Measuring the Environmental Impact of Wood Pellet Electricity: A Case Study of Enviva

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Executive Summary

As electric utilities increasingly move away from fossil fuels to meet international emission reduction commitments, all sources of renewable energy resources have experienced considerable growth. While solar photovoltaics and wind turbines are often the first technologies that come to mind, it is bioenergy that the International Energy Agency predicts will contribute the most renewable production over the next five years and account for more than 30% of growth. Specifically, wood pellet-based biomass is expected to grow by 9.2% CAGR up until 2025, reaching a 15.47 billion USD market. This growth is driven in large part by the attractive alternative of converting coal electricity generation facilities to use wood pellets. Converting an existing coal power plant is cheaper than building new power plants, provides continuous power to support grid reliability, and avoids the siting issues that can plague distributed renewable energy projects. At the same time, research publications and popular press articles have questioned the greenhouse gas benefits of wood-powered bioelectricity relative to coal. Biomass electricity production can be controversial, with environmental outcomes highly dependent on forest management and wood sourcing practices. The resulting confusion may confound policymakers who seek to develop sound, acceptable, and effective energy strategies that lower greenhouse gas emissions.

This report attempts to clarify the increasingly important role that sustainably produced wood pellets play in advancing urgent decarbonization efforts. Enviva is the world's largest producer of wood pellets, offering electric utilities a fuel to replace coal, and enabling them to generate power without interruption while reducing their greenhouse gas emissions. Enviva engaged Boundless Impact Investing (Boundless) to conduct an objective third party environmental assessment of electricity production in the UK using wood pellet-based biomass. Boundless measured the impact using Life Cycle Assessment (LCA) practices. The goals of this research were to:

- Substantiate the requirements needed to deem practices "sustainable";
- Quantify the carbon intensity, and other environmental impacts, for wood pellet electricity relative to alternative generation technologies; and
- Evaluate the market impacts when wood pellet electricity is deployed at power plants, thereby reducing the grid's reliance on fossil fuels.

To meet the first objective, this report includes a nuanced discussion around the practices that contribute to sustainable forest management and includes efforts to ensure sustainable practices are achieved and perpetuated for the Southeast U.S. fuels and European power markets. Undoubtedly, the environmental impact of biomass production depends upon case-specific practices, and this study concludes that poorly conceived systems could negatively impact ecosystems and climate objectives. In contrast, well-designed supply chains can not only deliver beneficial reductions in emissions, but also contribute to sustaining forest ecological functions through careful forest management.

Our study found that on one hand, Enviva (which does not own forest) is fully certified by the Sustainable Biomass Program (SBP) – a woody feedstock supply chain certification program, but only 23% of the wood Enviva sourced for pellet production was produced on forests that were certified to the more rigorous SFI, FSC, or ATFS certification schemes in 2018. These latter programs certify actual forest acres to rigorous on-the-ground certification standards, and between 8 and 25% of the forest land in the states where Enviva operates is certified overall. Forest volumes in the Southeastern U.S. have grown steadily while environmental quality has been managed and monitored as a result of increasingly efficient regulations, land management practices, and third-party certification processes.

Our research further considered the controversy surrounding "carbon neutrality". In this case study, wood pellet-based fuel is comprised of biogenic carbon derived from working forests that continuously recycle carbon from the atmosphere to trees then back to the atmosphere. By contrast, traditional fossil fuels are essentially a one-way trip from geologic storage of carbon to the atmosphere. Findings indicated that wood pellet electricity provides GHG emission benefits relative to coal electricity under the conditions examined. For these reasons, Boundless asserts that only by examining specific case studies can the environmental impact of wood pellet-based electricity be reliably understood.

To meet the second objective, a case study of wood pellet production using feedstock from the Southeast U.S. to supply power plants in the U.K was performed. This research demonstrated that well-designed wood pellet-based biomass electricity systems can yield far lower GHG emissions than traditional natural gas and coal-powered electricity. Carbon intensity and other environmental metrics were developed in order to compare U.K. wood pellet electricity against power generation sources such as coal, natural gas, solar photovoltaic, and wind. Wood pellet-based biomass life cycle GHG emissions were higher than for wind and solar, however, each was far below the emission rates for coal and natural gas. A 1:1 replacement of coal electricity was estimated to yield an 87% emission reduction using wood pellets, a 92% reduction using solar electricity, and a 97% reduction using wind turbine generation.

Finally, the market impacts when wood pellet electricity is deployed at power plants were evaluated, reducing the grid's overall reliance on fossil fuels and their associated GHG emissions. Power sector modeling for three regions was conducted, with expanding use of wood pellet fuel for the U.K., Germany, and Japan. Scenarios were modeled with variable contributions from wood pellet electricity, within the context of each country's efforts to expand renewable and nuclear contributions commensurate with their emission goals. In each case it was found that wood pellets significantly contributed to steep GHG reductions, as part of diverse generation portfolios that also expanded other renewable and nuclear supply. The nature of large complex power grids makes all of the above approaches to GHG mitigation compelling, by taking advantage of the unique attributes of each low carbon technology. For example, biomass generation can dynamically respond to balance the variable power supply from other intermittent renewable resources, thereby helping system operators prevent power disruption. While natural gas power often has excellent load balancing capabilities, its associated GHG intensity is significant. In summary, when sustainably designed wood biofuel supply chains yield low carbon intensity, wood pellet electricity holds exceptionally strategic value for decarbonization efforts in the countries evaluated. But wood biofuel should not be *presumed* GHG neutral in a holistic life-cycle sense without case-specific determinations to consider all inputs, sources, and sinks including land-use change issues, which are discussed in some detail below.

Background

After the United States, Canada, Western Europe, Australia and New Zealand began to experience stagnant economic growth due to petroleum shortages and escalating oil prices in the 1970s, alternative sources of energy, such as plant-based biomass, began to emerge as a solution to the crisis. Since then, large-scale commercial biomass and wood pellet-based biomass initiatives have gained momentum. In fact, the International Energy Agency expects bioenergy to not only be the largest source of growth in renewable production over the next five years but also to account for more than 30% of that growth.[1] Specifically, the use of wood pellet-based biomass is expected to grow by 9.2% CAGR up until 2025, reaching a 15.47 billion USD market.[2] To date, wood and wood residue remains the largest source of biomass energy.

In its simplest form, biomass contains stored energy from the sun. Biomass can be burned by thermal conversion and used for energy in the form of heat or electricity production. New regulations and subsidies, carbon pricing in Europe, depletion of fossil fuels and discussions surrounding CO2-induced climate change have widened the biomass market to include growth in wood pellet-based biomass electricity production for use in Europe and Asia. In addition to their low carbon attributes, these fuels offer attractive benefits for grid operators. That's because when intermittent wind and solar energy resources create stress on electricity grids, biomass power is "dispatchable," providing a flexible and reliable form of renewable electricity to balance supply and demand. Wood pellets are also an economically attractive option for power producers, because existing coal-based power plants can be retrofitted to utilize this fuel relatively easily and cost-effectively, while avoiding contentious public battles to site new infrastructure.

To support these growing markets for biomass, sustainable ecosystem management must be central to bioenergy supply chain operations. Properly managed forests offer the potential for a continuous supply of wood products, along with a sustainable and reliable form of low carbon fuel. Mismanaged forests are not only environmentally destructive but are detrimental to climate mitigation efforts, because as forested areas and wood volumes decrease, so do their carbon stocks.

As the world's largest producer of wood pellets, sustainable practices are essential motivations for Enviva's business operations.[3] Enviva owns and operates eight plants located in the southeastern United States. They produce nearly 4 million metric tons of wood pellets annually with global distribution, including to the U.K., Japan, Denmark, and the Netherlands.[4] Enviva's wood pellet fuel allows electric utilities to generate power without interruption, lowering their greenhouse gas (GHG) emissions on a lifecycle basis by reducing the use of coal, natural gas, and fuel oil throughout the power grid.

Using Life Cycle Analysis to Clarify Climate Impact Measurement

Due to the complex and land intensive nature of agriculture and forestry industries, concern for their environmental impact is warranted. That's why Life Cycle Analysis (LCA) is critical. LCA evolved out of energy studies in the 1960s and 1970s and has become a valuable decision support tool for engineering firms, policy makers, researchers and industry. LCA uses standardized methodologies to delineate a system level understanding of environmental outcomes. LCAs are enlisted to understand and evaluate the magnitude and significance of existing and potential environmental outcomes of technologies. This system-based, sustainability management approach analyzes impacts throughout the entire supply chain, including manufacture, product use and end-of-life technology disposal. Perhaps more than in any other industry, LCA is an established best practice in the bioenergy industry, spanning transportation fuels, building and process heat, and fuel for the power sector.

Investors, regulators and industry leaders rely on emissions forecasts that are reliable, accurate and supportive of effective GHG mitigation regulation, policies and programs. As such, these concerns are important to consider in this critical research. The reported uncertainties are discussed to aid in differentiating between problematic and sustainably managed low-carbon bioenergy supply chains. So while recent controversy is described below, the critical point of emphasis is that the impact of any bioenergy technology, as with any other technology, is highly case specific.

