R = \frac{d}{\lambda} = \frac{0.028}{0.042} = 0.67\ \frac{m^2k}{w}$. To achieve a standard level of thermal performance R=5 m².K/W, thickness must reach 0.21 m (i.e. a 7.5 multiplication).

Reported dimensions and characteristics are not definitive, since they are based on the prototypes that were created as part of this research & development project. In the context of mass industrialisation, these parameters could be changed to optimise ease of use for construction professionals, thermal performance, mechanical integrity or production costs for example.

Insulation panels are ready to use as non-load bearing insulation material for interior wall applications. They are similar to rigid panels (or boards) based on expanded cork, wood fibre, polyurethane or polystyrene for example, in their type of application and appearance.

Figure 1 : Maize pith-based insulation panels consist of 3 layers bound together by mulching film

Characteristics of maize pith-based insulation panels		
	Value	**Unit**
Length	1,10	m
Width	1,10	m
Thickness	0,028	m
Area	1,21	m^2
Volume	0,034	m^3
Density	79,00	kg/m^3
Mass	2,68	kg
Thermal conductivity	0,042	W/m.K
Thermal performance (R)	0,67	$m^2.K/W$
Thickness for R = 5 $m^2.K/W$	0,21	m

Table 1: Characteristics of maize pith-based insulation panels

4. Large-scale scenario: factory production of insulation panels based on maize

4.1 Production company's value chain

To assess the unit cost and sale price of the insulation material, the following large-scale scenario has been chosen. The company sources the main raw material – maize-pith – from a specialised supplier. This biomaterial is mixed with water and thermocompressed by a machine to form 3 layers that are bound together thanks to biodegradable mulching film. Panels are then packaged and stored until they are shipped to a building materials trader, who will sell the insulation panels directly to customers.

Many other indirect costs must be included to comprehensively assess production costs. The workshop is equipped with various tools, machinery, equipment and furniture that are essential to the manufacturing, packaging and storing stages. The company also incurs overhead costs such as rent, ICT expenses, office supplies, insurance and accounting fees, advertising expenses and also utilities (electricity, gas, water, telephone and internet) to support its activities. Finally, various taxes and contributions must be paid by the company and as such represent a cost.

4.2 Representative company

The simulation exercise focused on a small, fictitious company based in France. It is argued that the cost estimation results for France also roughly apply to the UK context. In real terms (i.e. once the £ to € exchange rate is accounted for) the price of identical raw materials, machinery, tools and equipment is quite homogeneous between France and the UK, given that they are both part of the European single, common market. However, other costs such as labour costs, rent, utilities and taxes may differ more significantly between France and the UK, for various institutional and contextual reasons. By adapting these prices to the UK context, one may precisely estimate unit production costs and sale price.

The legal structure selected is a *Société Coopérative d'Intérêt Collectif* (SCIC), i.e. a company where each member of the general assembly holds one vote regardless of his capital share, and which gathers three types of partners: salaried employees, beneficiaries (e.g. clients, suppliers etc.) and a third type of partner (e.g. company, financer charity etc.). SCIC companies need to comply with specific regulations which indirectly affect the amount of taxes they will have to pay. Between 57,5% and 100% of profits must be allocated to indivisible reserves. This share is deduced from the company's corporate tax.

4.3 Cost breakdown

4.3.1 Feasible output and labour

It was assumed that the company employs a total of 19 full-time workers: 1 support workers specialised in administrative and business-related tasks (supply chain, sales etc.), and two teams of 9 workers that work in two 7-hour long shifts (morning and afternoon for example). These workers manufacture maize pith insulation panels thanks to a thermocompression machine, and are also in charge of repair, maintenance, storage etc. Each worker will work for about 203 days a year, if all days off and working time reduction are deduced and if we take into account a 5% absenteeism rate. This represents a total of 1,624 effective hours (during which 1,421 are spent on the machines) annually per worker.

During each shift, the team of workers spends 7 hours operating the thermocompression machines and working on other tasks such as maintenance, preparation, cleaning and logistics. We assume a 2-to-1 relationship between the number of workers and thermocompression machines: there are two machines for every worker during a shift. As there are 9 workers in each shift, this implies that the factory is equipped with 18 thermocompression machines. In total, 30 minutes are required to produce 1 panel:

- The maize pith & water mixture is spread evenly in 2 square flexible glass wool frames. Each frame is then sent one after the other into the thermocompression machine for a duration of 9 minutes. The process takes 2*9 = 18 minutes. The two protective, dense, outer layers are thus obtained;
- A piece of pre-cut mulching film is placed on each outer layer. The core layer of maize pith mixed with water is spread horizontally on top of one of the outer layers. The remaining outer layer is placed on top of the 2 other layers, thus "sealing" the 3 layers together into a single panel. This process takes 3 minutes;
- The three-layered panel is thermocompressed for a duration of 9 minutes. The mulching film melts during the process, thus binding the 3 layers together.

Given that it takes 30 minutes to produce 1 prototype, 504 insulation panels can be produced every day by the factory. This translates into 120,657 panels per year, which is equivalent to 4,102.66 m^3, or around 323.36 tonnes.

When the layers are being thermocompressed for a duration of 9 minutes (for each layer) by the machine, workers are available for other tasks such as preparing the maize pith & water mixture, cutting mulching film, and various essential tasks such as maintenance, reparation, packing, logistics, cleaning etc. This explains why it is assumed that thermocompression machines are running for the *entire* length of the shift (7 hours).

4.3.2 Variable cost

4.3.2.1 Labor costs

Each worker is assumed to earn a gross salary of 1,600€ per month, which corresponds to 19,200€ annually. This is slightly higher than the minimum wage in France (1,522€). However, it has been established that the factory opens 252 days per year, after deducting the 104 days of weekend and the mean of 10 national holidays during the week per year. Therefore, regarding the total number of man-days worked, we reach a full time equivalent of 23,59 workers. Since employer contributions have been excluded from this figure, as they will be included later in the "Taxes" part, the total cost of the workforce for the company amounts to 452,928€ per year.

