3rd International Conference on Bio-Based Building Materials

June 26th - 28th 2019
Belfast, UK

OPPORTUNITIES FOR REDUCING GREENHOUSE GAS EMISSIONS OF INSULATION MATERIALS IN CANADA AFTER CANNABIS LEGALIZATION

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Abstract

The risk of shifting the environmental burden of a building from the use phase (i.e. emissions arising from the generation of energy consumed during heating and cooling operations) to the production stage (i.e. emissions arising during the manufacture of construction materials and their installation) is particularly true for buildings that require a lot of insulation to reduce their operational energy consumption. This is the case for cold countries like Canada, where regions can experience more than 7000 heating degrees days (i.e. annual sum of the number of degrees that a day's average temperature is below 18°C). Energy efficiency, when attained, is typically reached by means of traditional insulating materials: fiberglass, rock wool, spray foam and cellulose. However, the recent legalization of Cannabis for recreational use in Canada may lead to new opportunities for alternative, bio-based insulating materials. Cultivation of Cannabis will produce in fact a large amount of wooden and fibrous materials as by-products. The same by-products from a plant of the same genus but lower (−)-trans-Δ^9-tetrahydrocannabinol (Δ^9-THC) content (i.e. hemp) have been used in recent years to produce insulation materials and their supply is expected to expand in Canada due to a recent deregulation for hemp growers. The objectives of this study are to: (1) evaluate the environmental consequences of substituting the current fleet of insulators with fiber-based panels and composite materials made from the wooden core of the Cannabis plant and a binder (e.g. hempcrete), and (2) understand whether an opportunity could arise in Canada to reduce the environmental impacts of the building sector using by-products of Cannabis grown for recreational use. Preliminary results from a Life Cycle Assessment (LCA) confirm that potential greenhouse gas savings can be attained if bio-based composites and fibers are used in insulative material products.

Keywords:

Hempcrete; GHG emissions; Insulation; Legalization; Canada

1 INTRODUCTION

Reducing energy consumption for indoor space conditioning is among the top strategies to tackle climate change. This is imperative for cold countries like Canada, where energy for heating is the major source of buildings' life cycle greenhouse gas (GHG) emissions [Natural Resources Canada 2016]. One way to reduce the energy requirements is to increase the thermal resistance of the external walls with insulation materials. In Canada, four types of insulation products currently dominate the market: glass wool, mineral wool, cellulose and spray foam. Moreover, boards made from expanded polystyrene (EPS), polyisocyanurate, or polyurethane are employed as insulating sheathing [NAIMA Canada 2018]. Unfortunately, all these materials require energy to be produced and, therefore, they are also responsible for some amount of GHG emissions [Nordby 2013]. It is therefore important to avoid shifting the burden from the operational stage of the building to its construction stage [Arrigoni 2018]: are the GHG emissions spared by insulating the building nullified by the emissions produced during the manufacture of the insulation materials?

To avoid this risk, the use of building materials with low embodied carbon (i.e. materials with low GHG emissions during the manufacture, transport and construction stages) should be favored to minimize the life cycle GHG emissions of the building [Melià 2014].

Bio-based materials are perceived to belong to the aforementioned category and, for this reason, their use in buildings is growing [Peñaloza 2016]. One bio-based alternative to traditional insulation materials which is gaining attention all over the world is hempcrete: a composite material made from the wooden core of hemp stem and a binder, typically lime [Bevan 2008]. Beyond the good insulating properties, the success of the material is due to its low (or negative) carbon footprint [Arrigoni 2017].