For example, recent research has questioned the merits of bioenergy as well as industry standards in carbon accounting practices that are commonly used to measure carbon impact.[5,6,7] Given the compressed timeline for effective climate action, these concerns are critical. In addition to public confusion, regulators may feel increasingly uncertain about the emission impact of bioenergy, at a time when electric utilities seek to rapidly decarbonize their generation portfolios.

While the concerns raised are important, the research presented here does not focus on bioenergy supply chains with poor sustainability characteristics. The benefits of wood pellet-based biomass depend upon specifics and poorly conceived systems could negatively impact carbon emissions. The objective of this report is to consider how well-designed wood pellet–based fuel supply chains could deliver beneficial reductions in emissions given the fact that government and industry require these reduction strategies to include deep cuts in carbon emissions.

The nature of a large and complex power grid is that the most rapid and effective GHG abatement strategy is a comprehensive approach that takes advantage of unique attributes of each low carbon technology. Biomass generation facilities have the advantages that they can dynamically respond to balance power supply variability inherent to other intermittent renewable resources, helping system operators prevent power disruption. By helping remediate their intermittency challenges, biomass electricity may ultimately increase the rate at which solar and wind energy infrastructure can be deployed within power markets. This grid balancing service is commonly supported by natural gas power plants, resulting in significant GHG emissions.

Wood Pellet Biomass Alignment with Sustainable Development Goals

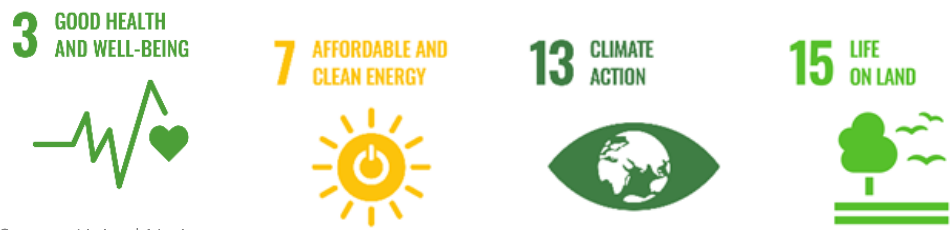
When the United Nations launched its 17 Sustainable Development Goals (SDGs) in 2012, its objective was to drive advance progress in the immediate environmental, political and economic challenges our world faced. Since then, The United Nations (UN) members adopted the SDGs as the core of its 2015 Sustainable Development Agenda with the purpose of providing a blueprint for peace and prosperity for people and the planet.[8] Generating electricity using wood pellet-based biomass aligns with four of these SDGs.

SDG 3: **Ensuring healthy lives and promoting well being for all at all ages.** Depending on characteristics of the facility that uses the wood pellets, wood pellet electricity generation reduces air pollutants relative to coal.

SDG 7: **Ensuring access to affordable, reliable, sustainable and modern energy for all.** Wood pellet electricity generation enables a reliable, clean and affordable form of electricity. As converting coal facilities to produce wood pellet electricity is cheaper than building new power plants and recycles the existing infrastructure, it provides a reliable and affordable alternative to fossil fuels.

SDG 13: **Taking urgent action to combat climate change**. Wood pellet electricity generation produces lower CO2e emissions compared to coal and traditional natural gas-powered electricity.

SDG 15: **Protecting and ensuring terrestrial ecosystems.** Millions of people around the world depend on life sustaining forest ecosystems for clean water, protection, food and jobs. As a result, forest growth and health are imperative. General biomass regulations in combination with Enviva's own sustainable measurement systems are designed to ensure that forest ecosystems are protected, as detailed in the following section.



Source: United Nations

The Case for Sustainable Forest Management

Since the European Commission (EC) introduced its recast Renewable Energy Directive (RED II) requiring biomass to be included in the EU framework, wood pellets shipped to Europe can only be derived from forestland marked for reforestation, and further criteria were also issued for biomass feedstock with special attention to land use changes.[9] These criteria were made to uphold the sustainability of biomass heat and electricity. According to RED II rules, areas for nature are to be protected, harvested forests are to be regenerated, and long-term production capacity and forest health are to be maintained and improved.[10,11]

However, criticism of the RED II Directive includes that it is oversimplified and that it overlooks the removal of forest residues as well as reducing soil carbon storage and nutrient availability, which might lead to a decline in soil fertility and tree growth.[12] In contrast to these important concerns, southern U.S. forests' annual growth is more than its combined harvest and natural mortality and have been for decades.[13] As a result, these forests contain more wood volume and carbon stock than they did up to 20 years ago. While not the subject of this paper, forests in the Northern and Western regions of the U.S. yield similar results for growth versus harvest and mortality.

The forest products industry is a major contributor to the U.S. economy. The U.S. government began selling virgin southern pine forests for timberland in the West Gulf Coast region immediately following the Civil War in late 1860s.[14] This emerging timber economy grew so quickly that by the end of the 1920s, virtually no old-growth forests remained. Ever since, most private forests in these regions have become working forests. Working forests are continuously managed to provide a steady supply of wood for the forest products industry. Working pine plantation forests in the Southeast take between 25 and 40 years to complete a cycle from harvesting to replanting. Throughout this continuous cycle, some one million American jobs are directly provided and nearly three million ancillary jobs are produced by forest work.

In many cases, working forests are artificially regenerated, which provides better control over tree spacing and types of trees, a higher survival rate of trees and ensures maximum growth due to species selection, site preparation for planting and other practices.[15] As growing trees compete for sunlight and nutrients, they tend to progress more slowly and less robustly in crowded forests. To increase forest production and health in the long term, a typical working forest undergoes one or two thinning cycles before being harvested a final time before regeneration occurs through planted or natural regeneration. Thinning means that a certain percentage of trees are harvested before the final harvest where all the remaining trees are removed. As a result of the thinning process, not only will the remaining trees grow faster and more robust, but also the wildflowers and other plants on the forest floor thrive due to increased exposure to sunlight. This positively affects the ecosystem as it creates more food and protection for forest animals and adds to the biodiversity of the forest site. Most of the trees and branches that are harvested during a thinning cycle are too small to be used by for long-lived high-value products, and instead are used to make wood pellets-based biomass or pulp and paper.

Once trees are fully-grown, they are ready to be harvested for the pulp and sawmill timber sectors. Different harvest methods exist, all of which have particular advantages and disadvantages. Some methods only remove some of the trees throughout the forest, while the rest are left for further growth. Other methods fully cut entire sections of forests. In southern pine plantations, thinning of some trees occurs once or twice before the final clearcut harvest occurs, followed quickly by replanting. Clearcut harvesting changes the look of the land immediately after harvest and can be aesthetically unappealing, however the rapid regrowth on these pine plantation sites ultimately recovers the forest and the aesthetics that go along with it in a few years.[16]

When looking at the life cycle of the biomass growth and harvest process, a long-term assessment of forest management practices is critical. If old forests were to be cut down specifically for biomass, without replanting or natural regeneration, biomass powered electricity would have higher GHG emissions than coal in most cases, due to its lower combustion efficiency. However, this is not the case.

Source: Adapted from Forest & Fish

Wood pellets used for biomass electricity production are created from low-grade trees and parts of trees that are generated as part of a traditional timber harvest and are only sourced from harvested forests that are managed for ongoing regeneration. Wood used for wood pellets are low-grade products from traditional timber harvests from working forests, which includes low-grade pulpwood, top-limbs, and residues from both pine and hardwood species. In a sustainably managed system, the carbon that is released as CO_2 during biofuel combustion is continuously balanced by CO_2 uptake from forest growth and is deemed "carbon neutral." Other sources of CO_2 emissions, such as diesel and electricity for harvest, processing, and transport are accounted for using life cycle analysis.

The economic reasoning behind the use of low-value tree parts for biomass explains why companies like Enviva make wood pellets from these woody materials. In order for biomass electricity to be economically viable, only woody materials with low economic value are used for the production of wood pellets. These materials cannot be used by other industries. These by-products include sawmill residue, including sawdust and shavings from sawmill facilities, as well as wood chips made in the forest from harvested low-quality trees. These feedstocks can also include small tree thinnings, branches and weak or deformed trees not suitable for use in a sawmill, whose removal contributes to healthy forest growth.

Enviva's Track & Trace™ system ensures transparency about where its wood feedstock is sourced. Based on this openly published data, Enviva's wood pellets were comprised of 17% sawmill residues and 83% by-products in

2018.[17] Of the 83% by-products, the distribution was roughly 50% wood chips and 50% roundwood. Some environmental groups contend that Enviva and other biomass producers source "whole trees" into their facilities, supported by photographs of tree logs going into wood pellet facilities.[18] Enviva acknowledges it does use trees in their intact form, but only those trees unsuitable for use in the sawmill and pulp industry because they are too small, contain defects or disease or are otherwise rejected for high value use like construction or sawtimber. Based on market prices, it is not economically feasible for forestland owners to sell high-value whole trees as low-value biomass feedstock, when these high-value trees would garner a much higher price as a higher quality raw material, such as logs for a sawmill.

