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# FOREST BIOENERGY AND CANADA'S 'CLEAN FUELS STANDARD'

## POTENTIAL CARBON IMPACTS

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# 1. INTRODUCTION AND POLICY BACKGROUND

The federal Government of Canada launched in 2016 a Pan-Canadian Framework (henceforth 'PCF') [1], a series of political initiatives aimed at achieving a reduction in overall GHG emissions of 30% by 2030 (compared to 2005 levels), and eventually net zero GHG emissions by 2050.

This multi-pronged approach relies on four pillars:

1. Pricing carbon emissions;
2. Complementary climate actions, specifically:
    - Decarbonizing further the electricity generation system;
    - Improving energy efficiency and promoting the use of **renewable energy** in the built environment;
    - Decarbonizing transportation through emission standards, zero-emission vehicles, and **cleaner fuels**;
    - Improving energy efficiency and promoting the use of **clean energy technologies** in industry and manufacturing sectors;
    - Enhancing carbon storage in forests, increased use of wood for products, increased use of bioenergy and bioproducts.
3. Increase adaptation and resilience to climate change;
4. Investing in clean technology, innovation, and jobs.

All the elements of the PCF highlighted in bold in the list above are affected by a proposed Clean Fuel Standard [2]. Similar to other schemes around the world, the Canadian's CFS aims to define baseline life cycle GHG emissions for the fuel mix supplied to the transport, residential, and industrial sectors, and promote a gradual reduction in total emissions by: i) reducing emissions at any points along the lifecycle of fossil fuels, for example, improving energy efficiency at refineries; ii) supplying low-carbon-intensity fuels, for example, ethanol and biodiesel; iii) switching to cleaner sources of energy, such as electric vehicles. Canada plans to introduce the CFS in two phases, starting with liquid fuels, and thus implicitly focusing on the transportation sector, and following then with CFS regulations for solid and gaseous fuels.

Canada's CFS schemes are likely to incentivize the use of forest biomass for energy. This might include pathways to use wood to produce advanced biofuels, as a carbon source in steel making, as an energy source in cement kilns, to produce synthetic natural gas etc... [3].

However, it has been proven that in many circumstances the additional harvest of forest biomass driven by bioenergy demand actually does not contribute to climate change mitigation for many years ("carbon debt"), especially in high latitudes with low forest growth rates, such as Canada [4–6]. Canadian policymakers and CFS stakeholders might have underestimated this issue as there has been no assessment to date of what impact the CFS could have on Canada's forest resources and wood flows. Even the increased use of primary logging residues, secondary industrial residues, and tertiary post-consumer wood feedstocks within the CFS sectors could indirectly lead to increased harvest rates by diverting those materials from existing uses.

Forests traditionally provide a multitude of services, ranging from flood protection to recreation [7,8]. While it is long known that maximizing all services is often impossible and that forest management objectives need to account for trade-offs across ecosystem services [8], there is an increasing pressure to manage forests to simultaneously obtain: growing C-sinks, improved habitats for biodiversity, and provision of renewable materials. Even the PCF itself assigns to Canada's forests a triple role in the climate mitigation efforts: to increase C-storage in-situ, to provide wood for products, and to provide biomass for energy.

Satisfying such high demands from forests require taking a holistic perspective to analyze bioenergy demand and uses not in isolation, but rather as part of the overall social-ecological system of Canada [9]. Only by adopting such a systemic perspective proper adaptive governance tools can be designed and put in place [9].

The aim of this report is to contribute to the evidence basis necessary to design proper governance instruments for bioenergy sustainability: firstly, I frame the problem by introducing the lessons learned in accounting for the carbon impacts of forest bioenergy; secondly, I synthetize the existing statistical datasets into a novel holistic picture of wood flows across Canada's economy; thirdly, I define the elements of the forest sector system and the relationships among them and I define potential first and second-order consequences of an increase in forest bioenergy demand due to the CFS. Finally, I compare the scenarios defined with the available literature to draw potential consequences on carbon emissions.

# 2. PROBLEM FRAMING

## 2.1 CARBON ACCOUNTING OF FOREST BIOENERGY: LESSONS LEARNED

Canada CFS, like many similar governance tools around the globe (e.g. EU Renewable Energy Directive, EU Fuel Quality Directive, US Renewable Fuel Standard), apply a form of life cycle assessment (LCA) to calculate the GHG performance of fossil and renewable fuels along their supply chain. Over the years, LCA has become a key tool in pursuing sustainable production and consumption patterns and it has been also increasingly integrated into the policymaking process, either at the stage of policy design and impact assessment, or directly into legislative documents [10].

Even though LCA is a standardized methodological approach, the ISO and multiple other standards available leave abundant freedom to the practitioners to choose the modelling framework they deem more relevant. Thus, the interpretation phase is crucial to make sure that the results are consistent with the defined goal and scope, and that the conclusions presented are robust. However, too often both practitioners and decision makers have overlooked this fundamental phase of the LCA and have drawn conclusions which are either not supported by the study performed or go well-beyond what the limitations of the study would allow [11]. Because of the political relevance of biofuels and bioenergy and the debate surrounding their sustainability, the last decade has seen great progress in understanding the methodological issues in sustainability assessment that might mislead policymakers and continue to fuel the debate. This section summarizes these findings.

Two main modelling principles are used in LCA practice. Attributional LCA (A-LCA) assesses the environmental impacts associated with all stages in the life cycle of a product, a process or a system, from cradle to grave (i.e. from raw material extraction through processing, manufacture, distribution, use, etc.). Consequential LCA (C-LCA) identifies the consequences of a decision within the relevant system on other systems and processes of the economy. Figure 1 illustrates the main differences between the two principles.

| | ATTRIBUTIONAL LCA | CONSEQUENTIAL LCA |
|---|---|---|
| OBJECTIVE | • To depict **potential environmental** impacts of a system over its life cycle | • To identify the **consequences** that a decision has on other systems, in the background and outside the boundaries. |
| MODELLING | • It uses **historical, average, measurable data** of known/knowable uncertainty.<br>• It includes all processes identified as relevant contributors to the system being studied.<br>• The analysed system **is modelled as it is** (or forecasted to be). | • The modelling is driven by market mechanisms, and potentially includes political interactions and changes in consumer behaviour.<br>• It models the studied system around these consequences, **as a hypothetical, generic supply chain.** |

Figure 1: Characteristics and objectives of the two main LCA modelling principles Source: [12]

This theoretical distinction between the two principles has often led to confusion and debate within the scientific community, so it is essential to clarify the role of these modelling approaches across the policy cycle. Figure 2 illustrates the proper analytical context in which different modelling approaches should, and have been, used across several examples. LCA models that support the implementation of specific legislative instruments respond to the specific requirements defined within the instrument itself, and those models are mainly based on attributional LCA approaches. They should be easy to calculate, well-defined, use a well-specified, easily accessible and stable inventory, and be of general validity across the temporal and spatial scales covered by the legislation [13]. This is clearly the case proposed for the Canadian CFS, as well as defined in other similar policy instruments, such as the EU Fuel Quality Directive or the EU Renewable Energy Directive [14,15].

On the other hand, LCA models that assess the impacts of strategic policy decisions can benefit from elements of consequential thinking. Studies that aim to assess large-scale impacts on the overall economy usually rely on economic models that cover multiple sectors of the economy, large geographic scales, and all relevant ecological processes [16]. Such studies have been undertaken to support the impact assessment of EU policy options (e.g. [17,18]) and focus on capturing as many interlinked consequences and feedback loops as possible, across scales, sectors, and environmental burdens, to avoid unintended consequences of policy decisions. Similar exercises are carried out regularly, usually employing various Integrated Assessment Models (IAMs), in many other contexts, such as: the IPCC Assessment Reports [19], to study potential sustainable development goals interactions [20], to study potential strategies for conservation of ecosystems and species, etc. [21].

An intermediate approach has emerged, based on attributional modelling but incorporating elements of consequential thinking. These assessments are easier to implement than large numerical models, but can still identify risks and mitigation strategies which are often overlooked by purely attributional LCA approaches [6,22]. This is also the approach taken in some regulatory frameworks; for instance, the California Low Carbon Fuel Standards incorporates also emission factors for indirect land use change (ILUC), and thanks to this choice has been effective in driving supply of waste-based biofuels at the expenses of crop-based biofuels [23,24].

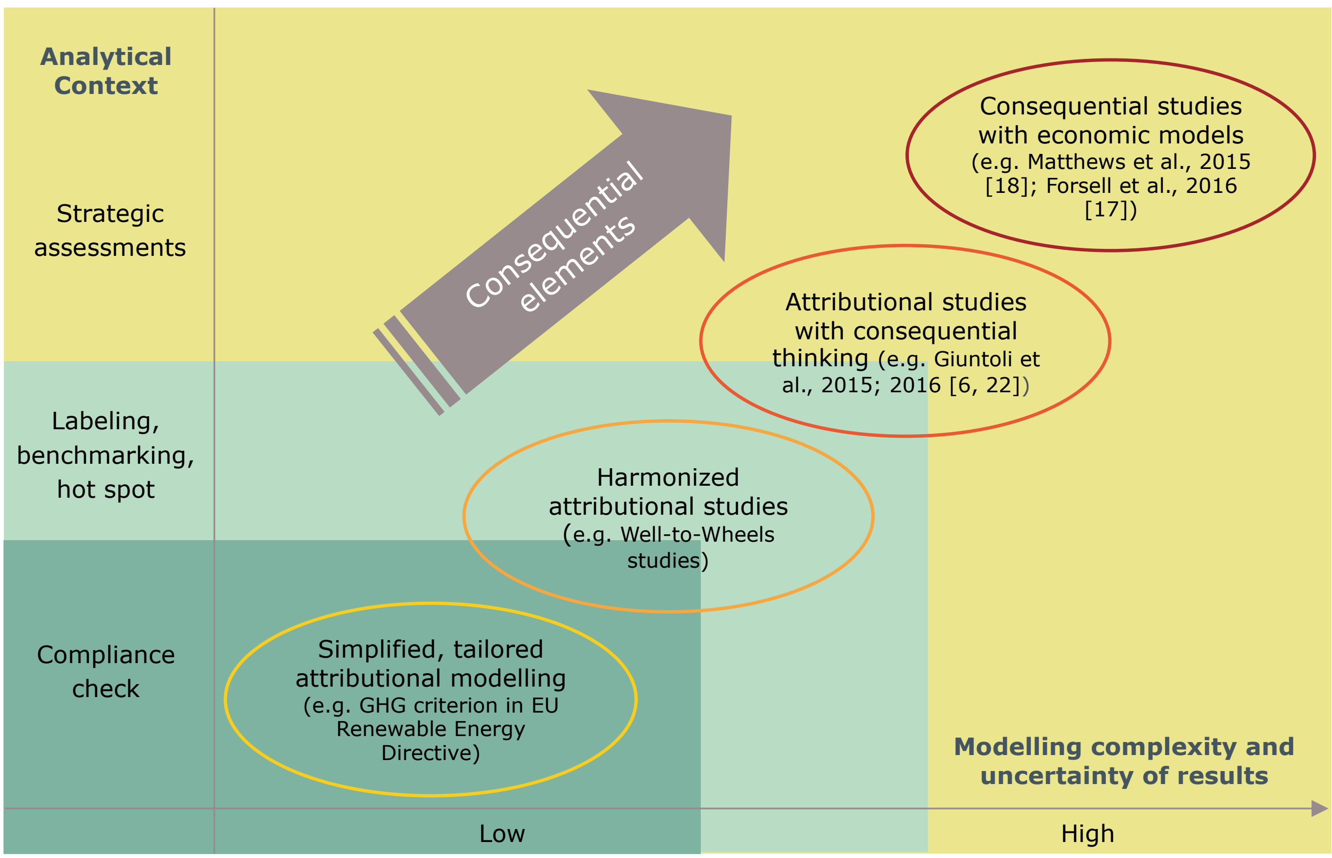


Figure 2: Examples of LCA studies used for policy support and LCA methodology implementation in EU policy, classified according to analytical context and modelling complexity. Source: Adapted from [12]

It is clear from these lessons learned, thus, that even though 'operationally', the Canadian CFS (at least for liquid biofuels) is going to be applying a fully attributional approach which excludes biogenic-C and market-mediated effects, the actual impacts of an increase in bioenergy demand on carbon emissions can only be grasped by focusing on strategic-type assessments, and thus considering all potential market-mediated effects and all carbon flows involved, including biogenic ones. This work provides support for such an assessment, focusing on the use of forest bioenergy.

