Scientific advisory report

The use of forest biomass to reduce greenhouse gas emissions in Quebec

Québec

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The use of forest biomass to reduce greenhouse gas emissions in Quebec

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Executive Summary

Background

The Intergovernmental Panel on Climate Change (IPCC, 2011) has supported the development of greenhouse gas (GHG) reduction targets aimed at stabilizing the global atmospheric concentration of CO_2 below 450 parts per million (PPM) by 2050. Quebec has undertaken to reduce its GHG emissions by 2012, 2020 and 2050 in keeping with this threshold and made a specific commitment to use forest biomass as a substitute for fossil fuels in order to meet its emission reduction objectives.

Mandate of the *Comité sur la contribution du secteur forestier à la lutte contre les changements climatiques* (Committee on the forest sector contribution to the fight against climate change)

In this context, the Committee's goal is to reach a common understanding of the science surrounding the issues related to forest biomass utilization for bioenergy, in order to support informed decision making. The Committee's findings and recommendations, which relate solely to Quebec, are based on a sustainable forest management approach that takes into account the importance of maintaining soil productivity and forest site productivity.

In this document, a forest biomass project involves the use of a single source of forest biomass or a combination of sources (harvest residues from forest management activities, residual biomass from industrial processes, post-consumption wood waste, and biomass from energy plantations) to produce energy in the form of heat, steam or electricity.

Highlights

- As the IPCC has stated, forest biomass is an important tool in the fight against climate change. Biomass is a renewable energy source which provides lasting climate-related benefits that accumulate over time.

- Initially, a biomass project may produce higher emissions than a reference scenario based on the use of fossil fuels. This "carbon debt" causes a delay in the reduction of GHG emissions.

- The type of forest biomass (for example, harvest residues, industrial waste, live trees) that is used has a significant influence on the time required to pay off the carbon debt (carbon debt recovery time).

- Reductions in GHG emissions are achieved more quickly in bioenergy projects that use residues from industrial processes or forest harvests, post-consumption wood waste, or biomass from energy plantations on abandoned farm lands.

- Carbon neutrality is not a good benchmark for evaluating forest biomass bioenergy projects. The fact that forest biomass projects cannot be considered carbon neutral does not mean that the use of forest biomass for energy should be ruled out.

- The shift to renewable energy sources in the energy supply system will take several decades. Bioenergy projects that bring about reductions in GHG emissions in the longer term should therefore also be part of a renewable energy strategy.

Committee recommendations

- The Committee recommends that every forest biomass project be evaluated through a comprehensive life-cycle analysis that considers the distribution of GHG emissions over time, including emissions from the forest ecosystem in which the biomass was harvested.

- In order to maximize reductions in GHG emissions over the short term (2020), the Committee recommends that priority be given to forest biomass projects that are characterized by:
  - the use of wood residues from all sources, or from dedicated biomass production activities such as energy plantations on non-forest land or intensification of forest management;
  - the use of high efficiency conversion methods to generate energy, such as heat production and cogeneration;
  - the replacement of coal on a priority basis, followed by oil products and then natural gas.

- In order to maximize reductions in GHG emissions over the medium and long term, the Committee recommends the continued development and analysis of forest biomass scenarios that could lead to real reductions by 2050.

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1. Climate change: an urgent issue

At present, climate change is an inescapable social issue which affects human populations and their environment at different scales and has scientific, economic and geopolitical dimensions. A consensus now exists within the global scientific community that the climate changes occurring at present have been caused largely by the greenhouse gases (GHG) released into the atmosphere by human activities, particularly the burning of fossil fuels and deforestation. The mean global surface temperature increased by about 0.74°C between 1906 and 2005 (Intergovernmental Panel on Climate Change, 2007). While this may seem like a small increase, it is indicative of the global warming trend that is occurring, as are the changes in global precipitation patterns and the increased frequency of extreme weather events.

In Quebec, the annual mean temperature increased by approximately 0.5 to 1.2°C between 1960 and 2003. By 2050, the temperature increase is expected to range from 2.5 to 3.8°C in southern Quebec, and from 4.5 to 6.5°C in northern Quebec. Precipitation is expected to increase by 8.6 to 18.9% in southern Quebec, and by 16.8 to 29.4% in northern Quebec. These climatic changes will have a significant impact on economic activities, human health, infrastructure and natural ecosystems in the province (Desjarlais et al., 2010).

In light of the observed and expected changes, the IPCC emphasized the need for prompt action and urged GHG emitters to help stabilize atmospheric CO_2 concentrations at or below the 450 ppm threshold by 2050. This would limit global warming to 2°C, a critical threshold beyond which major impacts on ecosystems are likely. In a recent report, the International Energy Agency stated that this 450 ppm threshold could be reached as early as 2017 unless radical action is taken (International Energy Agency, 2011). Under the Kyoto Protocol, the first international agreement aimed at reducing global GHG emissions, industrialized counties agreed to collectively reduce their GHG emissions by 5.2% from the 1990 level between 2008 and 2012.

