Master’s thesis

Two years

Environmental Science

Forest Carbon Dynamic - Positive and Negative perspectives on the use of Biomass Energy to replace Fossil Fuel

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Main field of study: Environmental Science
Semester, year: VT, 2018
To my beloved son, Kevin Marlon Pereira Lundmark
Acknowledgments

First of all, I would like to thank Bengt-Gunnar for accept to be my mentor and for all input and support during the construction of this thesis. Emilie Westin, thank for your cooperation and support. Matilda Lindmark, thank for your comments. I would also like to thank my dear cousin, Katuscia Soares Sosebee. I appreciate all the time you spent to help me. This thesis was not possible without the support and motivate from my family and friends during this two-year journey. This thesis is dedicated to my son, Kevin Marlon Pereira Lundmark, who is the love of my life. You are so young, but you understood better than anyone how study is important in life.

Kennia Danielle Souza Pereira Lundmark
Sundsvall, May 2018
Abstract

From 1970 to 2010, circa 78% of the Greenhouse gases emissions came from the emissions of CO₂ derived from industrial processes and fossil fuel combustion. The fossil energy resources (coal, oil and natural gas) increase the concentration of carbon dioxide in the atmosphere causing diverse changes related to global warming. Despite policies adopted to mitigate the climate change, global warming is not decreased.

This literature review will analyze and investigate the use of forest biomass to replace fossil fuel energy and how it can affect climate change. This study used secondary data to identify the main perspectives in the use of forest biomass to produce energy. The policies at the global, regional and national level are also described. How the national level is influenced by the international and regional level and how the policies match with the current knowledge on the theme.

The results showed that the use of forest biomass was better to replace coal than natural gas or oil, due to the payback time. The use of old-growth forests or natural forest increases the time to the released emissions to be offset. Residues showed to have faster payback time than other forest biomass, as well as, the use of this biomass avoid cut down trees. However, the use of residues can cause serious impacts, as biodiversity loss.

The conclusion was that the use of biomass will increase the CO₂ emissions, whether all emissions are included. Despite the payback time is faster to forest biomass than fossil fuel, biomass is not a good alternative to replace fossil fuel energy. Because of the combustion efficiency of biomass is less than fossil fuel to produce the same amount the energy. Regarding the policies, there are contradictions between the international and regional level about the use of forests. As also, regional level has contradictions in their criteria that should be avoided. If the forest biomass has to be use, this study recommended the use of residues.

Key words
forest biomass, carbon dynamic, replace, renewable energy, GHG emissions, climate change.
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1. Introduction

In the last decades, the increase of global temperature had drawn attention and it has alarmed the need for the decrease and stops the global warming. The increase of Greenhouse Gas Emissions (GHG), mainly the emissions of carbon dioxide (CO\textsubscript{2}), is responsible for the increase in the global temperature. According to the Intergovernmental Panel on Climate Change (IPCC) report (2014), the anthropogenic emissions are the highest in history, with large increase happened between 2000 and 2010. From 1970 to 2010, circa 78% of the Greenhouse gas emissions came from emissions of CO\textsubscript{2} derived from industrial processes and fossil fuel combustion. Thus, decrease the GHG emissions and the atmospheric carbon dioxide (CO\textsubscript{2}) is a great challenge to overcome.

1.1. Fossil Fuel and Climate Change

The carbon sequestration during millions of years from geological resources is introduced into the atmosphere, causing global warming (Sterman et al., 2018). Fossil energy resources (coal, oil and natural gas) increases the concentration of carbon dioxide in the atmosphere causing diverse changes related to the warming, such as melting glaciers, sea level rise, ocean acidification, etc. Although climate policies already adopted to decrease the warming, 2016 was the warmest record year according to Global Climate Change - NASA (n.d). This highlights the importance to decrease the GHG emissions.

In the past years, several studies had investigated the use of alternative energy resources with less impact than fossil energy. The concern about climate change and the use of fossil energy had increased the demand for renewable energy. EU policies and previous studies have suggested Forest Biomass (Figure 1) as a major resource to substitute fossil fuel, due to the assumption that emissions are offset by forest regrowth (Björjesson et al., 2017). This traditional way to produce energy has been used for many centuries and it continues to be used in rural areas and by some industries. However, the use of forest biomass is controversial and strongly debated due to the role of the forest as a carbon sink (Bentsen, 2017; Taeroe et al., 2017).

This study will analyze and investigate the use of forest biomass as an energy source to replace fossil fuel energy. Forest biomass has been used in many different sectors, such as paper industry, manufacturing, recreation, tourism, and construction. The products from manufacturing and construction can also be used to produce energy...
when they are discarded. These sectors delay the release of CO$_2$ emissions when compared to the forest harvested to directly produce energy.

In addition, I will present the main goals of policies at global, regional and national level. I will discuss the Paris Agreement, European policies and Swedish policies, at the global, regional and national level, respectively.

1.2. Background - Forest Carbon Dynamic

Forests play an important role in sequestration of carbon from the atmosphere and store carbon in living trees and decomposing organic matter in soil and litter (Luyssaert et al., 2008), see Figure 1. Dead roots, dead trees (standing and downed), soil organic matter, litter and living fine roots are part of the forest carbon stock (Sterman et al., 2018).

![Figure 1. Wood Forest Biomass - Carbon is stored in forest ecosystems in several components.](image)

Ter-Mikaelian et al. (2015) defined Forest Carbon, as everything in the aboveground and belowground dead organic matter, live trees, and understory vegetation.
Carbon from the atmosphere is constantly accumulated by forests, most in soil carbon pools and dead organic matter (European Academies Science Advisory Council [EASAC], 2017). Although younger forests have a higher rate of carbon assimilation from the atmosphere, old forests play an important role as a global carbon sink.

The early stages of regenerating forests may be a source of CO₂ because of the decomposition of residues and increase soil respiration. In such cases, the decomposition rates of coarse woody debris, soil organic matter and litter exceed the regrow rates (Luyssaert et al., 2008).

The main forces that influence the forest carbon pools are growth, mortality, decomposition, combustion to produce bioenergy and other use of forest biomass, such as timber harvest (Fig. 2). Standing live trees, biomass harvested during salvage

![Figure 2. Forest Carbon Dynamic. The white arrow represents the soil respiration and capture of carbon by the soil. The green arrow is the capture and release of carbon by the biomass. The light blue arrow represents the carbon release during the wood was decaying. The yellow texts identify the carbon sink in the forest ecosystem.](image)
operations, thinning and residues from harvest, thinning operations and mill processes are the typical sources of forest biomass to produce bioenergy (Ter-Mikaelian et al., 2015).

Bioenergy from Sustainable Managed Forest (SMF) has been considered a carbon neutral energy source, because forest regrowth compensates the CO₂ released (Mäkipää et al., 2015; Nabuurs et al., 2017; Repo et al., 2015b). Thus, there is an assumed balance between forests as a carbon sink and emissions (Nabuurs et al., 2017). However, other studies disagree with this conclusion (Björjesson et al., 2017; Holtsmark, 2013; Smyth et al., 2017).