4.3.2.2 Consumables

The 4 consumables used in the production process are: maize pith, water, mulching film and flexible glass wool frames. To produce one panel, 2.26 kg of maize pith, 1.27 kg (or liter) of water, 1.21 m² of mulching film and 0.23 m² of glass wool are required. Over a year, this represents 247 tons of maize pith, 138.64 m^3 of water, 132,091 m² of mulching film and 25,108 m² of flexible glass wool.

Mulching film and glass wool cost 43,241.04€ and 51,421.74 € annually in total. The cost of water will be discussed below in the "utilities" section (4.3.3.4).

The unit cost of maize pith is currently unknown, because it is considered as an agricultural co-product with no economic value, since it has not been valorized yet. According to UniLaSalle, maize pith accounts for around 10% of the mass of maize stalks. To produce the prototype, maize pith was provided free of charge to UniLaSalle by the company CORMO, a Swiss company that produces plant substrate and casing soil from the bark of maize stalks. It was not possible for CORMO to provide a price for maize pith, since it currently has no practical use or market. Therefore, the price of flax shives was used as a suitable approximation for the hypothetical price of maize pith, given their similarity. The unit cost of maize pith used in this study is thus that of flax shives: 0.33€ per kg. Based on that approximation, it was estimated that total cost of maize pith was of 80,280.22€ annually.

4.3.2.3 Packing consumables

27 maize pith insulation panels can be stacked on a europallet, therefore 4,022 europallets must be purchased every year, given total output, for a total cost of 111,407.18€ Each europallets is wrapped in plastic to protect the panels. The annual cost of packing plastic is 5,441.66€. The plastic wrapped europallets are stored and readily available when an order arrives.

4.3.3 Fixed costs

4.3.3.1 Manufacturing equipment

The thermocompression machine is the central component of the production process: it transforms the maize pith granulate & water mixture into solid panels thanks to compression and heating (200°C). Large-scale prototypes for the maize pith insulation panels were produced at the CoDEM **(Knowledge and competency transfer center regarding sustainable construction, formulation and characterization of eco-materials)**, on the Meyer KFK-XL double belt press, flatbed laminating machine. This 1,1*3 m machine is equipped with a double belt to move materials within the machine, through a heating zone, a pressure roller, and a cooling zone.

Such a machine would cost between 700,000 and 800,000€ euros upfront according to the Meyer company, although this figure could vary significantly depending on how the machine is customized, and where it is shipped. The purchase price of this machine has been assumed to be 750,000€. The purchase of 18 thermocompression machines (1 for every 2 workers) would thus require a 13.5 million € investment. When linearly amortized over 20 years, and assuming a 20% scrap value[2], this represents an annual cost of 540,000€.

Maintenance and repair costs must also be accounted for. It is difficult to model these costs precisely, given that they depend on multiple factors such as: quality of the machine, age of the machine, intensity of use, previous efforts to preserve the machine, contract (in-house vs. external reparations) etc. Nevertheless, the standard assumption was made that total accumulated maintenance and repair costs over the economic life of a machine are roughly equal to 75% of its initial purchase cost. Given that economic life is assumed to be 20 years and that total maintenance and repair costs over the economic life of one machine amount to 562,500€, overall maintenance and repair expenses for all machines add up to 506,250€ every year.

Finally, a number of tools must be purchased to facilitate various tasks in the production process (including utility knives to cut the panels neatly once they have passed through the thermocompression machine), for an annual cost of around 759.04€, when amortized over 5 years.

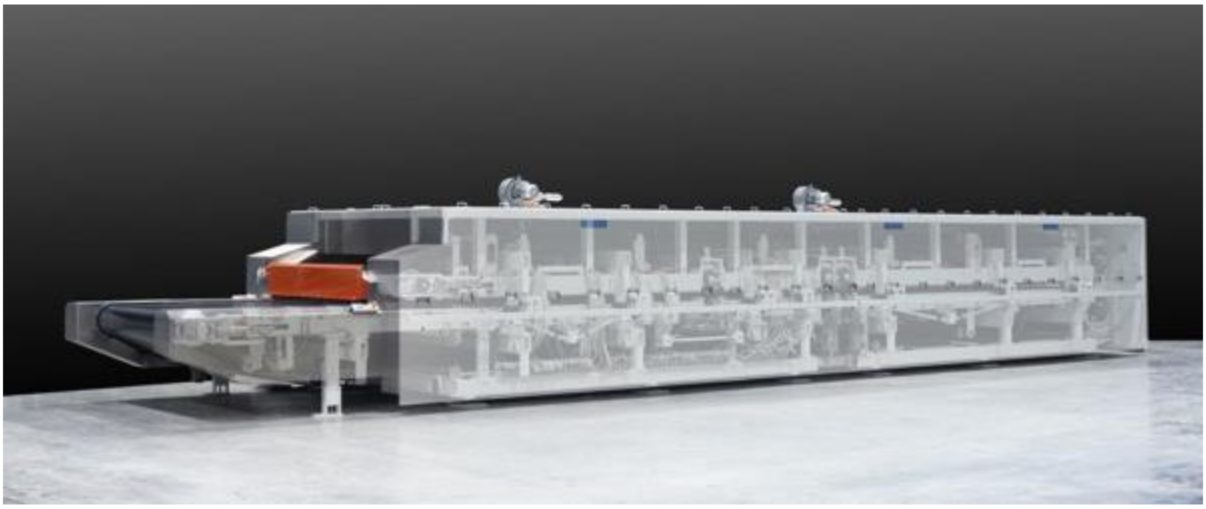

Figure 2: Meyer's KFK-XL thermocompression machine – https://www.meyer-machines.com

4.3.3.2 General workshop equipment

Various other machines, tools, pieces of equipment and furniture are necessary to support the manufacturing process. While it is difficult to compile an exhaustive list of all these items, we quantified some major ones and use them as a proxy for the workshop equipment costs in general.

