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Forest Products and Circular Economy Strategies: A Canadian Perspective

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Abstract: The Government of Canada has embraced circular economy and is supporting an increasing number of initiatives in the field. However, implementation examples remain scattered and certain stakeholders are eager to see a greater level of commitment from policy makers. The purpose of this study is to provide a Canadian perspective on how, and to what extent, forest products are compatible with circular economy strategies. This topic was investigated through interviews with 16 Canadian experts in eco-design, circular economy, forest products and/or waste management, with a focus on construction and packaging. Efforts made by forest industries at the manufacturing stage to reduce resource consumption were acknowledged, but the implementation of other circular economy strategies, such as reuse, recycling and energy recovery, is uneven. While there is low-hanging fruit for incremental improvements, such as the processing of recovered lumber in wood panels and not mixing cardboard fibres with other paper streams to avoid downcycling, several barriers to the widespread adoption of the most promising strategies were identified. The experts consulted proposed several solutions to accelerate the deployment of circular economy strategies for forest products, for which government interventions would need to be tailored to the different policy readiness levels (PRLs) observed in the construction and packaging sectors. With circularity having economy-wide implications, setting a clear policy direction at the national level, with a circular economy roadmap for Canada for example, could accelerate coordinated implementation within and across sectors, including forest industries.

Keywords: circular economy; forest sector; construction materials; packaging

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1. Introduction

With the goal of closing material cycles and generating wealth from resources already mobilized in the economy, the circular economy concept is gaining traction worldwide [1,2]. Its promise of decoupling economic growth from environmental degradation by phasing out linear consumption (take-make-waste or take-make-dispose) makes the concept appealing [3,4]. As the understanding of circular economy is refined, new jobs and business opportunities are being identified, making the concept a true contender to operationalize sustainable development [1,3,5].

The implementation of circular economy actions at scales spanning regions and whole territories has been experienced by several countries [1,5,6]. For instance, China has put forward circular economy in its 11th and its 12th Five-Year Plan for National Economic and Social Development, along with its "Circular Economy Promotion Law" [7,8]. The European Commission has made moves towards circular economy with its Circular Economy Action Plan, one of the main building blocks of the European Green Deal that complements related initiatives, such as the Ecodesign Directive and the EU Strategy for Plastics in the Circular Economy [9,10]. Japan and Germany also passed numerous laws, policies and acts from the

1990s onward that may now be regarded as promoting a circular economy [11,12]. Despite the increasing commitment to circular economy across the globe, some countries, such as the United States, New Zealand, Australia and Canada, have yet to decide how best to tackle the challenges of circular economy [1]. Addressing cultural, regulatory, market-mediated, and technological challenges together remains an open problem which may require country-specific solutions [13–15]. For example, the Government of Canada is involved in only a few nationwide initiatives that pertain to circular economy. These are the "Canada-wide action plan for extended producer responsibility", adopted by the Canadian Council of Ministers of the Environment (CCME) [16]; the "Strategy on zero plastic waste" [17]; and the Global Alliance on Circular Economy and Resource Efficiency [18]. However, that does not mean the absence of other circular economy initiatives across the country. For instance, Recycle BC, a not-for-profit organization in British Columbia (servicing over 98% of the province's residential customers), has joined the Ellen MacArthur Foundation initiative called "The new plastics economy" to apply circular economy principles to its territory [19]. RECYC-QUÉBEC, a provincial organization, is also financing projects to develop circular economy practices [20]. Key barriers, such as a lack of awareness and of demand, higher costs, lack of harmonized policies, siloed approaches, and gaps in innovation and technology were identified as preventing more widespread adoption in Canada [21].

Despite these barriers and scattered examples, certain Canadian industries are eager to see a greater level of commitment from policy makers towards circular economy. For example, the Canadian Bioeconomy Strategy (which comprises the forest and agricultural sectors) is an industry-driven initiative based on more than 400 businesses, calling for innovative policies with an emphasis on the role of both sectors in a circular economy [22]. Among the challenges raised are the need for a modern regulatory system that enables innovation and the development of an ecosystem (including opportunities to apply circular economy and to develop the required specialized workforce) to achieve both the environmental and economic benefits of circular economy. Additionally, in parallel with Circular Economy Leadership Canada—with membership representing retail, furniture, hygiene products and cement industries—several accelerators (Project Zero, Metal Tech Alley, Circular Opportunity Innovation Launchpad), material exchange networks (Ontario Materials Marketplace, Synergie Québec), and corporate networks (Canada Plastics Pact, Fashion Takes Action) are working to drive financial, regulatory, technical or cultural changes needed to mainstream circular economy practices across the country [21,23].

The transition to a circular bioeconomy has significant implications for Canadian forest industries in a context where demand for some traditional products, such as newsprint, is declining and investments are being made towards diversification. The sector is an important part of the country's economy as it contributes CAD 23.7 billion to Canada's GDP and directly employs over 200,000 people [24]. Lumber production continues to play a central role in Canada's forest sector. Firstly, softwood lumber is the most important product in terms of volume (57.7 million m^3) and export value (CAD 8.0 billion) in 2019 [24]. Secondly, sawmill residues also provide a large portion of the feedstock used for pulp manufacturing, with a total pulp production of 15.4 million tonnes in 2019 [24], which is either converted into different paper grades within Canada or exported as market pulp (CAD 8.0 billion in 2019) [24]. Thirdly, lumber can be further processed into engineered wood products, such as glue-laminated timber (glulam) and cross-laminated timber (CLT), enabling tall wood building construction.