Figure 3 illustrates the main pools and flows affecting the carbon balance of forest bioenergy [25]. The contribution of forest bioenergy to climate change mitigation results from the balance between responses taking place in-situ, i.e. the changes in forest carbon stock and sink, and responses ex-situ, such as potential substitution of other energy sources and of carbon-intensive materials (e.g. construction materials and biorefinery products). Additionally, effects on land use may have a significant impact on the final balance. Furthermore, time-dependent trends in emissions and sequestrations may play a significant role in defining the timescale of mitigation [6]. All the elements in this system, as well as their relationships, need to be carefully considered to study the potential system dynamics following an increased demand of bioenergy. The next section aims to sketch in general terms what these interactions may look like, while section 3 and 4 examine in detail the magnitude of these interactions for Canada and potential changes due to CFS.

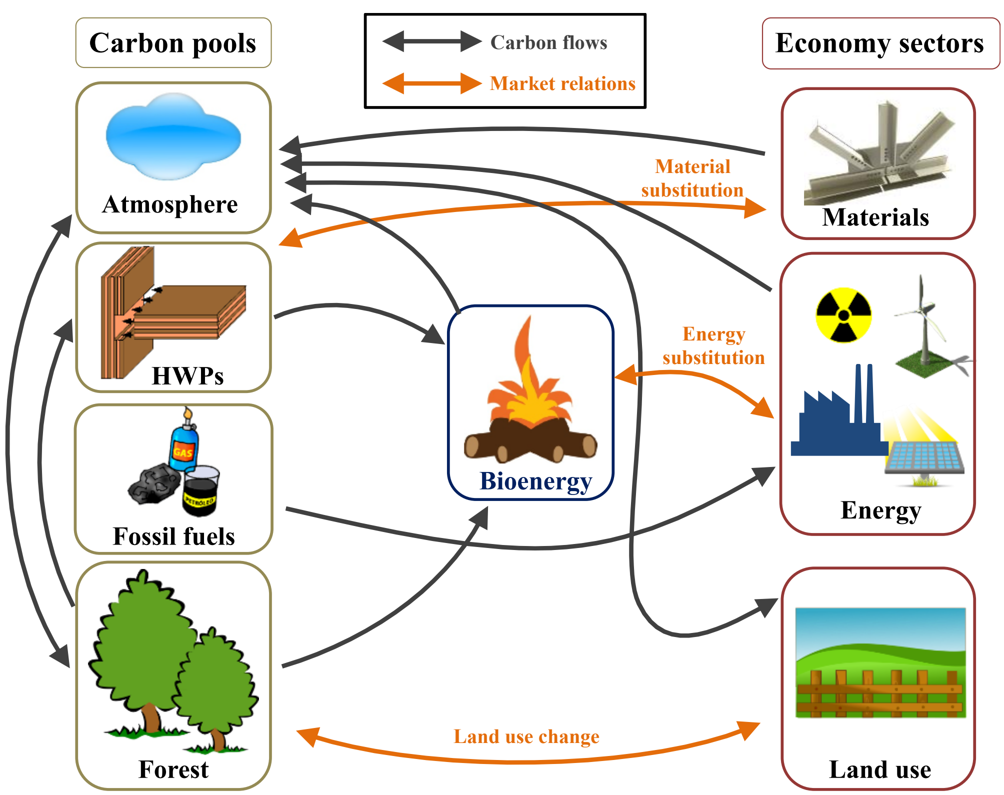


Figure 3: Representation of carbon pools, economy sectors and flows to be considered in an LCA study of forest bioenergy. Source: Adapted from [25]

## 2.2 RESPONSES OF THE FOREST SECTOR TO CHANGES IN BIOENERGY DEMAND

Figure 4 shows a simplified mapping of potential interactions between increased demand for forest-bioenergy and responses in the whole forest sector. This complex system includes multiple economic sectors (land rents, forest, materials, energy) and social actors, and presents many causal linkages and feedback loops, leading to multiple environmental impacts. For instance, the responses of the forest sector are influenced by other policy objectives (e.g. other PCF objectives as indicated in the Introduction) and eventual regulations (e.g. sustainability criteria), and by the impacts of climate change on future growing rates of forests and on natural disturbance trends. Social factors such as forest owners' behavior and cultural values have also a significant influence on forest management choices [26,27]. These mediating factors materialize in price signals for forest commodities and land which affect the responses from the forest sector.

I summarize the potential responses in three main categories affecting: 1) forest management practices, 2) the land use, or 3) consumption patterns.

The first type of response concerns forest management practices and in-situ carbon stocks and sinks. A typical response assumed in most of the existing literature (e.g. [4,6,28]) is increased extraction of primary forest sources, including actions such as expanding the removal of logging residues, raising pre-commercial and regular thinning intensity, and increasing the harvest intensity on commercial stands by shortening harvest rotations [29,30]. Additionally, areas of forest currently not under commercial management due to unfavorable socio-economic conditions may start to be commercially logged (increased area of active management). Finally, increased growth management responses aim at improving forest productivity to increase production of wood for bioenergy. These include, for instance: applying fertilization, shifting to fast-growing plantations, replanting with more productive hybrid tree species, and enhancing the C-stock of degraded stands [29,31–34].

The second response concerns consumption patterns of wood products. If additional demand for woody bioenergy results in higher prices for wood-based products, the forest sector will respond either by harvesting more wood or by displacing part of the existing material use of wood to energy [35]. This could lead to: i) a decrease in the demand for traditional wood products, and/or ii) market leakage, whereby part of the feedstock used for materials would be sourced from other geographical locations with associated impacts [36]. This response is important since Harvested Wood Products (HWP) contribute to climate mitigation both by storing carbon while in use, and by substituting other construction materials which are usually characterized by higher carbon footprints (Figure 3) [37,38].

Finally, forest bioenergy demand may also impact land-use and stimulate responses such as re-forestation of agricultural land, restoration of degraded or unproductive forestland, as well as favoring the maintenance of productive forests as forestland (i.e. avoiding potential deforestation) [39–41].

Indirect feedbacks can influence results in unexpected ways. For instance, increased demand for wood bioenergy could translate into increased demand for sawmill by-products and subsequently stimulate increased harvests and transformation of sawlogs [42]. On the other hand, increasing the relative attractiveness of energy wood may reorient forest management objectives from the production of quality industrial logs towards higher biomass outputs, thus reducing long-term supply of sawtimber in favor of smaller-diameter products, with potential wide-ranging consequences on the wood industry.

The changes listed above have very different timeframes for implementation and effects, as well as different economic returns. Collecting a larger share of logging residues and expanding areas of pre-commercial thinnings are short-term options for increasing bioenergy production [29], whereas fertilization, reforestation, and afforestation increase the supply of biomass with a considerable time lag. Further, increasing forest growth will reap rewards for forest owners only in the long term, and the profitability of these management strategies is thus often low [29].

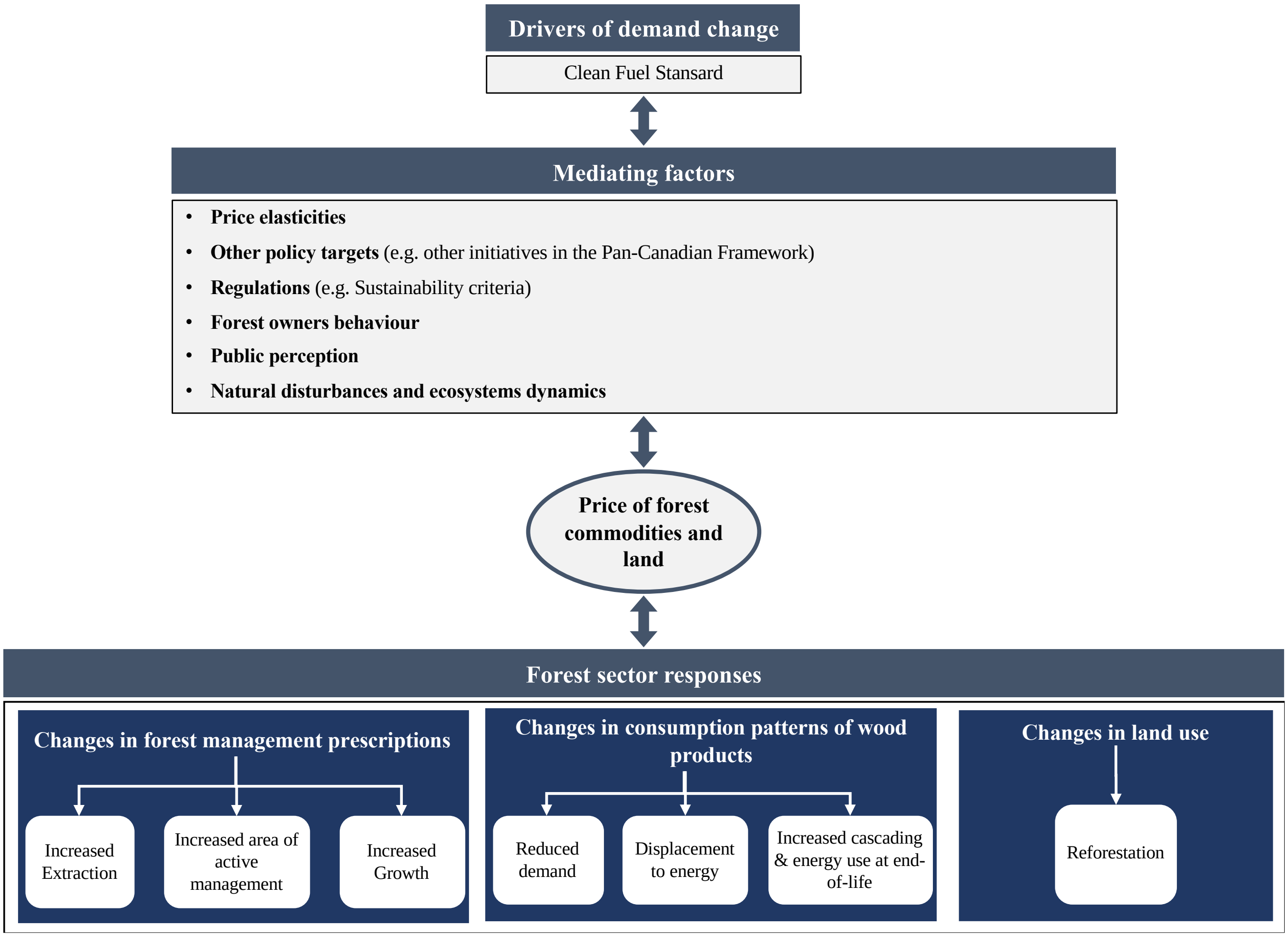


Figure 4: Schematics of the link between the drivers of change of demand wood-based bioenergy, potential changes in the forest sector and their link through mediating factors. Source: Adapted from [25]

## 2.3 CARBON IMPACTS OF FOREST RESPONSES

Each of the responses above may have a distinct effect on the carbon impacts of forest bioenergy. The use of modeling frameworks helps to account for the simultaneous effects of several responses and, potentially, for indirect feedbacks. However, it is helpful to try and identify the potential consequences of each response in a 'ceteris paribus' perspective (Table 1) since this information can be used to evaluate the potential impact of various combination of responses presented in Section 4.