The Intergovernmental Panel on Climate Change (IPCC)

The IPCC was established in 1988 by two United Nations (UN) agencies, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), to document climate change, gain insight into the underlying causes, project future climate change, identify potential impacts and come up with climate change mitigation and adaptation strategies (Intergovernmental Panel on Climate Change, 2007).

The IPCC produces reports at regular intervals on the current state of research in order to inform decision makers about the climate change implications of their choices.

The IPCC recognizes the importance of forestry and of forest products in the fight against climate change:

> "In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit." (Nabuurs et al., 2007)

The IPCC underscores the crucial role that bioenergy can play in mitigating GHG emissions as a substitute for fossil fuels (Chum et al., 2011). However, as the extensive scientific literature on the topic indicates, rigorous accounting of GHG emissions is necessary to ensure that emission reductions produce real benefits and that climate change mitigation strategies are effective (van Renssen, 2011).

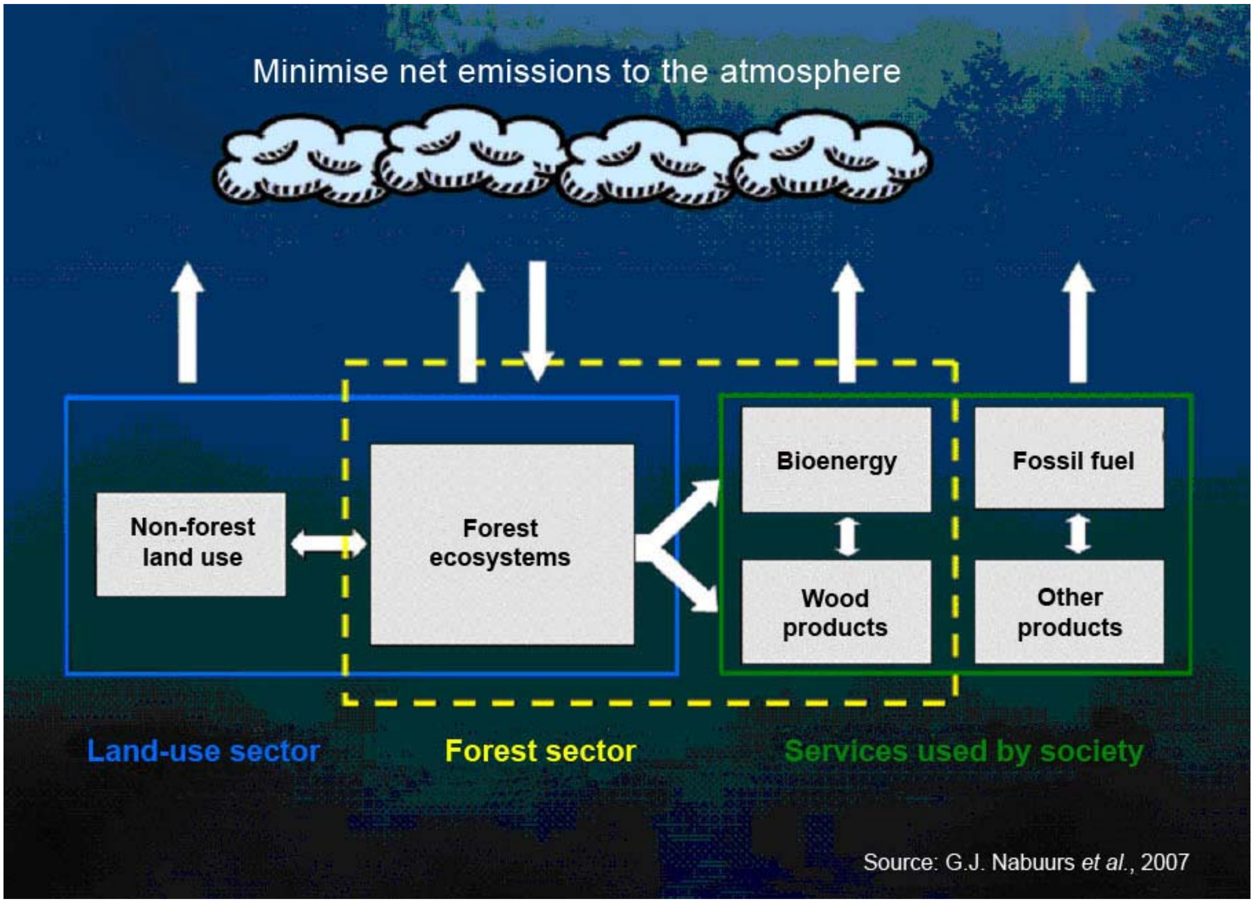

Figure 1: Forest sector contribution to GHG mitigation

Taking a broader perspective, if we want to incorporate renewable energies in today's energy system, major structural changes will be required over the coming decades (Moomaw et al., 2011). It took approximately 50 to 70 years for fossil fuels to come into widespread use (Kerr, 2010). The transition to renewable sources of energy, including forest biomass, will undoubtedly take just as long, mainly because of their lower energy density (i.e., the amount of energy produced per unit of mass) relative to fossil fuels. Consequently, given the urgency of the situation, actions that produce beneficial results rapidly should be implemented in the short term (e.g., by 2020). It is important to consider these target dates as milestones in the transformation of the energy system, which will likely take several decades.

2. Quebec context

Quebec has been engaged in the fight against climate change since 1992, when it embraced the objectives and principles of the United Nations Framework Convention on Climate Change (UNFCCC). In 2007, this commitment was strengthened when Quebec announced that it would abide by the Kyoto Protocol. The government adopted the following reduction targets for its GHG emissions relative to the 1990 level: reduction of 6% by 2012 and 20% by 2020. In 2001, at the New England Governors and Eastern Canadian Premiers Conference, Quebec also endorsed the objective of reducing GHG emissions regionally by 75 to 85%, by 2050, relative to the 2001 level.

In 2008, as part of the reform of its forest regime, Quebec's Ministère des Ressources naturelles (Department of Natural Resources and Wildlife) undertook to develop an industrial strategy based on high added-value products (Ministère des Ressources naturelles et de la Faune, 2008). One of the strategy's four areas of focus relates to the use of forest biomass for energy production. In 2009, under its action plan to develop forest biomass, the Quebec government emphasized the potential environmental gains from the development of the biomass sector in Quebec (Ministère des ressources naturelles et de la faune, 2009).

3. Mandate