Packing equipment (2 packing/wrapping machines, 2 wrapping tools and 2 pallet trucks) costs 563.14€ annually (amortised).

[2] Scrap value refers to the resale price of a machine at the end of its economic life

In terms of furniture, we assume that 36 worktables and 18 closets for tools must be purchased, for a total annual cost of 2,055.13€ when amortised over 10 years.

2 industrial hoovers and 2 high-pressure cleaning machines are used as a proxy for cleaning expenses. They amount to 142.98€ every year (amortised).

Finally, the storage room is fitted with 2*48 = 96 racks, each with a 1.87 m^3 storage capacity and a surface of 3.74 m². Total surface of the storage room, including space to maneuver between racks, is 270 m². The storage room is divided in two areas: one to store inputs, and the other for output (maize pith insulation panels). Each storage area has enough capacity to fill two large trucks (33m² for a 90m^3 truck). Given output per day and storage capacity, the storage room for output would be completely filled within 5.27 days.

In total, these additional expenses add up to around 4,377.59€ per year.

4.3.3.3 Office: rent, ICT, supplies

Total workshop area is estimated to be equal to 760 m². This comprises:

- 395 m² for the actual workshop fitted with the hydraulic press, the worktable and the closet for tools;
- 270 m² of storage space: half for raw materials, and the other half to store the output;
- 10 m² of furnished office space. The office is used when the employee works on business, sales, supplies and administration management activities;
- 30 m² for communal spaces, such as toilets, bathroom and a kitchen;
- Another 55 m² can be added to account for corridors and other spaces.

Given that the average rent for commercial spaces in the Seine-Maritime *département* in Normandy is about 5€/m²/month according to the website Cessionpme.com[3], total rent over a year amounts to 45,616.80€ annually.

The worker will need an office space fitted with a desk, chair, closet, and various office supplies and stationaries to carry out more managerial and administrative tasks. These costs add up to 80.04€ per year (furniture-related expenses are amortised).

Finally, the office will have to include IT equipment (computer, printing machine, telephone, etc.). Annual IT expenses have been estimated at 16,920.79€.

4.3.3.4 Utilities

Utilities include:

- Water consumption for 1 full-time worker is estimated to be around 25 m^3 year thanks to Eau de Paris' online calculator[4], and at any given time, there are 10 workers in the workshop. Additionally, the production of each insulation panel requires 1.27 liters of water, which translates into 150 m^3 every year in total. This comes at a total yearly cost of 2443.75€

[3] CessionPME (2019) accessed on 28/05/19 : https://www.cessionpme.com/annonce,location-entrepot-bureaux-saint-romain-de-colbosc-76430,1716181,A,offre.html. For any real estate advertisement, at the bottom of the webpage, the median rent in the same *département* is displayed

[4] Eau de Paris's website (2019) Calculez votre consommation d'eau. Accessed on 06/08 : http://www.eaudeparis.fr/calculez-votre-consommation-deau/

- Gas consumption for heating all areas in the workshop except storage facilities (so 2/3 of the total area roughly) is equal to 22,063 kWh/year according to ADEME (2014)[5], which estimates that a typical storage area or workshop consumes between 35 and 55 kWh/m²/year of gas for heating. Gas heating expenses represent 1,664.82€ annually.
- Electricity consumption, which is split between the electricity requirements of the 18 thermocompression machines[6] (4,524.66 MWh per year) and general consumption related to lighting, small equipment and appliances used in the workshop (25 kWh/m²/year) adds up to around 4,537.67 MWh per year. The annual electricity bill is equal to 335,072.02€.
- Internet access and telephone bills cost 180€ per year.

4.3.3.5 <u>Other fixed expenses</u>

A typical company must have a budget for fixed expenses such as insurance fees and accountancy fees. While these costs can vary significantly depending on the number of hours an accountant is hired or on the various options included in the insurance contract, we estimate that they come at a total annual cost of 27,200€, for a company with 19 employees.

We assumed that the equivalent of 2% of turnover was dedicated to advertising (so 64,600€ per year), given that the company does not sells insulation panels directly to construction professionals, but to traders of buildings materials instead.

The question of financing is beyond the scope of this study. However, it seems reasonable to assume that the owner of the company would take a loan to buy the 18 thermocompression machines upfront. Annual interests on this 10-year, 13.5 million € loan are estimated at 3,375.00€, with a real interest rate of 0.5% (nominal rate is 2% for a SME. Subtract the expected inflation rate over the next 10 years, which is expected to be of 1,5%, to get the real interest rate).

4.3.3.6 <u>Taxes</u>

In France, companies are required to pay three taxes: the *impôt sur les sociétés*, the *cotisation foncière des entreprises* and the *cotisation sur la valeur ajoutée des entreprises*. The latter two taxes constitute the *contribution économique territoriale* and their rates partly depend on the geographic location of the company.

To compute the *impôt sur les sociétés* owed by the company to the state, we assumed that 57,5% of accounting results would be allocated to *réserves impartageables* (indivisible reserves), because this is the minimum amount required by law for companies with the SCIC status. Projected turnover was estimated to be equal to 3,220,049.70€. As a result, the taxable fiscal result (381,761.29€) is part of the two lowest brackets, where the tax rate is 15% and 28% respectively, while the remaining fiscal result is subject to the normal 33% tax rate. The tax to be paid every year would be 101,937.56€.

The *cotisation foncière des entreprises* is levied on the yearly rental value of the workshop. Because the tax rate is determined at the municipal level, it somewhat varies across localities. Therefore, for simplicity, we apply the average local tax rate in the Seine-Maritime *département* (Normandy), which is 19%, and we assume that the localization coefficient is equal to 1. Additionally, the company benefits from various tax breaks,

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[5] ADEME (2014) Atelier type n°10 : atelier de stockage, *Ateliers industriels : fiches descriptives des ateliers-types*. Accessed on 28/05/19 : https://www.ademe.fr/sites/default/files/assets/documents/atelier-de-stockage-atelier-type-n10.pdf

[6] Assuming that each machine consumes 50% of its connected power load (which is 150kW) on average every day while it is running (so 3,032.4 hours a year)

because it is a newly created (no tax on the first year, 50% tax break the following year), industrial company (30% tax break). As a result, the company must pay 4,784.52€ per year in tax.