With the growing number of regulations, strategies and programs addressing climate change, the demand for forest-based products is expected to rise as they are considered sustainable, renewable and good contenders to replace many fossil-fuel-based products [25,26]. Although some initiatives falling under the umbrella of circular economy are found to be inefficient solutions for climate change mitigation [1,27], recent studies highlight the potential of certain forest products to effectively achieve reductions in carbon emissions [28–30]. Wood fibres can be used to produce bioplastics, advanced biomaterials, resins, electricity, heat, and fuel that substitute more carbon intensive alternatives—all while responding to traditional demand for lumber and the pulp and paper industries. Hence, the forest sector contribution to climate change mitigation is optimized when forest management practices and their influence on forest carbon stocks are considered in conjunction with the manufacturing and use of harvested wood products [31]. In parallel with certain single-use plastics are being banned [32], building codes are being revised to allow wood products in new applications, and actions are being taken to drive down the carbon intensity of activities and products across the entire economy [33]. Measures across this wide spectrum of economic activities could facilitate new business and development models, favoring cascading use (a sequential use of a resource in which the gradual degradation of the resource is accounted for) of forest-based products [1,26,27].

However, in order to optimize implementation of circular economy at a national scale, initiatives should be harmonized and target the specific needs and challenges faced by implicated industries [34–36]. For instance the use of residues and material exchange between forest sector industries are well established, implying that disruptions to current value chains will need to occur to further improve circularity in the sector [37,38]. Additionally, the cascading use of wood products was identified as one of the main strategies to further increase the circularity of the forest sector [39,40]. However, while some benefits and barriers to wood cascading are already documented, important challenges remain for its implementation [39,41]. Finnish research on the circularity potential of solid wood cascading highlighted the untapped potential of reusing wooden packages and furniture [40], but it was also found that recycling tended to compete with energy recovery. The identified barriers for cascading use were cost-effectiveness, market volume, the quality of recovered products, availability of products in multiple locations, legislation, and renewable energy targets. A greater commitment from policy makers was also found to be critical in the shift towards wood cascading and circularity.

Yet, key information about the Canadian forest sector, necessary to develop informed circular economy policies, is not available. There are no national statistics or reports that track the current status of circularity (i.e., material flow analysis models, circularity indicators and indexes grouping circularity indicators [42]), and no documentation on the specific challenges faced by the manufacturers or end-users in handling forest products throughout their life cycle. In a recent report by the Canadian Council of Academies, data gaps on biomass, waste generation, circular business practices (including recycling) and inconsistency between jurisdictions in instances where data do exist, were identified as barriers to effective policies and access to financing [23].

In the context where new policies implemented in response to a stronger commitment towards circular economy must solve current and future challenges of all sectors, including the forest sector, this paper provides a Canadian perspective on how, and to what extent, common forest products are compatible with key circular economy strategies. For products where strategies are not yet applied (i.e., reuse is uncommon for construction products), or for which implementation can prove particularly challenging, we sought to identify the barriers (sometimes technical, market-based, cultural, regulatory or a combination of these characteristics) that prevented their application and how those barriers could be overcome. This investigation contributes to the overarching aim of the study, which is to further contemplate what should shape future policies for a more circular Canadian forest sector. To do so, this study is structured as follows: Section 2 describes the methodology for the interviews, including the forest products assessed, the key circular economy strategies, and the questions provided to the interviewees. Section 3 presents results according to each topic and Section 4 provides outlooks for a more circular forest sector in Canada. Finally, Section 5 summarizes the main findings.

2. Materials and Methods

Interviews were conducted with 16 Canadian stakeholders with expertise in eco-design, circular economy, forest products, and/or waste management to obtain diverse perspectives on the capacity of the forest sector to benefit from opportunities associated with the transition to a circular economy. The interviewees were identified based on their expertise and knowledge in circular economy and eco-design or waste management for wood-based construction materials and/or packaging. Several strategies were used for the recruitment process. First, leading Canadian research organizations on forest products and circular economy were consulted to identify contact points with expertise on both topics. The same process was followed for leading provincial and municipal governments with innovative initiatives and ambitious commitments in the field. In parallel, a literature review was undertaken to identify interlocutors in academia. Additional participants were suggested by the initial list of interviewees contacted for the survey. The experts and the organizations they represent were selected to ensure coverage of all products; they were are not meant to be exhaustive or representative of all Canadian stakeholders in those multiple fields. The number of interviewees by organization type and product is provided at Table 1, with additional details in Supplementary Material File S3.

Table 1. Map of the 16 interviewees, by organization type and product.

	Construction Materials		Packaging	
Interviewees	**Lumber**	**Particleboard**	**Cardboard**	**CTMP**
Government	6	4	1	1
Academia	2	1	2	2
Industry and affiliated research institutes	3	2	3	3
Total	11	7	6	6

The interviews were conducted face-to-face, via videoconference, and were recorded to allow for subsequent reference, in order to validate and complement written notes taken during the interview. At least two interviewers were present at each interview, for the purpose of comparing the analysis of interviewees' answers.

The study focused on four primary manufacturing forest products within the two main industry subsectors (wood products and pulp and paper) as well as important end uses (construction and packaging). To better frame the discussions on the fate of products at their end-of-life, typical finished products or assemblies were selected for each product:

- Lumber, used in an interior wall for residential construction;
- Particleboard, used in a cabinet;
- Packaging cardboard, used in corrugated cardboard box;
- Chemi-thermomechanical pulp (CTMP), used in food packaging.