Hempcrete still represents a niche market in Canada [Dhakal 2017], but its diffusion is expected to expand in the next years since the regulation for hemp producers was recently eased. Hemp is in fact classified, taxonomically, as *Cannabis sativa* forma *sativa* and, although it was selectively bred to produce low levels of (−)-trans-Δ^9-tetrahydrocannabinol (Δ^9-THC), the chemical psychoactive compound [Hartsel 2016], its production is still regulated by Health Canada. However, in November 2016 Health Canada issued a Class Exemption in the *Controlled Drugs and Substances Act* in relation to the industrial hemp regulations in order to simplify the license application process [Health Canada 2016]. Industrial hemp is currently grown in Canada mainly for its seeds, which are used directly as food or processed into oil and proteins, and for its buds, flowers and leaves, which are used by licensed processors to make cannabinoid-based medicines. Most of the stems, which are the source of the biological component of hempcrete, are currently disposed of by burning with no income to the farmers. The main reason is the limited decortication equipment (i.e. the machineries that separate the fiber from the wooden core of the stem) operating in Canada. For the same reason, most of the hemp hurds used in the hempcrete applications in Canada are imported from Europe and China. Nevertheless, due to the growing demand for the building material, the Canadian supply of hemp hurds is expected to grow in the near future.

Moreover, in October 2018 Canada legalized Cannabis for recreational use. The plants from which the drug is extracted belong taxonomically to the same genus of hemp (i.e. Cannabis sativa), but they have higher Δ^9-THC contents and, in some cases, different appearance. These plants are also known under the name of "*marijuana*" and, in order to distinguish them from industrial hemp, they will be referred to from now on in the article with this name. In Figure 127 it is presented the shape of the different subspecies of Cannabis sativa: *Cannabis sativa sativa* (the one to which industrial hemp belongs to as well), *Cannabis sativa indica* and *Cannabis sativa ruderalis.*

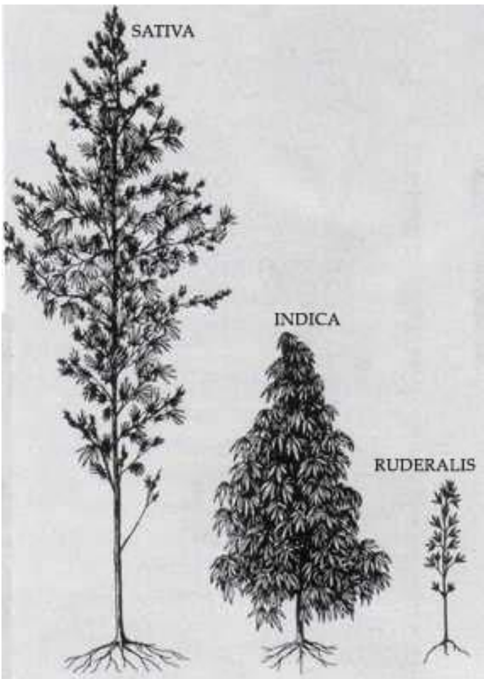

Figure 127. Different subspecies of the Cannabis sativa genus. Source: wikicommons; public domain.

To the best of our knowledge, there has been no attempt to date to make Cannabis-based insulation materials out of the stem of marijuana. However, if this was feasible, it could represent a further opportunity to the Canadian insulation market. In fact, stems of marijuana are typically discarded after harvesting and, if available machineries could decorticate them and hurds and fibers proved to have the same properties of the ones currently used, producers of hemp-based building materials could rely on a new source of raw material.

In the present article, the GHG emissions of traditional and alternative, bio-based insulation materials are compared in order to understand whether the upsurge of Cannabis-based products is advisable for the Canadian context. Moreover, the environmental implications of using stems from the marijuana plants to make insulating products were investigated via Life Cycle Assessment (LCA).

2 MATERIALS

The traditional insulating materials typically employed in Canada were compared to alternative bio-based materials containing Cannabis. Both the impacts of Cannabis-based materials made from traditional industrial hemp and, in a hypothetical scenario, from the residue of marijuana cultivation for medical and recreational use were considered. In particular, two different insulating products based on Cannabis were considered: blocks and panels.

Blocks are self-supporting rectangular-shaped building components, which incorporate a large fraction of hurds bound together by a lime-based binder [Arrigoni 2017]. The binder here considered is a mix of hydrated lime, hydraulic lime and pozzolan and corresponds to a mixture traditionally used for hempcrete materials [Ip 2012]. When installed, a mortar, typically composed of a hemp-lime mixture too, is generally applied between the blocks. In addition to providing thermal insulation, the material provides a good vapor permeability and moisture buffering abilities [Latif 2015]. On the other hand, panels are insulation mats made from a combination of fibers from Cannabis (85%) and polyester (15%). Different from the blocks, panels are made from the external fibers of the stems, already used worldwide for various applications such as textiles and ropes [Zampori 2013].