Certification processes and systems exist to ensure that feedstock used for wood pellets is sustainable. Third party certification is the best current accountability mechanism for clarifying biomass wood sourcing. Forest owners who want to sell their product as 'sustainable' or 'responsible' must follow guidelines and rules set out by these programs, which protect the ecosystem, wildlife, and clean water systems.[19] The three largest certification schemas in the US South are the Sustainable Forestry Initiative (SFI), the Forest Stewardship Council (FSC) and the American Tree Farm System (ATFS). These third-party forest certification programs ensure that forests are being responsibly managed, environmentally, socially, and economically, by forestland owners. Additionally, they may ensure end-use buyers that the wood in their product is sustainably sourced. These systems certify specific acreages of forests – i.e. they are land-based, certifying specific parcels on-the-ground.

Enviva, which does not own forest, is fully certified by the Sustainable Biomass Program (SBP), but only 23% of the wood Enviva sourced for pellet production was produced on forestland certified to the more rigorous SFI, FSC, or ATFS certification schemes in 2018.[20] Achieving higher rates of certification is challenged by the facts that more than 85% of forestland in the Southeast U.S. is privately owned, and many landowners own less than 2000 acres.[21] Small lots of forest tend not to be certified because achieving certification is a relatively expensive burden for the owners. As wood pellet feedstock products are usually sold for the lowest value, there is a risk that any market benefits of certifying forest products would not outweigh the costs for these small forest owners.

As a result, the SBP certification system was specifically designed for wood pellets and wood chips used for bioenergy and enables certified companies to demonstrate that they use woody biomass, like pellets and chips, from responsibly managed forests.[22] Although compatible, SBP does not replace the aforementioned forest certification programs but rather builds on established practices set out by them. SBP focuses on maintaining or increasing forest volume, conserving biodiversity and on preserving forests of high conservation value. It also focuses on administration practices throughout the entire supply chain process to ensure chain of custody is protected, ensuring that unsustainable wood is not mixed with sustainable wood.

When looking at the sustainability of wood products for any type of industry, including for the biomass industry, it is important to look at regional as well as state level forest metrics, such as total forest area and volume of standing timber over time. Private forests grow because landowners have an incentive to replant or naturally regenerate more trees than they cut down, which secures for them future revenue from sale of trees to the forest products industry. Enviva's proposition that as it buys low value and residue materials that cannot be sold to other industries, this incentive is even bigger and thus results in more trees and forestland. Researchers at Duke University and North Carolina State Universities confirmed these statements.[23] Their research found a direct positive connection between demand for wood pellets and forest areas. Research by the United States Department of Agriculture Forest Services also shows that overall volume of live trees grew by roughly 4 billion cubic feet in the period 2013-2018 in North Carolina alone.[13] Importantly, arguing that working private forests should be ‘left alone’ is not logical, as forests with little or no economic value are at a greater risk for conversion from forest to non-forest use.

Enviva’s Environmental Profile

An objective independently funded life cycle assessment of electricity production using Enviva’s wood pellets was conducted in the fall 2019. Using its customized methodology, Boundless quantitatively assessed the GHG emissions and other environmental impacts throughout the wood pellet life cycle, starting from raw material procurement, through pellet production and up to delivery to the fuel’s final destination in the United Kingdom.

The Boundless Impact Assessment compared wood pellet electricity to alternative forms of electricity production across several metrics, including:

- GHG impact
- Air quality pollutants
- Energy payback time
- Carbon payback time
- Cost of electricity
- Carbon return on Investment

Two external industry experts were hired to independently review the findings of Boundless’ assessment:

- Robert Eckard, PhD, of Momentum (USA), an energy and biomass technology, environmental and fund development specialist with a deep background in quantitative life cycle and economic analysis for advanced bioenergy.
- Charles Levesque, an environmental auditing and forest management specialist, licensed professional forester and CEO of Innovative Natural Resource Solutions, LLC.

GHG components of the Boundless Impact Assessment are summarized in the Impact Profile GHG Highlights section below. Interested readers should contact Boundless Impact Investment for a more comprehensive summary.

Following the initial impact assessment, a second phase of Enviva-funded research was conducted, with the objective of substantiating the requirements needed to deem practices “sustainable” and ensure positive climate benefits. It also aims to evaluate the market impacts when wood pellet electricity is used at customer facilities and to estimate the net impact on power sector GHG emissions.

To evaluate the latter, power sector modeling was conducted for the U.K., Germany and Japan to demonstrate the potential benefits of wood pellet electricity as part of each countries diverse electricity supply mix. Because these three countries are pursuing long-term GHG reductions, scenarios were modeled with variable contributions from wood pellet electricity, within the context of each country’s efforts to expand renewable and nuclear contributions commensurate with their emission goals. Each scenario and its impact on total power sector emissions is summarized in the Market Impact Assessment section below.

Impact Profile GHG Highlights for Wood Pellet-Based Electricity Production in the U.K.

The environmental impact of electricity produced in the UK using wood pellets from the Southeastern U.S. against other electricity sources was compared. The other electricity sources were coal, natural gas, photovoltaic and wind. In the comparison, the following processes were evaluated:

- Life cycle inputs and impacts for wood pellets
- Timber harvesting
- Transport from the forest to the pellet production plant
- Methane emissions from wood feedstock storage
- Pellet production
- Transport from the pellet production plant to the port
- Transport to the UK

As part of this study, the key performance indicators previously discussed were evaluated using a case study wherein sustainable forest management is an expressed goal. This case study considered a steady state in the production and consumption of wood, treating CO2 emissions from pellet storage and power plant fuel combustion as carbon neutral.

The assumptions around carbon flux and carbon neutrality are critical to any bioenergy LCA. As a common source of controversy in the bioenergy industry, such determinations must be case specific. Where bioenergy supply chains influence the conversion of forested land to non-forest uses, or otherwise result in declining carbon stock, then associated carbon analysis should account for those losses and critical assessment of economic and policy drivers is warranted. In this case study, biomass production comes explicitly from continuously harvested and regenerated "working forests" and not from the conversion of forestland to other non-forest uses. To the contrary, forest carbon stocks are increasing in the Southeast US. When looking at regional and state-level forests including all ownership types: area, volumes, and forest carbon stock have grown annually by a steady percentage.[13,24]

The primary economic drivers for working forest harvests are the highest value wood products such as sawlogs, which are sawn into boards, whereas the wood pellet raw materials are sourced primarily from by-products. Enviva's third-party audited sourcing requires that raw materials fit specified categories: leftover wood or waste materials disregarded by the timber industry.[25] These materials typically include sawmill residues, treetops, branches, and low-value trees that are too small or of too low quality to be used in other sectors of the forest products industry. The European Commission's Renewable Energy Directive (RED II), which regulates the fuel in this case study, sets criteria for feedstock with special attention to land-use change.[9] It states that areas designated for nature are to be protected, harvested forests are to be regenerated, and long-term production capacity and forest health are to be maintained and improved.[10,11] For example, the wood used for wood pellets cannot be sourced from forestland that are intended to be used for anything else other than reforestation.

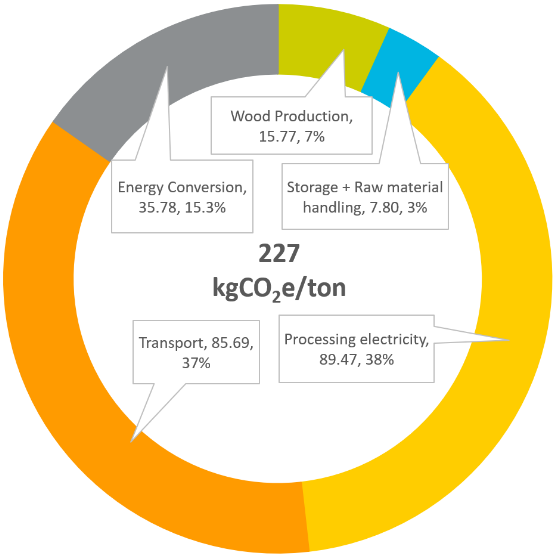
Perhaps the most confusing aspect of the carbon neutrality controversy is the accounting for the carbon in the biofuel itself. Biofuel should not be *presumed* GHG neutral in a holistic life-cycle sense without case-specific determinations to consider all inputs, sources, and sinks including land use change issues raised above. The carbon atoms in the fuel itself, while seemingly incontrovertibly neutral, remain controversial in research addressing broader industry concerns. From a purely physical viewpoint, the biogenic carbon atoms from regenerative forest or agricultural systems are absorbed from the atmosphere and are physically embodied within the woody and agricultural products. Those carbon atoms are released back to the atmosphere through decay (far more slowly for durable products) or combustion. Agricultural and forest systems continuously recycle carbon from the atmosphere to plants, then back to the atmosphere. In contrast to the recirculating biogenic carbon cycle, coal and gas combustion practically represents a one-way trip from geologic storage to the atmosphere, i.e., coal and natural gas formations re-sequester carbon only over millions of years. When wood pellets are used for electricity, continuously recycled biogenic carbon is displacing one-way-trip carbon from coal and natural gas.