The selected sub-sectors and products are among the forest products with the largest production volumes [24] in Canada, with the exception of CTMP for food packaging. In the wood product sub-sector, lumber represents by far the highest production volume and is a structural construction material, Even though oriented strand board (OSB), a structural panel, shows larger production volumes, particleboard was chosen in order to also include a non-structural construction material. Out of the main paper grades, packaging was chosen over newsprint and printing and writing paper, as demand for traditional paper products is expected to continue falling while packaging is expected to hold steady [24]. Lastly, CTMP complements more conventional products because it represents an emerging application where market growth is projected, namely because of the planned ban on certain single-use plastics [43].

Summary sheets describing the characteristics and manufacturing process of products were sent to the interviewees to ensure they had a common understanding of the forest products included in the study and their applications. The summary sheets are provided in Supplementary Material File S1.

Most interviewees preferred to focus on a single product (6 interviewees) or a single product category (8 interviewees), indicating that distinct considerations apply to their manufacturing, use and end-of-life stages. This is also explained by the fact that some organizations focus on one product type and that, within larger organizations with a broader mandate, different initiatives are put in place for construction and packaging materials respectively, with staff members responsible for one or the other.

The circular economy strategies discussed with the interviewees are based on the recent literature [1,12] and are comprehensive enough to cover actions undertaken at the design, use and end-of-life stages:

- Reduce resource consumption, for example, by optimizing manufacturing operations to reduce the use of inputs or by reducing the quantity of product used to deliver a given functionality;
- Extend the life of products and components, for example, by facilitating maintenance, repair and refurbishment or by selling the use of products as services;
- Reuse—consisting of the repeated use of a product without modification to its appearance or properties;
- Recycle—consisting of using recovered material in a manufacturing process as a substitute for virgin material;
- Energy recovery through thermal treatment processes, such as incineration with energy recovery, combustion in industrial boilers, pyrolysis or gasification.

The semi-structured interviews employed both closed- and open-ended questions. Four main topics were addressed in the questionnaire for each product (full interview guide provided in Supplementary Material File S2):

- Question 1: strategies that are currently applied;
- Question 2: strategies that could easily be applied but are not at the moment;
- Question 3: what characteristics facilitate or hinder the use of strategies;
- Question 4: changes required to products for the application of the most promising strategies.

Questions 1, 2 and 4 had a closed-ended component to allow for quantitative analysis of the strategies that were mentioned by interviewees. The list of strategies listed above were enumerated to interviewees for each of the products they chose to cover, allowing them to answer whether or not the strategies were currently applied (question 1), could easily be applied (question 2), and which strategy was the most promising (question 4). The results are reported in Tables 2–4. All questions also had an open-ended component to understand how the strategies were or could be applied, to what extent, and why (questions 1 to 3). Question 4 was more focused on the future and sought input on the conditions under which the widespread use of the most promising strategies could be envisioned. Thematic analysis was applied to the qualitative data collected during the interviews [44]. The structure of the questionnaire allows for the easy categorization of input provided by the experts under each product, with each circular economy strategy serving as the main theme for questions 1 and 2. For question 3, the main themes that emerged were the characteristics of the primary manufacturing product, characteristics of the finished product or assembly, and characteristics of the infrastructure for waste management. For question 4, several changes were proposed by interviewees, with key themes being product design and manufacturing, regulations and other policies, consumer behavior, and recycling infrastructure. After classification of individual input under the themes, common or diverging perspectives were identified. The classification of answers provided by individual interviewees under the selected themes is provided in Supplementary Material File S3 (interviewees are identified by a code to preserve anonymity). On certain occasions, it was possible to augment the input provided by interviewees with reports or studies conducted by their organizations.

Table 2. Strategies identified by interviewees as already implemented, by forest product.

Strategies	Lumber	Particleboard	Cardboard	CTMP
Reduce resource consumption	5/11	4/7	3/6	0/6
Extend the life of products	0/11	0/7	0/6	0/6
Reuse	4/11	0/7	1/6	0/6
Recycling	2/11	0/7	6/6	2/6
Energy Recovery	7/11	1/7	0/6	0/6
Other	2/11	0/7	2/6	4/6
Interviewees (out of 16) responding by product	11	7	6	6

Table 3. Strategies identified by interviewees that could easily be applied, by forest product.

Strategies	Lumber	Particleboard	Cardboard	CTMP
Reduce resource consumption	5/11	1/7	4/6	1/6
Extend the life of products	4/11	0/7	1/6	0/6
Reuse	4/11	1/7	4/6	0/6
Recycling	3/11	1/7	3/6	4/6
Energy Recovery	3/11	3/7	0/6	0/6
Other	0/11	0/7	1/6	2/6
Interviewees (out of 16) responding by product	11	7	6	6

Table 4. Most promising strategies identified by interviewees, by forest product.

Strategies	Lumber	Particleboard	Cardboard	CTMP
Reduce resource consumption	0/11	0/7	2/6	2/6
Extend the life of products	0/11	0/7	0/6	0/6
Reuse	11/11	0/7	1/6	0/6
Recycling	0/11	2/7	3/6	2/6
Energy recovery	0/11	5/7	0/6	0/6
Other	0/11	0/7	0/6	2/6
Interviewees (out of 16) responding by product	11	7	6	6

3. Results

The main findings from the analysis of the interviewees' responses are presented in three subsections, starting with an overview of the currently observed circular strategies, along with the forest product characteristics that facilitate these practices. Next, strategies that could easily be implemented are described jointly with factors that hinder their application, in order to help understand why they have not been adopted yet. This is followed by the most promising strategies selected by the interviewees, along with the changes required for widespread application. The results in Sections 3.1–3.3 reflect the thematic analysis performed on the answers provided by the interviewees.