To properly understand Table 1, the terminology used needs to be clarified. In this study the term 'carbon debt' is used to indicate the phenomenon for which the bioenergy scenario may produce higher carbon emissions compared to the fossil counterfactual/reference chosen for comparison, and the term 'payback time' as the time needed for the carbon debt to be repaid and for the bioenergy system to begin providing carbon mitigation. Once the payback time is reached, though, the bioenergy system still has contributed to global warming more than the fossil fuel system. Figure 5 illustrates these concepts. At the payback time, the cumulative emissions of the fossil and bioenergy systems are the same. However, the bioenergy system will have generated higher GHG emissions until that moment, leading to higher radiative forcing for an even longer of period. The atmospheric carbon parity point is the point in time when bioenergy may be considered carbon neutral, and this is not reached until the additional emissions caused by the bioenergy system until the payback time are saved by substituting fossil fuels combustion. At the moment in time when the savings (L1) equal the emissions due to bioenergy (L2) then the atmospheric carbon parity point is reached.

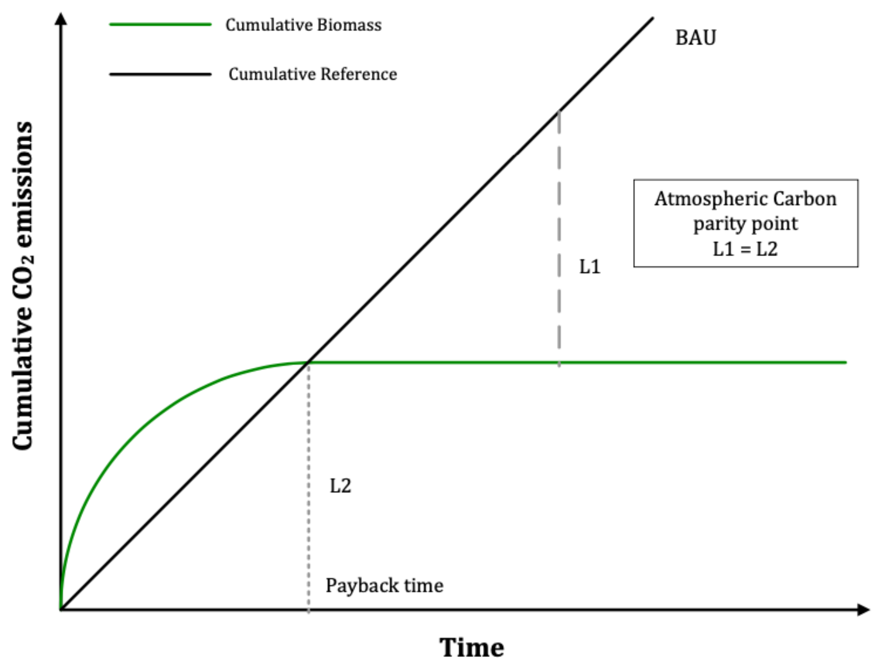


Figure 5: Visual description of payback time and atmospheric carbon parity point. Green Line: drop in the forest carbon stock due to bioenergy production; Black line: accumulated reduction in carbon emissions from substitution of fossil fuels. Source: [4]

Table 1: Summary of forest management responses to increased bioenergy demand and expected consequences for carbon accounting of bioenergy. Adapted from Agostini et al. [4] unless mentioned otherwise. Climate change mitigation is assessed relative to a reference scenario where bioenergy is assumed to replace fossil energy.

| Type of response | Forest management response to bioenergy demand | Expected consequences on carbon balance of bioenergy |
|---|---|---|
| **Increased extraction** | Increased removal of tops, branches and stumps [6,22]. | • The use of tops and branches may provide carbon mitigation in short-term (e.g. two decades).<br>• The use of stumps may not provide carbon mitigation before several decades.<br>• The use of logging residues for bioenergy as an alternative to slash burning provides immediate carbon benefits.<br>• In wildfire-prone areas, it may lower the fire hazard, hence reducing the risk of carbon emissions. |
| | Increased removal of salvage logs from infestation areas [5]. | Unclear. Use of salvage logs appears to improve GHG performance only if coupled with intensive re-establishment of forest stands.<br>In wildfire prone areas, it may lower fire hazard hence reducing the risk of carbon losses |
| | Increased harvest of stemwood of pulplog-quality. | The carbon balance of dedicated harvest of small stemwood of pulplog quality varies largely depending on the counterfactual considered and forest management responses accompanying the increased harvest. Payback times are in the range of decades. |
| | Increased harvest of stemwood of sawlog-quality. | The dedicated harvest of sawlogs for bioenergy is found to have payback times of centuries [4,43] |
| | Increased pre-commercial thinning (PCT) frequency/area. | PCT operations may be driven by bioenergy since selling the PCT biomass for energy can compensate partly for the cost of the operation. This operation might achieve carbon mitigation in the short-term by increasing biomass output, but only if the growth of the remaining stock is not affected [44].<br>Smyth et al. (2014) [45] shows no climate change mitigation for PCT used for bioenergy in Canada within 35 years. |
| | Increased regular thinning frequency/area. | Unclear. Regular thinning operations can produce multiple types of feedstocks, from pulplogs, to treetops and branches, and other logs unsuitable for pulp and paper use. Thinnings reduce the forest carbon stock, while improving the quality of the remaining timber. The overall carbon balance depends on many factors, including the growth-response of the remaining stock, the size and type of the thinned wood.<br>Additionally, thinning has been found to increase forest resilience to drought and wildfires [46], but intensive thinning could decrease resilience to wind damage [44,47]. |
| **Increased growth management** | Increased forest growth rates through improved silvicultural practices (e.g. fertilization). | Increasing forest growth produces additional biomass allowing increased removals maintaining or enhancing forest carbon stock. The impact of additional emissions of GHG from production and application of fertilizers (e.g. N2O) needs to be properly accounted in the overall carbon balance [48]. |

| | | |
|---|---|---|
| | Shift from natural forests to fast-growing plantations. | Unclear. Such a shift leads to a large release of carbon at the time of conversion plus a lower stock of carbon at the maturity of the stand, and potentially lower stock in the soil. Agostini et al. [4] find that mitigation could indeed be achieved in the medium term, due to the increased rate at which biomass is produced in the plantation.<br>Sterman et al. [49,50] estimate that this transition may still have higher emissions than coal for about 50-70 years. |
| | Change to higher yielding tree species during regeneration. | This response is linked to the previous. Improves carbon balance of bioenergy by increasing forest landscape productivity. |
| **Land use responses** | Avoided deforestation / Reforestation | These responses would improve carbon balance of bioenergy by increasing land carbon stocks and biomass resources additional to a scenario without bioenergy demand.<br>In case of avoided deforestation, the forest that is harvested is regenerated, instead of being converted to another land use, which may have been the case without the extra demand for bioenergy.<br>Bioenergy from reforestation activities could achieve carbon mitigation in the short-term, between a few years and a few decades, depending on the vegetation type, amount and status, present in the reforested land as well as the species replanted and operations required [4,51,52]. |
| **Consumption patterns** | Reduction in long-lived harvested wood products. | A reduction in long-lived wood products may worsen GHG balance of bioenergy because of reduction in storage of carbon in HWP pool and because of lower substitution of carbon-intensive materials. However, substitution factors are highly uncertain and would deserve further attention [37]. |

Now that the system boundaries and the system is presented in its general form and relationships (Figure 4), the next step in understanding the potential impacts of CFS and an increase in domestic bioenergy demand in Canada is to understand the specifics of the Canadian forest sector system, starting with defining in detail the current status of wood flows across Canada’s economy. This is presented in Section 3.

Section 4 then synthetizes existing literature to provide the *potential* responses of the Canadian forest sector to an increase in demand for forest bioenergy. Section 5 concludes by providing the limitations of the study, reasoned conclusions, and recommendations on the responses that should be promoted and the scenarios that should be discouraged.

# 3. WOOD FLOWS ACROSS CANADA'S ECONOMY

## 3.1 MAKING ORDER IN THE DATA: METHODOLOGY

In this section I point out some of the main methodological notes behind the calculations which have produced the results introduced in the following sections.

**Main data sources:**

The Wood Resource Balance presented in section 3.2.1 and the Sankey diagram in section 3.2.2 are produced exclusively from the following two data sources:

- Joint Forest Sector Questionnaire (JFSQ) (https://www.unece.org/forests/forestsfpmonlinedata/jfsq.html ) is used for the data on removals, production quantities, and net trade quantities of products from forests and other wooded lands.
- Joint Wood Energy Enquiry (JWEE) (https://www.unece.org/forests/jwee.html ) is used for all data referring to energy use of wood.
- Additionally, the conversion factors as well as input/output coefficient for wood industries, are taken from FAO (2020) [53].

The statistical datasets for wood used for energy in Canada, presented in section 3.2.3 are taken from the following sources:

- CEF2019 – '*Canada's Energy Future 2019*' by Canada Energy Regulator (https://www.cer-rec.gc.ca/nrg/ntgrtd/ftr/index-eng.html )
- NEUD – *National Energy Use Database* by Natural Resources Canada (https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/databases.cfm?attr=0 )
- STATCAN – Statistics Canada (https://www.statcan.gc.ca/eng/start ).

**Conversion factors and units of measure:**

The main difficulty when dealing with balances of biomass materials is to be able to report all quantities in a coherent unit of measurement. This means that several conversions might be needed before being able to aggregate data from different sources: from volume to mass, to energy basis. In this work I have tried to consistently use the conversion factors provided within each data source, and then to aggregate data across sources only once converted to the same unit. However, this implies that certain conversion factors might be different across data sources. Mainly: all conversion factors for data from JFSQ and JWEE come from FAO (2020) [53], while in order to covert data used in specific Canadian datasets (CEF2019, NEUD, STATCAN), I apply a factor of 18 MJ/kg dry for conversion between energy and mass (as used by Statistics Canada), and a value of 470 kg/m$^3$ as basic density to convert from mass to volume (from Table 3, pag. 38 of Saal et al. (2019) [54]).

**WRB and Sankey diagram compilation:**

- All values in the WRB are converted to the unit of 'volume of solid wood equivalent under bark [Mm$^3$ ub swe]. This is the same method applied in the EU by Cazzaniga et al. (2019a, b) [55,56] and it is considered to be the most effective way to produce a consistent balance of supply and uses. The swe unit implies that all quantities are reported back to the volume that a solid roundwood green log would occupy prior to any shrinkage. Further, all quantities are reported as under bark, while an overall amount of bark is calculated (through FAO (2020) [53] conversion factors) and considered to be fully utilized for energy as 'hogfuel'.
- Even though the JFSQ reports the production of secondary wood residues like chips & particles and residues, past exercises in this field [56] have taught us that it is more rigorous to calculate the secondary residues through mass/volume balances by using the input/output coefficients of the wood industries. I have used the same technique in this study, but this introduces an additional layer of complexity in the calculations and additional sources of uncertainty, especially in the use of generic input/output coefficients across all plants within the industry. Among all assumptions behind the WRB and Sankey diagram, this calculation is likely to be the most sensitive one to influence the final results.
- Building a Sankey diagram is not only for communication and visualization purposes, but the process itself leads to a better understanding of the wood flows; specifically, through mass-energy balances, it helps to quantify unknown flows. However, in some cases the number of unknown variables is higher than the number of equations available, and thus certain assumptions are needed to solve the system and define the whole Sankey. The main assumption that helped to unlock the rest of the diagram is that no chips are recirculated to the panel industry, but only white wood residues (i.e. sawdust and shavings), and thus that MDF and non-OSB fiberboard are produced only by residues. Even though a similar assumption was presented by Ghafghazi et al. (2017) [57], it is not certain that it reflects the reality of mass flows. Nonetheless, the overall conclusions of the study would not be affected by slight rearrangements of the wood flows.

**Datasets of wood used for energy in Canada (Section 3.2.3):**

This sub-section presents the different available sources of statistical data for wood used for energy in Canada.

JWEE:

Data from JWEE(2015) for Canada do not report any wood used for power generation, that category is explicitly indicated as 0. However, from all other statistical data sources it is clear that wood is indeed used to produce electricity in Canada. However, Canada divides clearly energy use in secondary uses (i.e. in residential, industrial, commercial, transport sectors) and energy used in thermal power plants. So, a plausible hypothesis is that JWEE data only include data for wood used in secondary uses and thus excludes wood used in power plants.