When forests are harvested and used for energy purpose, it creates a loss of carbon known as Carbon debt. Carbon debt is the difference between the sequestration of CO₂ from the new biomass and CO₂ emission from the biomass when it is converted to produce energy (Bentsen, 2017). The debt payback time is the time that it takes for this debt to be paid. Even when the payback time is reached, there is still a difference to be compensated. It is assumed that if the forest was unharvested it would have continued to accumulate carbon. Thus, this difference is between the amount of carbon accumulated when the payback time is reached, and the amount of the assumed carbon level if the forest was not harvested. When this deficit reaches to zero, it is called Carbon Parity (Nabuurs et al., 2017). Figure 3 illustrates the difference between the repayment of carbon debt and carbon parity. The time to reach the carbon parity will depend on the fossil fuel source to replace, the source of forest biomass used and the time that it will take to the forest to regrow to the level of carbon stock before harvesting (Ter-Mikaelian et al., 2015). Hence, it represents a complex system resulting in highly variable time scales.

1.2.1 - Forest Biomass - Sweden

In Sweden, more than 60% of the land is covered by forests (Lundmark et al., 2014) and more than 22 million hectares are productive managed forest (Cintas et al., 2017). The growth rate in Swedish forests, as well as in Europe, is larger than harvest rates. According, to Swedish National Forest Inventory by Swedish University of Agricultural Sciences [SLU] (n.d.), the annual harvest was 97.3 millions m³, while the total annual growth was about 121 million, in the year 2014. Because of that, Swedish
forests, as well as European forests, works as a carbon sink. Most of the country area is covered by boreal forests. Boreal forests provide lower rates of carbon storage due to less sunlight and cold temperatures compared to the other forests (Jackson et al., 2008).

**Figure 3.** Carbon level – Payback and Parity Time. The black line represents the average carbon storage in the forest. The red line is showing when the forest is harvested there is a decrease of the carbon store in the forest. However, when the forest starts to regrow, the forest starts to absorb carbon. The debt repayment is reached when the amount of the carbon is similar to the carbon in the unharvested forest. However, the carbon parity is not reached. It happens because an unharvested forest would have continued to accumulate carbon (blue line). Thus, the carbon parity is reached when the amount of carbon accumulated in the regrow forest reach the amount of the assumed carbon level if the forest was not harvested. The length time depend of forest productivity.

The dominant forest management method implemented in Sweden are: small trees and bushes are cleaned before logging large trees and 5% of the trees and stumps have to be left in the forests. Replanting occur about 2 years after final felling. Forest
owners certified a minimum of 5% of the forest is set aside as voluntary conservation aims.

In Sweden, forest biomass is the largest bioenergy source, around 85% (Cowie et al., 2013). Twenty-five millions m$^3$ of the solid biomass are used for energy purpose (Björheden, 2017). Swedish annual felling is 125 million m$^3$ of solid biomass, including branches, tops, foliage, small trees and stump roots. Forest fuel is from felling, harvest residues, industrial residues, and stemwood (De Jong et al., 2014).

Coarse woody debris is an important carbon store in natural forests, because old forests store large amount of carbon during their whole life cycle. Thus, if the coarse wood debris is unharvested, this carbon stored will be released slowly during the decomposition process. Siitonen (2001) estimated that the volume of coarse woody debris in the northern boreal zones is from 50 to 80 m$^3$/ha. These results are in line with Ranius et al. (2004), who predicted around 74 m$^3$/ha in natural forests in northern Sweden. In reality remaining natural forests present in Swedish nature reserves have a moderate levels of coarse woody debris around 24 m$^3$/ha (Jonsson et al., 2016). Managed forests by comparison have a low levels of dead wood (8 m$^3$ per hectare; ibid).

**1.3. The motivation of the study and Purpose**

What triggered the project was a letter with more than 700 signatures from Scientists to the EU Parliament regarding Forest Biomass (Annex 1). The scientists were concerned about increasing forest harvest rate to produce energy because it can increase CO$_2$ emissions and threaten biodiversity. They suggested the use of forest biomass should be restricted to waste and residues.

The purpose of this study is to analyze and investigate the use of forest biomass energy to replace fossil fuel energy and how it can affect the climate change. The use of forests residues as an alternative to increase the amount of energy produced from forest biomass will be also discussed in my analysis.

**1.4. Objective**

The objectives of this work are: (a) Identify across the most current scientific literature on the theme, the main perspectives (positive and negative) about the use of forest biomass to replace the fossil fuel. (b) How effective is the use of forest
biomass to decrease the CO₂ emissions? (c) Analyze how the Paris Agreement and EU regulation influence National Implementation.

2. Methodology

The study was a State-Of-The-Art Review and it has been conducted between January and May 2018.

The main literature selection was completed in the first 3 weeks of research. Boreal Forest was the target forest studied. As previously mentioned, the use of forest as an energy source was the study aim. Thus, other uses of forests (tourism, wood products and other) was not evaluated in this literature review. The literature selection did not include natural disturbances, e.g. fire, disease and etc.

This review builds on the information published in the last decades and the data collected were compared to achieve the purpose work.

The research began with data collection (secondary data) using the database “Web of Science”. To find and select papers used in the present work, I used the combine terms, “Carbon Dynamic AND forest Biomass”. The result was 130 papers and the relevant studies were screened by the title. Lastly, I used the “ancestry approach” to provide further data. “Ancestry approach” means that the references found in the first path were screened for additional information.

Additionally, relevant articles were suggested by the Reference Management Software & Researcher Network, Mendeley. Mendeley has been used to provide the information about the reference studied in this paper.

This scientific review used 5 references in its builds.

3. Results

The results identified both positive and negative perspectives on the use of forest biomass as a substitute for fossil fuel energy. Table 1 is a resume of the main arguments, positive (a favor to the use of forest biomass energy) and negative (facts against the use of forest biomass energy). In addition, the results provide how the current policies match with the current knowledge of the theme above. Finally, how the global and regional policies influence the implementation of Swedish national policies.
3.1. Perspectives on the use of forest biomass energy

Previous studies affirm that the use of biomass to produce energy will increase the CO$_2$ emission (Brack, 2017; Holtsmark, 2013; Mäkipää et al., 2015; Repo et al., 2015b; Sterman et al., 2018). However, emissions will be offset by the growth of regenerating forests (Bentsen, 2017; Nabuurs et al., 2017; Smyth et al., 2017). This offset occurs due to the process of CO$_2$ sequestration will start again when the forest starts to regrow. However, the time that it takes and the amount of CO$_2$ released from the use of forest biomass is an example of the problems debated.

It is obvious that the carbon stored in the wood is automatically released when it is used to produce energy. Nonetheless, some studies suggest that these emissions are not a major problem since the carbon release from the use of bioenergy is Carbon Neutral. This concept is also adopted in some policies, such as EU policies (see section 3.2).