The third tax owed is the *cotisation sur la valeur ajoutée des entreprises*. Since projected turnover is above 500,000€, the company is eligible to this tax. However, the company benefits from a tax break on the 1st year of its creation, which implies that over a given period of 10 years, it will only pay 42,709.02€ per year on average.

Finally, the company must pay employer contributions (*cotisations patronales*) on salaries to finance the French social security system. For a full-time worker earning a monthly gross wage of 1,600.00€ and employed by the company described in this study, the employer will pay 369€ (i.e. 23%) in contributions every month, according to the official online calculator[7]. Therefore, total employer contributions are equal to 104,456.52€ annually. A summary of the variable and fixed production costs is presented below in Tables 2.

4.3.4 Unit production cost

In sections 4.3.2 and 4.3.3, all the costs that must be incurred by the company to produce maize pith insulation panels over one year we described and quantified. The sum of all these costs adds up to 2,575,675.47€ annually, including taxes.

Total yearly feasible output was also estimated in section 4.3.1, where it was determined that 120,657 insulation panels could be produced in one year given our assumptions.

Unit cost is simply computed as total costs divided by total output for a given year:

$$unit\ cost\ in\ € = \frac{total\ costs}{total\ output} = \frac{variable\ costs + fixed\ costs}{total\ output}$$

Thus, each maize-pith based insulation material costs 21.35€ thanks to the simulation performed based on the data available and the assumptions made.

To facilitate comparisons with conventional insulation materials sold on the market, this figure can be converted into unit production costs per m² by dividing it by the area of the maize-pith based insulation material (1.21 m²). This gives us a unit production cost per m² of 17.64€ for a thermal resistance of 0.67 m².K/W associated with a thickness of 0.028 m.

To reach a standard thermal resistance R = 5 m².K/W, given a thermal conductivity of 0.042 W/mK, the insulation panel's thickness must be 0.21 m. Thus, unit production costs for a maize-pith based insulation material with R = 5 m².K/W are equal to 132.32€ per m², since thickness must be multiplied by 7.5 to reach the right level of thermal performance.

4.3.5 Gross margin, markup and sale price

Once the maize pith insulation panels are produced by the company (the "producer") that was modelled, they are not sold directly to construction professionals, but to building materials and construction distributors (henceforth called "distributors"). Thus to find the final selling price of the insulation panels, there are two subsequent steps: first, the producer's gross profit must be added to unit costs to obtain the producer's selling price; second, the distributor's operational costs and gross profit must be added to the producer's selling

[7] Pôle Emploi (2019) Estimation du coût d'un salarié. Accessed on 29/05/19: https://entreprise.pole-emploi.fr/cout-salarie/

price to find the final selling price of the insulation panel, i.e. the price that a client will have to pay in a retail store to purchase the panel.

Variable costs						
Input category	Input name	Quantity	Unit	Unit cost	Unit	Annual cost in €
Consumables	Maize pith	273 018	kg	0,33	€/kg	88 730,77
	Mulching film	145 995,70	m²	0,33	€/m²	47 792,73
	Flexible glass wool	27 751	m²	2,05	€/m²	56 834,56
Packing	Plastic wrap	105 620	m²	0,06	€/m²	6 014,46
	Europallets	4 445	europallets	27,70	€/europallet	123 134,26
Labour	Labour	23,59	full-time worke	1 600,00	€/hour (gross)	452 928,00
	Support staff	*1*				
	Workers	*18,00*				

Fixed costs						
Input category	Input name	Quantity	Unit	Unit cost	Unit	Annual cost in €
Manufacturing	Thermocompression machine	18	machines	750 000,00	€ (upfront)	540 000,00
	Repair and maintenance	18	machines	56 250,00	€/year	506 250,00
	Mixer	4	machines	2 003,60	€ (upfront)	200,36
	Various tools					759,04
Workshop equipment	Packing equipment					563,14
	Storage furniture					1 616,34
	Workshop furniture					2 055,13
	Workshop machinery					142,98
Office	Rent	760	m²	5,00	€/m²/month	45 616,80
	ICT expenses			0,00	of turnover	16 150,00
	Office supplies	1	sets	430,80	€ (upfront)	80,04
Utilities	Electricity	4 543 667	kWh	0,07	€/kWh + fixed cost	335 072,02
	Gas	22 063	kWh	0,07	€/kWh + fixed cost	1 664,82
	Water	625	m³	3,91	€/m³	2 443,75
	Telephone & internet	1,00	package	180,00	€/year	180,00
Other expenses	Insurance fees			17 000,00	€/year	17 000,00
	Accounting fees			10 200,00	€/year	10 200,00
	Advertising expenses			0,02	of turnover	64 400,00
	Interests on loan	13 500 000	€ loan	0,00	real interest rate	3 375,00
Tax	IS			101 937,56	€/year	101 937,56
	CFE			4 784,52	€/year	4 784,52
	CVAE			42 709,02	€/year	42 709,02
	Employer's contributions			104 456,52	€/year	104 456,52

Tables 2: Summary of variables and fixed costs associated with the production of maize pith-based insulation panels

4.3.5.1 Producer's selling price

Selling price and gross margin (or markup) are generally jointly determined.