The properties of the traditional and alternative insulating materials (i.e. density and thermal conductivity) considered in the present study are reported in Table 24. To estimate the amount of marijuana hurds and fibers that may be available from Cannabis cultivation for medical and recreational use, the statistics on the consumption of marijuana buds (i.e. the small stem protuberances that may develop into a flower, which contain the highest Δ^9-THC concentrations) were used. Consumption of Cannabis for medical and recreational use has been increasing by 4% each year since 2010, reaching a total consumption of 773.4 t in 2017 [Statistics Canada 2018]. Moreover, although the consumption levels are not expected to change significantly after legalization, Canadians will probably consume more in the years to come [Deloitte 2018].

Table 24. Properties materials and GHG emissions and removals during the production stage

Insulation material	Density	Thermal conductivity	Thickness [4.23 m^{2}K/W]	Thickness [5.11 m^{2}K/W]	GHG emissions	GHG removals
	kg/m^3	W/m·K	m	m	kg CO_2-e/kg	kg CO_2-e/kg
Glass wool	40	0.040	0.17	0.20	1.30	-
Mineral wool	100	0.040	0.17	0.20	1.40	-
Cellulose	50	0.040	0.17	0.20	0.53	1.84
Spray foam	20	0.035	0.15	0.18	2.90	-
EPS board	30	0.038	0.16	0.19	4.60	-
Cannabis blocks	330	0.070	0.30	0.36	0.51-0.55	0.74
Cannabis panels	30	0.070	0.30	0.36	0.79-0.97	1.56

Assuming a mass of dry buds and wet stem equal to, respectively, 7% and 52% of the whole wet plant [EZTRIM 2018], in line with the average yield of 21.02 ± 3.33 g of dry buds per plant [Janatová 2018], and an average water content of 40% in the stem [Warner 2017], approximately 3450 t of dry stems were produced to meet the Canadian demand in 2017. Considering the wooden core to be 75% of the whole stem, as in the case of industrial hemp [Zampori 2013], approximately 2580 t of hurds and 870 t of fibers could be produced each year if the Canadian consumption did not decline.

3 LIFE CYCLE ASSESSMENT

The potential GHG emissions and subsequent global warming due to the life cycle of the different insulation materials were calculated with the LCA tool, following the guidelines of the International Standard Organization: ISO 14040 [International Organization for Standardization 2006a] and ISO 14044 [International Organization for Standardization 2006b].

3.1 Functional unit

Functional unit considered in the assessment was 1 m^2 of insulation material resisting a specified conductive flow of heat. The unit to measure this resistance was the R-value, expressed in $m^2 \cdot K/W$ and two R-values were chosen for the analysis: 4.23 and 5.11 $m^2 \cdot K/W$. The two numbers correspond to the thermal insulation required, according to the latest building code, for walls in Ontario (Canada) in areas with, respectively, less and more than 5000 heating degrees days (i.e. annual sum of the number of degrees that a day's average temperature is below 18°C). In both cases the values are required for walls above grade in case space heating equipment have an annual fuel utilization efficiency of at least 90% [Ministry of Municipal Affairs and Housing 2011].

The thickness of the different insulation materials necessary to reach the two different R-values are reported in Table 24.

3.2 Life Cycle Inventory

Material properties and environmental exchanges for traditional products were gathered from version 3.5 of the Ecoinvent database, considering datasets referred to the Canadian context [Wernet 2016]. On the other hand, data from previous studies were used for Cannabis-based materials and the information was updated and adapted to the Canadian context. In particular, the study from Zampori et al. [2013] was used for panels made with Cannabis fibers while the one from Arrigoni et al. [2017] was used for blocks containing Cannabis hurds.

3.3 System boundaries

GHG emissions of the different materials were assessed *from cradle to gate*, including all the processes and transports up to the production plant. Different durability of the building components and end-of-life emissions were not accounted for in the analysis.