NEUD & STATCAN:

Data in NEUD are divided by secondary sector and by energy source, so I follow their separation for clarity.

*Industry data:*

After exchanges with experts within NRCan and StatCan, my understanding is that numbers for wood and black liquor used as fuels in industrial processes are captured in the StatCan Table 25-10-0025-01, which should then be equal to values in NEUD for Industry. The two numbers are indeed close, but not equal (in 2015: 432 PJ for NEUD, and 399 PJ for StatCan).

*Wood for electricity:*

NEUD also reports data of wood and black liquor used to produce electricity[1]. However, the numbers in NEUD do not coincide with any other number in StatCan tables. After exchanges with experts within NRCan and StatCan, my understanding is that the values for electricity generation from wood and black liquor within the industrial sector may be calculated as the difference between values in Table 25-10-0031-01 and Table 25-10-0025-01 (albeit this difference might include also steam produced by industries for sale). Data from NEUD Industry + Power generation equals indeed the total in StatCan Table 25-10-0031-01 (for 2015: 507.2 PJ in StatCan and NEUD). However, the metadata for StatCan Table 25-10-0031-01 clearly states that those values refer solely to the industrial sector and thus additional

[1] https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=egen&juris=00&rn=1&page=0

wood consumption in thermal power plants, reported in StatCan Table 25-10-0017-01, is added in the StatCan dataset.

CEF2019:

Even though the values in CEF2019 are taken mainly from NEUD and StatCan, no direct correspondence between numbers could be found, and that's why I report it as a separate possible dataset in Figure 8.

The main doubt with this dataset is that it is unclear whether the data are reported as final energy or as energy of fuel input. For instance, I have included the number for industrial demand of biomass energy as is (i.e. for 2015 equal to 367 PJ vs. 432 PJ reported in NEUD), but if that number is interpreted as final energy rather than input fuel energy, it could explain why the CEF2019 value is 85% of the NEUD value (85% being a common efficiency considered for heat produced from wood). But given the lack of clarity on the matter, I have left the values for CEF2019 as they are reported.

Additionally, this similar consideration would apply to residential use of wood: the number in CEF2019 is identical to the number reported in NEUD (i.e. for 2015, 171.4 PJ). So, if I were to interpret that number as final energy rather than input energy, it would need to be doubled to account for energy efficiency in space heating. However, the value so obtained (342 PJ) would be completely out of scale with the value reported in JWEE (158 PJ), which leads me to think that this number represents the actual fuel input energy and not the final heating energy.

## 3.2 RESULTS

### 3.2.1 WOOD RESOURCE BALANCE

The literature and official statistical data for Canada are surprisingly missing a full balance of wood resources and a full depiction of wood flows. So, the first necessary step was to recreate a full Wood Resource Balance (WRB) for the whole territory of Canada. I followed the process and methodology described by Cazzaniga et al. (2019a, b) for the EU and its Member States [55,56].

Table 2 presents the full Wood Resource Balance for Canada for the year 2015 which is the last year for which statistics of wood use for energy are available at the time of writing[2].

We can distill some important messages already from this exercise:

1. Material use of wood accounts for 75% of all uses, with energy only accounting for 25% of uses. This is in stark difference with the situation in the EU where the two quantities are almost equal [58].
2. In order to close the balance, we have to consider **8.7 Mm$^3$ ub swe of unaccounted sources**, meaning that the reported uses are actually higher than the reported sources of wood. While this is a mere 3% of the total sources (compared for instance to a 13% of unaccounted sources in the EU [56]), this data tells us that it is unlikely that there are surplus resources available (see section 4 for additional insights), and also that there might be harvest which is missed by official statistics.
3. Official statistics report almost 16 Mm$^3$ ub swe of direct wood (i.e. wood which was used for energy unprocessed) used in households, but only 4.6 Mm$^3$ ub swe of removals are indicated as fuelwood. It is known that small-scale harvest of fuelwood is often underreported [58], so it is a reasonable hypothesis that most of the unaccounted sources could be classified as unreported fuelwood harvest.
4. On the other hand, official statistics report a surprising value of 0 for wood used in power generation by electric utilities. This is in contrast with other sources of official statistics in Canada (see section 3.2.3 for additional insights).

[2] At the time of the writing of this report (October 2020), the UNECE/FAO Joint Wood Energy Enquiry has not yet published the results for the year 2017.

5. Finally, tertiary sources of wood (i.e. Post-consumer wood) are almost insignificant in Canada in 2015, as opposed to EU where this source accounted for 4% of total sources of wood.

Table 2: Wood resource balance for Canada in the year 2015. Data are reported in m³ solid wood equivalent (swe) under bark.

| Sources | | 1000 m³ ub swe | Share | Share | 1000 m³ ub swe | Uses | |
|---|---|---|---|---|---|---|---|
| Primary sources | Sawlogs and veneer logs (conifer): Removals | 118076 | 44.7% | 38.1% | 100700 | Sawmill industry (conifer) | Materials |
| | Sawlogs and veneer logs (non-conifer): Removals | 11065 | 4.2% | 1.3% | 3439 | Sawmill industry (non-conifer) | |
| | Pulpwood (conifer): Removals | 7915 | 3.0% | 0.4% | 1171 | Veneer sheets industry | |
| | Pulpwood (non-conifer): Removals | 12424 | 4.7% | 1.4% | 3704 | Plywood industry | |
| | Other industrial roundwood (conifer): Removals | 98 | 0.0% | 4.3% | 11389 | OSB industry | |
| | Other Industrial roundwood (non-conifer): Removals | 1779 | 0.7% | 1.0% | 2549 | Particle board (non-OSB) industry | |
| | Industrial roundwood (conifer): Net trade | -2704 | -1.0% | 0.6% | 1528 | Fiberboard industry | |
| | Industrial roundwood (non-conifer): Net trade | 1260 | 0.5% | 6.7% | 17806 | Mechanical pulp industry | |
| | Fuel wood (conifer): Removals | 1317 | 0.5% | 18.0% | 47502 | Chemical pulp industry | |
| | Fuel wood (non-conifer): Removals | 3322 | 1.3% | 1.3% | 3560 | Dissolving pulp industry | |
| | Fuel wood: Net trade | -37 | 0.0% | 1.7% | 4389 | Wood pellets industry | |
| | Bark / Hogfuel | 17922 | 6.8% | *75%* | *197736* | *Sub-total wood for materials* | |
| Secondary sources | Chips and particles: Production | 41205 | 15.6% | 5.8% | 15387 | Direct wood (Residential) | Wood for energy |
| | Chips and particles: Net trade | 1711 | 0.6% | 0.0% | 0 | Direct wood (Power) | |
| | Wood residues: Production | 13796 | 5.2% | 0.0% | 0 | Direct wood (Industrial) | |
| | Wood residues: Net Trade | 499 | 0.2% | 1.2% | 3150 | Indirect wood (Residential) | |
| | Wood pellets: Production | 4389 | 1.7% | 0.0% | 0 | Indirect wood (Power) | |
| | Wood pellets: Net Trade | -3340 | -1.3% | 18.2% | 48048 | Indirect wood (Industrial) | |
| | Black liquor: Production | 24853 | 9.4% | *25%* | *66584* | *Sub-total wood for energy* | |
| Tertiary | Post-consumer wood: Production | 74 | 0.0% | | | | |
| | Unaccounted sources | 8695 | 3.3% | | | | |
| **Total sources** | | **264320** | | | **264320** | **Total uses** | |

### 3.2.2 SANKEY DIAGRAM OF WOOD FLOWS

Thanks to the data assembled in the WRB, it is possible to recreate a detailed picture of the flows of wood across Canada's economy with just a few assumptions (detailed in section 3.1).

Figure 6 introduces a full Sankey diagram with all flows of woody biomass in Canada. This exercise reveals that the pulp industry and the panel industry in Canada rely on sawmill residues (wood chips and white wood residues like sawdust and shavings) for a significant share of their feedstocks. Indeed 45% of inputs to the pulp and paper industry, equal to 30.7 $Mm^3$ ub swe, appeared to derive from sawmill residues in 2015.

It is also clear that a substantial fraction of materials used for energy is spent pulping liquor used within the pulp industry, accounting for 24.9 $Mm^3$ ub swe, or 36% of all energy use of wood. The second most important source for energy are residues produced from sawmills and from the panel industry, accounting together for 22.4 $Mm^3$ ub swe, or 32% of all energy uses. Hogfuel is produced in many operations across the forest sector, it consists mainly of bark and other residues, and it accounts for 17.9 $Mm^3$, or 26% of all energy use. As highlighted in the previous section, direct fuel wood harvest only accounts for 4.6 $Mm^3$ ub swe, or 6.5% of all energy uses. As of 2015, only a minimal part of post-consumer wood was used for energy recovery (0.07 $Mm^3$ ub swe).

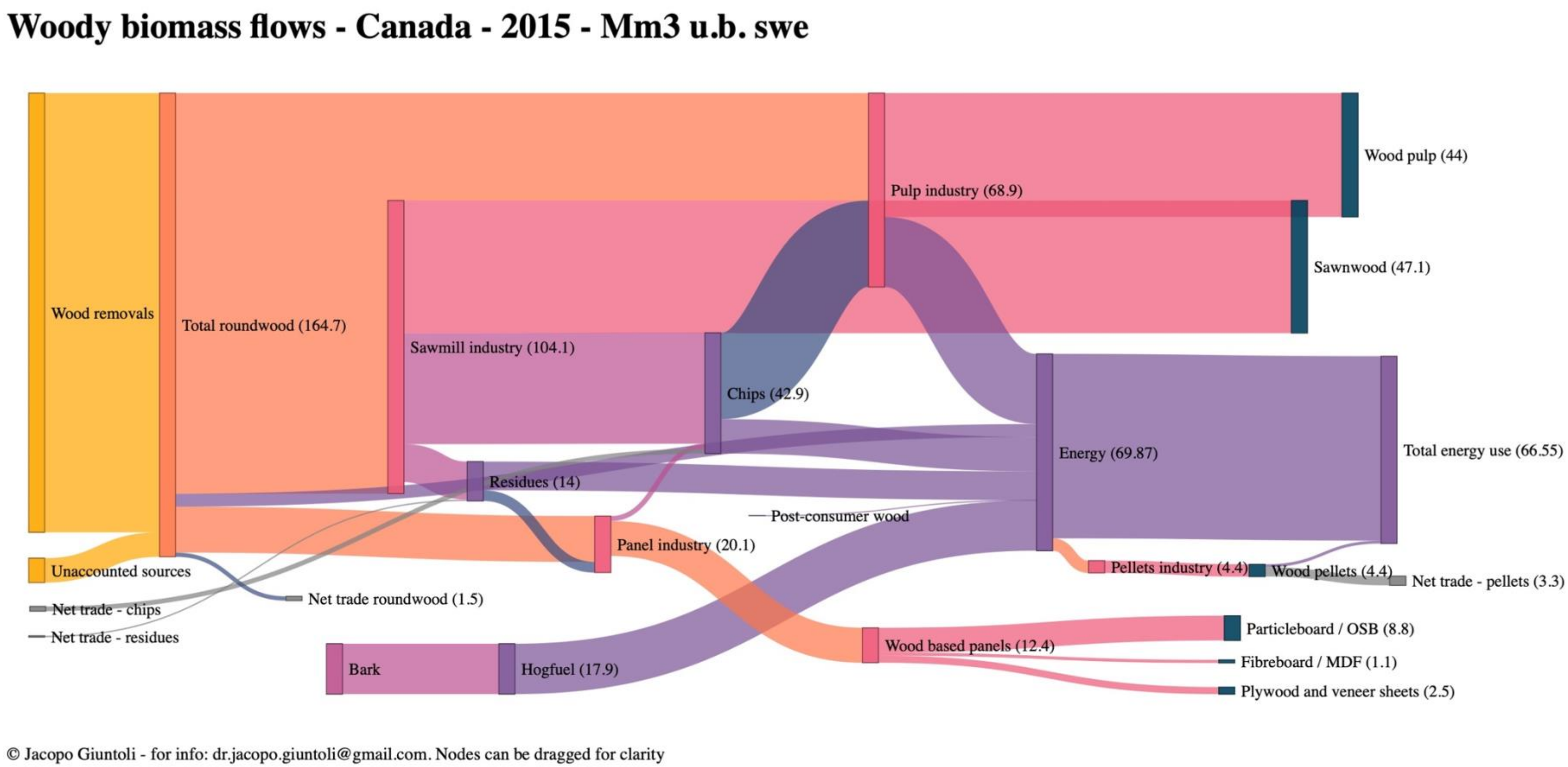


Figure 6: Sankey diagram of wood biomass flows across Canada's economy in 2015. Numbers are reported in Mm$^3$ under bark solid wood equivalent basis.