For example, once the unit production costs are known, it can be decided that each maize pith insulation panel will be sold by the producer for 26.70€ to the distributor, in which case the gross margin ratio is 20%, since:

$$gross\ margin\ ratio\ in\ \% = \frac{turnover - total\ costs}{turnover} \times 100 = \frac{sale\ price - unit\ cost}{sale\ price} \times 100$$

Similarly, it can be decided to apply a 25% markup on the unit production costs of the insulation panel to obtain a selling price of 26.70€, since $markup\ (in\ \%) = \frac{gross\ margin\ rate}{1 - gross\ margin\ rate}$.

It can thus be seen that gross margin, markup and sale price are all inextricably linked. The choice of their value depends on several factors, the main one being the company's market power. Market power refers to the ability for a company to raise and maintain its sale price above the price that normally would prevail in a more competitive market environment. A company with strong market power can effectively increase prices without losing too many customers to competitors (thereby increasing its turnover).

Market power depends on many determinants such as the size of the company's market share, market structure (regulations, barriers to entry, relationships between upside and downside companies and competitors etc.) and the firms' long-term strategy (advertising, strategic behavior, collusion etc.) for example. Thus, the degree of market power depends both on the sector and on the company itself.

Given that the company being modelled does not fall in a specific sector (since it would be the first firm producing maize pith-based insulation materials) the average gross margin rate that prevails in one sector cannot be straightforwardly applied. For simplicity, a 20% gross margin rate (equivalent to a 25% markup on unit production costs) we chosen, based on mean gross margin rates in the following sectors[8] that are closely related to the activity considered:

- *Préparation de fibres textiles et filature* (textile fiber preparation and spinning): 18%[9];
- *Fabrication d'articles en bois, liège, vannerie et sparterie* (manufacture of wooden and cork products, basketry and plaiting materials): 21%;
- *Fabrication d'articles en papier ou en carton* (manufacture of paper or carboard products): 24%.

A 20% gross margin rate is equivalent to a 25% markup on unit production costs. This yields the following selling prices to the distributor:

- 26.70€ for a single maize pith insulation panel;
- 22.06€ for 1 m² with R = 0.67 m².K/W;
- 165.42€ for 1 m² with R = 5 m².K/W.

4.3.5.2 Distributor's selling price (final price)

The distributor buys insulation panels from the producer for 26.70€ per unit. To find the final price of the panels - the price at which they would be sold by the distributor to clients - the same reasoning is applied. In France, building materials and construction distributors fall in the *autres commerces de gros* sector (other wholesale retailers), where the average gross margin rate in 2016 was 27%[10]. This is equivalent to applying a 37% markup rate on the producer's price, which gives us the following final selling prices:

- 36.56€ for a single maize pith insulation panel;
- 30.22€ for 1 m² with R = 0.67 m².K/W;
- 226.62€ for 1 m² with R = 5 m².K/W.

The key results of the economic assessment are presented in the table 3.

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[8] For m = gross margin rate; p = selling price and c = unit production cost, we have: $m = \frac{p-c}{p} \times 100 \Leftrightarrow p = \frac{1}{1-m}c$ $\Leftrightarrow price = (1 + markup) \times unit\ costs$, where $markup\ (in\ \%) = \frac{gross\ margin\ rate}{1-gross\ margin\ rate}$

[9] INSEE (2016) Caractéristiques comptables, financières et d'emploi des entreprises - Ratios comptables au niveau groupe, *ESANE*. Accessed on 04/06/19 : https://www.insee.fr/fr/statistiques/3560263?sommaire=3560277

[10] Those are the latest figures available. INSEE (2016) Caractéristiques comptables, financières et d'emploi des entreprises - Ratios comptables au niveau groupe, *ESANE*. Accessed on 04/06/19 : https://www.insee.fr/fr/statistiques/3560263?sommaire=3560277

Producer	Total costs per year in €	2 575 675,47
	Total output per year	120 657,60
	Unit cost in € per insulation panel for R = 0.67 m².K/W	21,35
	Unit cost in € per m² for R = 0.67 m².K/W	17,64
	Unit cost in € per m² for R = 5 m².K/W	132,32
	Gross margin rate in %	20%
	Markup rate in %	25%
	Sale price in € of an insulation panel for R = 0.67 m².K/W	26,7
	Sale price in € per m² for R = 0.67 m².K/W	22,06
	Sale price in € per m² for R = 5 m².K/W	165,42
	Turnover in € per year	3 220 049,70
Distributor	Gross margin rate in %	27%
	Markup rate in %	37%
	Final sale price in € of an insulation panel for R = 0.67 m².K/W	36,56
	Final sale price in € per m² for R = 0.67 m².K/W	30,22
	Final sale price in € per m² for R = 5 m².K/W	226,62

Table 3: Key results of the economic assessment: producer's selling price (in blue) and distributor's selling price (in black)

5. Comparison with conventional insulation materials

Figure 3 thereafter compares the final sale price (excluding VAT) in € per m² of conventional, bio-based and waste-based insulation materials including the maize pith insulation material, for a thermal performance of R = 5 m².K/W. Comparison prices are all derived from CEREMA (2017)[11]. These prices are those that a final consumer would face in a retailer of building and construction materials.

Mineral wool, glass wool and maize-pith are among the cheapest insulation products available on the market in France. Bio-based insulation materials such as hemp and flax wool, hemp wool, wood fiber and sheep wool, and waste-based insulation materials (recycled cotton wool and cellulose wadding) are sold at about 20€/m².

Maize pith insulation panels are more expensive than any other type of insulation materials: they appear not to be price competitive.

This can largely be explained by the higher unit production costs of the maize pith panels. The next parts of this report will investigate the breakdown of production costs and explore potential cost-minimizing strategies.