3.1. Circular Economy Strategies Currently Implemented

As shown in Table 2, efforts made by forest industries at the manufacturing stage to improve the efficiency of processes and *reduce resource consumption* were generally acknowledged, with their adoption perceived as usually driven by an economic, more than an environmental, imperative. The implementation of other circular economy strategies varies greatly between products, as discussed in the following sections. While measures that relate to *extending the life of products*, for which implementation does not appear significant for any forest products, occurrences for *reuse*, *recycling* and *energy recovery* were identified for at least two out of the four products.

Better resource utilization for *lumber* production mostly consists of achieving higher yields (i.e., roundwood to lumber ratio) and maximizing the uses of sawmill residues. Energy recovery appears to be the only other strategy more widely applied, mostly in heavy industry (e.g., alternative fuel for cement kilns) or heat plants. Other actions relying on reuse and recycling are limited to niche markets, for example, with old growth lumber used for furniture and recovered lumber used for particleboard manufacturing in one Canadian facility (Tafisa Canada, Lac-Mégantic, QC, Canada). The recovery of lumber appears to be more prominent in Vancouver than other cities, where it is driven by deconstruction and green demolition by-laws [45].

Several characteristics of lumber that make the product well adapted to circular economy strategies were mentioned by interviewees. First, it is a clean material (if not treated) that can be assembled without glues and resins and is well preserved if not exposed to the environment. Furthermore, infrastructure exists in some locations to sort construction and demolition waste. Old growth lumber, used in older buildings, has a high value, which helps cover the costs associated with its recovery.

The picture painted by interviewees for *particleboard* is quite different than for lumber. On the one hand, it was recognized that particleboard manufacturing provides a valuable outlet for sawmill residues, and there is ongoing work to minimize losses when making individual components for cabinetry or furniture from larger particleboard sheets. However, the end-of-life options are very limited, except perhaps energy recovery under very particular conditions, and particleboard appears to have no attributes that facilitate the application of the strategies mentioned above.

Recycling is clearly a very common strategy for *cardboard*, with the material showing high recycling rates in Canada. Furthermore, energy efficiency improvements at pulp and paper mills and the basis weight or grammage (i.e., area density) reduction in both liners and corrugated medium, through the use of dry strength additives, resulted in a reduction in resource consumption. If too soiled by organic waste to be accepted for recycling, cardboard can end up in the composting stream. Some cases of reuse in a business-to-business setting were also mentioned. Recycling is now facilitated by the development of inks and glues compatible with the re-pulping process. Wood fibres in cardboard can also be recycled multiple times because the loss of fibre length at each recycling cycle is relatively small. Lastly, in the case of corrugated cardboard boxes, the amount of tape used is usually minimal, which in turn reduces the amount of waste generated during recycling.

Food containers made of molded pulp were recognized as an emerging application for *CTMP*, and composting was considered a more probable practice than recycling. The fact that these containers are compostable and compatible with the food waste stream makes composting the most likely outcome, since such containers would mostly be used in food courts and for takeout. However, food-grade CTMP contains high-quality fibres that can be recycled in multiple other paper grades in situations where it is not, or only lightly, soiled.

3.2. Circular Economy Strategies Easily Applicable

For each product, a variety of strategies that could be applied easily, i.e., without significant changes to the product itself or how it is used, were identified by interviewees (Table 3). In some cases, further improvements were proposed along the lines of what was already applied; for all products, at least one interviewee suggested that additional efficiency gains could be achieved at the manufacturing stage. In addition, it was mentioned that measures in place in certain regions or companies whose feasibility was now demonstrated could be more broadly applied across the country. In other cases, innovative or “first-in-kind” approaches were put forward. In all cases, reasons were sought to explain why such strategies, which should be implemented without too much difficulty, are not already.

There appear to be low-hanging fruit to increase the circularity of *lumber*. At the manufacturing stage, there can remain unutilized residues, but their conversion into value added products is limited by local or regional demand as their transportation over long distances is cost-prohibitive. It was also suggested that engineered wood products, such as cross-laminated timber (CLT), could be made from small-diameter logs that are currently not sent to sawmills, but are either left in the forest or chipped for other uses. In buildings, recovered lumber could be reused for non-structural applications, such as non-load bearing walls, without concerns for safety. Preventive maintenance could also extend the service life of buildings, and thus assemblies in which lumber is used. It was also shown that lumber could be processed into oriented strand board (OSB), medium-density fibreboard (MDF), particleboard (PB), or converted into biochar. A major factor hindering the application of most strategies is the fact that buildings are not designed for deconstruction and that, consequently, demolition is faster and cheaper. Furthermore, fastener removal is difficult and labor-intensive, and there is a poor sorting of waste on construction and demolition sites. This makes it hard, without the presence of local by-laws, to tap into what is a very large pool of construction and demolition waste, especially in larger Canadian cities.