But, why forest biomass is considered carbon neutral? According to Brack (2017), there are two perspectives. The first perspective is that it is a natural process, so the growth rates compensate the carbon emitted during the burning process to produce energy. In other words, it is considered a recycling of carbon. The second perspective is related to the way that emissions are reported. When the biomass is used to produce energy, only the emissions from the land-use sector are reported. In this way, in order to avoid double accounting emissions, the emissions from the energy sector are not included. It is defined as the “instantaneous oxidation” principle, which assumes that the carbon release to the atmosphere is only relevant for the harvest process (EASAC, 2017).

However, emissions from harvesting and combustion are not the only processes that release emissions derived from the forest biomass energy. CO$_2$ is also released during processing and transportation (Sterman et al., 2018). Thus, these emissions should also be included in the calculation of carbon balance when suggesting that forest biomass are carbon neutral.

Despite that the use of forest biomass release CO$_2$, the emissions generated from the replacement will be compensated in decades (Khanna et al., 2016). Contrary to the fossil fuel that takes millions of years to compensate. The emissions that are not released from fossil fuel, due to the replacement of fossil fuel for biomass, is known as the energy substitution effect (Nabuurs et al., 2017; Sterman et al., 2018). In other words, it is the benefits of decrease the emissions from fossil fuel.
<table>
<thead>
<tr>
<th>Category</th>
<th>Positive Perspectives</th>
<th>Negative Perspectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ emissions</strong></td>
<td>The emissions increase but decrease afterward (Bentsen, 2017)</td>
<td>CO₂ emission increase due to the harvesting of forest (Mäkipää et al., 2015)</td>
</tr>
<tr>
<td></td>
<td>Biomass emissions are offset in decades compared to fossil emissions that take millions of years (Khanna et al., 2016)</td>
<td>CO₂ release during harvesting, combustion, processing, and transport (Sterman et al., 2018)</td>
</tr>
<tr>
<td><strong>Carbon Neutral</strong></td>
<td>Natural process (Brack, 2017)</td>
<td>To avoid double counting, the emissions from the energy sector are not reported (Brack, 2017)</td>
</tr>
<tr>
<td></td>
<td>Forest biomass is carbon neutral, thus biofuel has been considered carbon neutral fuel (Sterman et al., 2018)</td>
<td>Processing and transport also release CO₂ and they are not counting in the calculation of carbon balance (Sterman et al., 2018)</td>
</tr>
<tr>
<td><strong>Substitution of fossil fuel</strong></td>
<td>Create the energy substitution effect (Nabuurs et al., 2017)</td>
<td>Decrease the biodiversity (Hammar et al., 2015)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The decrease of C balance annulate the substitution effect (Pukkala, 2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not generate benefits to the GHG emissions (Repo et al., 2015b)</td>
</tr>
<tr>
<td><strong>Combustion</strong></td>
<td></td>
<td>Carbon lost immediately (Sterman et al., 2018)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biomass is not effective burning compared to fossil fuel (Sterman et al., 2018)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emit more C per unit of energy (Khanna et al., 2016)</td>
</tr>
<tr>
<td><strong>Increase harvesting</strong></td>
<td>Increase the energy production, e.g. increase 10% stump harvesting would generate 5TWh (Ortiz et al., 2016)</td>
<td>The decrease of C sink and stock in the forests (Repo et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>Can increase the use of biomass to produce energy (Smyth et al., 2017)</td>
<td>Change the forest and forest ecosystem (Felton et al., 2016)</td>
</tr>
<tr>
<td></td>
<td>Not release carbon stock in the trees (Smyth et al., 2017)</td>
<td>Impact the water quality (De Jong et al., 2017)</td>
</tr>
<tr>
<td></td>
<td>Provide benefits to the climate and forestry industry (Brack, 2017)</td>
<td>Dangerous to red-listed wood-living species (De Jong et al., 2014)</td>
</tr>
<tr>
<td></td>
<td>Bioenergy from residues can achieve parity early than the thinning wood (Nabuur et al., 2017)</td>
<td>Raise the carbon emissions by 40% compared to fossil fuel emissions (Mäkipää et al., 2015)</td>
</tr>
<tr>
<td></td>
<td>The use continue will decrease the emissions (Smyth et al., 2017)</td>
<td>Loss of habitat and create a homogenized environment (Ortiz et al., 2016)</td>
</tr>
<tr>
<td></td>
<td>Great to improve the production of bioenergy without compromise the carbon stock (Smyth et al., 2017)</td>
<td>Decrease forest productivity (Hammar et al., 2015)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Damage the soil such as increase compaction, soil erosion, aeration, depletion of nutrients and increase soil temperature and water content (Ortiz et al., 2016)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Viable to use only in high decay rates (Giuntoli et al., 2016)</td>
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<td></td>
<td></td>
<td>Benefits depending on what source will replace, how they are used and the efficiency of the technology to convert in energy (Gustavsson et al., 2015)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The negative effect on the biodiversity (Hammar et al., 2015)</td>
</tr>
<tr>
<td><strong>Use of residues</strong></td>
<td>Bioenergy from Sustainable Managed Forest are carbon neutral (Mäkipää et al., 2015)</td>
<td>Harvesting old forest increase the payback time and parity (Bentson, 2017)</td>
</tr>
<tr>
<td></td>
<td>The use of Sustainable Managed Forest can increase the potential for the forest to be used as an alternative to mitigate the climate (Cintas et al., 2016)</td>
<td>Negative effect on the climate, due to the conversion of deciduous forest to coniferous forests (Naudts et al., 2016)</td>
</tr>
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<td></td>
<td></td>
<td>Replanting species with fast growth in managed forests can strongly affect the climate impact of used wood (Sterman et al., 2018)</td>
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<tr>
<td><strong>Type of forest</strong></td>
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</tbody>
</table>
Table 1. Main perspectives (positive and negative) on the use of forest biomass to produce energy based on the literature review.

On the other hand, some studies suggested that the substitution of fossil fuel energy with biomass energy will not generate benefits for GHG emissions (Mäkipää et al., 2015; Repo et al., 2015b). In addition, Pukkala (2014) state that the substitution effect of fuel is canceled when it occurs a decrease of carbon balance, for example from the harvesting of stumps, coarse roots, and branches for bioenergy production. Moreover, the demand of biomass and local/regional circumstances can also influence the carbon balance results for the forest (Cintas et al., 2016).

Another important factor used to explain why the use of forest biomass is not a good substitute for fossil fuel is that the burning of biomass is not as effective as the burning of fossil fuel. It happens because the combustion efficiency of wood is less than fossil fuel to convert to energy (Sterman et al., 2018). Thus, it will require extra biomass to produce the same amount of energy and it will emit further CO₂, thereby the carbon debt will raise (Khanna et al., 2016; Nabuurs et al., 2017; Sterman et al., 2018). Graphic 1 compares the carbon dioxide emissions per kgCO₂ / kWh for wood, coal, oil and natural gas.