[11] CEREMA (2017) *Les coûts des matériaux biosourcés dans la construction* – Etat de la connaissance 2016

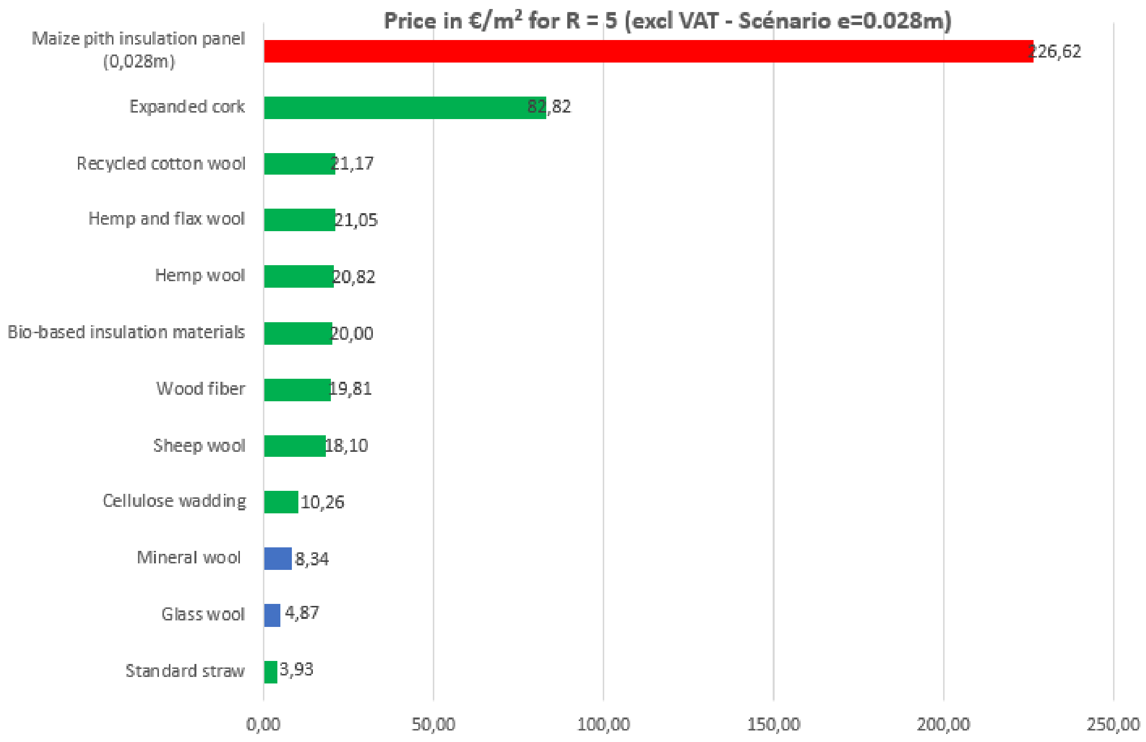

Figure 3: Comparison of conventional, bio-based, and waste-based insulation materials with maize insulation panel

6. Cost-minimizing strategies

Figure 3 showed that the maize pith insulation panels produced under the conditions described in this study appear not to be price competitive. By analyzing the distribution of production costs, the production process and the potential for economies of scale, cost-reduction opportunities can be ca identified.

Figure 4 shows the breakdown of total annual production costs. The manufacturing process is by far the largest factor influencing costs. More than one third of production costs originate from the acquisition, repair and maintenance of thermocompression machines. Each thermocompression machines costs 750,000€ upfront, or 30,000€ each year, when linearly amortised over 20 years. Expenses to repair and maintain these machines in good condition are of the same magnitude: 28,125€ annually for each machine. If the electricity consumption bill associated with each machine (22,134.04€) is also accounted for, running a thermocompression machine over one-year costs 80,259.04€. Given that each machine produces 6,065 panels per year, we can already see that the unit costs solely associated with running the machine (i.e. excluding all other costs) are significant: "machine" costs per m² for R = 5 m².K/W are 82.43€.

Cost-minimizing strategies should primarily focus on **improving the productivity** of the thermocompression machines (i.e. output per unit of time) or **reducing the costs** associated with acquiring and running them (i.e. costs per unit of time), since:

$$unit\ production\ costs\ in\ € = \frac{total\ costs\ per\ unit\ of\ time}{total\ output\ per\ unit\ of\ time}$$

6.1 Improving machine productivity

The thermocompression machines selected can produce only 2 insulation panels per hour, since each of the three layers that constitutes the panel must spend 9 minutes in the machine. Potential ways to improve the economic performance of the thermocompression machines are presented below:

- **Faster machines** would bring unit production costs down by increasing output per unit of time, although there are technical and physical limits to this, and electricity consumption would likely increase;
- **More energy efficient machines** would also help bring costs down by reducing the electricity bill, which represents 28% of machine running costs;
- Purchasing **cheaper machines** that have the same output per unit of time would also reduce costs;
- Unit production costs could be reduced if the company acquired **larger machines** that can heat and compress 2 panels at the same time (rather than just 1) and that are also less than twice as expensive as current ones.

6.2 Producing thicker panels

Another strategy to enhance machine productivity would consist in **producing thicker panels** to increase output per unit of time. The insulation panels that were modelled so far are extremely thin (2.8 cm), so their thermal performance is somehow limited (R = 0.67 m².K/W), even though their thermal conductivity is advantageous. As a consequence, the unit production cost (and hence price) per m² of insulation panels for a thermal performance R = 5 m².K/W (i.e. with thickness = 21 cm) are 7.5 times larger than those associated with 1 m² with a 2.8 cm thickness, even though the only major difference between the two is their thickness. Put differently, to insulate 1m² with a target thermal performance R = 5 m².K/W, a construction professional would have to buy and stack 7.5 "thin" insulation panels, instead of buying only one "thick" insulation panel.

Thus, a solution would be to increase the thickness of the panels produced. This change would increase total production costs only marginally – as more raw materials would be required, and perhaps more electricity - but total output per unit of time would become much larger, since each panel would be much thicker. In other words, **machine running costs would remain roughly the same, while the quantity of output per unit of time would increase drastically**.