A different approach to crediting the carbon absorption that occurs during plant growth is charging the carbon emissions at the time of combustion, creating a "carbon debt" to be paid back via future growth cycles. The notion that bioelectricity temporarily emits more carbon than coal, or that bioelectricity does not "pay back" its carbon for many years, results from this choice in accounting practice. Carbon-debt accounting is not an objectively "right way" to measure GHG impact, nor is it more intuitive than crediting biogenic carbon during forest growth. Regardless of accounting practice, equivalent regenerative systems ultimately reach the same steady state carbon flux and yield long-term emission reductions relative to coal. In the case of EU markets, regulators account for the biofuel's embodied carbon as neutral, consistent with the physical biogenic carbon cycle. The electricity market analysis for this research conforms to this regulatory standard. But, importantly, it includes additional inputs for possible methane emissions from feedstock storage, which is important to include. While this is not included in regulatory calculations, it comprises a small but material carbon impact that should be well-managed in order to ensure biomass energy maximizes carbon impacts.

In doing so, the GHG emissions of wood pellet derived electricity in the U.K. were estimated as 227 kgCO2e per ton fuel consumed, equivalent to 0.13 kgCO2e/kWh. This emission rate can be much lower, on a case-by-case basis, at locations where waste heat recovery is practical (i.e., combined heat and power systems.)

A summary of contributions from each process step is illustrated below:

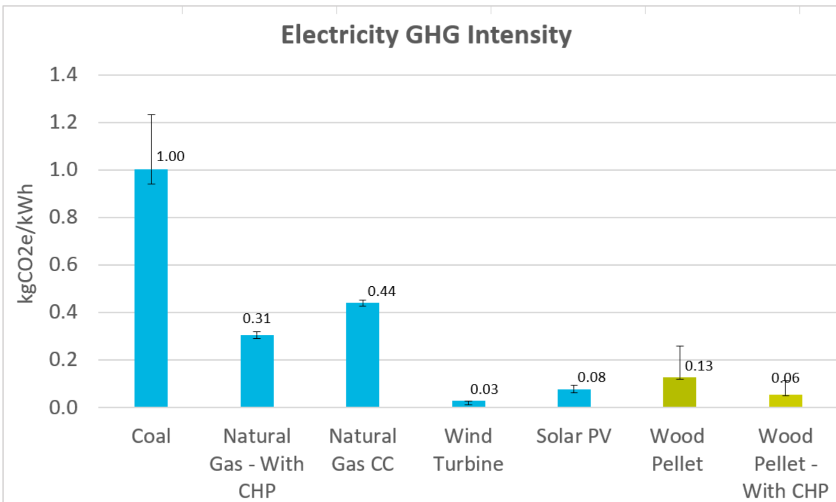
- Transport is 37%
- Processing of wood pellets is 38%
- Storage is 3%
- Energy conversion is 15%
- Wood production is 7%

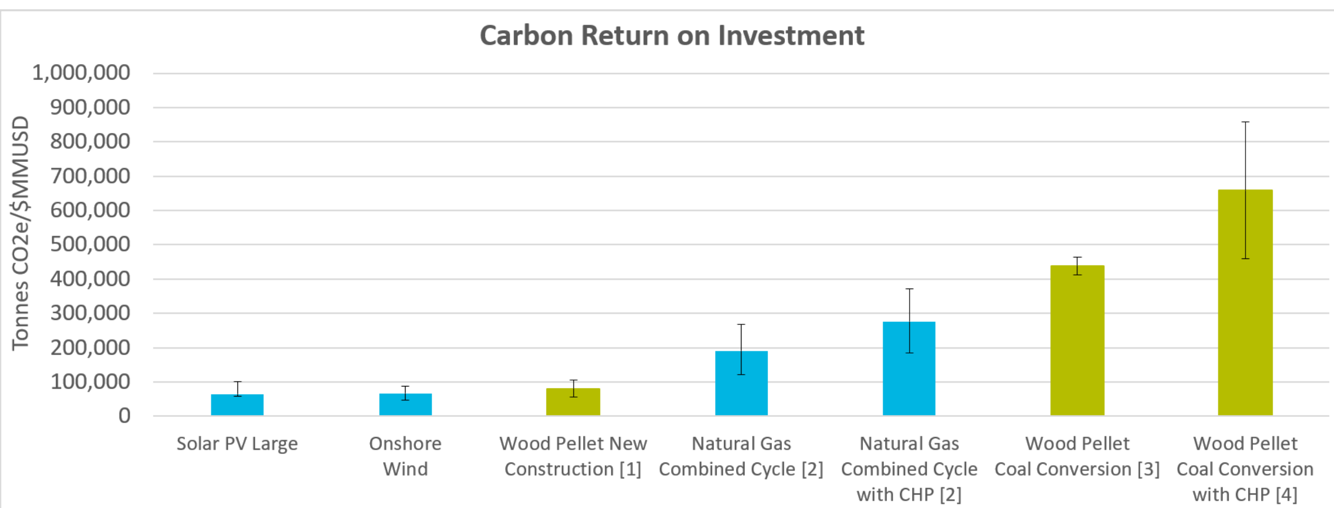


Transportation steps include trucking raw material from the forest to the pellet processing facility and finished pellet product to U.S. ports, and ocean transport to the U.K. Storage includes methane emissions during the storage of wood feedstocks, as well as emissions during raw material handling.

When looking at the entire life cycle, electricity generated using wood pellet-based biomass emits far less GHG emissions per kilowatt-hour than coal (87% reduction) and natural gas based (71% reduction) electricity. Analysis showed that wood pellet electricity's GHG intensity was somewhat higher than rates commonly reported for wind and solar technologies. However, each was far below the emission rates for coal and natural gas. Based on estimated and reported values, a 1:1 replacement of coal electricity with wood pellets would yield an 87% GHG emission reduction using wood pellets, a 92% reduction using solar electricity and a 97% reduction using wind turbine generation.

The research included third-party industry analysis, which indicated that coal plants can be converted to use wood pellet fuel at far lower capital costs than is required to construct new renewable generation infrastructure. This lower construction cost, coupled with a higher amount of annual generating capability, results in a very high Carbon Return On Investment (CROI). CROI is a metric that estimates carbon savings are per one million US$ invested in a technology. As shown below, a coal plant that is converted to use wood pellets has an extremely high CROI when the residual heat of combustion can be used as part of an integrated Combined Heat and Power (CHP) system. For each one million $USD invested in coal-conversion, 658,000 tons of CO2e are avoided from coal power and natural gas heat when CHP is included. Investing in a new small-scale dedicated biomass facility without CHP, while being more expensive, was still estimated to save 80,800 tons of CO2e per million $USD invested, comparing favorably to wind and solar due to the high annual electricity production of wood pellet power plants. Natural gas power plants score favorably in the CROI metric due to low capital cost. Importantly, however, natural gas is not capable of achieving the deep emission reductions. Therefore, the total contribution of natural gas to the generation mix must be limited to achieve climate stabilizing emission levels.





[1] New construction of electricity only wood-pellet biomass power plant with inital capital cost of 2,717 $/kW.
[2] See discussion in report text regarding the limitations of natural gas for achieving deep decarbonization objectives.
[3] Conversion of existing coal power plant to use wood pellets with initial capital cost of 270 $/kW.
[4] Conversion of existing CHP coal power plant to use wood pellets with initial capital cost of 270 $/kW.

Market Analysis – Wood Pellet Electricity Lowering Power Sector Emissions

In analyzing the potential for wood pellet electricity to reduce GHG emissions with increased utilization in national electricity sectors, case studies in the United Kingdom, Japan, as well as the region comprised by Germany and neighboring countries, were considered. Each of these countries has ambitious goals to expand clean energy as discussed separately below.

A utility capacity expansion model was used, along with the wood pellet life cycle electricity emission factors as shown in the previous chapter, to assess the market-wide net GHG emission impacts.[26] As is generally true for renewable resources, increasing wood pellet fuel use will consequently reduce power generation from coal, natural gas and diesel as grid operators preferentially "dispatch" the lower cost and lower emission renewable resources to meet demand. Specific to wood pellet electricity, however, is the direct 1:1 replacement of coal electricity generation through fuel switching efforts at individual power plant facilities. Both the direct substitution and secondary dispatch effects are captured in the modeling.

For each region, the existing fleet of power plants and renewable generation was characterized based on data from the open-source Global Power Plants Database (GPPD).[27] The modeling was further calibrated (via fuel prices, renewable technology performance, and recent power plant additions and retirements), such that the simulated generation mix closely resembled historical operations as reported by the International Energy Agency (IEA).[28] Energy demand was based on IEA reported values and held constant for the duration of the analysis.