**Graphic 1.** Carbon dioxide emissions per kgCO₂ / kWh of wood, coal, oil and natural gas (Source data from Renewable energies and climate protection (n.d.)).
Another concern about the use of forest biomass is the harvest rate. How can we increase the harvest rate without compromising the carbon storage? Forest Residues emerged as a major alternative, and residues have been suggested as a mitigator to climate change (Hammar et al., 2015). In this case, residues are described as a solution because its use will not release carbon stock in trees. Smyth et al. (2017) cited another reason: “... if residues are not used for bioenergy, they would progressively decay over time...”. And Ortiz et al. (2016) cited that “the emissions from bioenergy combustion is compensated for over the longer term mainly by emissions that would have occurred anyway”. In other words, CO₂ release from residues during the slow decomposition process.

Opposite to that argument, Repo et al. (2015a) state that the use of residues should decrease the amount of carbon stock in the forests. Furthermore, Mäkipää et al. (2015) results showed that the use of biomass residues as a substitute for fossil fuel can raise carbon emissions. Because when residues are not harvested, the CO₂ is released slowly during decomposition. The opposite happens in harvesting to energy production, CO₂ is lost immediately. The use of residues can increase the CO₂ emission by 40% when compared to the fossil fuel emissions (EASAC, 2017; Mäkipää et al., 2015). These arguments challenge the use of this type of biomass.

However, Giuntoli et al. (2016), argues that the use of residues is viable to use if decay rates are high. Because the duration and rate of carbon loss would be related to the decomposition rate of the residues (Repo et al., 2015b). Repo et al. (2012) have a similar opinion. These authors affirm that the GHG emissions depend on the decomposition rate of the removed residues.

Furthermore, the use of residues can provide benefits, however, it will depend on several factors. Gustavsson et al. (2015) stated that the use of residues will have benefits depending on what fossil source it will replace, and how they are used. The efficiency of the technology to convert in energy is another important factor.

Branches and foliage have high nutrients contents than stumps and coarse roots, which it will decrease the fertility, consequently, it may affect the biomass growth (Pukkala, 2014). However, these residues have high decompositions rates than stumps and coarse roots, which it will impact less.

Diverse impacts are derived from stump harvesting, most due to the changes in the soil structure. According, to Ortiz et al. (2016), there are many impacts related to stumps harvesting. Such as soil erosion, aeration, depletion of nutrients, increase the compaction, increase soil temperature and water content. Increase the soil
respiration, decrease forest productivity and habitat loss are other examples of impacts from the use of stumps.

However, Pukkala (2014) emphasized that the impacts can be limited if the stumps harvesting come only from clear-felling sites, while branches can come from clear-felling and thinning. Nevertheless, the partial benefits from stumps and coarse roots can take at least 100 years to reach carbon parity.

Despite the impacts generated from the use of residues, there are authors who claim that the use of residues can have benefits for the climate. Hammar et al. (2015) found that the carbon storage was similar when the residues were or were not removed from the forest to bioenergy. Furthermore, Repo et al. (2015b) and Smyth et al. (2017) quoted that continuous use of bioenergy will decrease the emissions. Thus, the use of residues to replace the fossil fuel offset the loss of carbon stock (Hammar et al., 2015). However, to have better quality fuel for combustion is recommended to leave the biomass foliage in the forest (Mäkipää et al., 2015). It will avoid damage biomass combustion due to ash content of foliage that can reduce the heat transfer.

Residues may be a good alternative to mitigate the climate change. Repo et al. (2015a) quote that “the most cost-effective way to produce carbon-neutral bioenergy from forest residues was to collect only branches and balance for the carbon loss by low levels of forest fertilization”. Furthermore, Brack (2017), affirm that over the short and medium term, residues can be considered carbon neutral.

Likewise, it was observed that residues reach the payback time faster than other biomass when it is used to replace coal (see table 2) (Bentsen, 2017). Consequently, parity times vary depending on the kind of biomass used to produce energy. Nabuur et al. (2017), found that the bioenergy from residues can achieve parity much early than the thinning wood. Furthermore, these authors concluded that “the absolute size of the removed biomass does not matter for the parity “.

In their study, Ortiz et al. (2016) found that the use of stumps as a substitute for natural gas gave a parity time of 12-16 years. While tops and branches achieved the parity time between 8-12 years. Despite stumps has bigger climate impact than tops and branches, the use of both can increase the use of forest to produce energy.

Bentsen (2017) demonstrated that the disturbance in the carbon dynamics in the ecosystem will influence carbon debt and the payback time. The payback time is influenced by many different factors. For this reason, the payback time can differ between studies. Examples of factors that influence the payback time are: which source to replace, how to replace the source, type of biomass used, the residues
decomposition rates, the efficiency to convert and, climate zone (Hammar et al., 2015; Smyth et al., 2017). The kind of the model used can also influence the final results. As for instance in Ortiz et al. (2016), the authors caveat that the model used can affect the parity time since the model will depend on if the decomposition of wood organic material is slow or not.

<table>
<thead>
<tr>
<th>Forest Source</th>
<th>Source to replace</th>
<th>Payback time</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>coal</td>
<td>44-104 y</td>
<td>Sterman et al., 2018</td>
</tr>
<tr>
<td></td>
<td>natural gas</td>
<td>105 y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>oil</td>
<td>133 y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>oil</td>
<td>31 y</td>
<td></td>
</tr>
<tr>
<td>Residues</td>
<td>coal</td>
<td>18 y</td>
<td>Bentsen, 2017</td>
</tr>
<tr>
<td>Stumps</td>
<td>coal</td>
<td>14 y</td>
<td></td>
</tr>
<tr>
<td>Roundwood</td>
<td>coal</td>
<td>102 y</td>
<td></td>
</tr>
<tr>
<td>Whole trees</td>
<td>coal</td>
<td>74 y</td>
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Table 2. Payback time from different sources.

Another example is related to the difference of type of forests. In plantation forest, the carbon store is smaller than in natural forests (Bentsen, 2017; Schlesinger, 2018). For this reason, it takes more time to payback the carbon debt released to the atmosphere from old carbon rich forest than compared to managed forests with low carbon stores. When old forests are harvested the carbon store will be lost and it can take decades to be replaced. It happens because regrow is a slow process (Ter-Mikaelian et al., 2015). Hence, the use of natural forest instead of agricultural lands or plantations forest will increase the payback time.

In the case of Sustainable Forest Management were found that depending on the management used, Sustainable Forest Management can generate negative effects on the climate, such as the conversion of deciduous forests to coniferous forests (Naudts et al., 2016). Land-cover change result also in changes in the canopy roughness, albedo and evapotranspiration from the land surface, and may contribute to global warming. In addition, replanting with species with fast growth in managed forests can strongly affect the climate impact of used wood because the carbon density is not similar (Sterman et al., 2018). However, the increase of forest management increases
the potential for the forest to be used as an alternative to mitigate the climate change (Cintas et al., 2016).

The use of residues can change the forest and the forest ecosystem, as residues can decrease biodiversity (Felton et al., 2016; Hammar et al., 2015) and cause impacts on the water quality (De Jong et al., 2017). Furthermore, De Jong et al. (2017) cites that harvesting should have more impacts depending on factors, such as volume harvested, which biomass is used and the location.