In view of the changing knowledge base, Forêt Québec commissioned a group of scientists, experts and stakeholders (the Comité sur la contribution du secteur forestier à la lutte contre les changements climatiques) to prepare an advisory report on the contribution of forest biomass to the fight against climate change. The objective was to provide a summary of the current state of scientific knowledge in this area and to support future policies and actions of the Ministère des Ressources naturelles. The Committee's final aim is to develop a common vision of the science related to forest biomass in order to better understand what role this type of biomass can play in reducing GHG emission, and in order to identify and prioritize the most promising actions in this regard.

In this document, the Committee does not deal with non-gaseous by-products of wood and fossil fuel combustion, such as fine particulates or soot, in spite of their impact on climate. The report focuses on the contribution that forest biomass utilization for bioenergy makes to the GHG balance. It should be noted that, for simplicity's sake, the total GHG emissions from forest biomass combustion and from fossil fuel combustion are expressed in terms of their respective CO_2 equivalent emissions.

In Quebec, the benefits of CO_2 emission reductions resulting from the use of forest biomass for bioenergy must be evaluated according to a sustainable forest management approach which requires that economic, social and environmental aspects be taken into account in decision making (Ministère des Ressources naturelles et de la Faune, 2010). The development of the bioenergy sector therefore depends on the social acceptability of forest biomass practices and must promote the economic vitality of the regions concerned. Environmental monitoring, prevention of impacts through the identification of sites at risk (Thiffault et al., 2011) and appropriate regulation of harvesting intensity are also an inherent part of project development.

4. Contribution of forest biomass to CO_2 emissions reductions

Biomass utilization is often characterized as “carbon neutral,” a notion based on the fact that the carbon released into the atmosphere as CO_2 from biomass combustion was previously removed from the atmosphere as CO_2 during plant growth. In the context of bioenergy project analysis, this is a flawed concept, because it does not consider the temporal distribution of CO_2 emissions or the options to be considered in evaluating such projects. For example, if trees are not harvested for bioenergy, they continue to absorb atmospheric carbon. When biomass is burned, not only does carbon sequestration end but carbon dioxide is released into the atmosphere. The use of the carbon neutrality assumption in assessing bioenergy projects has been invalidated by many international scientific studies (Searchinger et al., 2009; Cherubini et al., 2011; Haberl et al., 2012), by the U.S. Environmental Protection Agency and by the European Environment Agency’s scientific committee. In short, carbon neutrality therefore cannot be used as a scientific basis for developing bioenergy policy.

Setting aside the carbon neutral assumption does not invalidate the use of forest biomass for bioenergy for emission reduction. Instead, bioenergy policies must be developed by taking into account the temporal dynamics of CO_2 emissions from biomass projects relative to a fossil fuel based reference scenario. This is important in order to promote bioenergy options that provide benefits within a reasonable time frame.