3.4 GHG emissions and removals

The method adopted for the characterization of the different emissions was the Global Warming Potential over 100 years (GWP100) proposed by the Intergovernmental Panel on Climate Change (IPCC).

As any other bio-based building component, Cannabis-based products store in the material some carbon that was removed from the atmosphere in the form of carbon dioxide by the plant during its growth. However, this carbon may end up back to the atmosphere if the material was burnt or landfilled at the end of its life and the emissions were not captured. For this reason, GHG removals need to be accounted for separately in the GWP100 assessment. Nevertheless, when mixed with lime, Cannabis hurds mineralize and do not undergo decay when landfilled [Courard 2011]. Moreover, hempcrete blocks could be crushed at their end-of-life and mixed with new binder to form new product [Arrigoni 2017]. Therefore, in the case of Cannabis-lime mixtures, carbon will be most likely stored in the material for a period longer than the time horizon considered in the GWP100 metric.

Furthermore, materials containing lime sequester additional CO_2 from the atmosphere during their lifetime through the carbonation reaction [Sinka 2018]. However, previous studies highlighted that the material undergoes very slow carbonation and won't probably reach the full carbonation during its life cycle [Arrigoni 2017]. For this reason, the carbon storage due to carbonation was not accounted for in the present study

3.5 Allocation

The Ecoinvent cut-off system model approach was adopted for the analysis. In case of co-productions, an allocation based on the revenue was chosen to divide the impacts among the different products. On the other hand, the GHG removals were allocated according to the mass of the co-products and reflected the real amount of carbon stored inside the materials.

Currently hurds to make hempcrete in Canada are imported from Europe and China. Since no information was available on the yields and prices of the different hemp products in China, the revenue allocation used in Zampori et al. [2013] referred to the Italian market was used for this study and 61% of the impacts arising from the cultivation and processing stages was allocated to the hurds, and the remaining (i.e. 39%) to the fibres.

However, since Canadian hurds are planned to be used in the future, a different allocation procedure based on the revenues that could be generated on the Canadian market was envisioned with the help of hemp producers for this scenario as well. Yields, revenues and allocation factors for industrial non-organic hemp co-products used for the study are reported in Table 25. Nevertheless, it is important to underline that this was a first attempt to subdivide the impacts, but results may change in case different market values were given to the co-products.

Table 25. Allocation factors for hemp co-products based on Canadian yields and prices.

	Yield [t/ha]	Price [CAD$/t]	Allocation factors
Seeds	1.0	1100	0.44
Fibers	1.1	200	0.09
Hurds	3.4	200	0.27
Buds, flowers and leaves (dry)	0.6	900	0.20

Allocation factors were calculated also for the scenario where the by-products of marijuana cultivation were not discarded by the producers and were placed on the market. Fibers and hurds were supposed to be sold at the same price of their counterparts from hemp cultivation. Allocation factors are shown in Table 26: in this case, yields refer to the whole Canadian market, based on the calculations previously presented. The price for dry buds considered was the average price reported by Statistics Canada for medical and non-medical purposes in 2017 [Statistics Canada 2018].

Table 26. Allocation factors for marijuana co-products based on Canadian yields and prices.

	Yield [kt/y]	Price [CAD$/t]	Allocation factors
Dry buds	0.77	$8*10^6$	1.00
Fibers	0.64	200	0.00
Hurds	1.94	200	0.00

Based on a revenue allocation, which is considered to be a fairer way of allocating the impacts compared to a method based on physical properties when, as in the present case, co-products have disproportionate market values [Seto 2017], impacts arising from the cultivation of marijuana should be entirely attributed to the dry buds, even in the case fibers and hurds obtained from the stem were sold. The only emissions to be attributed to the materials used to make insulation products should be the ones arising from processes carried out purposely for them, such as decortication. However, given the limited information on the emissions relative to specific processes, also these impacts were allocated among all the co-products. Therefore, fibers and hurds from marijuana cultivations were considered to be available burden-free to the user.