### 3.2.3 HOW MUCH WOOD IS REALLY USED FOR ENERGY IN CANADA?

At least four alternative data sources exist detailing the use of wood and spent pulping liquor in various sectors of Canada's economy, as illustrated in Figure 8. As detailed in section 3.1, I assembled and compared all the data sources: i) the data reported in the UNECE Joint Wood Energy Enquiry (JWEE; used for the WRB and the Sankey diagram) [59]; ii) data reported in the report 'Canada's Energy Future 2019' (CEF2019) [60]; iii) data reported in the National Energy Use Database (NEUD) [61]; iii) compilation of data from official Statistics Canada (STATCAN). Figure 7 summarizes the various data sources and results for each relevant sector.

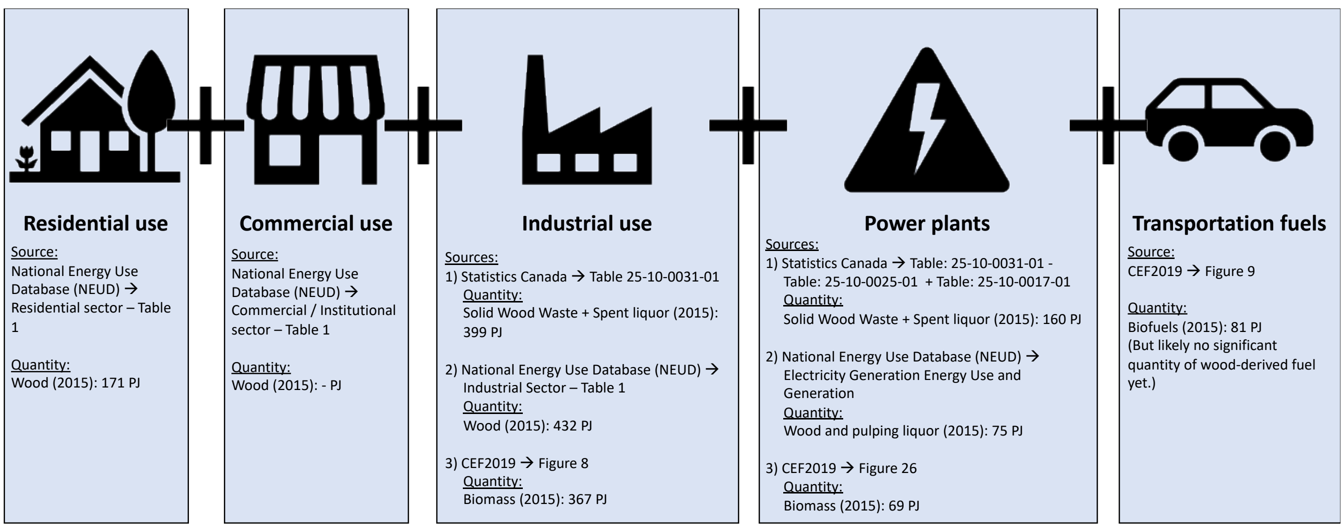


Figure 7: Summary of sources and datasets used for the calculations in this section. Further methodological details are provided in section 3.1.

As shown in Figure 8, the numbers provided by JWEE correspond to the lowest amount of wood for energy reported across the statistical datasets. As highlighted in section 3.2.1, JWEE data do not report any wood used for power generation, and comparing the JWEE number with data in the other sets seem to confirm this. On the other hand, data for power generation from wood resources is treated slightly differently between NEUD and STATCAN which could be the source of disagreement among these two datasets.

Regardless of these differences, the main message from Figure 8 is that the data referring to 'total uses' of wood in the WRB and Sankey diagram above might be underestimated by a share between 6% - 27%, which translates into an amount between 4.0 and 18.6 $Mm^3$

under bark solid wood equivalent (ub swe) Thus, it is likely that the amount of unreported sources might be closer to 13 – 27 Mm$^3$, equal to about 5%-10% of total sources (Figure 9).

I recommend that these numbers be clarified and vetted with the various Canadian statistical offices. Nonetheless, it is not surprising that differences exist across multiple datasets as similar inconsistencies are reported across the EU as well, and since wood for energy does not seem to have been a priority for Canada until recently.

If confirmed (regardless of the actual level of under-reporting), these findings are important because they highlight how rather than having underutilized resources ready to be used for energy, it appears that Canada might be underestimating the amount of wood already harvested and used for energy. The next step, thus, would be to identify and understand where do these unreported sources of bioenergy actually come from: are these the result of wood harvested directly for energy, e.g. primary residues already collected but not reported? are these the result of small-scale harvest on private properties used for residential purposes? Might there be an issue in accounting for mill residues (see section 3.1)? If woody bioenergy becomes an increasingly important resource within Canada, these issues should be investigated carefully.

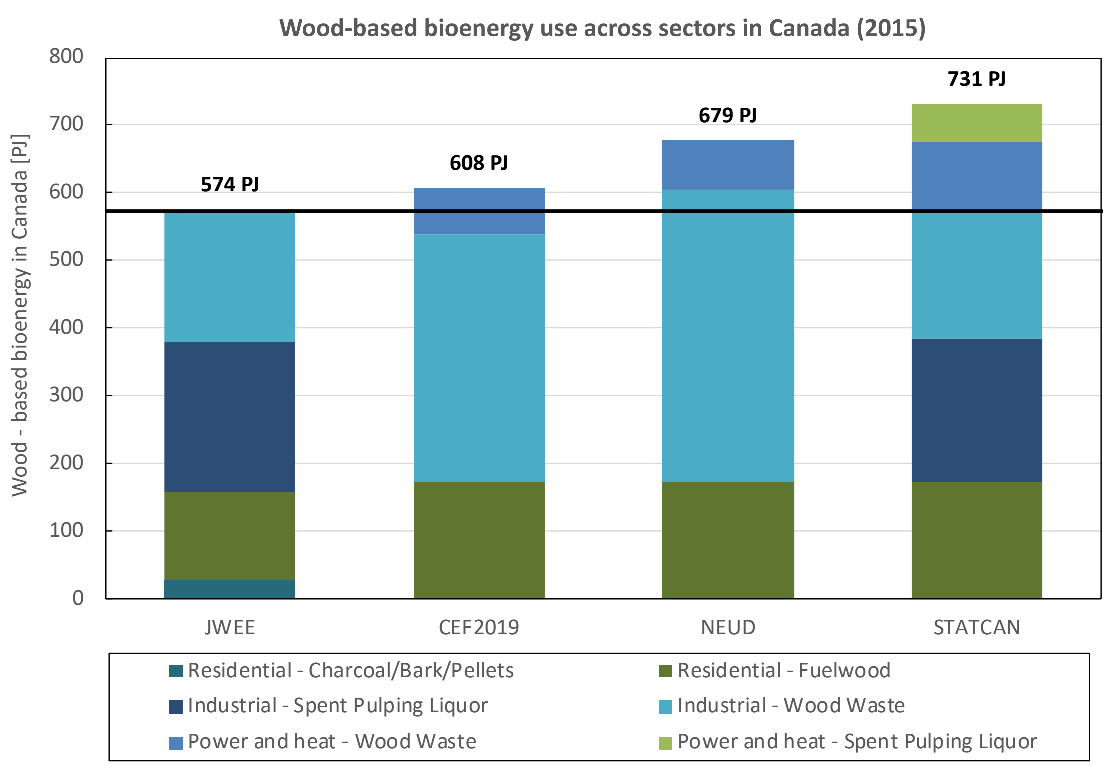


Figure 8: Wood energy use across the residential, industrial, and power sectors in Canada in 2015 from three different statistical sources.

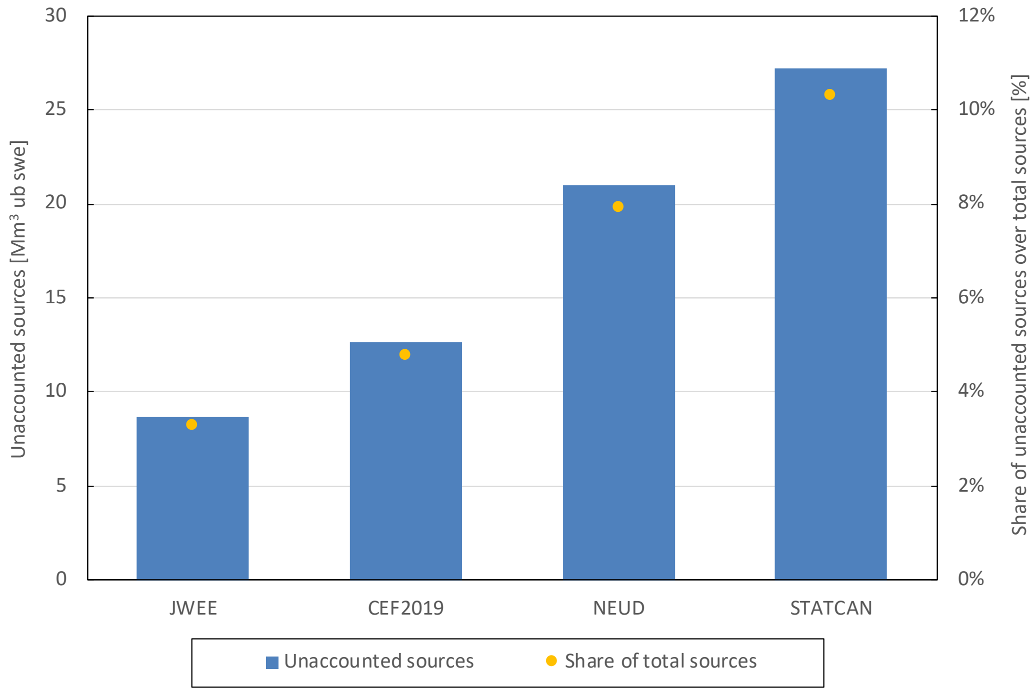


Figure 9: Magnitude of the amount and share of 'unaccounted sources' in total sources in the WRB for 2015 based on various statistical datasets. Values are in $Mm^3$ ub swe on the left axis and as a share of total sources on the right axis.

## 3.3 FUTURE ENERGY USE OF WOOD IN CANADA

Departing from the possible quantities of wood used for energy in 2015, it is possible to extrapolate the quantities of woody biomass that might be demanded in 2030. The future forecast derives from the exercise presented in CEF2019 [60]. To be noticed that this forecast exercise does not include CFS policies because it only includes policies already approved by mid-2019. Another scenario exists [62] which includes additional policy measures, among which is the expected CFS; unfortunately detailed results for this scenario could not be found. Nonetheless, in a first approximation, we can consider the available results from CEF2019 as a lower boundary of the quantities of wood bioenergy that might be demanded by 2030 once the CFS is fully implemented.

Figure 10a presents the potential increase in wood used for energy on an energy basis, while Figure 10b presents the results on a volume swe basis for coherency with the WRB and Sankey diagram presented earlier. First of all, the total energy use in the Canadian economy is still foreseen to increase annually until 2030. The scenario shows an increase in the use of wood for energy, albeit not homogeneously across sectors. For instance, the residential sector is expected to reduce its use of wood for energy by about 7% in 2030, likely due to increased thermal efficiency of buildings, the use of higher efficiency wood stoves, and a shift to electricity-driven heat pumps. The industrial use of wood for energy (as a source of process heat and power), is projected to slightly increase by +1.6% by 2030. On the other hand, for the use of wood for electricity generation, the CEF2019 shows a large increase of +61%. Additionally, CEF2019 forecasts an increase of +20% of energy from biofuels in the transport sector; however I only consider that 5% of the increased quantity of biofuels might actually consist of wood-derived liquid biofuels (i.e. about 230,000 dry tons of wood used to produce biofuels, which is a reasonable size for a second generation biofuel plant).