CO_2 emissions from forest biomass combustion are typically higher per unit of energy produced than those from the burning of fossil fuels because biomass contains less energy per unit of carbon than oil products and natural gas. In addition, biomass often has lower conversion efficiency than fossil fuels. These two factors lead to a carbon debt in the first few years of most forest biomass based bioenergy projects. This state of affairs is widely recognized in the international scientific literature (Bird et al., 2011). Carbon debt recovery can take anywhere from a few years to several decades, a period whose length is determined in large part by the CO_2 dynamics of the biological system from which the biomass is sourced.

The biological processes of the carbon cycle ultimately favour the use of forest biomass for bioenergy. Compared with fossil fuel consumption, bioenergy from forest biomass always leads to a reduction in CO_2 emissions, provided the forest is managed sustainably, because the trees re-grow and because harvest residues and industrial wood waste end up decomposing naturally. In a biomass project, a fossil fuel with a cycle of millions of years is replaced by a biological fuel with a cycle ranging from a few years to a few decades. The issue here is not to show that a gain exists, but rather to determine when it will occur and how large it will be.

4.1 Sources of forest biomass

The main forest biomass sources consist of residues from forest management activities, salvaged wood, residual biomass from industrial processing and from post-consumption wood waste, and energy plantations. Harvesting of living trees in natural forests for bioenergy production is not a common practice. In this report, it is considered a temporary option that may be envisaged to alleviate disruptions in the supply of the other biomass sources mentioned above.

4.1.1 Residues from forest management activities

Residues from forest management activities consist of all the extracted woody material that is not destined for processing into traditional forest products. This includes the branches and crowns of trees (where the bole is used to manufacture traditional forest products) and poor-quality non-merchantable stems or non-commercial species cut down during silvicultural operations.

4.1.2 Salvaged wood

This biomass source comprises dead trees in stands affected by fire or insect outbreaks that have become unsuitable for processing into traditional forest products.

4.1.3 Residual biomass from industrial processing

Bark, sawdust and pulping liquor (“black liquor”) are the main by-products of industrial processes (Paré et al., 2011; Dymond et al., 2010). The large majority of residual biomass from manufacturing processes is already slated for the manufacture of wood products, such as particleboard and pulp, as well as for energy production (heat and/or electricity) (Paré et al., 2011). However, the proportion of residual biomass that is used for these different applications varies over time and depends on industry requirements.

4.1.4 Post-consumption wood waste

Post-consumption wood residues consist of urban wood waste mainly from demolition activities. A large portion of post-consumption residues are used to manufacture solid products, but some of this material ends up in landfills. The *Quebec Residual Materials Management Policy – 2011-2015 Action Plan (Allier économie et environnement)* stipulates that, as of 2014, wood residues can no longer be sent to landfill sites. This could increase the availability of usable wood residues for energy production (Ministère du Développement durable, de l’Environnement et des Parcs, 2011).

4.1.5 Energy plantations

Using agricultural, fallow and marginal land to establish short-rotation plantations of trees or shrubs destined for energy production increases the amount of available biomass thanks to the plantations’ higher productivity per unit area (Paré et al., 2011; Réseau ligniculture Québec, 2008). The use of energy plantations raises a number of issues. These plantations have higher CO_2 emissions than those associated with biomass extracted from natural forests because of the agricultural mode of production used. In spite of their proximity to users, these plantations are often not economically viable because of the opportunity cost associated with removing agricultural land from production (Natural Resources Canada, 2010a and b; Réseau ligniculture Québec, 2008). In Quebec, a large portion of agricultural land is currently fallow and could, theoretically, be converted to energy plantations. Because these plantations are dedicated to bioenergy production and because the alternative is to leave the land fallow, which is not conducive to carbon sequestration, this biomass source can be considered carbon neutral, aside from the CO_2 emissions associated with the biomass harvested. Intensified forest management aimed at biomass production could also hypothetically generate excess biomass volumes that would likewise be carbon neutral because of all the CO_2 sequestered before the biomass is burned.

4.2 Contribution of the different biomass sources to emissions reductions

The CO_2 emissions reductions associated with the use of forest biomass as a substitute for fossil fuels is assessed by comparing the emissions in a “bioenergy scenario” (biomass utilization for energy) with those in a reference scenario (representing the situation that would exist without the biomass project). In practical terms, this involves determining all the activities associated with a biomass project in the bioenergy scenario and comparing all the sinks (processes that remove CO_2 from the atmosphere) that exist over time, as well as the total emissions associated with the production of a given amount of energy for each scenario. This is called a comparative life-cycle assessment.