4 RESULTS

In Table 24 the *cradle-to-gate* GHG emissions and removals to manufacture 1 kg of each insulating materials are reported. For Cannabis-based materials two values are presented, representing the minimum and maximum impact depending on the source of the biological component: European hemp, Canadian hemp or Canadian marijuana. In addition to the variation in the transportation impacts, results vary according to the market value of the hurds and fibers with respect to the other Cannabis co-products. The minimum impact represents the case the insulating products are manufactured with local materials, sourced from marijuana plantations. On the other hand, the worst case is the one where Cannabis-based products use hurds and fibers from industrial hemp cultivated in Europe. The transportation impacts and the higher value of hurds and fibers in Europe penalized this choice.

However, a comparison of insulating materials based on the unit of mass is misleading when products have different densities and/or thermal insulation properties. So, the GHG emissions, removals and balance per functional unit (i.e. 1 m^2 of insulating material guaranteeing a specified thermal resistance) were calculated and the results are presented in Figure 128: in Figure 128a, the case where the heating degree days are less than 5000 and an R-value of 4.23 m^2K/W is required is shown, while in Figure 128b is presented the case for colder climates (i.e. more than 5000 heating degree days).

Values for cannabis block refer to the present Canadian scenario, where hurds and fibers are imported from hemp cultivations in Europe. Results show that in terms of GHG emissions, which correspond to the GHG balance in case the material does not store any biogenic carbon, cellulose is the best, followed by Cannabis-based panels, spray foam and glass wool. On the other hand, the product responsible for the highest GHG emissions up to the manufacturing plant is Cannabis block, due to the large amount of binder in the material and the lower thermal insulation properties with respect to traditional materials. The ranking did not change when higher insulating performances are required and the GHG savings using traditional materials instead of hempcrete are even larger (see Figure 128b).

Nevertheless, if GHG removals are included in the equation, the materials with the best performing GHG balance are the bio-based products in both the climatic conditions. Cannabis block would be the best choice due to the large volume occupied and the relatively large amount of carbon that can be stored in the product, making it an effective carbon sink. Cannabis-based panels and cellulose exhibited larger removals than emissions too, but not enough information on their durability and end of life treatments is available to draw conclusions on their GHG balance in the time horizon considered (i.e. 100 years).

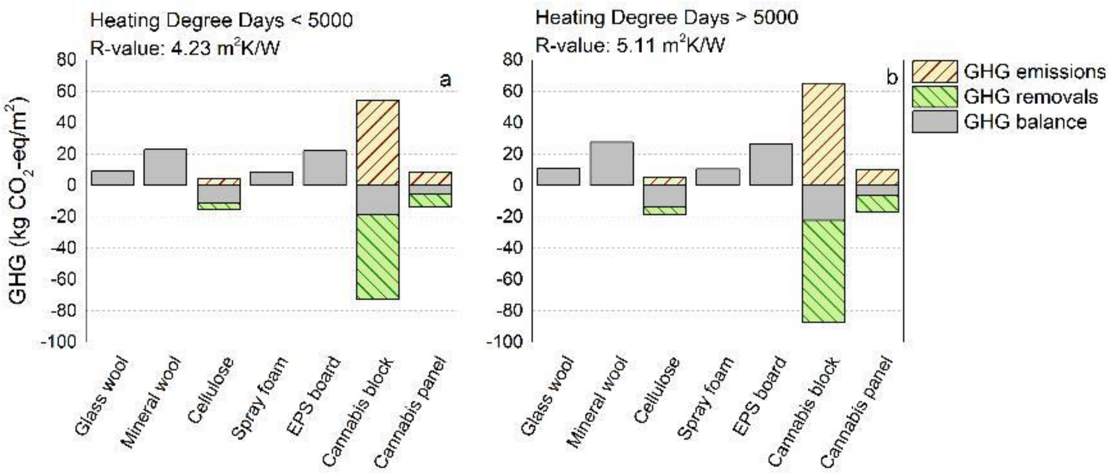

Figure 128. GHG emissions, removals and balance of the different insulating materials per functional unit in the two climatic scenarios considered

Variation in the impacts if products from Canadian cultivations are used instead of hurds from Europe to produce insulation blocks is shown in Figure 129. Although the amount of carbon stored in the final product does not change, GHG emissions reduce if long-distance transport is avoided and local by-products are employed. Moreover, emissions allocated to the hurds further reduce if the material is sourced from marijuana stems. Nevertheless, the GHG balance difference with respect to the results obtained using hurds from Canadian industrial hemp is limited to the fact that even in the case of industrial hemp, only a fraction (i.e. 27%) of the cultivation process is allocated to the hurds.