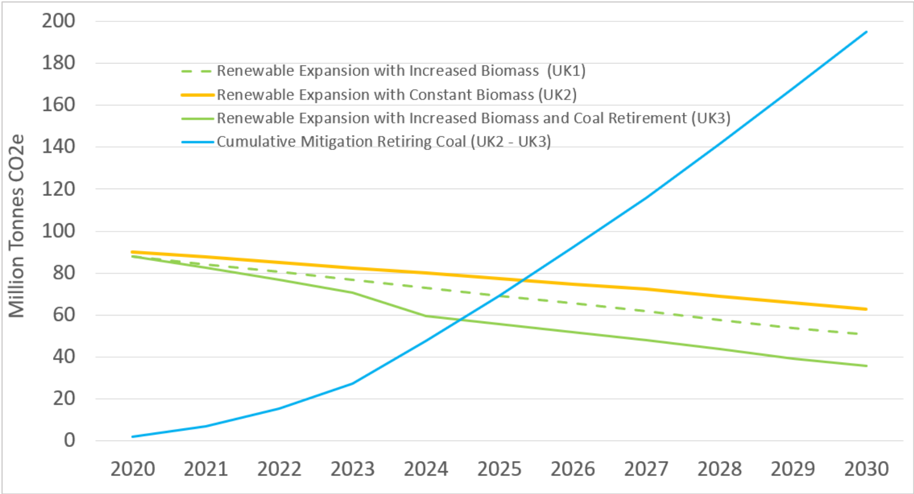
United Kingdom Electricity Market Impact

In the U.K., reliance on coal has been drastically reduced over the past two decades, now providing only 5% of electricity supply.[29] Natural gas is the largest contributor to electricity supply, providing 39%, while nuclear power provides roughly 20%. The U.K.'s Department for Business, Energy & Industrial Strategy recently estimated that renewable energy supply could increase from 40% in 2018 to 59% by 2030, under the current suite of existing policies. The GHG emission reductions were examined that might be achieved by meeting 59% of the U.K.'s electricity supply by uniformly increasing wind, solar and biomass electricity from current levels to 1.8-times higher contributions by 2030. As illustrated below, this strategy resulted in an impressive 43% reduction in GHG emissions over the period of 2020 to 2030 (See Scenario UK1 in the figure below).

Wood pellet electricity was a major contributor to the emission reductions in the scenario described above. To estimate its impact, this scenario was replicated *without* expanded contributions from wood pellet fuel. Given the U.K. generation supply mix, reducing this contribution effectively requires grid-operators to use higher-emitting natural gas to make up the difference. GHG emissions still declined (See Scenario UK2), but less so, achieving a 31% reduction from 2020 levels, compared to a 43% reduction in UK1 Scenario. Comparing 2030 GHG emissions directly, levels were 24% higher without the expanded wood pellet contributions.

A third scenario was simulated to consider taking advantage of wood pellet's unique ability to substitute for coal. In scenario UK3, in addition to expanded contributions of wind, solar, and wood pellet electricity, the U.K.'s remaining coal generation was phased out by 2024 as anticipated. The result was a 59% decline in GHG emissions.

The potential for wood pellets to reduce U.K. emissions through their supplemental expansion in addition to wind and solar, can be characterized by the 43% lower GHG emissions in Scenario UK3 (with expanded wood pellet and coal completely displaced) versus UK2 (with constant biomass and coal maintained). The cumulative 2020-2030 GHG savings between the two scenarios was 195 million tonnes CO2e. These GHG savings are the equivalent to taking 4.0 million vehicles off the road for a 10-year period.



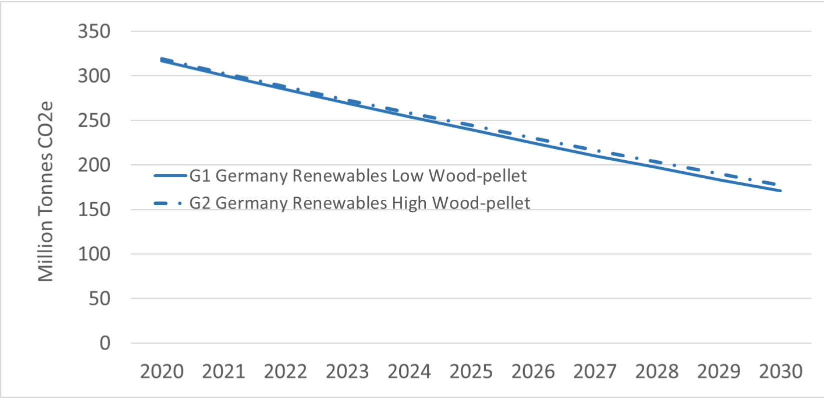
Germany Electricity Market Impact

While Germany still relies on substantial contributions of coal and natural gas for its electricity supply (32% and 19% respectively in 2018), national mandates require increasing the power sector's renewable contributions from approximately 40% currently, to 65% by 2030. As noted in recent reporting, however, the utility industry has identified challenges to site solar and wind infrastructure as a major obstacle to achieving this goal with calls to ease regulatory restrictions. Increasing wood pellet utilization is one strategy to mitigate these siting challenges by utilizing low emission renewable resources at existing coal facilities. Such a strategy was evaluated at the regional level, considering a major substitution of wood pellets for coal within the power markets of Germany and several of its grid-connected neighbors like Denmark, Luxembourg and the Netherlands.

To approximate the German mandate, a scenario was modelled, wherein the multinational power sector increases renewables from 32% to 60% by 2030, of which 15% derived from bioenergy. The resulting impact of this strategy, as illustrated in Scenario G1 below, was a 44% reduction in GHG emissions from simulated 2020 levels. In Scenario G2, an alternative scenario was considered in which bioelectricity was held constant at 6.6%, and only contributions from wind and solar resources were increased to achieve the renewable target. This scenario achieved slightly deeper emission reductions, 46% below simulated 2020 levels.

The relatively small difference in emission profiles observed between the two scenarios is worth noting. In life cycle emissions reporting above, wood pellet electricity carbon intensity was demonstrated to be higher than for wind or solar electricity. In regulatory emissions reporting it is common for bioenergy to account for its life cycle GHG emissions. Other renewable sources, as well as nuclear power, do not typically report their life cycle emissions and are treated as zero emission resources. Even so, the wood pellet scenario performs nearly as well because it disproportionately substitutes for coal due to its 1:1 substitution, whereas other renewables are displacing a higher proportion of natural gas as a result of changes in system wide dispatch.[30] Accounting for life cycle emissions for wind, solar, and any associated battery storage would increase emissions in Scenario G2, relative to G1. Put simply, even though wood pellet fuel may have higher life cycle emissions than wind and solar technologies, full life cycle accounting for all technologies, in addition to accounting for market impacts, may negate or nearly negate this disadvantage.

Given the ability of wood pellet electricity to provide reliable power, this type of direct substitution for coal is viable. In contrast, attempting to increase intermittent renewables in place of dispatchable resources becomes increasingly challenging for grid operators. While technically feasible, energy storage is ultimately required when intermittent renewables reach very high levels. Such an addition of battery storage requires additional costs as well as its own life cycle environmental impact. There are several other non-emission benefits worth considering. Conversion of existing coal facilities mitigate the sitting challenges discussed previously. Additionally, the low cost of wood pellet conversion means that financial resources can be reduced in the power sector. Perhaps most importantly, the reliability challenges of intermittent renewables are lessened with fewer requirements for, often expensive, battery storage.



Japan Electricity Market Impact

Japan's electricity market faces unique challenges stemming from the shutdown of the nuclear power industry following the tsunami-induced accident at the Fukushima Daiichi power station in 2011. Prior to 2011, Japan generated a large proportion of its electricity from nuclear power – a strategic asset for a country without native coal and gas resources.

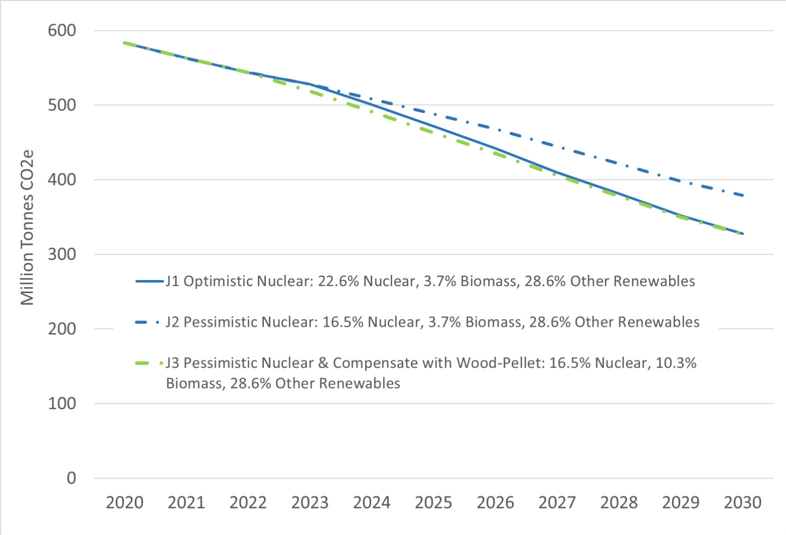
Since 2011, only a small number of reactors have re-started while several others have been permanently retired. Japan's energy planners still consider the many other idle nuclear power facilities as important components of long-term energy strategy. These reactors can be categorized as likely to restart, uncertain to restart, and unlikely to restart. Those deemed uncertain and unlikely face a combination of technical, economic, and public opposition.