The complexity of comparative life-cycle assessment depends on the complexity of the choices and consequences associated with the establishment of a forest biomass bioenergy project and the complexity of the technologies used. These analyses show that the type of forest biomass used has a strong influence on the time frame in which projects generate reductions in GHG emissions. All other things being equal, the different types of forest biomass can be grouped in three carbon debt recovery time frames. The number of years characterizing each time frame is approximate and corresponds to a project involving efficient energy extraction from biomass (for example, a heat generation project).

Short term (less than 10 years): post-consumption wood residues, industrial residues, harvest residues and other forest management residues that decompose rapidly (for example, small trees from pre-commercial thinning operations) and biomass extracted from short-rotation afforestation plantations.

Medium term (10 to 20 years): wood salvaged following natural disturbances, stumps and large stems of non-commercial species cut during harvesting operations and left on site.

Long term (several decades): live trees from natural forests or from plantations resulting from the conversion of mature forests.

It is easy to establish the reference scenario and compare it with the bioenergy scenario when the biomass sources for bioenergy production consist of harvest residues, post-consumption wood waste, residues from industrial processes (e.g., pulping liquor) or another type of residual biomass, which, if not used, would decompose and release CO_2 to the atmosphere within a short time period. In these cases, CO_2 emission reductions are certain and achieved rapidly with little risk. This is also true for biomass from an area specifically managed to obtain surplus biomass, such as energy plantations established on abandoned agricultural land.

With biomass sources such as live trees, the benefits of emission reductions are long-term, uncertain and less predictable. In the reference scenario, these trees would likely continue to absorb carbon for a number of years, thereby offsetting fossil fuel emissions. However, alternatively, the trees might be subjected to a natural disturbance such as a fire or insect outbreak, or they might be harvested to obtain other products. Since many assumptions can be made, it is more difficult to predict the carbon debt payback period and the real benefits (reduced GHG concentrations) over the long term.

The conversion of natural forests to biomass energy plantations is known to have an adverse effect on climate. Replacing a mature forest with an energy plantation results in significant emissions of CO_2 owing to the decrease in carbon stocks. In such cases, the carbon debt recovery period is often very long, despite the fact that the biomass utilization offsets fossil fuel use (Righelato and Spracklen, 2007).

4.3 Other important factors

The degree of certainty associated with achieving benefits from the use of forest biomass for bioenergy and the time frame in which these benefits are obtained depend on the forest biomass source used. Other factors may also have an effect, specifically the method used to convert the biomass to energy (energy generation efficiency) and the type of fossil fuel replaced.

4.3.1 Energy conversion methods

The amount of useful energy obtained from forest biomass depends on the conversion method used. For example, the conversion efficiency for the production of electricity by thermal power plants ranges from 35 to 45%, compared with an efficiency of 90% and 85% for boilers generating heat alone and boilers used for cogeneration (heating and electricity combined), respectively (European Environment Agency, 2010). Energy conversion methods can therefore be prioritized as follows:

1. Heat and cogeneration
2. Electricity
3. Biofuel

4.3.2 Fossil fuels replaced

Some fossil fuels release more CO_2 per unit of energy than others, and replacement of those fuels on a priority basis leads to earlier and larger climate change mitigation benefits in a bioenergy project. Fossil fuels can be ranked in decreasing order of CO_2 (kg/GJ) emissions; the fuel with the highest emissions therefore represents the top priority for biomass substitution (Agence de l’efficacité énergétique, 2009):

1. Coal: 92,385 kg CO_2/GJ
2. Heavy fuel oil: 74,032 kg CO_2/GJ
3. Light fuel oil, diesel: 70,483/72,125 kg CO_2/GJ
4. Gasoline: 68,145/73,156 kg CO_2/GJ
5. Natural gas: 50,198 kg CO_2/GJ

In addition, very high pre-consumption (upstream) emissions are associated with the extraction of some fossil fuels. For example, all the methods used to extract oil generate significant upstream emissions which are much higher than those associated with forest biomass. Upstream emissions may be especially high in connection with oil extraction by steam injection or flaring, the burning off of waste gas during oil extraction. Flaring is still performed in some oil wells not yet connected to a natural gas pipeline. The refining process also generates significant emissions because of the combustion of waste gas from the fractional distillation process. Collectively, these emission sources account for 25% of smokestack emissions (Air Resource Board, 2009; Manomet Center for Conservation Sciences, 2010).

Table 1 shows the important effect that biomass type and project parameters have on the carbon debt recovery period. Certification processes related to liquid biofuels incorporate a time-related criterion (Scarlat and Dallemand, 2011; van Dam, Junginger and Faaij, 2010). It is generally recognized that the effects on GHG emissions must be calculated using a horizon of 20 or 30 years (ibid).