These changes will affect the amount of carbon stored in the soil and vegetation, as well as the growth rates and decomposition rates of the biomass (Bentsen, 2017; Nabuurs et al., 2017). All these impacts can annul the benefits of substitute the energy resource (Mäkipää et al., 2015; Pukkala, 2014; Repo et al., 2015b).

The divergence in opinions is evident about this theme. Some studies, as Nabburs et al. (2017), affirm that forest will not affect the climate change due to the long-lived system and because they are quickly fixed when compared to the fossil fuel. Furthermore, the use of forest biomass, despite the loss of carbon, will compensate the decrease of emission when replacing fossil fuel (Mäkipää et al., 2015). However, other studies do not agree about these assumptions, because the forests affect the climate change, as example Sterman et al. (2018).

3.1.1 - Biomass in Sweden

Sweden has low forest productivity in North than in South, which means slow growth. The South forests produce more biomass which generates a bigger return than North forests because of the difference in climate zone. For this reason, the payback time will be longer in Northern than Southern regions. This will influence the parity time. However, Ortiz et al. (2016) found that the parity time difference was small, only 4 years between south and north regions.

Boreal Forest is the type of forest most present in the country. The regrowth process is slow and it can take decades to recover the tree carbon stock after harvest (Ter-Mikaelian et al., 2015). Different species of trees influence the growth rate in the forest.

The stumps from deciduous forest provide more biomass per stumps than the originated from coniferous trees (Ortiz et al., 2016). Swedish stump harvesting is currently limited to about 0.1% of the final feeling area. According to Ortiz et al.
(2016), stump harvest has the potential to increase to 10%, which it would generate 5TWh (ca 23% of the energy production in the country).

Swedish Forestry Agency, as cited in De Jong et al. (2017), identified slash as the most important forest biomass to produce energy in Sweden. These authors cited that the slash from clear-cut and thinning has a high amount of nutrients. Furthermore, the slash from thinning negatively affect forest productivity more than clear cuts.
The slash can be harvested 50% of the annual harvest area, from both clear cuts and thinnings. According to the Swedish Forestry Agency, as cited in De Jong et al. (2017), this rate will not reduce the possibility to reach the environmental objectives.

About the biofuel production in Sweden, De Jong et al. (2014) states that Swedish biofuel market is increasing around 1.5 million cubic meters of wood per year. Consequently, research has been raised focusing on the objective to increase biomass in the forests.

The Swedish Forestry Industries clearly states that the use of forest will provide climate benefits. They claim to follow the sustainable approach and emphasized the importance of doing it.

“The more we use our forests, the more climate benefit they provide” (Swedish Forestry Industry (a), n.d., para. 6).
The use of residues as an alternative to improve the production are also emphasized, as well as, the importance to have policies that incentive the use of biofuels.

“Residues from forestry and forest industry are an important, renewable source of energy for industry and society as a whole. The EU is currently developing a new sustainability policy for biofuels. Here, it is vital that any regulations are wisely framed so that they promote, rather than impede, the use of sustainable bioenergy” (Swedish Forestry Industry(b), n.d., para. 1).

3.2.- Policies

Table 3 is a summary of the main parts of the Paris Agreement, EU Policies and Swedish Policies.

3.2.1- Paris Agreement

In 2015, all nations reached a landmark agreement, the Paris Agreement established at the COP21 meeting, within the United Nations Framework Convention on Climate
Change (UNFCCC) (European Commission, n.d.). It was the first time that all nations committed themselves to the same cause. The UN Paris agreement was a global plan to reduce the emissions by combat the climate change through keeping the temperature below 2°C Celsius above pre-industrial levels.

<table>
<thead>
<tr>
<th><strong>Paris Agreement</strong></th>
<th><strong>EU Policies</strong></th>
<th><strong>Sweden</strong></th>
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<tbody>
<tr>
<td>Article 2 (1a) - &quot;Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels...&quot;</td>
<td>&quot;EU 20% target for energy consumption which relies on legally binding national targets until 2020.&quot;</td>
<td>&quot;By 2020, emissions of greenhouse gases in Sweden (...) should be reduced by 40 percent compared with 1990.&quot;</td>
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<td>Article 4 (1) - &quot;In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible...&quot;</td>
<td>The European Council endorsed a binding EU target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990.&quot;</td>
<td>&quot;An EU target of at least 27% is set for the share of renewable energy consumed in the EU in 2030. This target will be binding at EU level.&quot;</td>
</tr>
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<td>Article 5 (1) - &quot;Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4 (...), of the Convention, including forests.&quot;</td>
<td>LULUCF - Article (1) - &quot;...contribute to achieving the objectives of the Paris Agreement and meeting the greenhouse gas emission reduction target...&quot;</td>
<td>&quot;By 2045, Sweden is to have no net emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions.&quot;</td>
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<td>&quot;It is thus appropriate to establish a Union binding target of at least 35% share of renewable energy to be accompanied by national targets.&quot;</td>
<td>&quot;The Swedish Parliament (Riksdagen) has, at the suggestion of the Government, decided that the proportion of renewable energy in 2020 will be at least 50% of the total energy usage.&quot;</td>
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**Table 3. Resume of Paris Agreement, European Union, and Swedish targets.**

Paris Agreement points out the importance of forests as store and sink of carbon rather a source of energy. The agreement suggested afforestation and forest management as strategies for the climate change mitigation (EASAC, 2017; Naudts et al., 2016). These actions should enhance the carbon stock, remove CO₂ from the atmosphere and consequently decrease the global warming.

Aiming to reach the goals from Paris Agreement, diverse changes are to be adopted at global, regional and national level.
3.2.2. Regional Policies - European Union (EU)

With the aim to be the climate leaders, the European Union developed regional goals that all members should follow. EU fully promotes the use of Renewable Energy sources as an alternative to mitigate the climate change. Renewable energy may also promote the reduction of the dependence on energy imports (Björheden, 2017). Within the EU, Forest biomass is the most significant source and it is expected to be the source capable to reach the EU targets, as well as, Paris Agreement. However, all member states were free to set their own national targets.

In 2009, the European Renewable Energy Policy developed a number of targets for 2020. Reach 20% of the use of renewable energy in the total of energy consumption and decrease in 20% GHG emissions (Hammar et al., 2015; Mäkipää et al., 2015; Sterman et al., 2018). This “20-20-20” target was based on the Carbon Neutrality from the biomass which shows positive effects on the climate mitigation (Nabuurs et al., 2017).

In 2014, the EU Commission has set a new target for 2030. In 2030, 27% of the total energy consumption must be from renewable energy (Giuntoli et al., 2016; Mäkipää et al., 2015; Nabuurs et al., 2017). Half of this goal should come from Biomass (EASAC, 2017; Nabuurs et al., 2017). This resource is the largest renewable energy source in Europe (Giuntoli et al., 2016) and has been described as an important alternative for the production of renewable energy to reach both targets (EASAC, 2017). The European Parliament proposed to increase the percentage of the target to 35% to be accompanied by National targets (EU policies, 2016).

Another goal for 2030, is that all EU member states must reduce the carbon release to the atmosphere and decrease 40% of the Greenhouses Gases (GHG) emissions compared with 1990 (Giuntoli et al., 2016).