While the fate of Japan's nuclear fleet remains uncertain, continued reliance on non-domestic energy resources is undesirable and expensive. Therefore, considerable growth in renewable resources, particularly solar PV installations have grown rapidly with policy incentives. Japan's strategic energy plan (SEP) provides a roadmap for intended future electricity resource. It outlines desired contributions across a diverse array of expanded renewable resources. In addition, Japan's ambitious, but uncertain, goal is to re-start enough of its nuclear fleet to generate roughly 22% of its electricity supply by 2030.

Three scenarios were developed to consider how varying degrees of successful nuclear restarts could impact Japan's power sector GHG emissions. In particular, the role that wood pellet electricity could offer in providing an "emissions hedge" to maintain low emissions in the case of a low rate of nuclear restarts was considered. Below, the GHG emissions for each of the three scenarios for Japan's electricity sector are plotted.

In scenario J1, it is assumed that nuclear unit restarts are successful and reach 22% of electricity supply by 2030. Further, contributions prescribed in Japan's SEP were implemented to meet the following contributions to the national generation mix in Scenario J1: 9% hydroelectricity, 7% solar, 7% wind energy, 4% biofuels, 1% geothermal. The net impact on GHG emissions for this scenario was a 44% reduction by 2030, from simulated 2020 levels. Importantly, the J1 emission reduction relies on an assumption that a large portion of Japan's nuclear industry can be successfully restarted. This cannot be taken for granted as several nuclear units are deemed uncertain to restart.[31]

In scenario J2, the relative increase in power sector emissions if those uncertain nuclear units do not restart was demonstrated. Instead of the 44% reduction, only a 35% GHG reduction is achieved. In scenario J3, the use of wood pellet electricity as a "carbon hedge" was simulated, in the event those nuclear units follow the pessimistic trajectory in Scenario J2. In scenario J3, the same carbon trajectory is maintained, as in the J1 optimistic nuclear scenario, by converting several of Japan's coal-fired power plants to use wood pellets and increasing the total biofuel contribution to the power sector from 3.7% to 10.3%.



Analysis of Japan's nuclear industry uncertainty was performed with detailed unit-level consideration of which individual nuclear units are considered likely, uncertain, or unlikely to resume operation. These outcomes will dramatically impact Japan's national CO2 profile relative to international commitments, such that contingency planning around GHG emission impacts is warranted. Modeling results indicate that substituting wood pellet fuel for coal at the levels simulated above (J3), may offer Japan an important hedge against emissions increases. This strategy offers one approach for Japan to maintain its proposed CO2 targets, in the case that troubled nuclear reactors are unable to restart.

Conclusion

Wood pellet-based electricity generation has been found to be a reliable and dispatchable source of renewable electricity, helping remediate the intermittency challenges of solar and wind sources. Compared to coal and traditional natural gas-powered electricity, wood pellet-based biomass electricity is a sustainable form of electricity, provided the forests producing the wood are sustainably managed. Previous analysis showed that it results in significantly less GHG emissions per kWh compared to coal and traditional natural gas, 87% and 71% respectively. For every $1 million dollars invested in combined heat and power biomass facilities, as much as 658,000 kilograms of CO2e emissions can be saved.

The potential for wood pellet-based biomass electricity to displace GHG emissions were analyzed for the U.K., German and Japanese power sectors. Low carbon wood-electricity may be an important adaptive technology to move energy sectors toward deeper decarbonization. It was also found that using wood pellets to displace fossil fuels can provide a valuable tool for countries pursuing GHG reductions.

The positive performance attributes of wood pellet electricity can also increase the rate at which solar and wind energy infrastructure can be deployed. Sustainably produced wood pellet-based biomass can ultimately balance the kind of power supply variability that occurs with wind, solar and other intermittent forms of renewable energy. This balance is critical to helping system operators prevent power disruption.

The environmental benefits of using wood pellet-based biomass electricity production over coal and natural gas are significant when the wood used to create the wood pellets is composed of secondary materials and sustainably sourced from a working forest landscape. Significant GHG savings can be achieved when efficient regulations, best practices, and 3rd party verification processes are in place, although wood pellet-based biomass powered electricity can be very controversial when forests are not sustainably managed.

Forest volume has been growing steadily in the U.S. as a result of more sustainable practices, but biomass-powered electricity cannot be approved to be environmentally safe on a categorical basis. The research presented here does not address bioenergy supply chains with poor sustainability practices. Therefore, the benefits of biomass are case-specific. The objective of this study was to analyze how sustainably sourced wood pellets compare to coal and traditional natural gas, and whether it might deliver beneficial emissions reductions and in which case those benefits occur. Government and industry still urgently need to continue putting resources towards forms of energy that result in a more reliable and carbon neutral grid.

Appendix: Discussion on Carbon Neutrality and LCA Accounting Practices

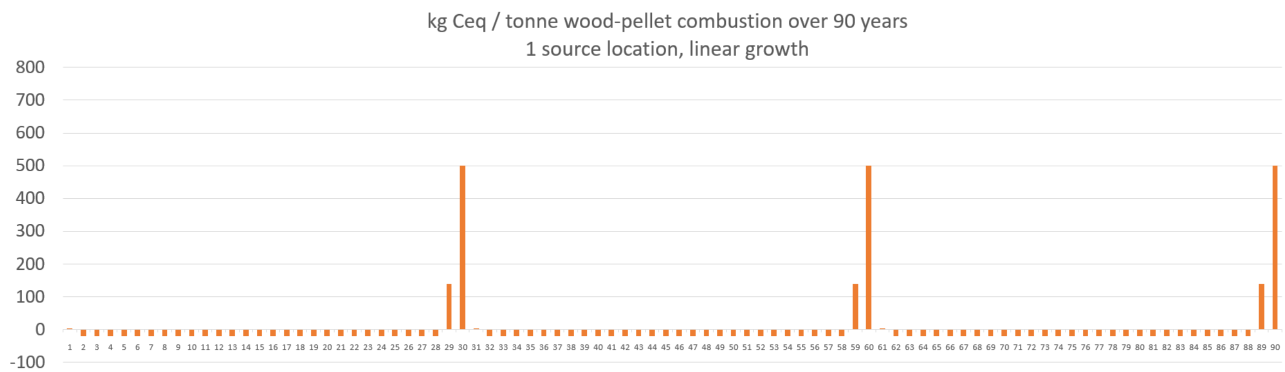
Whether the biogenic carbon flux of raw material supply is justifiably carbon-neutral is a critical determination when evaluating carbon intensity for any bioenergy supply chain. Three pre-conditions helped assure us that our carbon-neutral assumption was valid: A) that net increases in forest carbon stocks are occurring for the geographic area of study, B) that raw materials are sourced from mill residues and forest-harvest by-products, and C) that biomass production is not derived from the conversion of forestland to other non-forest uses with harmful ecological and emission consequences. Regarding condition A, the South-eastern U.S. is one such region where the total carbon stock of forest biomass is demonstrably increasing over recent decades. When looking at regional and state-level forests including all ownership types; area, volumes, and forest carbon stock have grown annually by a steady percentage.[13,24] Regarding condition B, Enviva's third-party audited sustainable sourcing requires that raw materials fit specified categories; leftover wood or waste materials disregarded by the timber industry.[25] These materials typically include sawmill residues, treetops, branches, and whole trees that are too small or of too low quality to be used in other sectors of the forest products industry. Regarding condition C, the European Commission's Renewable Energy Directive (RED II) sets criteria for feedstock for biofuels, bioliquids, and biomass, with special attention to land-use change.[9] It states that areas designated for nature are to be protected, harvested forests are to be regenerated, and long-term production capacity and forest health are to be maintained and improved.[10,11] For example, the wood used for the production of wood pellets cannot be sourced from forestland that are intended to be used for anything else than reforestation. US-based wood pellet suppliers are subject to these rules for their European importers to label the wood pellets as sustainable biomass.