Table 1 Examples of carbon debt recovery times relative to the main parameters of projects (analysis methods may vary among projects)

Debt (years)	Type of forest biomass used	Method of conversion (energy produced)	Fossil fuel replaced	Reference
4	Branches	Heat	Natural gas	Repo, Tuomi and Lisk, 2010
6	Harvest residues[1]	Heat	Fuel oil	Bernier and Paré, 2012
22	Stumps	Heat	Natural gas	Repo, Tuomi and Lisk, 2010
70-75	Merchantable stems[2]	Heat (residential and urban heating)	Fuel oil	Manuilova and Johnston, 2011
74	Harvest residues	Ethanol	Gasoline (E85 fuel)	McKechnie et al., 2011
90	Whole trees[3]	Heat	Fuel oil	Bernier and Paré, 2012
> 100	Whole trees	Ethanol	Gasoline (E85 fuel)	McKechnie et al., 2011

1. Harvest residues: non-commercial portions of tree, generally the branches and, sometimes, the stem tip.
2. Stem: main part of tree between stump and top
3. Whole tree: all the aerial parts of the tree, including the stem and the branches.

5. Simplified example of life-cycle assessment of a bioenergy project

This section provides an example of the calculation of CO_2 emissions under a bioenergy scenario compared with a reference scenario involving the use of a fossil fuel for heat production. In this example, the biomass source is forest harvest residues and the fossil fuel is heavy fuel oil. In the reference scenario, the harvest residues are left in the forest, where they decompose over time. The choice of harvest residues as a biomass source simplifies the example considerably while permitting comparison with the reference scenario and accounting for CO_2 fluxes over time.

5.1 Combustion emissions

Annual combustion emissions consist of the sum of smokestack emissions and the upstream emissions associated with fuel extraction, transport and pre-processing (Cherubini, 2010). Smokestack emissions depend on the fuel emission factor and on the efficiency of the energy conversion process. The emission factor, an inherent property of each fuel, can be defined as the amount of CO_2 released from the production of a given amount of energy under ideal conditions. Emission factors are expressed in kilograms of CO_2 emitted per gigajoule of energy produced (kg CO_2/GJ). In our example, we use the IPCC's emission factor (lower heating value of the fuel [LHV]) of 112 kg CO_2/GJ for wood and 74 kg CO_2/GJ for fuel oil.

Parameters of the example

Biomass scenario:
- Use of harvest residues
- CO_2 generation

Total emissions = Combustion emissions

Reference scenario:
- Decomposition of harvest residues in the forest
- Production of energy from heavy fuel oil

Total emissions = Combustion emissions from heavy fuel oil + Emissions from residues left in the forest

The efficiency of the conversion process relates to the percentage of total energy recovered by the process. We have used 85% efficiency for both scenarios in our example.

Finally, the upstream emission values (i.e., emissions associated with the supply chain) used in this example are about 5.6 kg CO_2/GJ, or 5% of the emission factor for biomass (Repo, Tuomi and Liski, 2010), compared with 18.5 kg CO_2/GJ, or 25% of the emission factor for heavy fuel oil (Air Resource Board, 2009). Table 2 illustrates how the combustion emissions are calculated.

Table 2 Calculation of CO_2 combustion emissions for the example

Factors that influence combustion emissions[1]	Bioenergy scenario (harvest residues)	Reference scenario (heavy fuel oil)
Emission factor (kg CO_2/GJ)[2]	112*	74.1*
÷ Efficiency of the conversion process (%)	85	85
= Smokestack emissions (kg CO_2/GJ)	131.8	87.6
+ Upstream emissions (kg CO_2/GJ)	5.6	18.5
= Combustion CO_2 emissions (kg CO_2/GJ)	137	106

1. For the production of one GJ of energy.
2. The IPCC default emission factors correspond to the LHV.

5.2 CO_2emissions from in-forest decomposition of harvest residues (reference scenario)

To complete the analysis, the reference scenario must account for CO_2 emissions from the in-forest decomposition of harvest residues that would have been burned in the biomass project. The temporal dynamics of the emissions associated with these residues differ greatly in the two scenarios. In the reference scenario, the biomass left in the forest decomposes gradually and releases CO_2 over a number of years, whereas in the bioenergy scenario, biomass combustion results in the immediate generation of smokestack emissions.

Table 3 illustrates the temporal distribution of CO_2 emissions for a single year of energy production. In both scenarios, the combustion emissions occur during the year of energy production. However, in the reference scenario (heavy fuel oil), the biomass left on cutovers decomposes gradually, generating CO_2 emissions that are added to those resulting from combustion. The total cumulative emissions from the heavy fuel oil scenario exceed those from the biomass scenario beginning in the fourth year, because of the gradual decomposition of harvest residues that are not burned.