At this stage, the maximum expected thickness technically feasible with the available machine to produce panels is **10 cm**. This thickness was then used for the following cost modelling. This would increase by a ratio of approx. **3.57** (10/2.8) the few costs that are directly related to the volume of each panel:

- Maize pith, water and glass wool requirements must be multiplied by 3.57 (and mulching film too for the sake of the argument, although this might not be necessary);
- The mixers would need to have a higher capacity (50 liters instead of 20 liters), increasing their price;
- Assumption was made that electricity consumption per machine would double[12] as more energy would be required to heat, compress and cool the thicker panels;

[12] This number was chosen arbitrarily for the sake of the argument and due to the lack of precise technical information regarding the factors that influence the thermocompression machine's electricity consumption. Electricity consumption would probably not increase by the same amount as the increase in the thickness of panels, as a significant part of a machine's energy consumption is "fixed", in the sense that it is uncorrelated with the volume of raw material that is processed.

- More voluminous panels would take more time to prepare, process and handle, so it was assumed that in total it would take 40 minutes to produce one "thick" panel (instead of 30 minutes for a "thin" one), thus reducing output per unit of time;
- Storage space would have to increase significantly to account for the fact that the daily volume of inputs and of the volume outputs would each be multiplied by 2.68 according to the estimates made (and not by 3.57, since fewer – although thicker -, panels would be produced per day).

However, **all the other costs that are not proportional to panels' volume would remain unaffected** (labor and fixed costs essentially). Therefore, total costs would only rise by 29.7% according to our simulation. Importantly, volume of output per day would increase by around 168%, since each panel that is produced would be much thicker. Therefore, **unit production costs would fall by 51.6%,** to reach 64.08€ per m² for R = 5 m².K/W (instead of 132.32€). The final selling price would be reduced by the same amount if the gross margin rate remains constant, thus reaching 109.73€ per m² for R = 5 m².K/W. **This simple change in the thickness of the insulation panels significantly increased their price-competitiveness relative to other insulation materials.**

6.3 Labor productivity

Strategies focusing on labor costs and productivity would have more limited effects on unit production costs. The labor productivity cannot be significantly improved, since it was already assumed that each worker operates 2 machines at the same time, and during the time that machines are thermocompressing the panels, workers are busy on other tasks (preparation, maintenance, logistics etc.). In other words, labor productivity is constrained by machine productivity. Another strategy would consist in having 3 shifts of 9 workers instead of just 2 shifts in order to use the thermocompression machines more intensively, and thus better amortize their fixed cost. However, this may not necessarily bring down unit costs significantly, as machines may wear down faster, thereby increasing maintenance and repair costs while reducing their economic life.

6.4 Economies of scale

Figure 8 thereafter plots the inverse relationship between the number of workers - which is directly proportional to the number of thermocompression machines and to output - and unit production costs. As the number of workers rises, output increases in a proportional way, while total costs increase by a smaller amount, so unit production costs fall. The existence of economies of scale arises from the fact that fixed costs represent a significant share of total costs (around 25%): as output increases, fixed costs can be spread over a larger number of units. Figure 5 shows that there are important economies of scale when the number of workers (i.e. total output) is low, but these economies of scale diminish almost completely once the number of workers reaches 19. Beyond 19 workers, unit production costs rise again because fixed costs increase faster than output (for example, a new support worker must be hired, more machinery must be bought, storage area must increase etc.). In short, opportunities for economies of scale are exhausted once a certain size is reached. To further exploit economies of scale, the organization of the factory would have to be redesigned more fundamentally.

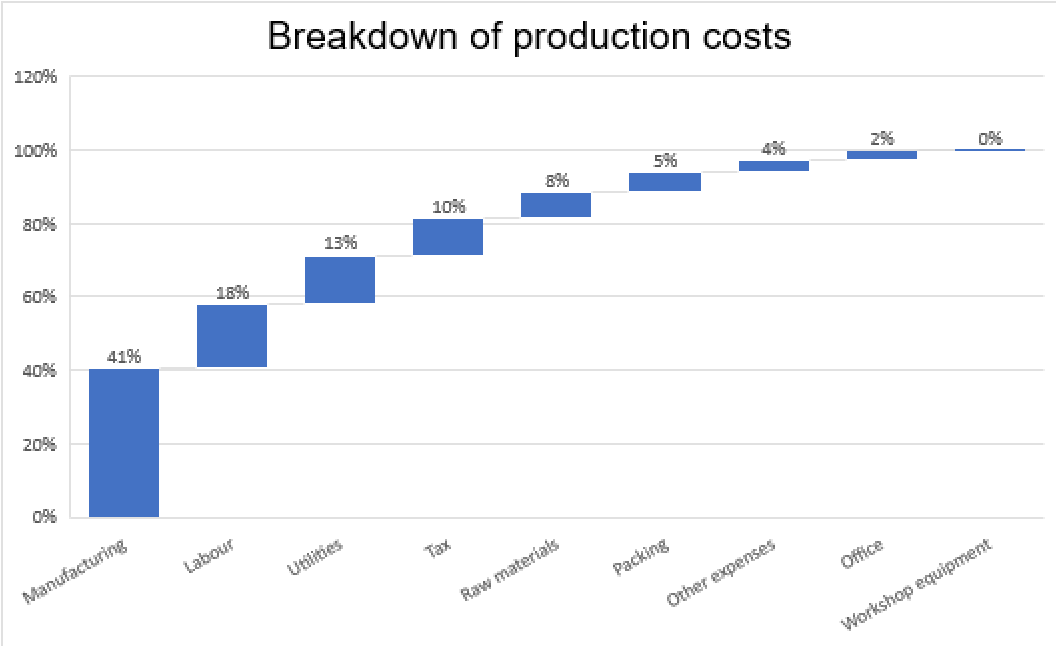

Figure 4: Breakdown of production costs for the maize pith-based insulation panel. "Manufacturing" refers to the acquisition, repair and maintenance costs of the thermocompression machines