Fewer options were proposed for *particleboard* than for lumber. While reuse is technically possible, it would most likely require the implementation of take-back programs, as well as components that could be used interchangeably between different products lines, such as cabinetry or furniture. Energy recovery in high-temperature applications or advanced conversion processes appears to be the most feasible strategy at the moment; however, resins and laminates are a source of concern for regulatory bodies with regard to the emission of atmospheric pollutants. A main barrier to the extension of the life of products made from particleboard or to their recycling, is their low resistance to wear and moisture and the fact that they cannot be repaired. At end-of-life, these products are usually mixed with other types of demolition or household waste, making them harder to recover. Finally, wood particles usually have short fibre lengths and cannot be separated from the resins, making their recovery and conversion into other forest products, such as fibreboard, unfeasible.

With recycling being the fate for large volumes of *cardboard*, further improvement to the re-pulping process would allow wood fibres to be used more than seven times, which is currently seen as a ceiling. The recycling of cardboard back into cardboard, rather than lower grades of paper, can also be increased if it is not mixed with other paper waste. After a single use, boxes are usually still in very good condition and could be reused multiple times before being sent to recycling. However, it was also mentioned that coatings or other treatments to improve resistance for reuse could make recycling more difficult. Increasing volumes of smaller corrugated cardboard boxes, due to of e-commerce and home delivery, cannot be separated from lower grades of paper using existing recycling equipment which is designed for larger boxes, resulting in downcycling of the material. Mixed roadside collection and the subsequent exposure to moisture or soiled materials have a similar impact on the quality of the recovered material. It was also reported that the high rate and ease of recycling, which is usually perceived as positive, impedes the reuse of corrugated cardboard, which would require more complex logistics but could also deliver increased environmental benefits. Lastly, the lack of coordination between waste generators, sorting centres and producers of recycled cardboard makes it difficult to maintain the appropriate level of quality and consistency across the supply chain.

The production of a variety of food containers and packaging with *CTMP* using molding equipment is a relatively recent development, and it was suggested that there is still room to optimize the design of products to use less pulp. This is especially important when competing with low-weight, well-established, cheaper plastic alternatives. The bleaching of the pulp should be avoided when not required for functional purposes, as it requires energy and chemicals. While recycling was considered preferable from an environmental standpoint, it was suggested that food containers or packaging will likely be too soiled for recycling. Barrier material, when needed for water or grease resistance, should either be easily removable to allow for recycling or be compostable. The low density of the material is also expected by some interviewees to result in high transportation costs to recycling or composting facilities.

3.3. Most Promising Circular Economy Strategies

Numerous strategies could theoretically be implemented across the entire life cycle (from cradle to grave, or cradle to cradle) for each of the four forest products included in this study. The most promising strategies identified by interviewees (Table 4) help to prioritize further technological development or policy measures that are required to improve the circularity of the Canadian forest sector.

For *lumber*, reuse in buildings clearly stands out as the preferred best strategy of the interviewees. Climate change benefits were raised as one of the main reasons: recovered lumber requires less energy than lumber made from sawlogs, and reuse significantly extends the period of time that carbon, initially transferred from forest land, remains stored in the built environment. Furthermore, reuse in construction does not prevent further cascading, either through recycling or energy recovery, at the moment when buildings using recovered material are themselves demolished or deconstructed. However, to make the reuse of lumber the norm rather than the exception, interviewees also mentioned that several technological and policy changes would be required. First, the adoption of design for disassembly (DfD) in the construction sector appears to be an essential pre-requisite for a significant improvement to the recovery rate of lumber (DfD can minimize the number of different components and connections, ensure accessible connections, reduce reliance on binders, and encourage use of reusable or recyclable materials) [46]. Off-site construction and prefabrication is believed to be better adapted to DfD approaches, as it allows for the assembly of components or modules in a standardized way. Changes to the Model National Building Code of Canada, and references to this Model Code under provincial regulations, were also proposed to facilitate the use of recovered lumber for structural reuse. Other measures to support the demand for recovered material, such as green procurement and requirements on recycled content, were presented as essential complements to requirements for deconstruction or green demolition. The simultaneous growth of both the supply and demand of recovered lumber is essential to avoid stockpiling material, which results in losses, both in quality and from storage costs. Providing information on the origin and the initial specifications directly on the pieces of lumber was also identified as a way to increase confidence in the recovered material and facilitate the re-grading process. Ultimately, the changes proposed cover the entire value chain, from manufacturers, architects and engineers, contractors and builders, to demolition companies. It also requires the involvement of regulating departments and agencies. The magnitude of the changes proposed for practices that are well established would require investments in education, whether in trades or post-secondary programs, or in continuing education for construction workers and professionals.

Energy recovery appeared to be the most feasible option for *particleboard* according to most interviewees, but recycling was also proposed, namely through its re-introduction in limited amounts in the particleboard manufacturing process. The use of resins and laminates that do not result in toxic emissions under combustion temperatures that prevail in biomass boilers is required for the use of particleboard in more common energy recovery applications. With regard to recycling, reversible or dissolvable resins were also identified as a way to separate the different constituents of particleboard at its end-of-life, allowing for their reuse in particleboard manufacturing or other applications. Lastly, it was suggested that the use of particleboard "as is" might decline in the future, and its replacement or combination with materials that are more durable or repairable would allow for the extension of the life of products.