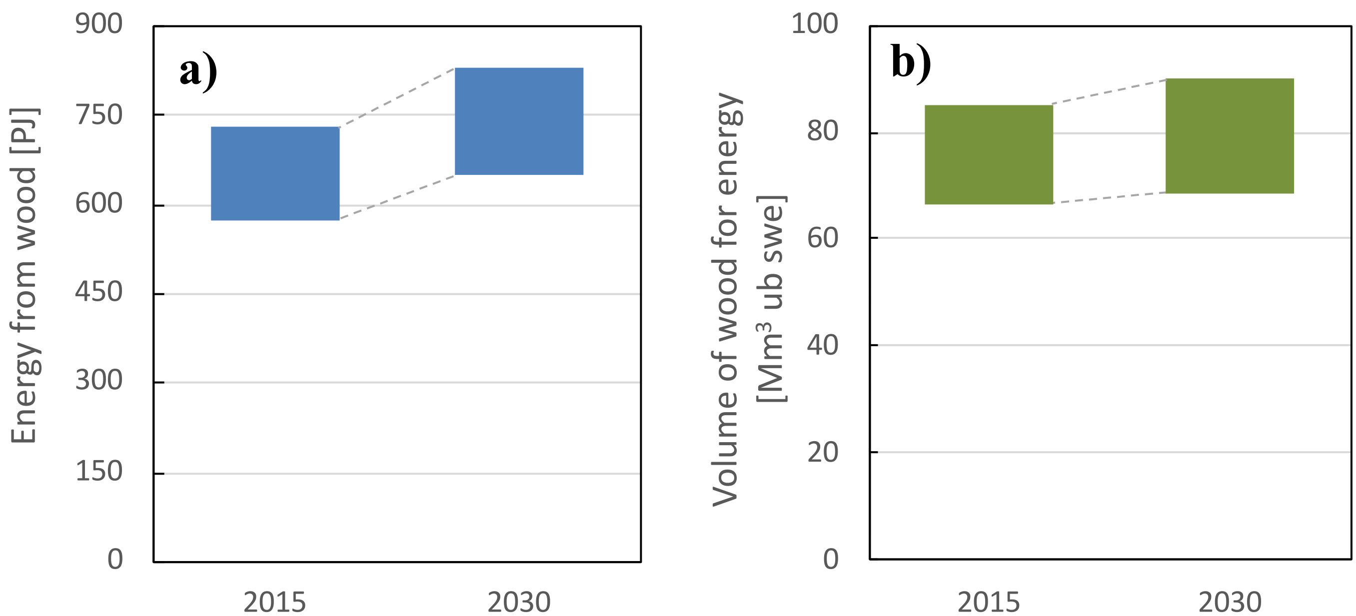


Figure 10: Present and forecasted use of wood for energy in Canada, on an energy basis (a) and on a volume basis (b). The range of values reflects the potential amounts of wood for energy deriving from the four statistical datasets in section 3.2.

With these forecasted changes, thus, the overall amount of wood for energy would increase by between 2 and 5 $Mm^3$ ub swe by 2030, which is an increase of 3.1% - 5.6% over the amount used in 2015. As highlighted above, many assumptions underpin these numbers, nonetheless they provide a useful indication of the additional amount of wood that is likely to be used in 2030. It is likely that CFS policies would actually increase this amount, especially in the transportation sector (provided technological improvements take place and lignocellulosic biofuels become a competitive alternative) and in certain industrial processes, while the power sector is not covered by the CFS and thus likely not affected by this specific policy initiative. These numbers are used in the next section to sketch potential feedback loops across the forest sector in Canada.

# 4. ANALYSIS OF POTENTIAL RESPONSES AND CARBON IMPACT OF INCREASED USE OF FOREST BIOENERGY IN CFS SECTORS

## 4.1 POTENTIAL SUPPLY RESPONSES ACROSS CANADA'S FOREST SECTOR

Section 3 demonstrated that there is still uncertainty around the actual amount of wood used for energy in Canada at present, and that forward-looking scenarios forecast an increase in the use of wood for energy of about 3%-5.6% by 2030, even without CFS policies.

In this section we illustrate the potential responses of the forest sector to this expected increase in demand and the associated impacts on overall C-balance. This analysis borrows elements from the analysis published in Giuntoli et al. (2020) [25], but focuses on the whole forest sector, thus including forest management and wood products production and consumption, and descends further into the particulars of the Canadian situation. Relevant literature is presented below for each of the responses and used to quantify, or at least reflect upon, the total C-impacts.

Figure 11 presents a guide on how to interpret the potential responses of the forest sector that are analyzed in detail below. The various potential sources of wood for energy are grouped in nodes as primary, secondary, and tertiary. The numbered yellow arrows represent potential interactions and flows among the various nodes; the numbers are recalled in the following sections.

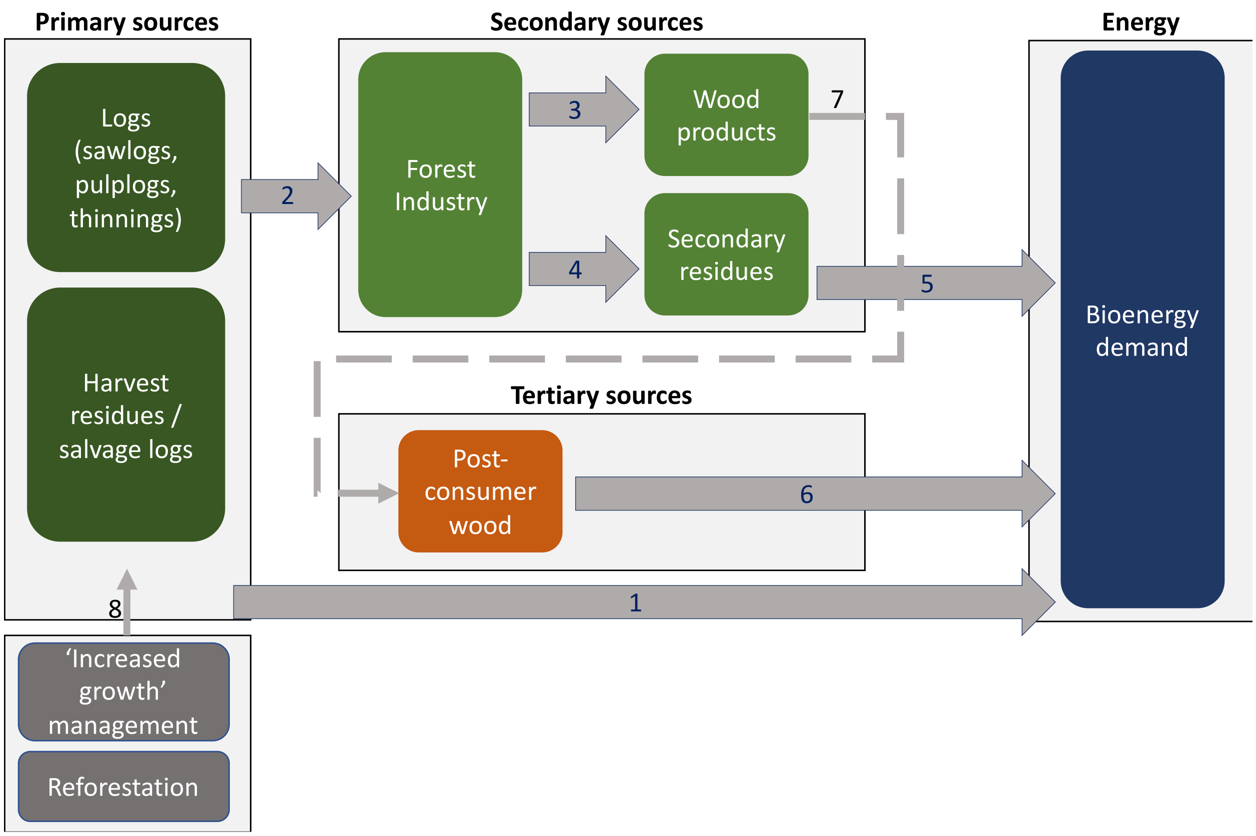


Figure 11: Schematic of wood flows and potential responses of the forest sector in Canada.

## A. INCREASED EXTRACTION OF PRIMARY BIOMASS.

In the first case examined, I consider that the additional bioenergy supply is satisfied by an increased supply of logs, e.g. through additional clearfelling or thinning operations, or by an increased supply of primary residues, i.e. logging residues (branches, tops, stumps) and salvage logs. Flow 1 in Figure 11 is thus increased. It is helpful to disaggregate the two responses as the quantities and impacts associated with them are very different.

### A.1) Dedicated harvest of logs for bioenergy

While most of the literature in Canada highlights how the main source of bioenergy is, and will likely remain, residual streams (i.e. primary logging residues or secondary industrial residues), Smyth et al. (2014) [45] did indeed investigate the carbon impacts of increasing clearfelling and increasing thinning area (and thus quantity of wood) for bioenergy.

Specifically, they modelled an increased stemwood harvest of 2.84 Mt(dry)/year from clearfelling and an increase of 1.3 Mt(dry)/year of commercial and pre-commercial thinnings by 2050. These quantities represent just a modest increase of between 2% and 5% of the current clearcut harvest. When converted to volume basis, to be comparable with the quantities in Figure 6, these convert to 6.0 and 2.8 $Mm^3$ swe, respectively. Taken together, these additional removals correspond to 40% of 2015 non-logs roundwood removals (i.e. pulpwood and other industrial roundwood). However, these additional resources could alone satisfy the increased demand for wood bioenergy forecasted by 2030.

Smyth et al. (2014) [45] find a clearly negative impact of increasing harvest on the total carbon balance of the forest sector, since the loss of carbon in the forest associated with the increased harvest of logs (see Table 1 and Figure 3 for details on these concepts) would not be compensated for by substitution benefits across Canada's economy. The authors find that no climate change mitigation would be achieved by 2050 through any of those two strategies. Therefore, **this scenario should be avoided**.

<u>A.2) Increased collection of logging residues and salvage logs.</u>

For the second response, the increased primary supply of wood to energy could be achieved by increasing the removal, collection, and use of forest residues and salvage logs. As indicated in Table 1, logging residues intended strictly as tree tops and branches have relatively short payback times. Some authors may include in the 'residues' category every wood product which is not economically profitable, including, e.g., crooked and small dimension stemwood produced during clearcut operations, thinning stems of pulplog quality, and even stumps. Establishing whether or not the energy use of these latter feedstocks actually contribute to carbon emissions mitigation is not straightforward.

In the last decade, the potential availability as well as technical, economic, and sustainable limitations to the recoverability of logging residues in Canada have been assessed in many publications. I collected the main estimates of potential availability from authoritative studies and reported them in boxplot format in Figure 12. To be noticed, these numbers may refer to slightly different concepts: while most studies exclude stumps from the available potential of residues, some studies report the total available potential [63] and thus show a high estimate (i.e. 31 Mt dry/yr), while other studies reduced the theoretical potential by 50% to account for techno-economic, as well as ecological, limitations to the extraction of residues (e.g. retention rates in the forest) [64]. Additionally, the studies employ different techniques to provide their estimates, ranging from statistical methods based on reported harvests, to numerical modelling, to remote sensing techniques.

Overall, though, the literature presents us an average value of 20.5 Mt dry/yr as available logging residues even when accounting for certain technical and ecological limitations. This number translates into about 43.6 $Mm^3$ of available wood for energy. Even if a part of this potential was already used for energy, and thus included in the figures in section 3.2, a fraction of this amount could easily cover the increasing demand for wood for energy by 2030 and beyond. In addition to this potential for harvest residues, studies report an even larger amount of residues available as salvage logging from fire or pest-affected stands. For instance, Mansuy et al. (2017) [64] reported an average of 47 Mt dry/yr available from fire-affected stands, while Dymond et al. (2010) [65] reported an average of 51 Mt dry/yr available from stands affected by natural disturbances. These numbers could easily cover the whole demand of wood for energy in Canada and also supply the growing industry of wood pellets for export.