According to Björheden (2017) and Eurostat (n.d.), eleven European member states already surpassed their own targets on renewable energy for 2020 (see Map 1). The countries are Sweden (53.8%), Finland (38.7%), Denmark (32.2%), Estonia (28.8%), Croatia (28.3%), Lithuania (25.6%), Romania (25%), Bulgaria (18.8%), Italy (17.4%), Czech Republic (14.9%) and Hungary (14.2%). The best results come from the countries with strong national regulation and strong forestry sector, as Sweden and Finland (Björheden, 2017). But the highest producers of energy from biomass are Italy, Germany, and UK (Brack, 2017).
Map 1. The eleven countries that already reached their own target for 2020 (source data from Eurostat, n.d.).
An important information about the biofuels from the EU policies are included in EU sustainability criteria. It contains a caveat that the biofuel cannot come from areas with high carbon stock, such as Natural forests (De Jong et al., 2014; EU Sustainability criteria, n.d.). The biofuel has to reduce CO₂ emissions and protect biodiversity to count as sustainable renewable energy and to receive government support (EU Sustainability criteria, n.d.).

The European Commission proposed the inclusion of the Land Use, Land Use Change and Forestry (LULUCF) in the Europe climate and energy to 2030 (Grassi and Pilli, 2017). For the period of 2021 to 2030, all Member States may report the emission from Managed Forest Land using Forest Reference Level. It will possible make the greenhouse gases emissions and removals from this sector to be an account for EU’s emissions reductions targets (EASAC, 2017). EU members have to control their emissions to not emit more than removal rates (Pilli et al., 2016). This goal is quoted in the article 4 of the regulation.

Article 4 - Commitments: “For the period from 2021 to 2025 and from 2026 to 2030..., each Member State shall ensure that emissions do not exceed removals, calculated as the sum of total emissions and removals on their territory in the land accounting categories referred to in Article 2 combined, as accounted in accordance with this Regulation”. (Council of European Union [CEU] (2017), p. 21).

However, before the emissions be reported by the Member States, it is crucial that forest reference level is specified in the regulation. EASAC (2017) referenced the Forest Reference Levels as the carbon stock at some base year. However, which period has to be based has been discussed.

The European Commission Proposal suggests that the Forest Reference Level will be estimated based in the historical Reference Period, 1990-2009 (Grassi and Pilli, 2017). European Parliament does not agree with this period. The Parliament suggested as the new reference period, 2000-2012 (European Parliament, 2017). In December 2017, the final position of council recommended that the new reference period should be based on the continuation of sustainable forest management practices.
“The Commission reiterates that, in line with its proposal, the proposed Forest Reference Level shall be based on an estimate of the future carbon sink in a forest, made by projecting forward the recorded forest characteristics and the forest management practices and intensity documented in a historical Reference Period (2000-2009)” (CEU (2017), Annex 2, p.48).

At this recommended period, the average carbon sink was 372 million tonnes CO$_2$ equivalent per year for the Union, from managed forest land. That period suggested will permit an increase in the land sector. However, the argument used is that this increase will not cause impacts, as long as it will continue under the line of “no-debt” emissions. “No-debt” emissions mean the emit rate is equal to removal rate.

It is important to inform that this reference period is not what the scientific community advocate. The scientific community advocates “net-net” accounting. It means not change the current amount of forest carbon sink. The European Forest act as carbon sink, but the amount is not as large. Graphic 2 shows the carbon storage in those reference periods suggested.

Graphic 2. Carbon storage level during the different reference period suggested. Member States has to report their emission from the year 2021 to 2030. The orange line represents the first reference period suggested by the European Commission Proposal. The dark blue line shows the second reference period suggested by European Parliament. The orange line shows the final position of the European
Council. The black dashed line represents the current forest carbon sink (“net-net” accounting). No-debt means that the storage and released of CO$_2$ is equal. This graphic was adapted from Grassi and Pilli (2017), figure 3, p. 19.

Furthermore, another concern in this regulation is the way that biomass exported should be reported in LULUCF sector. Because it can create one false data of decrease of CO$_2$ emissions. For example, consumers countries can benefit from the accounting rules and not reporting their emissions from the energy sector (EASAC, 2017). Besides the country that provides the feedstock is responsible for the LULUCF report, according to the “instantaneous oxidation” principle.

EU policy has agreed to add Land Use, Land Use Change, and Forestry (LULUCF) regulation, in target 2030 before the year 2020.

3.2.3 – National Policies – Sweden

The Swedish Environmental Code, Forestry Policy, and Swedish Forestry Act are responsible for the Swedish regulations (De Jong et al. 2017). According to the Swedish Environmental Protection Agency (n.d.), the Swedish goals follow the goals adopted within the European Union and integrated by international agreements, as Paris Agreement.

For 2020, the goal adopted was a 50% increase in the use of renewable energy compared to 1990 (Hammar et al., 2015). This goal was already reached, since 53.8% was the energy consumption from renewable energy in 2016, as showed in the EU policies section above. According to Björheden (2017), it was possible due to the national incentives and efficient certificate for renewable energy and a tax deduction in the transport sector.

Swedish goal to GHG emissions is to reduce around 20 million tonnes of Carbon dioxide (40% the GHG emissions compared to the year 1990) following the EU target to 2020. By 2030, the GHG emissions should be at least 63% lower than 1990 (Swedish Environmental Protection Agency, n.d.). By 2050, the GHG emissions release has to be null (Björheden, 2017; Börjesson et al., 2017; Hammar et al., 2015).

However, the National Bioeconomy strategy has larger ambitions and this target year was tightened to 2045 (Cintas et al., 2017; Swedish Environmental Protection Agency, n.d.). Although Sweden incentives the use of biomass energy by CO$_2$ taxes on fossil
fuels, around 90% of the energy used in the transport sector still comes from fossil fuel (Börjesson et al., 2017), despite one of the goals by 2030 is road transport free from fossil fuel (Cintas et al., 2017).

Currently, 30% of the bioenergy used in Sweden comes from logging residues and organic waste (Björjesson et al., 2017). In 2015, only 20% of the harvested residues were used as bioenergy (Gustavsson et al., 2015).

There are 16 environmental quality objectives in Sweden, out of which two are relevant for this study. These are objective 1 - Reduced Climate Impact and objective 12 - Sustainable Forests (Environmental Objectives, n.d.). Although the focus of this study is not biodiversity, it is important to cite that these two objectives emphasized the importance to preserve the biodiversity.

Objective 1 quote that “… concentrations of greenhouse gases in the atmosphere must be stabilized at a level that will prevent dangerous anthropogenic interference with the climate system. This goal must be achieved in such a way and at such a pace that biological diversity is preserved… and other goals of sustainable development are not jeopardized”. (Environmental Objectives, n.d., para. 1).

Objective 12 quotes that "The value of forests and forest land for biological production must be protected, at the same time as biological diversity…”. (Environmental Objectives, n.d., para. 1).