Given the fact that *cardboard* recycling is already well implemented, several interviewees selected it as the most promising strategy. However, increasing the current recycling rates would require either more separation and collection of the different paper streams at the source or the improvement of sorting technologies for single-stream recycling so that cardboard is not contaminated or mixed with lower grades of paper. Others also emphasized that further efforts could be made upstream to minimize material use in packaging, either with lower weight liners or medium or optimized box sizes. One interviewee highlighted that while cardboard boxes were often only used once, they usually retained their original characteristics and could, therefore, serve the same function multiple times. As reuse might not be feasible for e-commerce packaging, where products are shipped directly to customers, take-back programs were suggested in business-to-business delivery, for example, by food wholesalers and distributors or moving companies. New applications could also be considered for cardboard, including longer-lived products, such as furniture or automotive parts.

CTMP, when used for food containers or packaging, competes with materials that can usually provide the same function while being lighter and cheaper. Hence, reducing resource use was mentioned as an important factor for greater adoption, either to lower the cost or lessen the environmental footprint. The optimization of container or packaging design through the use of additives or new molding technologies, was considered essential to reduce fibre use and better compare to plastics on a weight basis. Some interviewees mentioned that recycling is preferable for such high-quality, food-grade fibres, while others considered composting to be a more realistic end-of-life route. The use of barrier materials, which could be cleaned and were compatible with existing re-pulping processes, was proposed to allow recycling, as it would avoid fibres being soiled through contact with food. Whether the material is destined for recycling or composting, making waste-sorting facilities easily accessible in public spaces, such as food courts, is essential to avoid landfilling or incineration. It was also suggested that single-use products, including those made from renewable resources such as CTMP, should be replaced with reusable alternatives whenever possible.

4. Discussion: Moving toward a More Circular Forest Sector in Canada

The Government of Canada, as well as some provincial and local governments, have embraced circular economy and are supporting an increasing number of initiatives in this field. Generally, these focus on sectors or goods with a direct connection to customers (e.g., construction, packaging, clothing and cars) that also have direct repercussions for forest industries. The experts interviewed as part of this study proposed several solutions to accelerate the deployment of circular economy strategies for forest products, including new policies or changes to existing policies. Solutions targeted one or more of the main categories of barriers found in the literature that are cultural, regulatory, technical, or market-based [13–15]. For example, reuse of lumber spans all four categories, particleboard solutions were mainly geared towards technical barriers, while improved recycling of cardboard and CTMP covered both cultural and technical aspects. This corroborates the idea of interdependency between barriers recently identified in a literature review on the cascading of wood products [39], which in turn suggests the need for integrated solutions. Given the complexity and economy-wide implications of the transition to a circular economy [1,38], interventions will likely be needed across jurisdictions (e.g., federal, provincial/territorial, municipal) and will consist of a suite of policies (e.g., taxes, regulations, subsidies and grants, information, services, education and consultation) tailored to match the specific barriers encountered [47]. Therefore, identifying which policies are currently the most needed in Canada is challenging, especially when taking into account differences that exist between regions and sectors.

The concept of policy readiness level (PRL) is used to shed more light on this question in order to derive relevant recommendations from the results of this study. The definition of PRLs is an extension of technological readiness levels (TRLs), which describe the maturity of technologies along a 9-point scale [48]. PRLs described by Rowan and Casey [49] were adapted by the authors (Table 5) to not only reflect the level of development and implementation of the policies themselves, but also to consider the capacity of impacted stakeholders to adapt their practices and behaviors in a way consistent with the objectives of a policy. This notion is central to the policy readiness tool developed by Nykiforuk et al. [50], which uses Rogers's diffusion of innovation theory to recommend appropriate strategies for policy change, depending on whether communities or organizations targeted by the policy are “innovators”, “in the majority”, or “late adopters”.

Table 5. Description of policy readiness levels (PRLs).

Policy Readiness Levels (PRLs)	Description	Policy Examples
PRL 1—Problem identification	Basic research to identify the problem or issue	Grants for university research
PRL 2—Evidence gathering	Collection of data and other information to assess the nature and extent of the problem	Capacity building in the public service
PRL 3—Problem validation	Consultation with stakeholders to validate the problem and evaluate the need for government intervention	Consultations, publications
PRL 4—Formulation of solutions	Elaboration of proposed solutions, identification of considerations and modeling of outcomes	Discussion paper, roadmap
PRL 5—First testing of proposed solutions	Policies implemented at a small scale; development of the underlying technological solutions	Subsidies for industrial research and development
PRL 6—Proposed solutions validated	Measurement of outcomes and dissemination of results to increase awareness of problem and demonstrate feasibility of solutions	Case studies, voluntary guidelines
PRL 7—Refinement of solutions	Retesting and adaptation of solutions in different settings to obtain further evidence and gain feedback from stakeholders	Subsidies for demonstrations and early deployment
PRL 8—Integration of solutions	Coordination within and between government levels (federal, regional, local) for optimal delivery of solutions	Strategy, harmonization of programs
PRL 9—Comprehensive policy implementation	Policy solutions proven at a large scale with expected outcomes met; continued monitoring and evaluation	Regulations, taxes