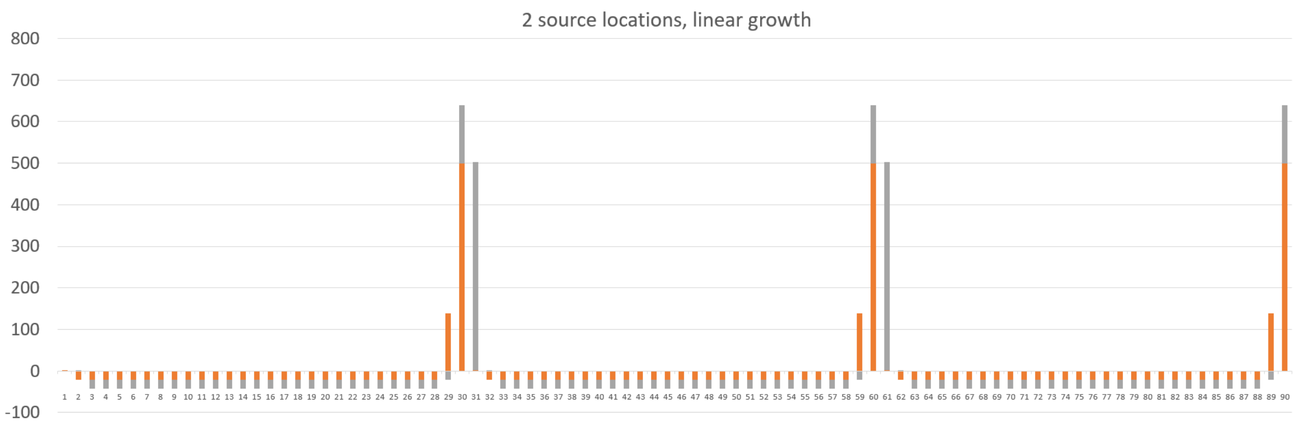
As discussed above, accounting for the net carbon flux of biogenic resources is vital to reliable planning and regulation of greenhouse gas emissions, and for which objective critical research is warranted. Research that is generically critical of biomass, however, has perpetuated confusion in the popular press and misguided policy-makers with regard to climate benefits when sustainable forest management is practiced, and carbon-neutrality is valid. One such claim is that biomass electricity emits more carbon than coal. This claim is selectively applied to the combustion process itself. Owing to fuel and combustion chemistry, the thermal efficiency for coal combustion may be higher than for biomass combustion, more so when using green wood chips as opposed to dry wood pellets examined herein, and more so without waste heat recovery (i.e., CHP). The rate of CO2 released during power plant combustion, however, should not be conflated with the total system CO2 impact given proper life-cycle accounting. The lower thermal efficiency for biomass is only one component of total carbon intensity and does not reflect the net carbon-intensity of the fuel. As demonstrated in this study, replacing coal with low carbon-intensity wood pellets yields substantial carbon mitigation. Opponents also argue, generically, that burning biomass for electricity may increase CO2 levels in the short run, incurring a carbon debt. They share concerns that this increase in atmospheric CO2 emissions will have a direct worsening effect on global warming. It is important to note that global temperatures are relatively insensitive to short term changes in CO2 emissions, as it is a function of long term cumulative CO2 emissions.[32]

Below questions are raised over the timing of carbon uptake and emissions (carbon debt), and the relative long-term emission implications of low-carbon intensity wood pellet versus coal-fired electricity. To do so, a simple carbon-neutral production of one metric tonne wood pellet fuel that repeats over a 30-year cycle was examined, with assumptions shown in the following table.

	kg C / tonne pellet	C Source
Establish	2.54	External Fuel
Average Annual Growth (29 years)	-20.85	Internal C-Cycle
Harvest and Transport	6.12	External Fuel
Drying	104.74	Internal C-Cycle
Process and Ship	49.00	External Fuel
Combustion	500.00	Internal C-Cycle
Total Internal C-cycle emissions	604.74	Drying & Combustion
Total Carbon Uptake During Growth	-604.74	29 years growth
Total External fuel -source C emissions	57.66	Establish, Harvest, Transport

As illustrated in Figure A4-1a, forest establishment in year-1 is responsible for a small amount of life-cycle emissions. Growth in years 2 – 29 is assumed linear and carbon uptake is represented as a negative value. In year 29, carbon emissions result from harvest, processing, and transport (external fuel sources) as well as for biomass drying (internal carbon cycle). In year 30, the wood pellet fuel is consumed releasing the carbon in the pellet. The total carbon uptake is equal to the emissions released from biomass drying and combustion (carbon neutral). The cycle repeats starting in years 31 and 61. Of course, a biofuel supplier must source its raw materials from multiple locations in order to provide a recurring supply of fuel. In Figure A4-1b, the carbon flux associated from a second source location is illustrated in gray bars, established in year 2 and with fuel combustion in year 31). In Figure A4-1c, a continuous supply from 30 source locations is illustrated and the total net annual carbon flux is shown in the green, with steady-state emissions of 58 kg C / tonne beginning in year 30 and onward.





BOUNDLESS IMPACT INVESTING

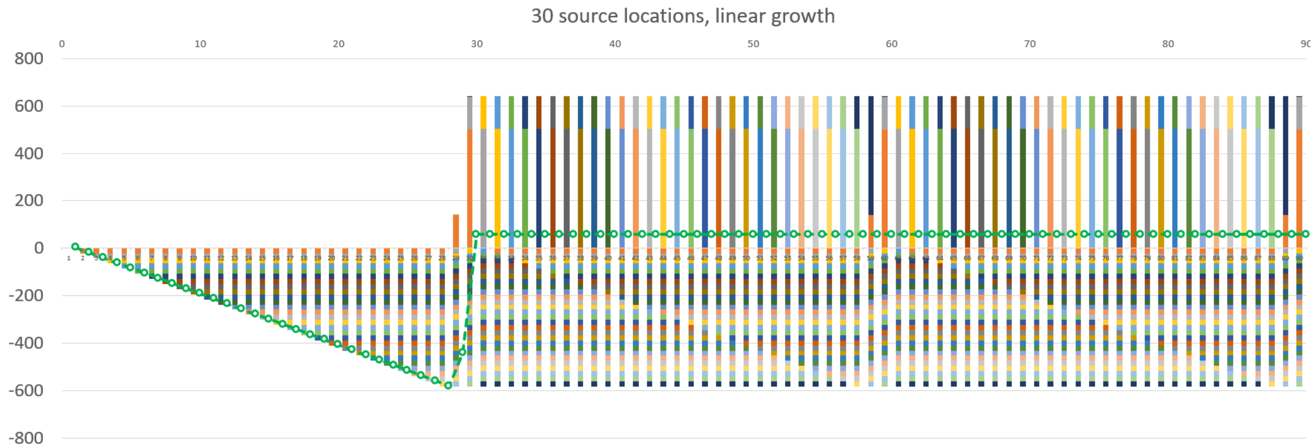
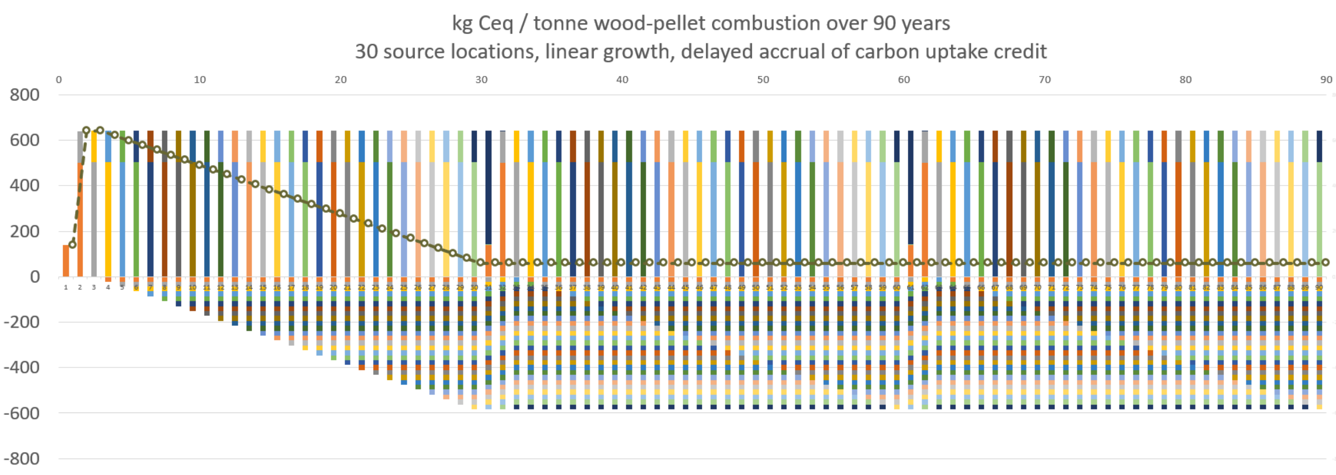


Figure A4-1a, b, c. Carbon flux for a thirty-year regenerative fuel system derived from one source location (top - a), two source locations (middle – b), and 30 source locations (bottom – c) with total annual emissions plotted in green. The rate of forest growth is assumed linear over 29 years, raw material production and processing occurs at the end of year 29 and fuel combustion at the beginning of year 30.

While boundless does not advocate such an approach, in Figure A4-2 the implications of a carbon-debt LCA accounting approach are illustrated, i.e., not crediting biomass fuels with carbon uptake during growth. Importantly, these different accounting practices are applied to the same 30-year production scenario as in A4-1, ***meaning that real world emission impacts in both cases are identical***. In Figure A4-1, the industry standard accounting choice credits 100% of the biogenic carbon uptake to the biomass fuel, prior to combustion. In other words, all the carbon uptake during plant growth offsets the same carbon released during combustion. In Figure A-42a, none of the biogenic carbon uptake is credited prior to combustion. Carbon emissions are released during biomass production, processing, and combustion. The accrual of carbon credit is delayed corresponding with future regenerative forest growth. The net emissions from this system are shown in the brown line in Figure A4-2a and can be compared to the green line in Figure A4-1c (bottom). ***Regardless of LCA accounting choice, the same annual emissions of 58 kg/tonne result as steady state conditions,*** i.e., the same equilibrium emission rate from the perspective of the LCA accountant. The same equilibrium emission rate is demonstrated for the 30-source system when regenerative growth and fuel production occur as a continuous steady state operation, shown by the black line in Figure A4-2b (bottom).