Swedish Environmental Protection Agency (2016) quote in the first report, Information on LULUCF actions by Sweden, that “Forest management has been a large carbon sink from 1990 to 2015”. During the years 2013-2015, the net removals in forest management was -34,1 Mton CO₂ eq. It was larger than forest management reference level, -41,336 Mton CO₂ eq.

To Forest Land, LULUCF regulation suggests some measures to reduce emissions and increase or maintain removals. Such as the use of harvesting residues as bioenergy, enhancing carbon stocks in forest soil and avoiding methods that increase GHG emissions.

The regulation also mentions that the Swedish forest policy focuses on sustainable forest management and conserving biodiversity (Pilli et al., 2016). Additionally, new policies can contribute to a decrease in emissions from deforestation, such protect land with high carbon content.

Furthermore, Swedish Environmental Protection Agency (2016) quoted that “Forest biodiversity is also important for the adaptation to climate change”.

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4. Discussion

Based on the results of this study, it was observed that most of the divergences are related to how the biomass should replace fossil fuel and decrease the CO$_2$ emissions or whether the use of biomass also increase carbon dioxide in the atmosphere. This literature review noticed that the use of biomass may substitute the emission from fossil fuel energy (energy substitution effect), but it does imply that biomass in short term will decrease the CO$_2$ emissions. The interval between the carbon release and the carbon sequestration is significant, despite that it is faster than for fossil fuel. Hence, the emissions will increase because the carbon released will not be offset before the new harvesting, and CO$_2$ will also be release by the energy sector itself. Thus, there is not the time for the debt be paid before the new rotation start.

This confused picture could be avoided if all the emissions from the use of forest biomass was accounted for in the carbon balance. It means the emission from all process to produce energy: harvesting, processing, transport, and combustion. Unfortunately, this is not the case. Hence, it, there is wrong interpretation on the neutrality of the carbon from biomass. This affirmation that forest biomass is carbon neutral seem to disregard the biosphere CO$_2$ flow (Cintas et al., 2016) even though it is part of one natural process of recycling carbon (Khanna et al., 2016).

The use of old-growth forest intensify the CO$_2$ released and lower what is stored in the forest. It is known that natural forests and growing forests are a large reservoir of the carbon and it will take a long time to replace this amount of CO$_2$ released if they are harvested. Moreover, for decades, scientists mistakenly thought that old-growth forests cease to accumulate carbon (Holm, 2015; Luyssaert et al., 2008). Currently, it is known that also very old forests accumulate carbon during their whole life cycle (Luyssaert et al., 2008). Thus, the use of these forests is contrary with the objective of decrease the CO$_2$ emissions. In addition, the use of old-growth forests is opposite to other sustainability criteria. EASAC (2017) states that protect old growth and the native forest is one form to protect the biodiversity, without compromise the use of forest to produce energy. Because these forests are biodiversity hotspots.

Also concerning the use of harvest residues, the benefits to the forest cannot be so positive as some authors suggested. I agree that the use of residues avoid harvesting of trees, and reduce the need to harvest old trees. However, the problems originating from residue harvest can generate irreversible effects. The loss of biodiversity is the most dangerous impact related to increasing the use of forest biomass. If biodiversity
is reduced, it will affect the capacity of the ecosystems to adapt to disturbances and can cause local extinctions of species (EASAC, 2017). For example, the decrease of deadwood can be a severe threat to red-listed wood-living species. Cowie et al. (2013) explain that the extraction of stumps will create a homogenized environment because some habitats disappear and decrease the amount of dead organic material. It is one large price to pay! Do we want to sacrifice the forest biodiversity to produce energy?

If it is necessary to use the residues to improve the energy production or avoid the use of trees, it is better to use the residues with high decomposition rate. It should depend on the size and chemical quality of residues, and climate zone (Repo et al., 2012). However, also forest residue as bioenergy decreases GHG emissions only in long perspective.

Regarding the policies, it is fundamental that the policy makers use the current knowledge on the use of biomass before they create targets. All impacts have to be considerate, thus avoiding conflicts between goals, such CO₂ and biodiversity targets. According to data from EASAC (2017), around 40% of the potential areas to produce energy in EU is located in the 30% top areas of biodiversity. Unfortunately, strategies and adaptation to mitigate climate change may come into conflict to the intention to reach biodiversity goals, conservation, and restoration of habitats in the forest sector.

If the objective is to reach established goals, changes must be made. The EU should incentivize all member states to substitute the fossil fuel energy for renewable energy through the carbon tax for CO₂ emissions from fossil fuel and other incentives (EASAC, 2017). Unfortunately, the current incentives at global and EU levels, to reach the agreements and targets are weak (Björheden, 2017).

At the national level, it is different. Sweden had the best performance in the use of renewable energy in comparison to other EU member states, due to strong forest industry knowledge and strong National policies implemented. Investments in the sector to replace the fossil fuel and taxation to the emissions were fundamental to this success. However, according to, Ståhls et al. (2011), the policies do not contribute with solutions, only with domestic fossil emissions. Unfortunately, this study agrees with this affirmation.
If the aim is to decrease the CO$_2$ emissions, there are other renewable energies which will provide better results. If the other renewable energy sources are more efficient to replace fossil fuel, it will be better focus in these to mitigate climate change. It was cited in Ortiz et al. (2016), that biomass is less efficient to decrease the CO$_2$ atmospheric than other renewable energy. As an example, the payback time from wind and solar is faster than decades for forest bioenergy (EASAC, 2017).

During this literature review, some gaps were observed. In the analysis of the emissions from the use of biomass, the biophysical aspects are neglected, such as albedo and other GHG gases. Cowie et al. (2013) affirm that changes in the flow the other GHG gases can affect the final results. Another gap founded, is that the previous studies used models to predict the benefits in the use of forest biomass, and the results are influenced by which model are used. So, it is necessary to have a standard model to follow. In particular, the use of different scales influences the final results. It happens because results can be negative at stand scale, but positive at the landscape scale. Besides, there is a lack of information about the amount of carbon in the soil, which needs to be investigated. Finally, it is difficult to predict the future demand for bioenergy. All these factors, together the importance to choose which source will be replaced, will affect the final results.

Previous studies observed better results when coal is replaced (Bentsen, 2017; Cintas et al., 2016; Cowie et al., 2013; Gustavsson et al., 2015). It was observed that the substitution of coal will generate more savings in the emissions and promote fast return when compared to the other fossil fuel.

If the use of biomass so increase, additional forest management measures need to be taken to re-establish the carbon stocks and sequestration. It can be done though improving forest productivity (Cintas et al., 2017). When the forests have high productivity, consequently the payback time will be shorter. Furthermore, the use of forest energy can be combined with different energy sources. Gustavsson et al. (2015) suggest the use of wind and solar energy to supply the energy to transport sector, while biomass can supply the chemicals and materials. In this way, the forest biomass can be used more optimal and limit large increase in the harvesting.
5. Conclusion

Based on this results, this study does not support the use of forest biomass energy as a great substitute for fossil fuel energy. As well as, the use of biomass energy will not decrease the CO$_2$ emissions over short time frames, so forest biomass is not a good alternative to mitigate climate change. To solve one problem by creating another problem is not the best solution. There are other renewable energy sources with less impact that can be used to substitute the fossil fuel energy to decrease the CO$_2$ emissions.