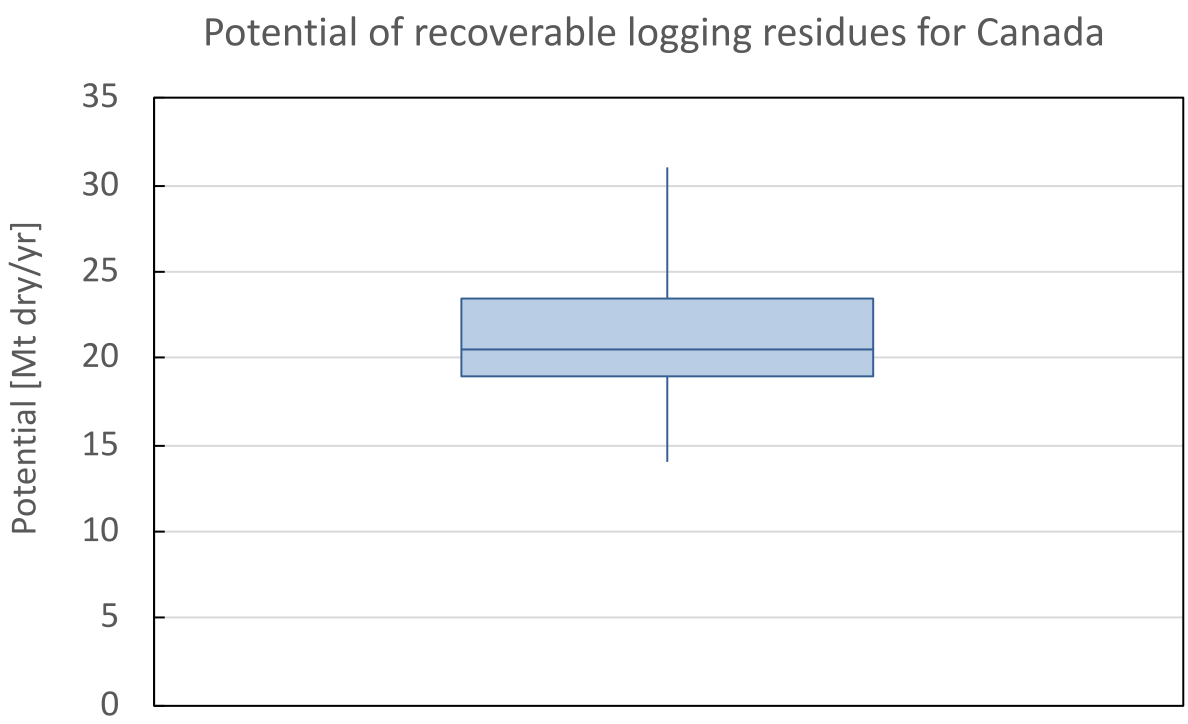


Figure 12: Collection of literature data estimating the potential for logging residues to be collected across Canada. Sources: [45,63–68]

The carbon benefits of using these resources, though, cannot be taken for granted. As detailed in Table 1, using logging residues for energy does not always generate immediate carbon mitigation. The most positive outcome is obtained when slash-burning (i.e. the practice of burning piles of residues at forest roadside either for pest prevention or fire control, or simply to dispose of the material) is avoided in favor of bioenergy production; in that case the climate benefits are immediate [5,6,69]. However, when the alternative fate of the residues is decomposition on the forest floor, payback times can range from a few years to more than a century (especially for slow-decaying coarse residues such as stumps) [6].

Smyth et al. (2017) [67] accounted for all the conditions above and for a mix of different residues in their model, and they found an average payback time of 6 years, with scenario results ranging up to 15 years when using harvest residues for bioenergy. Smyth et al. (2020) [69] finds immediate carbon benefits for British Columbia when slashburning is stopped and part (25%) of harvest residues are collected and used for bioenergy production (stumps are excluded from the residues removed). Nonetheless, Laganiére et al. (2017) [5] find that logging residues used to produce electricity in Canada, substituting natural gas electricity, would not achieve carbon mitigation before 100 years. Shorter payback times are found when residues are used to substitute fossil sources for the production of heat (due to lower differences in conversion efficiency). Additionally, they also investigated the use of salvage logs for energy, and they found that carbon mitigation is barely achieved (with a payback time of 90 years) when the logs are used to substitute coal as a source of heat, but no carbon mitigation is achieved in any other scenario. Carbon mitigation is achieved over shorter time periods only if the disturbed stand is replanted with faster-growing species; however this latter scenario is prone to potentially negative consequences on biodiversity which are out of the scope of this report, but should not be forgotten in a holistic assessment of bioenergy sustainability [7].

Overall, this assessment reveals that the potential available to use harvest residues and salvage logs for energy is high in Canada and alone would be sufficient to cover large part of the current and future demand of wood for energy.

While an increased use of these resources has the potential to provide climate change mitigation immediately or in a short-term, some risks remain. Indeed, most of the literature explicitly excludes stumps from the biomass availability potentials and from carbon accounting exercises [67]; and currently biomass harvesting guidelines across Canada's territories largely forbid or limit the removal of stumps for root rot prevention [70]. However, despite these existing safeguards and the currently scarce interest in large-scale stump removal for energy, the additional demand for woody biomass could easily lead to an increase in stump harvesting in Canada [71,72]. Therefore, I recommend the following safeguards and governance tools as necessary to achieve climate change mitigation:

1. Prioritize the collection and use of logging residues which would be otherwise burned at roadside;
2. Apply harvesting and management guidelines to guarantee that collection of residues is carried out in a way which does not negatively affect local biodiversity;
3. Discourage (or forbid altogether) the removal and collection of stumps and other coarse deadwood residues which might have important ecological functions, and which would not contribute to carbon emissions mitigation in the short term;
4. Favor the use of biomass to directly substitute coal where possible.

<u>A.3) Increased growth followed by increased harvest</u>

Rather than a simple increase in extraction of biomass from forests, an increase in bioenergy demand may also spark changes in forest management aimed at increasing forest growth or expanding forest land (flow nr. 8 in Figure 11). These responses are analyzed in depth in Giuntoli & Searle (2019) [73]. However, they found that none of these responses was likely directly linked to demand for wood pellets. Given that wood pellets sold on the international markets might have a much higher price than the bioenergy used for industrial and residential uses, as covered by CFS, I see it unlikely that CFS initiatives, and their effects on market prices, alone might drive these responses. However, an additional pillar of the PCF is indeed to increase the storage of C in forests, as well as a more recent commitment to the planting of 2 billion trees [62]; meaning that an increase in forest growth and forest area could indeed be a parallel activity under the PCF. Nonetheless, the timescales of such initiatives would be well beyond the 2030 timeframe and thus no wood for bioenergy would be obtained from these additional sources within the temporal scale of this assessment. On longer timescales, initiatives on increasing forest area or productivity will have indeed an advantage in the future when they might deliver additional wood to be used in the economy, together with increasing the C-sink of the biosphere.

## B. INCREASED USE OF SECONDARY RESIDUES

In this second case, I consider that flow nr. 5 might increase to supply more secondary residues (wood chips, sawdust, hogfuel) to be used as an energy source in industrial installations. Within this response, I see at least three cases which deserve more in-depth consideration.

### B.1) Better efficiency along the supply chain: surplus of secondary residues.

The more immediate case for scenario B.1 would be the valorization of unused secondary residues. For instance, Ghafghazi et al. (2017) [57] cite studies reporting that in 2004 there might have been up to 2.7 Mt dry of unutilized mill residues in Canada. However, their own research reveals that in 2013 only about 1.44 Mt dry of surplus residues might have been available across Canada (equal to about 3.1 $Mm^3$ swe). Dymond & Kamp (2014) [74] found a similar result for British Columbia: through a detailed survey across the forest industry, they showed that harvest numbers were consistently higher than the reported uses, indicating potential surplus of mill residues.

However, with the novel statistical analysis that I presented in section 3, I show that the situation in 2015 is quite different, with the total uses of wood now exceeding the reported harvest by at least 3.3%, but more likely by an amount between 5% and 10% (Section 3.2.3) . Provided the uncertainties highlighted in previous sections, my hypothesis is that the industry has already adapted to the available surplus of mill residues and has found new outlets for these resources, especially in the form of production of wood pellets for export. As indicated by Giuntoli et al., (2020) [22] indeed the production of wood pellets in Canada has increased by about 1.25 Mt dry/year between 2013-2018, and it might have absorbed most of the surplus of sawmill residues identified by previous studies.

Overall, my assessment is that the surplus of secondary mill residues is at present minimal, if existent at all, **and is basically irrelevant for supplying the future increase in bioenergy use**.

### B.2) Displacement & competition with other wood industries

If there were a decreasing demand in wood products, an increase in flows nr. 5 (from secondary products to bioenergy) and nr. 4 (forest industry to secondary products) in Figure 11 could be accompanied by a decrease in flow nr. 3 (forest industry to wood products), for instance with sawmills and other wood industries shifting their production towards more residues and energy generation, at the expenses of wood products.

While some tuning in the internal parameters of wood industries could take place to maximize profit and benefit from eventual additional bioenergy demand, this is unlikely to occur at large scale as bioenergy would have to reach very high price points, and at the same time demand for wood products decrease dramatically. The latter especially is counter to other initiatives in the PCF (such as incentivizing the use of wood products). Nonetheless, competition might affect the wood industries which rely on the cheapest feedstocks, such as the panel industry. Hope et al. (2020) [75] simulated the possible competition for sawmill residues across various sectors and industries once PCF measures start to affect the price of fossil carbon and the CFS enters into force. They find that indeed in the mid-to-long term, PCF initiatives might contribute to making wood bioenergy attractive to industrial actors which might in turn price-out the panel industry. The second-order effects of this price mechanism might be multiple, including the following possibilities where in brackets I try to estimate whether the overall carbon impact might be positive and lead to mitigation or negative):

i. Demand for wood panels decreases elastically in favor of non-wood materials, causing an increase in GHG emissions and use of non-renewable resources (*negative*);
ii. Demand for wood panels decreases elastically in favor of imported wood panels with subsequent third-order effects in other countries (*unclear*);
iii. Demand for pulp continues to decrease due to exogenous factors such as digitalization, and sawmill residues resources are freed and diverted to energy (*neutral* – independent from bioenergy demand);
iv. Development of new, cheaper supply chains of wood fibre such as using harvest residues (reflecting Scenario A.2: Increased collection of logging residues and salvage logs – *likely positive* under the caveats explained in A.2);
v. The panel industry develops additional supply chains based on additional harvest of virgin pulpwood (reverting to Scenario A1 – *negative*);
vi. Production of sawnwood might increase together with the production of sawmill residues, as further discussed below in scenario B.3.

The forest sector has strong interlinkages across sectors and geographic scales that might lead to unexpected effects, and as highlighted above, several potential routes lead to negative overall carbon balance and to the use of virgin roundwood directly for energy purposes. My recommendation is to investigate these potential second and third-order effects through appropriate economic-equilibrium models in order to highlight potential criticalities. This is further explored in the next scenario.

B.3) Energy as a driver of increased wood products production and consumption.

Modelling exercises focusing on the EU situation [17,42] have shown that the demand of forest bioenergy is strongly linked to the production of sawnwood. This is explained by the fact that models forecast an increased demand of sawmill residues as a primary feedstock for the bioenergy industry, this would in turn increase the price of sawmill residues and make sawmills more profitable, which in turn would stimulate an increased production of sawnwood. This is a likely possibility also for Canada, as shown in Figure 11, where an increase in flow 5 (from secondary products to bioenergy), given a constant ratio between flow 4 and flow 3 (i.e. production of sawnwood increases proportionally to production of sawmill residues), would basically translate into an increase in harvest of roundwood (flow 2).