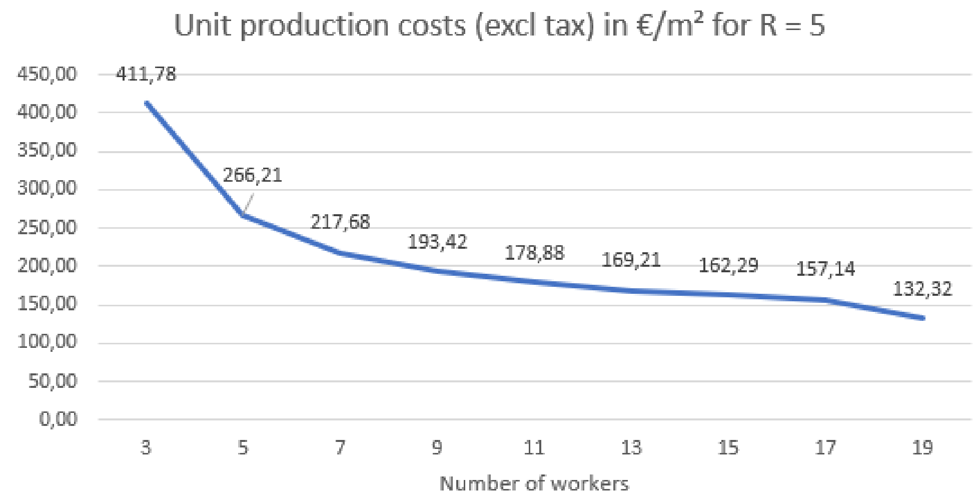

Figure 5: Economies of scale: as the number of workers and machines (and hence output) increases, unit production costs fall. Economies of scale are exhausted beyond 19 workers.

7. Conclusion

UniLaSalle has developed innovative, bio-based insulation panels that are obtained by heating and compressing a maize pith and water mixture. These panels consist of three layers bound together by a biodegradable mulching film: a thick inner layer of insulation material is sandwiched between two thinner and denser outer protective layers. The panels are rigid and have a low thermal conductivity so they can be used for internal, non-load bearing, wall insulation applications.

To estimate the unit production cost and final price of insulation panels, a model measuring all the inputs and associated costs was built. It should be noted that the present simulation exercise relies on certain assumptions and on the available data, hence results and prices presented in this report should not be taken at face value. Rather, they give an indication of the distribution and magnitude of the various costs associated with the production process and provide a basis for exploring cost-reduction and massification strategies. The model that was developed is a simulation tool that can easily be modified to explore how changes in production parameters affect unit costs.

The manufacturing process for maize pith-based insulation panels is capital-intensive because 18 large, expensive thermocompression machines must be acquired according to the simulation performed. These machines account for more than a third of unit production costs. Thus, fixed costs represent a large share of total costs compared to variable costs, which implies that there are opportunities for economies of scale. The company that would produce the insulation panels could profitably sell them to building materials and construction retailers for **165.42€ per m²** for a thermal performance R = 5 m².K/W according to the model developed, assuming a 20% gross margin rate. It was estimated that the retailers would then sell them for **226.62€ per m²** to construction professionals.

The maize pith-based insulation panels produced under the conditions described in this study would be **more expensive** than bio-based and waste-based insulation materials with a similar level of thermal performance. A simple strategy to improve the price-competitiveness of the insulation panels would consist in **manufacturing thicker panels (from 2.8cm to 10cm)** without significantly changing the production process. The simulation performed suggests that this simple change would **divide unit productions costs by two**, meaning that the panels could be priced at **109.73€ per m²** for R = 5 m².K/W. This measure, combined with improvements in the productivity of the thermocompression machines, could feasibly bring down unit production costs – and hence the final price - to more competitive levels. The technical feasibility of these changes would have to be investigated in greater depth with an industrial partner to provide more accurate cost estimates and develop further optimization strategies.

8. Limitations

The results presented in this report should be treated with caution, as they are estimates derived from a simple modelling exercise. Cost and price estimates are inaccurate because some of the data we use and some of the assumptions and calculations we have made are imprecise. These issues are inherent to any modelling or forecasting work. One should bear in mind that the bio-based insulation panels remains at the prototype-stage, it is not yet produced or commercialized. The goal of this economic assessment was simply to produce a first approximation of production costs, and hence of the selling price, to compare it with competing insulation materials, and to explore cost-reduction strategies.

Below are some reasons why production costs might be underestimated and/or overestimated.

Production costs may be overestimated:

- Unit input costs might be reduced if raw materials, packages, machinery etc. are bought in large quantities to earn discounts.
- The production process could be further optimized to improve labor productivity. For example, the hypothetical 1-to-1 relationship between the number of workers and thermocompression machines may be too conservative. Perhaps two workers could realistically operate three thermocompression machines. Improvements of this kind could significantly increase labor productivity and drive unit production costs down.

Production costs may be underestimated:

- Due to time, resource and data constraints, the modelling exercise is not perfectly exhaustive. Some cost categories and components may be missing (e.g. some tools, equipment etc.). However, the most significant and relevant ones have been accounted for.

9. Bibliography

ADEME (2014) Atelier type n°10 : atelier de stockage, *Ateliers industriels : fiches descriptives des ateliers-types*. Accessed on 28/05/19 : https://www.ademe.fr/sites/default/files/assets/documents/atelier-de-stockage-atelier-type-n10.pdf

CEREMA (2017) *Les coûts des matériaux biosourcés dans la construction* – Etat de la connaissance 2016

CessionPME (2019) accessed on 28/05/19 : https://www.cessionpme.com/annonce,location-entrepot-bureaux-saint-romain-de-colbosc-76430,1716181,A,offre.html

INSEE (2016) Caractéristiques comptables, financières et d'emploi des entreprises - Ratios comptables au niveau groupe, *ESANE*. Accessed on 04/06/19 :
https://www.insee.fr/fr/statistiques/3560263?sommaire=3560277

Pôle Emploi (2019) Estimation du coût d'un salarié. Accessed on 29/05/19: https://entreprise.pole-emploi.fr/cout-salarie/

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