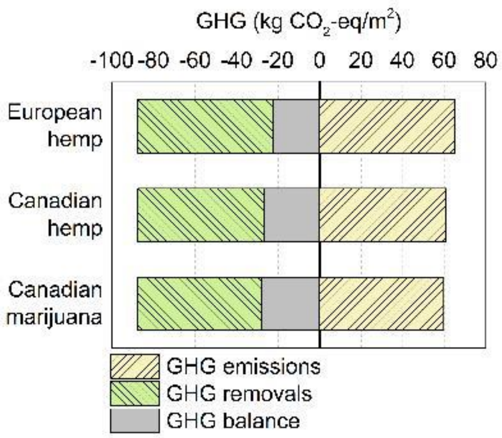

Figure 129. GHG emissions, removals and balance of 1 m^2 of Cannabis blocks with an R-value of 5.11 m^2K/W made with hurds from industrial European hemp, industrial Canadian hemp and Canadian marijuana plantations.

5 DISCUSSION AND CONCLUSIONS

In the present article, a comparison of the GHG emissions and removals of traditional insulating materials used in Canada with alternative Cannabis-based products was performed. Moreover, the GHG implications of using stems from Cannabis grown for medical and recreational use, recently legalized in Canada, instead of the hurds typically employed for Cannabis-based building products (i.e. hurds from plants with lower Δ^9-THC content, known under the name of *hemp*) was assessed.

Results showed that if the analysis is limited to the life cycle GHG emissions, as internationally adopted metric suggest, Cannabis-based building products are not necessarily better than traditional materials. To the contrary, lime-Cannabis composite materials performed significantly worse than insulators such as cellulose, glass wool or spray foam. However, if biogenic carbon storage was taken into account, Cannabis-lime composite products proved to be the best solution in terms of GHG balance in a 100-year scenario. Moreover, given the fast-growing nature of Cannabis, these products could be considered an efficient way to store carbon and therefore fight climate change [Pittau 2018].

Furthermore, using by-products from the recently legalized Cannabis cultivation from medical and recreational use would guarantee even better performances than the currently used hempcrete products. Considering Cannabis-lime blocks with a 1.3 binder-to-hurds ratio [Arrigoni 2017] and panels with 85% in mass of Cannabis fibers, in a zone with less than 5000 heating degree days, by-products from newly legalized plantations could be used to insulate up to 18 ha of new walls each year if marijuana consumption would not decline in the future. To get some perspective, they could be used to insulate each year ten skyscrapers with the dimensions of the current tallest building in Toronto (i.e. the 300-m high First Canadian Place). This would allow, in the best end-of-life scenario for the Cannabis-based products, to have a net annual removal of approximately 1600 t of CO_2, making it a concrete action to curb global warming. This value could be even larger if lime carbonation was taken into account. Moreover, in addition to the lower GHG emissions arising from new cultivation, using by-product instead of new material could guarantee benefits in terms of land use change and other environmental impacts not accounted for in the present assessment.

6 FUTURE RESEARCH

The present study was a first attempt to evaluate the possible GHG benefits of using the by-products of Cannabis cultivations to insulate new and existing buildings. Given the positive outcomes of the assessment, further research on the feasibility of the process (e.g. decortication of the marijuana plants) and the hygrothermal properties of the hurds (known to be dependent on the length of time that the plant is allowed to grow before harvesting) will be performed. Moreover, a complete cradle-to-grave LCA, including other environmental impact categories and a sensitivity analysis on the assumptions and allocations used in the present study, should be assessed to understand whether this could represent a real strategy to help Canada to meet the international GHG reduction goals.

7 ACKNOWLEDGMENTS

The authors acknowledge support of Professor Panesar's NSERC Discovery Grant and her Early Career Hart Professorship for this work.

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