Table 3 Total cumulative CO_2 emissions

Year	Biomass scenario	Reference scenario (heavy fuel oil)			
	Combustion emissions (kg CO_2)	Combustion emissions (kg CO_2)	Emissions from harvest residues[1] (kg CO_2)	Total emissions (combustion + residues) (kg CO_2)	Total cumulative emissions (kg CO_2)
0	137	106	8	114	114
1	-	-	7	8	122
2	-	-	7	7	130
3	-	-	6	7	136
4	-	-	6	6	143
5	-	-	6	6	149
6	-	-	5	6	154
7	-	-	5	5	160
8	-	-	5	5	165
…	…	…	…	…	…
100	-	-	0	0	243

1. The figures in the column"emissions from harvest residues" are based on 6% annual decomposition of the amount of residues required to produce one GJ of energy.

In this example, after energy production in year "0," it takes three additional years in the biomass scenario for the total emissions to equal those of the reference scenario (heavy fuel oil). In other words, the bioenergy produced in year "0" created a CO_2 debt that was paid off in three years; from this point on, the bioenergy that is generated produces benefits in terms of reductions in CO_2 emissions.

5.3 Cumulative emissions from a biomass project

In a real project, energy is generated over a sequence of years. Each year, combustion emissions and emissions from residues are generated from new areas in which forest residues decompose and gradually release CO_2. Table 4 contains a comparison of biomass (B) and heavy fuel oil (H) scenarios spanning several years. The first set of B and H columns, in bold, represent the total annual emissions for the two scenarios, taken from Table 3 beginning with year "0." For each year, there is a new set of columns B and H which correspond to the total emissions associated with energy production during this year, according to the two scenarios. The "Difference" column shows that, between year 6 and year 7, the cumulative CO_2 debt at the start of the project is fully recovered. The lines for 20, 50 and 100 years show how GHG emission reductions accumulate over the life of the project.

Table 4 Total cumulative CO_2 emissions from a biomass project

Year	**Annual emissions** (kg/CO_2)																		Total annual emissions (kg/CO_2)		Total cumulative emissions (kg/CO_2)		Diffe-rence[1] (kg/CO_2)
	B	H	B	H	B	H	B	H	B	H	B	H	B	H	B	H	B	H	B	H	B	H	H-B
0	137	114																	137	114	137	114	-23
1	--	8	137	114															137	122	274	236	-38
2	--	7	--	8	137	114													137	130	411	366	-45
3	--	7	--	7	--	8	137	114											137	136	548	502	-46
4	--	6	--	7	--	7	--	8	137	114									137	143	685	645	-40
5	--	6	--	6	--	7	--	7	--	8	137	114							137	149	822	794	-28
6	--	6	--	6	--	6	--	7	--	7	--	8	137	114					137	154	959	948	-11
7	--	5	--	6	--	6	--	6	--	7	--	7	--	8	137	114			137	160	1096	1108	12
8	--	5	--	5	--	6	--	6	--	6	--	7	--	7	--		137	114	137	165	1233	1273	40
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20		2																	137	206	2877	3549	672
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50		0																	137	237	6987	10355	3368
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
100		0																	137	243	13837	22434	8597

1. The “Difference” column indicates the cumulative reductions in CO_2 emissions from the biomass scenario: a negative figure represents CO_2 emissions that are higher initially in the biomass scenario. The reductions in CO_2 emissions resulting from the biomass scenario continue throughout the life of the project, as illustrated in Figure 2.

Figure 2 presents the results from the “Difference” column in the above table. The figure illustrates how, over a period of 100 years, the climate benefits of avoided emissions accumulate throughout the remainder of the project from this recovery point. The enlarged portion of Figure 2 shows the dynamics of carbon debt recovery in the early years of the project.