The results presented in Sections 3.1–3.3 indicate that a single PRL cannot be defined for the adoption of circular economy strategies in the forest sector and related end-use sectors. While the concept of a circular built environment is still nascent, circular economy practices are more common in the packaging industry, driven by well-established policies such as extended producer responsibility (EPR) schemes used in multiple provinces [23]. The construction sector exhibits a lower PRL (generally between 1 and 4), mainly because fundamental policy issues are still not fully identified (PRL 1), significant gaps remain for evidence gathering (PRL 2), and because different interpretations of the problem and associated solutions are still being elaborated (PRLs 3 and 4). This is consistent with a recent report on the current state of circular economy in Canada, where construction was identified as a sector with significant opportunities, but which has only just begun to make some progress [23]. For example, EPR schemes were not implemented for construction materials even though this was planned under the 2009 Canadian Council of Ministers of the Environment (CCME) Canada-wide Action Plan for Extended Producer Responsibility [23]. In a few instances, the first testing of solutions (PRL 5) was reported by interviewees (e.g., deconstruction and green demolition bylaws in Vancouver), but this is the exception rather than the norm [51]. On the other hand, the PRL is higher for the packaging industry, with policies already in place (such as investments in recycling facilities, extended product responsibility, and funding available to manufacturers for eco-design projects) [16,52] or in development (ban of certain single-use plastic items, extension of deposit refund schemes) [43], at least in certain parts of the country, indicating a PRL of around 7 or 8. However, recent events highlighted flaws in the current policies (e.g., China’s ban on the import of plastic waste and other types of wastes, new types of waste, or a shift in the origin of waste because of the COVID-19 pandemic), namely that they do not adequately address gaps between what is generated, what is recovered, and the demand for recycled material. The fact that there are no well-established policies in Canada beyond pilots directly dedicated to circular economy strategies, such as industrial symbiosis or the cascading use of wood products, indicates that the PRL for the forest sector as a whole is undoubtedly below 8. The same observation was made for all economic sectors, with the lack of comprehensive and coordinated policies on circular economy across jurisdictions in Canada resulting in a circularity rate (i.e., contribution of recycled and recovered materials to total material use) estimated at only 6.1% [23].

Raising awareness in the construction sector on the growing importance of circularity for both customers and governments is indicated. This requires, among other things, more robust evidence of the current performance of the sector, especially on the value lost because of low recovery rates of materials in the built environment (construction, renovation and demolition). At the moment, it appears premature to set stringent requirements for the built environment, namely because of a lack of commercially available building systems or technologies that allow circular construction, maintenance and deconstruction. For example, despite the fact that a Canadian standard on design for disassembly and adaptability was adopted in 2006 [51], none of the experts interviewed mentioned it being used by industry. With reuse highlighted as the most promising strategy for lumber, a better understanding of the policy factors that hinder it, namely embedded in the National Model Building Code, is an essential starting point. Investments in research, development and demonstration (RD&D) for more products, assemblies and whole buildings that enable circular economy strategies are also required prior to testing policies, such as those that encourage or mandate the recovery of materials from buildings. Technological development is especially needed to reduce the cost of materials recovery and to improve their quality since several experts interviewed mentioned that recovered materials cannot usually compete with virgin materials on both aspects. These technical and economic challenges are similar to those faced in the Finnish forest sector [40]. Experts also raised that mandating building deconstruction does not in itself create demand for recovered materials. Hence, governments could play a role through green procurement initiatives, thereby creating the level of demand required to justify investments across the supply chain (manufacturers, deconstructors, recyclers, builders) once technologies and processes are sufficiently developed to lower the cost premium to a competitive level, again pointing to similarity with the Finnish forest sector [40]. At a later stage, material passports for buildings [53] could also be mandated, so that quantities and characteristics of materials in buildings are tracked over the entire period from construction to dismantling, which would in turn allow the planning for their recovery and reuse. Overall, the interviews conducted indicate that there is currently no general agreement on what circularity means for the construction sector nor on the steps required to achieve this. Therefore, defining a roadmap for a circular built environment in Canada seems critical at this point in time, in parallel with accelerating emerging initiatives at the local or regional scale.

With policies that relate to packaging being more advanced than those for construction materials, recommendations focus on their refinement and extension, rather than activities associated with earlier PRLs (problem identification and validation, formulation and testing of solutions). Waste management policies, which are primarily a matter of provincial and territorial concern, could include targets for both the quantity and quality of recovered material rather than for quantity only. This would provide a stronger driver for investments in recycling and composting infrastructure that not only increase recovery rates but also the usability of the material generated. In certain circumstances, separation at the source might be more cost-effective than better sorting equipment at recycling facilities in order to avoid value loss for certain grades of paper. Clear definitions for recyclability and compostability, as well as standards that characterize the compatibility of recovered materials with a variety of real-world processes, would also lead to a better handling of such materials. This is especially relevant in a context where new wood-based packaging solutions are expected to appear on the market, as consumers move away from certain single-use plastic items, and considering that the ability of the existing infrastructure to process these products is not guaranteed. Along the same lines, restrictions on materials that are hard to either recycle or compost would address contamination issues that result in a loss of value or the need for additional processing equipment. With demand for recovered material being as important, or more important, than the capacity to generate supply, a minimum recycled content for a selection of products is also worth considering.