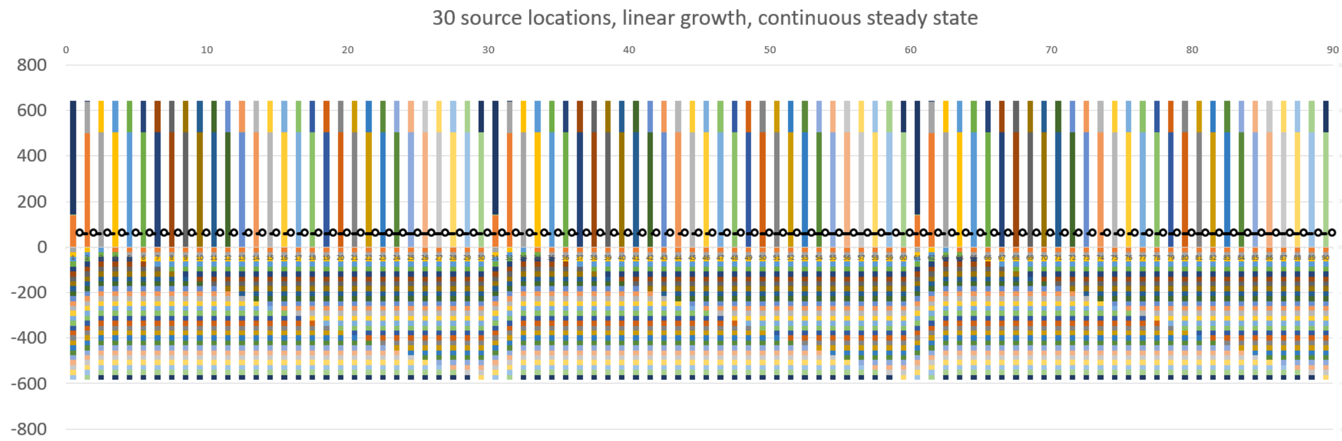


Figure A4-2a, b. Carbon emissions are examined for simple thirty-year regenerative fuel system where the rate of forest growth is assumed linear over 29 years, raw material production and processing occurs at the end of year 29 and fuel combustion at the beginning of year 30. At top (a), none of the biogenic carbon uptake is credited prior to combustion, delaying the accrual of credit for carbon uptake to correspond with future regenerative growth. In contrast, illustrated at bottom (b) are net emissions for a 30-source regenerative system at continuous steady state conditions.

From the LCA accounting perspective, negating the convention that credits carbon uptake during biomass growth (instead assigning a carbon debt at the time of combustion) provides no real-world emission benefit, yet has the potential to confound practical emission regulations. LCA based regulation of bioenergy GHG is often complicated, particularly when offsets from physically disparate systems are integrated (See (Kaufman, et al. 2010)[33] for discussion of the associated variability of LCA practices for regulatory bioenergy accounting). That the physically-embodied carbon in the biomass was extracted from the atmosphere during its photosynthetic growth is an unambiguous and logical basis for crediting carbon released during combustion. The carbon-debt approach to LCA accounting would seemingly require a non-literal assignment of carbon offsets occurring as a result of some other plant growth occurring in some other future landscape. Such a scheme would undermine reliable GHG regulation, with obvious potential for impractical, inaccurate, and un-auditable carbon accounting. In addition to being illogical and impractical, not crediting carbon uptake during biomass growth creates an obvious disincentive for low carbon regenerative fuel systems. While the LCA accounting choice does not affect actual emissions, it does have the potential to create disincentives for low-carbon fuel supply, by delaying payment or incentives received as reward for emissions mitigation occurring earlier in its life-cycle.

Lastly, the question of whether sustainably managed biomass offers emission benefits relative to coal is addressed. Following on the analysis above, Figure A-43 presents comparisons of low-carbon wood pellet fuel versus an equivalent amount of electricity generation from coal. To stress the point introduced earlier, the thermal efficiency of coal combustion is assumed to be 5% better than for wood pellets. Upstream emissions from coal mining and transport are assumed to contribute 15% of coal's total life-cycle emissions.

BOUNDLESS IMPACT INVESTING

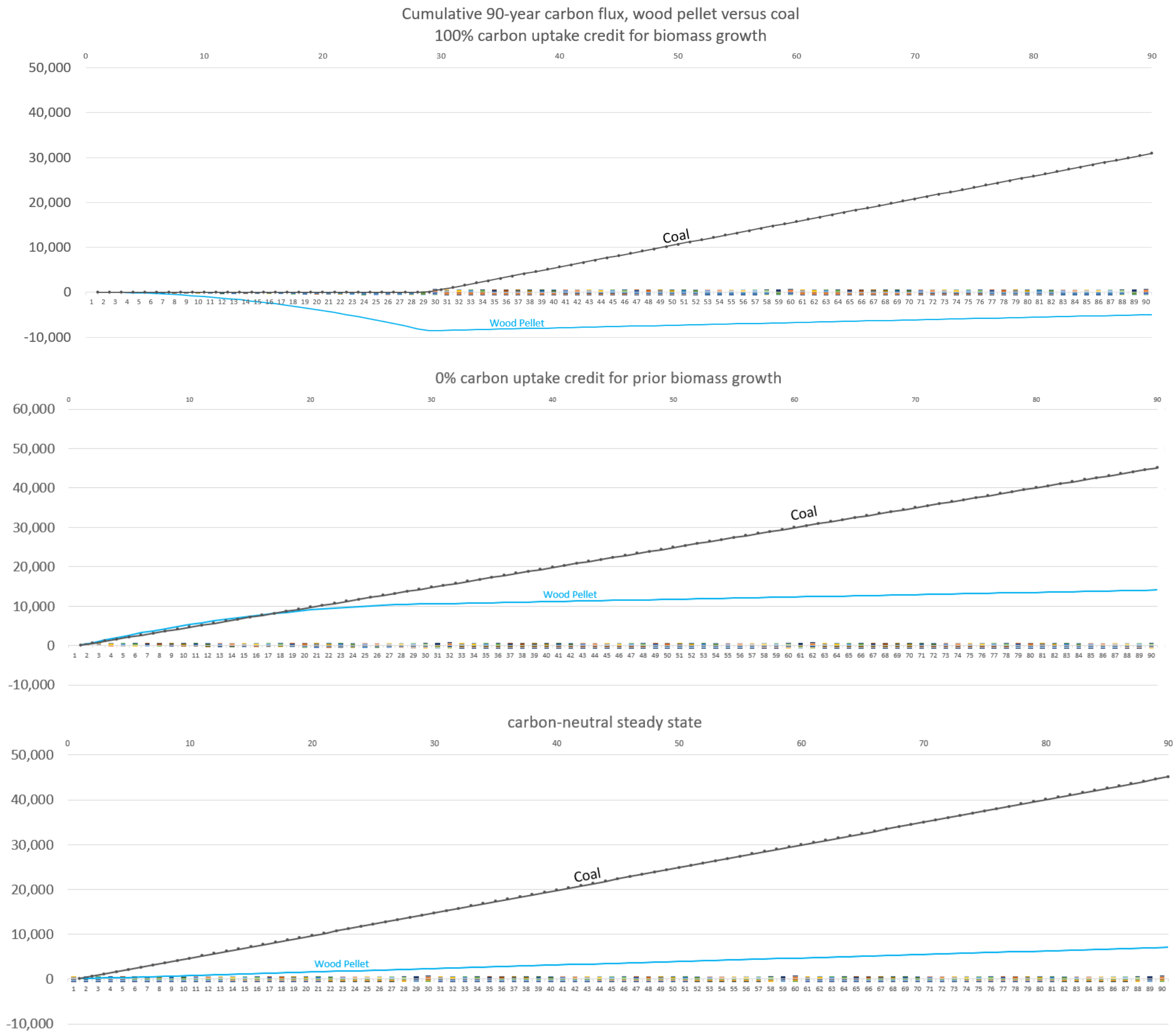


Figure A4-3 compares long term cumulative emissions for wood pellet versus coal, with carbon credit from forest growth applied to wood pellets using 3 accounting approaches: ***all prior*** carbon uptake credited during forest growth (a – top), ***no prior*** carbon uptake during forest growth (b – middle), and as a carbon-neutral ***steady state*** system (c – bottom).

In all three cases illustrated in Figure A4-3, the real-world emissions are identical, but only the accounting choices change. In each case, the long term emissions are dramatically lower for wood pellet fuel relative to coal. At A4-3b (middle) the slightly higher thermal efficiency results in lower initial emissions, but this advantage continuously diminishes as wood pellet carbon credit accrues from subsequent forest growth. The accounting practice that better addresses urgent climate concerns is the current industry practice that more accurately accounts for the literal carbon flux occurring from regenerative bioenergy systems (a or c). In the case of long-time working forests, such as in the Southeastern U.S., the comparison of wood pellet to coal fuel is likely best represented by steady state conditions, as illustrated in A4-3c above.

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