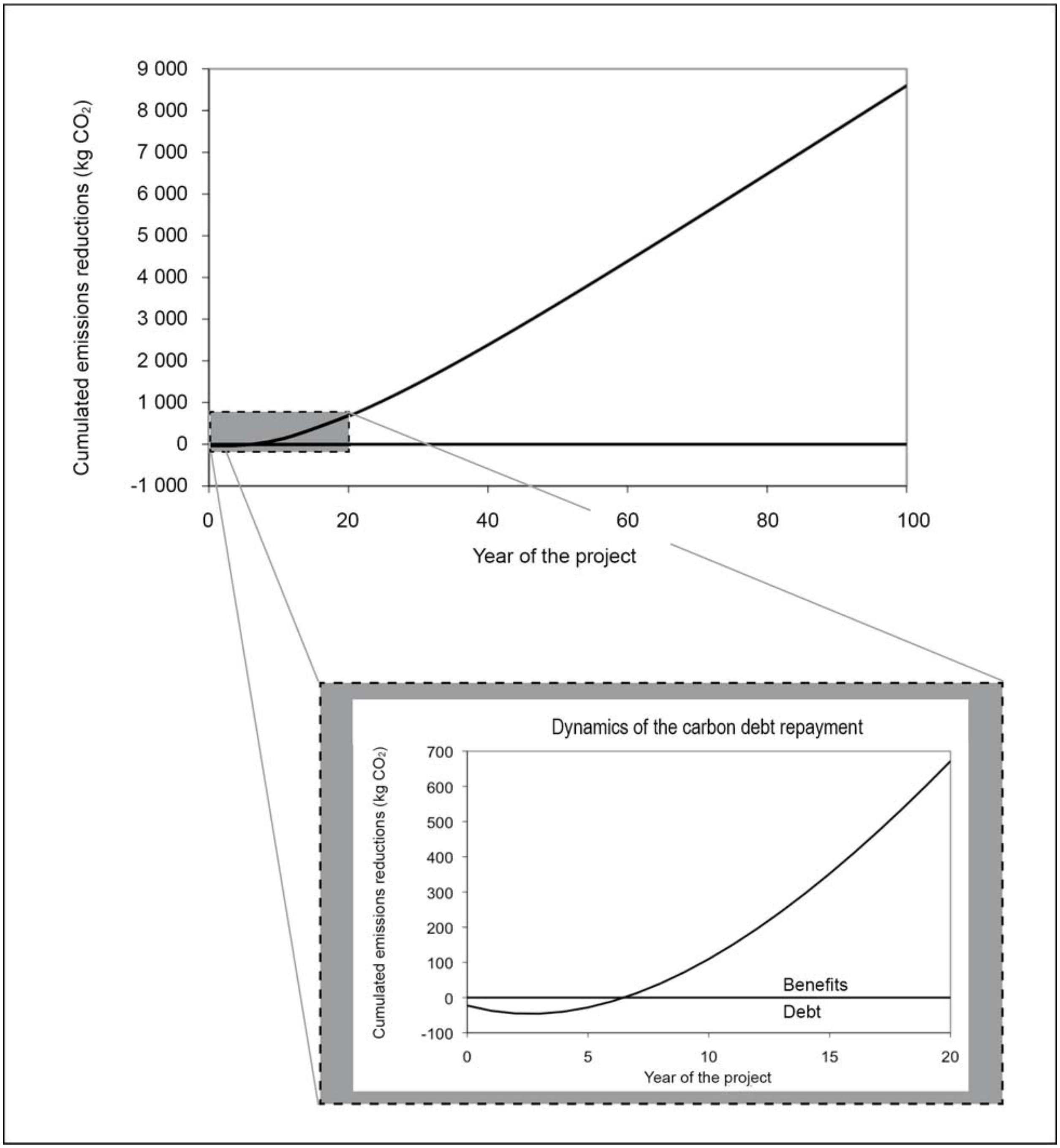

Figure 2: Cumulative CO_2 emissions reductions in the example

Conclusion

The use of forest biomass for bioenergy results in reductions in CO_2 emissions, provided that the biomass project offsets fossil fuel use. The challenge is to quantify the emissions benefits and determine the time it takes to achieve them. We know that emissions reductions are achieved faster when energy is produced from a type of biomass that decomposes quickly, including most residual biomass or biomass produced specifically for energy production. Technological options influence the magnitude of these benefits and the associated time horizon.

An effective policy for fighting climate change should give priority to biomass sources that quickly produce benefits which are easy to quantify. It should also promote the most effective methods of energy conversion and the replacement of fossil fuels that generate high CO_2 emissions per unit of energy. These are the foundations of the recent bioenergy policy developed by the State of Massachusetts (Massachusetts Department of Energy Resources, 2011).

The shift in the energy supply system will, in all likelihood, take several decades. Since the development of a vigorous and effective bioenergy sector cannot be based solely on the creation of a dynamic market, it is advisable to also consider a portfolio of bioenergy options including options that will yield climate benefits over the longer term. Initially, the latter options should obviously make up a smaller proportion of the portfolio. Their gradual deployment will permit the desired transformation of energy infrastructure to a renewable energy based system.

In addition to permitting reductions in GHG emissions, forest biomass has the potential to contribute to the attainment of other social and economic objectives, including energy self-sufficiency in Quebec, reduced heating costs for institutional buildings, regional job creation and retention, enhanced forest sector viability through the creation of new products, and increased reclamation of wood waste. This set of benefits on its own could justify the implementation of forest bioenergy projects. Nonetheless, if we want to show that the projects are justified on the basis of CO_2 emissions reductions, a rigorous analysis of their contribution to climate change mitigation must always be carried out.

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