The two main issues to be explored for this scenario are the following: 1) would market forces be enough to stimulate this scenario; 2) Would the scenario achieve an overall climate mitigation or not?

Concerning the first point, Forsell et al. (2016) [76] find that this scenario is particularly relevant when the direct use of roundwood for energy (i.e. Scenario A1) is **explicitly forbidden by the policy**. However, Jonsson & Rinaldi (2017) [42] find that market forces (i.e. increased demand for wood pellets in EU) would be enough to stimulate an increase in sawnwood production and subsequent sawnwood export. However, it is not clear from these exercises what would happen on the global sawnwood market: for instance, a large increase in sawnwood production which is not followed by a proportional increase in demand could simply deflate once more the price of sawnwood and drive sawmills to shift their output share, favoring more residues over sawnwood basically leading again to scenario A1 where sawlogs are used for energy (additionally, this scenario could also take place to bypass eventual legislation forbidding the use of roundwood directly for energy).

On the second aspect of overall GHG performance, both studies mentioned above state clearly that a simultaneous increase of sawnwood and sawmill residues would lead to increase harvest levels from forests. Therefore, this increased depletion of forest C-stock would have to be balanced by the substitution of construction products, the accumulation of C in the HWP pool, and the substitution of fossil fuels.

None of the modeling frameworks described above has fully clarified the two issues I raise: Forsell et al. (2016) [17,76] did not include a representation of the construction materials' market in their modelling framework nor used substitution factors as proxy, and thus did not completely quantify the carbon impacts of the scenarios assessed. Jonsson & Rinaldi (2017) [42] did not include a full GHG accounting in their economic analysis. The modelling framework employed by Smyth et al. (2014) [45], on the other hand, has a detailed and overarching biophysical framework to account for the carbon flows, but it does not include an economic model to account for market-mediated effects. Therefore, my main recommendation **is that this scenario should be further studied and modelled to better understand its overall carbon balance and the governance and policy requirements to achieve the highest benefits.**

It is hard to speculate on what the final carbon impact of this scenario would be for Canada; however, it is likely that it might achieve a much better result than scenario A.1 where increased wood harvest is solely dedicated to energy use. Due to the triple benefit of using wood for long-lived wood products (see Section 2), this scenario could simply realize as a direct consequence of actively promoting the use of wood for materials through dedicated policies, rather than promoting the use of forest bioenergy. In that case, bioenergy feedstock would be generated as a by-product of increased wood materials production and its carbon impact would likely be positive. Matthews and colleagues (2018) [33] have reached similar conclusions for the EU. Although there are already signs of the shift towards a more holistic governance of the sustainability of the whole bioeconomy [77] as opposed to the existing sectorial policies.

## C. INCREASED RECOVERY OF TERTIARY SOURCES

The final scenario to increase bioenergy use would be to increase the recovery of post-consumer wood (PCW), thus increasing flow nr. 6 in Figure 11.

As of 2015, only 0.07 $Mm^3$ of postconsumer wood were recorded as being used for energy generation in Canada; this value represents barely a 0.3% of the total wood products (excl. pulp and paper) consumed in the same year. While data on wood waste management is particularly scant in Canada, Sidders et al. (2008) [63] calculated the potential amount of available urban wood residues, based on population density, to be equal to 9.8 Mt dry/yr, or about 20.8 $Mm^3$/yr. This value confirms my previous estimate, that the amount used currently equals only to 0.33% of the available potential.

C.1) Increased recovery of post-consumer wood

Therefore, there is large potential available of this resource that could be recovered through improved waste management and used for energy generation.

Evaluating the carbon balance of using post-consumer wood for energy is not straightforward. The first aspect to be considered is the presence of potential contaminants (e.g. resins, paints etc.…) that when combusted might release large amounts of N2O and thus significantly increase the GHG emissions of bioenergy from PCW. For instance, Röder & Thornley (2018) [78] found that the presence of urea formaldehyde and urea melamine in MDF could lead to higher GHG emissions from PCW bioenergy compared to using natural gas or fuel oil.

Secondly, the actual alternative use of PCW needs to be considered to evaluate the net benefits/impacts of using PCW for bioenergy. Let's consider that around 97% of Canada's waste is landfilled [79], and that wood does not degrade significantly in landfills. On the other hand, when PCW is used for bioenergy, the biogenic-C is released immediately, producing more $CO_2$ than even using coal[3] [4]. Therefore, landfilling PCW will always be more beneficial to the climate than using PCW for bioenergy.

This said, this analysis focuses solely on carbon and GHG emissions, but there are many additional aspects to be considered when evaluating the environmental and overall sustainability of bioenergy recovery vis a vis landfilling. Indeed, disposal is placed at the bottom of the waste hierarchy, and other factors such as resource efficiency, land occupation, economic return etc.…should be fully evaluated [80]. Additionally, when comparing PCW to other bioenergy feedstocks, such as a logs or even logging residues, impacts on ecosystems besides carbon, should be carefully evaluated: increasing bioenergy use by removing logging residues which might constitute important habitats for several species [6] might have a more detrimental impact than using PCW.

My recommendation is to investigate further the potential for PCW bioenergy across Canada and its carbon impacts compared to other bioenergy sources, as this hasn't been tackled yet in any of the strategic assessment found in the literature. Nonetheless, even with

[3] E.g. consider that wood has a Lower Heating value of 19 MJ/kg dry, and that 50% of dry wood mass is Carbon, this brings to: 19 / 0.5 * 44/12 = 139 $gCO_2$/MJ of dry wood. Coal emissions can be considered around 112 $gCO_2$ eq./MJ coal according to Giuntoli et al. (2017) [81]

the existing uncertainty, my recommendation is to favor the use of PCW to satisfy part of the bioenergy demand, and especially **to actively promote it in situations in which sawmill residues are unavailable, slash burning is not practiced regularly, and access to pulplogs and other roundwood is abundant and would thus be the likely main source for new bioenergy installations.**

# 5. LIMITATIONS, CONCLUSIONS AND RECOMMENDATIONS

This report aims to shine some clarity on the potential climate impacts due to an increased demand of wood for bioenergy in Canada following the implementation of the expected Clean Fuels Standard and other climate mitigation initiatives linked to the Pan-Canadian Framework. The political will from the Federal Government is to achieve a 30% GHG emissions reduction by 2030 compared to 2005, and to achieve a net zero GHG emissions by 2050.

However, lessons learned in the past decade of bioenergy policy have shown that initiatives aimed at increasing the use of bioenergy can impact complex social-ecological systems across geographical, temporal, and jurisdictional scales [58]. Hence, this work had the main goal of providing a clear framing of the problem to support policy makers in designing the proper governance tools to guarantee that their good intentions are realized. Firstly, I introduced the issues with carbon accounting of forest bioenergy as emerging from a decade of experience in EU and US. The main message of section 2 is to properly interpret the results of LCA studies, and especially that simplified GHG accounting, such as the one expected to be used in Canada's CFS, does not capture the actual carbon impact of the whole policy, since biogenic-C emissions and potential market-mediated impacts are excluded.

In section 3, I provided a more systemic perspective on the potential impacts of policy decisions. I used official statistics on wood removals and uses to sketch a full picture of the whole forestry sector in Canada. This exercise presents a compelling evidence of wood flows across Canada's economy and it attempts to reconcile several diverging datasets from official Canadian sources on wood-based bioenergy. The picture emerging is that existing uses of wood already exceed the officially reported wood removals by at least 3.3%, but likely this value could amount to between 5-10%. It also emerges clearly that for Canada, similarly to other countries who have tackled this issue before, statistical data on wood consumption for energy are incomplete and would deserve further investigation to clearly pinpoint the origin of the unaccounted wood removals.

Based on current amounts of wood-based bioenergy, I have then calculated the amount of additional wood resources that are forecasted to be used for energy by 2030 and I have found this number to be between 2 $Mm^3$ and 5 $Mm^3$ of additional wood-based bioenergy under a scenario including many climate policies, but excluding CFS. This number highlights how the current expectations for wood bioenergy are quite low in Canada, although this might change with the full implementation of CFS and additional measures to reach the

2030/2050 climate targets. However, these numbers are still low compared to the size of the forest sector in Canada (between 1% and 3% of total removals).

In section 4 I have tried to sketch the causal relationships among the various industries to define the potential responses of the system to an increased demand of wood-based bioenergy. From the available literature, I have defined seven main possible scenarios, and I have then qualified their potential impacts on carbon emissions. Table 3 summarizes my qualitative conclusions and assessment. Additionally, I have drawn some recommendations for the governance of sustainable bioenergy based on these findings. The two scenarios which are mainly studied in the literature involve the increased use of harvest residues (i.e. tops and branches from clearfelling operations) as well as the potential use of surplus sawmill residues. This report clarifies that the latter is actually irrelevant at this stage since wood uses already exceed removals rather than the opposite. Concerning the use of harvest residues, the literature reports very large amounts potentially available for collection and use, as well as even higher amounts of salvage logs available from stands affected by natural disturbances. While the use of harvest residues for energy is likely to have better climate mitigation potential than harvesting additional roundwood for energy, there are still safeguards that should be implemented to avoid negative impacts, listed in Table 3.

This study has certain limitations. To begin with, all datasets used are taken from official statistical sources, so any error in those datasets will be translated into this work. Secondly, despite enquiring for clarification on the data presented in section 3.2.3 with the various Canadian entities responsible for these data, I was unable to resolve all discrepancies; Figure 8, thus, represents my best understanding of these datasets, but misinterpretation is possible. Nonetheless, the considerations and conclusions of this report would likely remain the same even if this is the case.

Finally, while this work focuses on impacts on carbon emissions, the potential environmental impacts and benefits of bioenergy are much broader, especially on local biodiversity and ecosystems' health. We refer the reader to Giuntoli et al. (2020) [25] for a first impression on other potential impacts and relevant literature.

Table 3: Summary table of assessment of potential scenarios resulting from increased demand of wood for bioenergy in Canada, the potential associated C-impacts and the governance recommendations learned through this report.

| Supply source | Scenario | Potential availability | Potential C-impacts | Governance recommendation |
|---|---|---|---|---|
| Primary | A.1) Dedicated harvest of logs for bioenergy | Very high (potentially) | Very negative | Avoid |
| | A.2) Increased collection of logging residues and salvage logs | High | From very good to very negative | 1. Prioritize the collection and use of logging residues which would be burned at roadside;<br>2. Apply management guidelines to guarantee that collection of residues is carried out in a way which does not negatively affect local biodiversity;<br>3. Discourage (or forbid) the removal and collection of stumps and other coarse deadwood residues which might have important ecological functions;<br>4. Favor the use of biomass to directly substitute coal where possible. |
| | A.3) Increased growth followed by increased harvest | Very high (potentially) | Good | Promote (already in PCF priorities), but wood will be available only in the long-term |
| Secondary | B.1) Better efficiency along the supply chain: surplus of secondary residues. | None | Very good | Irrelevant |

| | | | | |
|---|---|---|---|---|
| | B.2) Displacement & competition with other wood industries | Price driven | From negative to positive | • Second and third-order effects should be evaluated carefully through economic modelling.<br>• Design policy tools to avoid the use of virgin roundwood directly for energy. |
| | B.3) Energy as a driver of increased wood products production and consumption. | Price driven | Uncertain | • Scenario should be modelled to quantify potential benefits or impacts.<br>• Design more holistic governance tools for the whole bioeconomy rather than sectorial, bioenergy, incentives.<br>• For instance, direct support for domestic production of long-lived wood products, rather than bioenergy, could promote this scenario, with bioenergy as a by-product. |
| Tertiary | C.1) Increased energy recovery from post-consumer wood | High | Likely negative | • Evaluate broader sustainability aspects (beyond carbon) of landfilling vs energy recovery on a case-by-case basis.<br>• Actively promote increased energy recovery in situations in which sawmill residues are unavailable, slash burning is not practiced regularly, and access to pulplogs and other roundwood is abundant and would thus be the likely main source for new bioenergy installations. |

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