Policies to support circular practices in the forest sector need to recognize the fact that Canada is a leading exporter of forest products, meaning that products manufactured domestically are mostly consumed abroad; the USA and China are its main trading partners, with 68.1% and 15.4% of exports in 2019 [54], respectively. The implementation of strategies that relate to the use and end-of-life of products largely depends on policies adopted not only in Canada, but also in the USA, with the North American market still lagging behind global leaders (e.g., the EU, Japan) in terms of demand for circular solutions. Nevertheless, moving towards a more circular forest sector in Canada can serve as a stepping stone to access emerging markets in certain leading North American regions (e.g., Great Lakes Circular Economy Partnership), states (e.g., Oregon, California) or cities (e.g., New York City, Houston). This observation contrasts with recent studies on circular economy and the forest sector, where the implications of international trade are not mentioned [37–39]. However, such interlinkages, resulting mostly from supply chains and end-of-life value chains operating across national borders, are acknowledged by the OECD in its work on resource efficiency and circular economy [55]. With the sector already showing a high conversion efficiency, further gains likely depend on better integration with other industries, for example, through industrial symbiosis projects [1]. This would make it possible to derive value for currently underutilized resources (e.g., harvest residues, smaller diameter trees, non-commercial species, waste heat and CO_2). In communities where the forest sector is the sole economic driver and where such integration is not an option, large facilities such as pulp and paper mills and sawmills could act as anchors for additional bioproduct manufacturers. In both cases, further deployment of circular economy practices would depend on policy support for the net-zero transition (with forest industries acting as a provider of low-carbon inputs to other sectors) and a growing bioeconomy (with greater use of low-value wood fibre driven by an increasing demand for bio-based solutions). Overall, the recommendations put forward based on the interviewees held with a selection of Canadian experts echo key policy drivers for a more circular and innovative forest bioeconomy identified by Ladu et al. [47], which include “awareness raising policies”, “R&D policies” and “climate change”. While “sustainable forest management policies” was also part of their best policy mix [47], it did not emerge in this study, most likely because of intentional focus on a selection of forest products rather than the sector as a whole.

At first, interest in the circular economy for the Government of Canada was mainly driven by plastic pollution making the headlines, leading to the adoption of the Oceans Plastics Charter by the G7 in 2018. The program of the World Circular Economy Forum (WCEF), held in Canada in September 2021 [56], indicates that the discussion now extends to multiple other sectors and industries. Going forward, policies will be needed to support emerging circular practices not only for plastic, but for all other material types, goods and services. A first step would be to address the lack of comprehensive and robust data on material flows at a national level, which hinders the capacity of all stakeholders, including governments and researchers, to understand the current state of affairs, identify barriers and bottlenecks, and assess the projected outcomes of proposed solutions through modeling [23]. Currently, national physical flow accounts include only an energy account, a greenhouse gas account and a water account [57], with Canadian statistics on material flows significantly less developed than statistics on energy flows. The timing also appears right to develop a circular economy roadmap for Canada, building on research activities that have accelerated over the last few years and are based on emerging coalitions that convene industry, government and civil society (e.g., Circular Economy Leadership Canada). Led by champions to be identified at the federal level (e.g., Environment and Climate Change Canada, Natural Resources Canada, Innovation, Science and Economic Development Canada) and provincial/territorial level (e.g., Canadian Council of Environment Ministers, Canadian Council of Forest Ministers, Energy and Mines Ministers’ Conference), the roadmap would provide a clear vision for the future, set general performance targets, and identify key policy levers, based on engagement with a broad and diverse set of stakeholders. By setting national priorities, a circular economy roadmap would also serve as a reference point for all departments, ministries and agencies across jurisdictions which seek to align economic (innovation, trade), social (labor, regional development) and environmental (climate change, biodiversity) policies with circular economy.

5. Conclusions

With circular economy emerging as a policy priority for the Government of Canada, attention towards its implementation in various sectors, including the forest sector, is increasing. Interviews were conducted with Canadian experts to evaluate the current adoption of circular economy strategies for forest products and to identify opportunities for improvement. Measures to improve resource consumption at the manufacturing stage, which are currently in place for all products (lumber, particleboard, cardboard and CTMP) across the forest sector, with opportunities for further improvement also identified. While end-of-life strategies were seldom used for lumber, and even less so for particleboard, they were more common for cardboard and CTMP in packaging. Low-hanging fruit for incremental improvements of circularity were identified for all products, except particleboard. For example, recovered lumber could be processed into wood panels, downcycling of cardboard fibres could be avoided if not mixed with other paper streams, and the recycling of molded CTMP packaging could be facilitated by the selection of proper barrier materials. In the case of construction materials, significant barriers were identified for the implementation of the most promising strategies: for lumber, large-scale recovery is virtually impossible because buildings are not designed for deconstruction and disassembly; for particleboard, the use of resins and laminates limits the possibilities for energy recovery. In the case of packaging materials, there was closer alignment between the most promising strategies and the ones that are either already in place or could easily be implemented.

Building on the solutions proposed by experts to accelerate the deployment of circular economy strategies for forest products, it was argued that the policy readiness level is different in the construction sector and the packaging industry. Bringing relevant stakeholders together to come to a general agreement on what circularity means for the construction sector, in parallel with targeted support for the development of technologies that allow disassembly and deconstruction, are currently key next steps for the adoption of more circular practices. For packaging, the existing policy framework needs to be refined and extended, in parallel with investments in waste management infrastructure, to promote the recovery and reintroduction of materials in manufacturing processes. Circular economy has multiple implications for practice and policy, and those will likely vary, at least to some extent, for different forest products and their associated end uses. This study, without being all encompassing with regard to the experts consulted, the forest products covered, or the circular economy strategies proposed, nevertheless provides timely findings to inform emerging government and industry initiatives. Since the transition to a more circular economy has economy-wide implications that go well beyond the forest sector, it is first recommended (1) to develop a circular economy roadmap for Canada and (2) to improve national material flow accounts to move towards a common understanding of priority issues, potential solutions and, ultimately, track progress towards targets. This strong foundation will in turn enable the development and deployment of technologies and measures for forest products in their wide range of applications.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/en15030673/s1, File S1: Product Summary Sheets. File S2: Interview Guide. File S3: Interviewee profiles and thematic analysis grids.

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