The policies targets should not be contradictory to each other. When EU policies suggest improving the use of forest biomass, it is contradictory with Paris Agreement goals. Furthermore, EU policies have contradictions between their criteria which should be avoided. There is a lack of important information that should be used as a base to the targets.

If the forest biomass has to be use, this study recommended the use of residues. It is at least problematic and it has faster payback time than other biomass.
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https://doi.org/10.1088/1748-9326/aaa512


7. Appendix

7.1 - Definitions

- **Albedo** - is the reflection of the light that reaches the canopy of the forest.
- **Carbon Balance** - is the difference between the sequestered and released carbon (Pukkala, 2014).
- **Forest carbon stock** - the sum of the carbon present in the trees, soil, and litter.
- **Carbon debit** - is the loss of carbon from the forest that needs to be regrown by the new stand (Nabuurs et al., 2017).
- **Carbon Neutral** - means that any CO₂ emissions are released into the atmosphere.
- **Carbon Parity** - the time to reach the difference between the payback time and the amount of carbon that should be stocked if the forest was not harvested (EASAC, 2017).
- **Carbon Sink** - means that CO₂ release from soil respiration and decomposition of other organic matter is smaller than carbon sequestered by the growing forest. There is a positive carbon balance (Pukkala, 2014).
- **Carbon Source** - is the opposite of carbon sink. It means that the soil respiration is bigger than carbon sequestered by the growing forest. There is a negative carbon balance (Pukkala, 2014).
- **Energy substitute effect** - is the reduction in the use of fossil fuel energy when the forest biomass is burned to replace fossil fuel (Nabuurs et al., 2017).
- **Forest Baseline scenario** - the reference level that countries are supposed to report their achievement in reducing CO₂ emissions by substituting fossil energy with energy from forest biomass.
- **Slash** - residues containing fine and coarse woody debris from logging.
LETTER FROM SCIENTISTS TO THE EU PARLIAMENT REGARDING FOREST BIOMASS
(updated January 14, 2018)

To Members of the European Parliament,

As the European Parliament commendably moves to expand the renewable energy directive, we strongly urge members of Parliament to amend the present directive to avoid expansive harm to the world’s forests and the acceleration of climate change. The flaw in the directive lies in provisions that would let countries, power plants and factories claim credit toward renewable energy targets for deliberately cutting down trees to burn them for energy. The solution should be to restrict the forest biomass eligible under the directive to residues and wastes.

For decades, European producers of paper and timber products have generated electricity and heat as beneficial by-products using wood wastes and limited forest residues. Since most of these waste materials would decompose and release carbon dioxide within a few years, using them to displace fossil fuels can reduce net carbon dioxide emissions to the atmosphere in a few years as well. By contrast, cutting down trees for bioenergy releases carbon that would otherwise stay locked up in forests, and diverting wood otherwise used for wood products will cause more cutting elsewhere to replace them.

Even if forests are allowed to regrow, using wood deliberately harvested for burning will increase carbon in the atmosphere and warming for decades to centuries – as many studies have shown – even when wood replaces coal, oil or natural gas. The reasons are fundamental and occur regardless of whether forest management is “sustainable.” Burning wood is inefficient and therefore emits far more carbon than burning fossil fuels for each kilowatt hour of electricity produced. Harvesting wood also properly leaves some biomass behind to protect soils, such as roots and small branches, which decompose and emit carbon. The result is a large “carbon debt.” Regrowing trees and displacement of fossil fuels may eventually pay off this “carbon debt” but only over long periods. Overall, allowing the harvest and burning of wood under the directive will transform large reductions otherwise achieved through solar and wind into large increases in carbon in the atmosphere by 2050.
Time matters. Placing an additional carbon load in the atmosphere for decades means permanent damages due to more rapid melting of glaciers and thawing of permafrost, and more packing of heat and acidity into the world’s oceans. At a critical moment when countries need to be “buying time” against climate change, this approach amounts to “selling” the world’s limited time to combat it.

The adverse implications not just for carbon but for global forests and biodiversity are also large. More than 100% of Europe’s annual harvest of wood would be needed to supply just one third of the expanded renewable energy directive. Because demand for wood and paper will remain, the result will be increased degradation of forests around the world. The example Europe would set for other countries would be even more dangerous. Europe has been properly encouraging countries such as Indonesia and Brazil to protect their forests, but the message of this directive is “cut your forests so long as someone burns them for energy.” Once countries invest in such efforts, fixing the error may become impossible. If the world moves to supply just an additional 3% of global energy with wood, it must double its commercial cuttings of the world’s forests.

By 1850, the use of wood for bioenergy helped drive the near deforestation of western Europe even when Europeans consumed far less energy than they do today. Although coal helped to save the forests of Europe, the solution to replacing coal is not to go back to burning forests, but instead to replace fossil fuels with low carbon sources, such as solar and wind. We urge European legislators to amend the present directive to restrict eligible forest biomass to appropriately defined residues and wastes because the fates of much of the world’s forests and the climate are literally at stake.

Initial signatories:

- , Professor, Oxford Martin School, former Chief Scientist to the government of the United Kingdom
- , Professor, Yale University, former Chairman, Department of Economics, fellow American Academy of Arts and Sciences, winner of the Frisch Medal of the Econometric Society.
- , Professor, Stanford University and Carnegie Institution for Science, Coordinating lead author or lead author of multiple IPCC reports.
- , Research Director, CNRS, Mediterranean Institute of marine and terrestrial Biodiversity and Ecology, Aix-en-Provence, member Académie d’Agriculture de France, Coordinating lead author and lead author of multiple IPCC reports,
Chair Sustainability Economics of Human Settlement at Technische Universität Berlin, Leader, leader Mercator Research Institute on Global Commons and Climate Change, Lead author of IPCC V Assessment Report and coordinator of appendix on bioenergy.

President, Woods Hole Research Center, former Senior Advisor White Office of Science and Technology Policy, Contributing author of multiple IPCC reports

Professor University of California at Berkeley, Director Renewable and Appropriate Energy Laboratory, Coordinating lead author or lead author of multiple IPCC reports.

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Professor Princeton University, Recipient, U.S. National Medal of Science, member U.S. National Academy of Sciences

Professor Humboldt University and Co-Chair of Potsdam Institute for Climate Research, lead author of multiple IPCC reports

Professor, University College London, Lead author IPCC report and Winner International Cosmos Prize

Emeritus Professor, Tufts University, Lead author of multiple IPCC reports

Director Emeritus Missouri Botanical Society, Recipient U.S. National Medal of Science and former President of American Association for Advancement of Science

Research Scholar, Princeton University and Senior Fellow, World Resources Institute

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782. Astrid Helena Huechacona Ruiz, Centro de Investigación Científica de Yucatán
783. Patrick Gonzalez, Associate Adjunct Professor, University of California, Berkeley
784. Werner Arber, Emeritus Professor of Molecular Mikrobiology, University of Basel, Winner Nobel Prize.